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Research Article
Phenology of *Ceratitis capitata* (Wiedemann) and *Bactrocera zonata* (Saunders) under Egyptian Agroecosystems in Four Horticultural Crops

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Abstract

Background and Objective: Mediterranean fruit fly (MFF), *Ceratitis capitata* and peach fruit fly (PFF), *Bactrocera zonata* are the most economically significant pests threatening Egypt's horticulture crops. Therefore, the present investigation aims to study the forecasting of female and male periodical appearances, female field generations as well as the interaction among both sexes as a base for taking action on fly-control measures. **Materials and Methods:** Periodical appearance of males and females of both species in mango, apple, plum and navel orange orchards in the Egyptian agroecosystems were studied in 2019 and 2020, using sex and synthetic olfactory attractant traps synchronized with certain abiotic factors. The data were subjected to CoStat Software (2008). **Results:** MFF females appeared earlier than PFF females on apple host, with a discrepancy between them on some hosts from one season to another. A positive relationship was recorded between activities of MFF sexes all along the study as well as between PFF sexes in the first season. No clear relation was found between fruit fly species activity and weather parameters. MFF and PFF females had numerous generations per year, four to six generations for MFF and three to five for PFF. **Conclusion:** This study clears the periodical appearance of males and females of PFF and MFF in the field under Egyptian agro-ecosystems, this information could be helpful in forecasting and controlling actions in orchards of these fruit species.

Key words: Degree days, fruit flies, hosts, prediction, tephritidae, six generations, forecasting

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Fruit flies (Tephritidae) are one of the world's most significant insect pests. The Mediterranean fruit fly (MFF) [*Ceratitis capitata* (Wiedemann)] and the peach fruit fly (PFF) [*Bactrocera zonata* (Saunders)] are two of the most common fruit flies in Egypt. They are considered serious pests of fruits and vegetables. PFF, a main horticultural insect pest, is present all year, it is found throughout Egypt[1-3]. It infects over 40 fruit crops, such as peach, guava and mango as main hosts and apricot, fig and citrus as secondary hosts, it has also been detected in wild host plants[4]. MFF threatens over 300 fruit varieties, including Kumquat, Pacific almond, guava, apple, mango and citrus fruits[5]. Both pests inflict annual losses to Egyptian agriculture, estimated to be worth $100 million.

Appearance and generations of males of fruit-fly populations may vary from year to year and from host to host, however, they can be predicted using degree-days[6,7]. The relation between the seasonal occurrence of fruit flies and host plant phenology might help to explain the population dynamics of these pests. In addition, the abundance of fruit flies depends on the temperature, rainfall, relative moisture and host phenology[8]. So, forecasting insect-pest activity based on day degree units might improve the timing of pest management practices, preventing the overuse of insecticides in perennial fruit crops.

Several studies on fruit fly monitoring show that male flies' presence and abundance usually occur in the field, even when suitable hosts or females are absent. However, females are the economically destructive form and their incidence in the field must be known. Despite the economic importance of MFF and PFF in Egypt, no information is available about the seasonal occurrence of females on important host plants, also, no information is available on the number of their generations present throughout the year.

Therefore, the goals of this study were to monitor the relationship among MFF and PFF males and females throughout the year and to determine the number of field generations in four major fruit crops. This baseline information will help to forecast both fruit fly species' periodic activity as a tool for integrated pest management programs.

MATERIALS AND METHODS

Study area: Field trials were carried out in four orchards in the Egyptian Itay-El Baroud habitat system (N 30.30°, E 30.49°), from Jan 1st, 2019-Dec 31st, 2020. Orchards were planted with plum (*Prunus domestica*, 6.3 ha), apple (*Malus domestica*, 4.2 ha), mango (*Mangifera indica*, 8.4 ha, different varieties) and navel orange (*Citrus sinensis*, 6.3 ha).

Monitoring incidence of MFF and PFF males: Jackson traps baited with a cotton wick (5 cm long and 1 cm diameter) contain 2 mL of trimedlure for MFF (technical, manufactured in the USA by Farmavet LTD) and methyl eugenol for PFF (98%, manufactured by Sinoway International, Jiangsu, Co., Ltd.,-China), with malathion (57%, 8:2 v:v) as the killing agent. Fly species monitoring required one trap/ha of the tested hosts (plum, apple, mango and navel orange). Traps were hung in tree canopies at 1.5-2 m above the ground, 50-65 m apart to avoid trap interference[9]. Weekly trap inspections provided the number of males/trap/day. The trap cotton wick was replaced every month when baited with methyl eugenol traps and every 15 days with trimedlure.

Monitoring incidence of MFF and PFF females: Plastic bottle traps (PB)[10] containing the olfactory attractant, a 5% solution of ammonium acetate ($NH_4CH_3CO_2$), were placed in the tested hosts. Four traps per host were hung in tree canopies at 1.5 to 2 m height above the ground, about 25 m apart. Traps were inspected weekly and captured flies were identified, sexed and counted as the number of captured Females/Trap/Day (FTD). Also, weekly trap maintenance was conducted.

Effect of weather factors on trap catches of MFF and PFF: Trap catches of both fruit fly species, MFF and PFF and meteorological data (air temperature (maximum and minimum) (°C) and relative humidity (%) gathered from NASA/power SRB, location (N 31.033°, E 30.4377°) were served to study the influence of weather factors on MFF and PFF. Correlation analysis estimated the relationship between weekly trap catches of males and females of PFF/MFF and mean weather parameters for every standard week.

Predicting the number and duration of annual generations of MFF and PFF females: Determining accumulated degree-days (ADD) helped predict the number of MFF and PFF generations, starting from the first catch of MFF and PFF females in orchards during the 2019 and 2020 seasons. Meteorological parameters of field maximum and minimum temperatures were transformed into heat units using 11.84°C as the lower threshold temperature for PFF. The expected number of generations depended on the mean thermal units (487.92 ADD) required to complete a generation of PFF[7,11]. As for MFF, the lower threshold temperature was 12.39°C, with 345.56 ADD[12].

Statistical analysis: The trapped number of fruit flies per inspection date (Week) was subjected to a one-way randomised block with repeated measures analysis of variance (ANOVA), using CoStat Software (2008). Phenology

experiments were completely randomized designs, transformed (log n+1) data were subjected to split-block Analysis of Variance (ANOVA). Means were compared by a Tukey-Kramer test (p = 0.05). Pearson's correlation (r) was performed for parametric data and Spearman's correlation (ρ) for no-parametric data.

RESULTS

Monitoring males and females of MFF and PFF: Field plot incidence of males and females of MFF and PFF based on trap-catch showed two to four peaks of activity of both sexes of each species in all tested hosts (mango, apple, navel orange and plum), through the tested seasons 2019 and 2020.

Season 2019

MFF: Figure 1a showed that MFF-male activity was throughout the year in both mango and navel orange orchards, meanwhile, male activity was seasonal in both, plum and apple orchards. Likewise, MFF female activity was seasonal on the tested hosts. Trapped flies depended significantly on the on both, host species and inspection date (males, host: F = 7.0134 e28, df = 3, p<0.00001, inspection date: F = 6.076 e28, df = 51, p<0.00001, Females: host: F = 11192, df = 3, p<0.00001, inspection date: F = 4.393e27, df = 51, p<0.00001). In parallel to these results, a highly significant interaction effect was obtained between host species and inspection date on the abundance of females (F = 1820.65, df = 153, p<0.00001). Females were

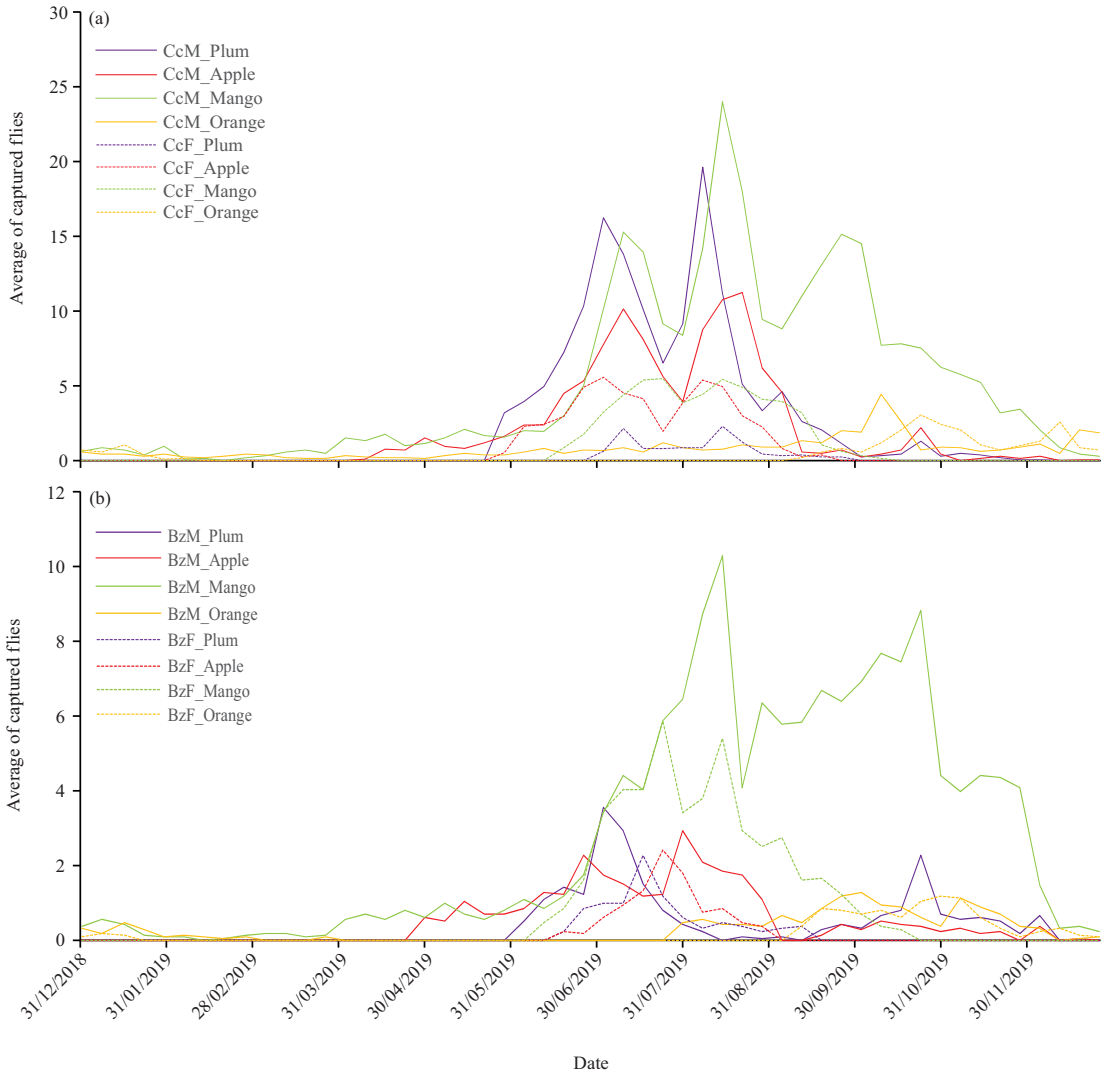

Fig. 1(a-b): Weekly mean number of males and females captured of (a) *C. capitata* and (b) and *B. zonata* by attractant traps and field generation peaks in the tested orchards during 2019 season

Cc: *Ceratitis capitata*, M: Male, F: Female, Bz: *Bactrocera zonata*, M: Male and F: Female

more abundant in mango than those in apple, navel orange and plum orchards, respectively. The first trapped female was detected in the apple orchard in May, followed by mango (in June) and plum (in July), where the highest activity in plum synchronized with that in mango. Meanwhile, females were trapped in navel orange throughout winter, up to February and again from September to the end of December.

PFF: Regarding PFF, Fig. 1b showed that males were active throughout the year in mango orchards. However, they had two periods of activity in navel orange and seasonal activity in apple and plum orchards. Similarly, PFF female activity was seasonally on the tested hosts, similar to MFF females. This activity was significantly different based on the tested hosts and date (males, host: $F = 7.255e28$, $df = 3$, $p<0.00001$, date: $F = 5.358e28$, $df = 51$, $p<0.0000$ and females, (host, $F = 3.0223e30$, $df = 3$, $p = 0.0000$, date: $F = 1356e28$, $df = 51$, $p<0.00001$). Similar to the number of MFF males, the mango orchard had the highest density of trapped PFF males, followed by apple, plum and navel orange orchards, respectively. Also, females of this species were more abundant in mango, followed by apple, navel orange and plum orchards. Noteworthy, the first trapped females were recorded in the mango orchard (Jun 2nd week), followed by plum and apple orchards in June 3rd week, in navel orange, they were firstly trapped through the winter in Jan and again from the 2nd week of Sep to the end of Dec.

A positive correlation (0.91-0.36) between MFF male and female activity was recorded (Table S1), based on host type. Also, the field activity of PFF males was correlated (0.55-0.74) with that of females, based on the host type.

Furthermore, Table S2 showed a high correlation between male and female field activity of both fly species on plum, apple and mango hosts with T° max and T° min. However, no significant correlation was found on both fly species male and female field activity with RH%. The same trend was achieved with males of MFF and PFF on navel orange. PFF females also correlated with To min, while MFF females did not correlate with both, T° max or T° min. On the other hand, the female activity of both species did correlate with RH%.

Season 2020

MFF: Figure 2a showed that MFF males were active throughout the year in the navel orange orchard and nearly along the year in the mango orchard, meanwhile, in the plum and apple orchards, they had a similar season activity that of 2019. MFF female activity on tested hosts was similar during the 2019 and 2020 seasons (Fig. 2b). However, they significantly depended on the host kind (males, host: $F = 3596.00$, $df = 3$, $p<0.00001$, inspection date, $F = 9844.6153$, $df = 51$, $p<0.00001$ and females, host: $F = 1.118e29$, $df = 3$, $p<0.00001$, time: $F = 7.117e28$, $df = 3$, $p<0.00001$). Furthermore, a highly significant interaction was recorded between host kind and inspection date on male abundance ($F = 3053.69$, $df = 153$, $p = 0.0000$). However, the apple orchard had the highest density of trapped males, followed by the plum, mango and navel orange orchard. However, no interaction was obtained between host kind and inspection date on female abundance. Females from the 2nd season started their activity earlier than those from the 1st season, with the same population pattern on the tested hosts. Similar to those in 2019 but with higher densities, females were more abundant in mango than the apple, navel orange and plum.

PFF: PFF male activity in 2020 (Fig. 2b) was similar to that in 2019, on both plum and apple orchards, while they were nearly active throughout the year on mango and seasonal on navel orange. While the PFF female activity on all tested hosts in 2020 was similar to 2019. This activity was significantly different, based on the host kind and inspection date (males: $F = 3.5931e29$, $df = 3$, $p<0.00001$, date: $F = 5.6713e28$, $df = 3$, $p<0.00001$ and female: host, $F = 1342486.6$, $df = 3$, $p<0.00001$, date, $F = 124389.37$, $df = 51$, $p<0.00001$). Furthermore, a highly significant interaction was recorded between host kind and inspection date on female abundance ($F = 83744.309$, $df = 153$, $p = 0.0000$).

Males had higher densities than in the 1st season on both mango and plum and lower densities on navel orange and apple. Males kept the higher density in mango, followed by plum, navel orange and apple, respectively. The first trapped females were recorded in mango and plum orchards, at equivalent dates to those in 2019. Also, they were timely recorded in the navel orange orchard through the 1st period in winter, while during the 2nd period, they were recorded earlier (Aug 3rd week). In the apple orchard, females were recorded later than in the 1st season (July 1st week). The general mean density of females was higher in 2020. Similar to 2019, the highest female density in 2020 was achieved in a mango orchard, followed by navel orange, plum and apple orchards.

A positive relationship (0.29-0.72) was recorded between the density of females and males of MFF in the field (Table S1). Also, a high correlation was obtained between the activity of PFF in males and females (0.65-0.82) in mango and navel orange orchards, however, it was not significant in plum and apple orchards.

Table S3 showed variations in the response of MFF and PFF to weather parameters. T° max and T° min were highly

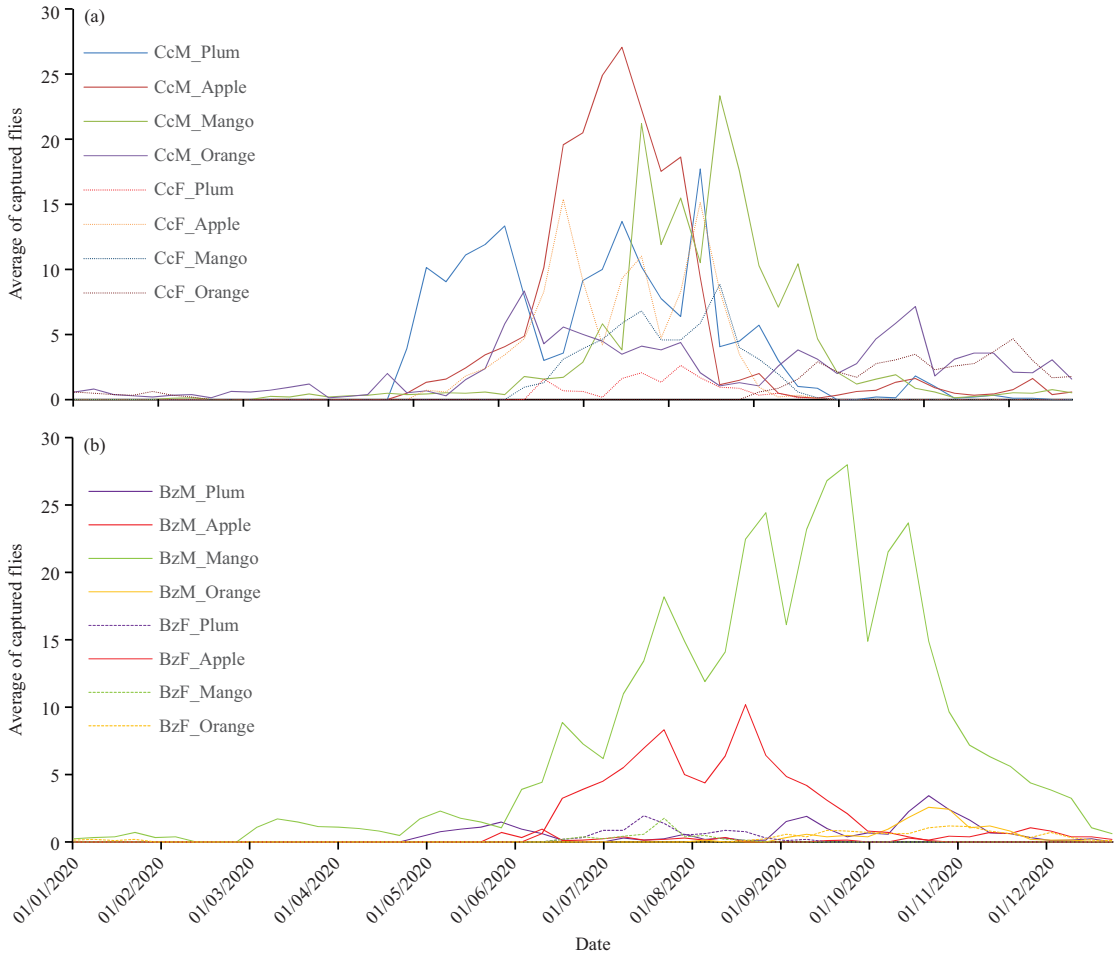

Fig. 2(a-b): Weekly mean number of males and females captured of (a) *C. capitata* and (b) *B. zonata* by attractant traps and field generation peaks in the tested orchards during the 2020 season
Cc: *Ceratitis capitata*, M: Male, F: female, Bz: *Bactrocera zonata*, M: Male and F: Female

positive in plum and mango orchards, while RH% negatively correlated very highly with both fruit fly species. A similar relation was obtained between weather parameters and fruit fly species in the apple orchard, except for To max and MPFF. On navel orange, there were variations between fruit fly species and weather parameters, MMFF was highly correlated with all parameters, FPFF and MPFF related significantly with To min and RH%, while FMFF was related significantly with RH%.

Generations of MFF and PFF females

Season 2019: The MFF females took from 1480-1789 ADD to develop, meanwhile, PFF took from 1622-2492 ADD as shown in Table S4 and Table 1, concerning ADD.

MFF: The 1st generation of MFF females was detected for the first time in the apple orchard in mid-spring (27th May). According to the ADD, females had five field generations on this host, being the 3rd one, the most destructive generation, followed in descending order by the 4th, 2nd and 1st generation, however, the 5th generation did not cause damage. This species also exhibited five generations in the mango orchard, the 1st generation began on Jun 17th and females continued in the field until Oct 8th. The 1st generation did not produce observed damage to fruits, meanwhile, the dangerous generations, in descending order, were the 3rd, 2nd, 4th and 5th. In the plum orchard, females had four generations, the 3rd and 1st generations were the damaging generations for plum fruits, followed by the 2nd generation. Also, in the navel orange orchard, females produced four generations. The 1st generation did not cause any fruit damage, while the more destructive generations were the 3rd and the 2nd. Noteworthy, the 4th generation continued in the field up to Feb 12th of next year.

Table 1: Approximated duration of several generation numbers of MFF, *C. capitata* and PFF, *B. zonata* and accumulated degree-days units on apple, plum, mango and navel orange orchards throughout the 2019 season at El-Beheira governorate, Egypt

		Generation numbers														
		1st			2nd			3rd			4th			5th		
Host	Fruit fly species	From	To	ADD	From	To	ADD	From	To	ADD	From	To	ADD	From	To	ADD
Apple	MFF	27/5	20/6 25d*	354.18	21/6	12/7 22	359.23	13/7	3/8 22d	359.92	4/8	25/8 22d	356.56	26/8	16/9 21	359.1
	PFF	19/6	18/7 30d	490.7	19/7	18/8 31d	492	19/8	26/8 8d	502.2	-	-	-	-	-	-
Plum	MFF	1/7	22/7 22d	355.8	23/7	13/8 22d	356.9	14/8	4/9 22d	360.2	5/9	25/9 21	356.7	-	-	-
	PFF	19/6	18/7 30d	490.7	19/7	18/8 31d	492	19/8	9/9 22d	502.2	-	-	-	-	-	-
Mangoes	MFF	17/6	8/7 22d	355	9/7	31/7 22d	358.69	1/8	22/8 22d	355.86	23/8	13/9 22d	360.07	14/9 24d	10/8	354.92
	PFF	10/6	10/7 31d	497.9	11/7	9/8 30d	488.5	10/8	9/9 31d	488.5	10/9	12/10 33d	500.7	13/10	14/10 2d	488.1
Navel orange	MFF	9/9	4/10 30d	354.02	5/10	1/11 28d	350.94	2/11	16/12 45d	349.74	18/12	12/2/ 2020	348.48	-	-	-
	PFF	9/9	11/10 33d	500	12/10	26/11 33d	490	27/11	22/1/ 2020	488	-	-	-	-	-	-

MFF: Mediterranean fruit fly, PFF: Peach fruit fly, ADD: Accumulated-degree-days and d*: Generation duration (day)

PFF: PFF female was first detected in the mango orchard, where females had five generations. The 2nd generation was the most dangerous, followed by the 3rd, 4th and 1st, respectively. The first fruit fly generation in apple and plum was recorded 1 week later than in mango, on Jun 19th, followed by two generations each. In the plum orchard, the 1st PFF generation was higher density and more dangerous than the 2nd one. While in the apple orchard, the 2nd generation had a higher abundance than the 1st one. Remarkably, the 3rd generation stayed 8 days with no fruit damage. Similar to apple and plum, PFF had three generations on the navel orange orchard, oranges were at risk by the 2nd and the 3rd generations and the last one continued in the field until Jan 22nd, 2020.

Season 2020: MFF needed 1438-2142 ADD and PFF 1534-2507 ADD to develop (Table S4 and Table 2).

MFF: The 1st generation of MFF females was detected for the first time in the mango orchard on 7th May, this generation began earlier than in the 1st season, followed by five more. The 1st and 2nd generations were not very active on mangoes, while the 3rd and 4th caused fruit damage. In the apple orchard, MFF produced five generations, the 2nd and 3rd generations were more dangerous for apple fruits. Also, in the plum orchard, the MFF females had five generations, the first began on June 18th and the 5th disappeared after nine days with no damage, however, the 3rd generation was more destructive for plums, followed by the 2nd, 1st and 4th. In the navel orange orchard, females had four field generations. The 1st generation had no damage, while the most destructive generation was the 3rd.

PFF: The 1st generation of PFF females was detected in the mango orchard. Based on ADD, five generations of the fly were recorded on this host. The 1st generation in both seasons began at a similar time (Jun 11th). The 2nd and 3rd generations were the most dangerous for mangoes, followed by the 1st and 4th, while the 5th stayed only one day with no effects. One week after the appearance of flies in the mango orchard, the 1st generation in plum was recorded (Jun 18th), followed by two generations. The 1st generation was the most destructive for plum fruits, followed by the 2nd generation, while the 3rd one was hazardless. In the apple orchard, the PFF had three generations, the 1st one appeared on Jul 2nd, with a higher risk for fruits, followed by the 2nd generation, the last generation lasted only three days, with no effects. In navel orange, PFF had three field generations. Navel oranges were at risk by the 2nd and 3rd generations, especially the 3rd one.

Table 2: Approximated duration of several generations of MFF, *C. capitata* and PFF, *B. zonata* and accumulated degree-days units on apple, plum, mango and navel orange orchards throughout the 2020 season, at El-Beheira Governorate, Egypt

		Generation numbers																
		1st			2nd			3rd			4th			5th			6th		
Host	Fruit fly species	From	To	ADD	From	To	ADD	From	To	ADD	From	To	ADD	From	To	ADD	From	To	ADD
Apple	MFF	11/6	4/7 24d*	351.9	5/7	27/7 24d	356.14	28/7	17/8 20d	356.81	18/8	9/9 23d	344.89	10/9	24/9 15d	357.95	-	-	-
	PFF	2/7	1/8 31d	500.6	2/8	28/8 30d	501.8	1/9	3/9 3d	498.8	-	-	-	-	-	-	-	-	-
Plum	MFF	18/6	10/7 23d	350.3	11/7	2/8 23d	356.4	3/8	23/8 27d	355.9	24/8	15/9 23d	345.4	16/9	24/9 9d	349	-	-	-
	PFF	19/6	18/7 31d	495.7	19/7	17/8 30d	503.4	18/8	10/9 24d	491.3	-	-	-	-	-	-	-	-	-
Mangoes	MFF	7/5	6/6 31d	348.8	7/6	31/6 24d	349.8	1/7	23/7 23d	345.4	24/7	14/8 22d	359.6	15/8	5/9 22d	358	6/9	24/9 19d	345.8
	PFF	11/6	12/7 31d	492.3	13/7	12/8 31d	504.2	13/8	12/9 31d	506.4	13/9	20/10 38d	501	21/10	22/10 1d	490.7	-	-	-
Navel orange	MFF	3/9	26/9 24d	346.5	27/9	27/10 31d	348	28/10	17/12 51d	349.7	18/12	-	-	-	-	-	-	-	-
	PFF	20/8	25/9 37d	493	26/9	1/11 37d	501	2/11	-	495	-	-	-	-	-	-	-	-	-

MFF: Mediterranean fruit fly, PFF: Peach fruit fly, ADD: Accumulated-degree-days and d*: Generation duration (day)

DISCUSSION

Suitable hosts of PFF and MFF are available all year round under the Egyptian agro-ecosystem conditions. Furthermore, the seasonal fluctuation of males and females of MFF and PFF showed an overlapped multivoltine pattern. On navel orange orchards, MFF males were active throughout the 2019 and 2020 seasons, while PFF males were active throughout the 1st tested season, 2019 and in part of the second season in 2020. In the mango orchard, males of both fruit fly species were active during most of the season. Also, the activity of PFF and MFF males was seasonal in plum and apple orchards, throughout both tested seasons. These results are in parallel with those of Abdel-Galil *et al.*[1], who mentioned that PFF males were active all year round. Host species affect the population level of both PFF and MFF males, during 2019, densities were higher on mango than those on apple, navel orange and plum orchards. In the 2nd season, also PFF was higher in density on mango than those on plum, navel orange and apple. These results also agree with Radonjić *et al.*[13], who mentioned that the population densities of MFF are affected by host species and variety. El-Gendy and Nassar[3] reported that differences in population density levels of PFF and MFF males in a specific area might be due to the availability and sequence of host plants. However, MFF males in the 2nd season on apple and plum were higher than those in mango and navel orange hosts. This switch on population numbers from different hosts probably was caused by immigrant flies dropping from post-harvest fruits, a suitable reservoir of these pests, for instance, navel orange fruits are preserved on the trees until Mar, dropping all along this time. PFF and MFF male abundance reached the highest levels during the harvest period from June to August in apple and plum, from July-October in mango and from September-December in navel orange orchards. These results agree with Saeed *et al.*[7], the highest peaks of PFF in mango orchards occurred in October.

Our findings reveal that MFF females flew 1-7 weeks earlier than those of PFF in navel oranges, apples and plums. Thus, MFF females invade their hosts during the fruiting stage before PFF females. Furthermore, the appearance of PFF and MFF females in the field was related to the host phenology of the tested hosts. The highest catch of flies happened during the fruiting and fruit ripening period[2]. Females of MFF had a strong relationship with the host phenology, with a sequential availability of ripe or semi-ripe fruits[14]. All these indicate that host availability might be an essential factor influencing the phenology of PFF and MFF in the tested area, PFF and MFF male and female arrival in Egypt agro-ecosystems was similar on the same host during the tested seasons. Whereas, natural fruit hosts can be used by PFF, depending on their fruit phenology[15]. According to de Villiers *et al.*[16], on the phenology of *C. capitata*, *C. rosa* and *C. cosyra*, host availability was more relevant than climate. It might be the determinant factor in the seasonal phenology of all three species.

The present results revealed that PFF females had an additional generation compared to MFF, independently of hosts or seasons. In parallel to these findings, Khalil *et al.*[6] reported that PFF males had 6-8 generations per year in North Sinai, El-Beheira and Asyut, Egypt, during season 2008, according to ADD. Also, Saeed *et al.*[7] mentioned 7 field generations of PFF males in Kafer El-Shikh, Egypt, from May, 2014-April, 2015.

The present findings evidenced that the incidence of MFF and PFF females in the field varied with fruit. These results were in parallel with those of El-Gendy and Villanueva-Jimenez[15] in laboratory assays of PFF host preference, where mango was the most preferred host, followed by peach and apple, respectively. Also, El-Gendy[4] demonstrated that mango was the most preferred host of PFF, compared to apricot, peach and plum, while apple was the last one. However, in the 2nd season, the abundance of MFF males and females in the field and emerged flies from apple samples were higher than mango, navel orange and plum.

CONCLUSION

The current study's findings demonstrated the relationship between PFF and MFF in Egyptian agro-ecosystems and provided a baseline on the periodical appearance of males and females of PFF and MFF in the field. Furthermore, the study appraised and predestined the field generations of PFF and MFF female flies on four significant commercial hosts in Egypt.

SIGNIFICANCE STATEMENT

This study revealed for the first time the periodical activity of PFF and MFF females in the field related to tested hosts. This study will help the applicator of control implement the control techniques against fly at a suitable time.

REFERENCES

1. Abdel-Galil, F.A., M.A. Amro, A.S.H. Abdel-Moniem and O.O. El-Fandary, 2010. Population fluctuations and interspecific competition between Tephritid flies attacking fruit crops in the New Valley Oases, Egypt. Arch. Phytopathol. Plant Prot., 43: 647-659.

2. Khan, R.A. and M. Naveed, 2017. Occurrence and seasonal abundance of fruit fly, *Bactrocera zonata* saunders (Diptera: Tephritidae) in relation to meteorological factors. Pak. J. Zool., 49: 999-1003.
3. El-Gendy, I.R. and A.M.K. Nassar, 2014. Delimiting survey and seasonal activity of peach fruit fly, *Bactrocera zonata* and Mediterranean fruit fly, *Ceratitis capitata* (Diptera: Tephritidae) at El-Beheira Governorate, Egypt. Egypt. Acad. J. Biol. Sci. A. Entomol., 7: 157-169.
4. El-Gendy, I.R., 2017. Host preference of the peach fruit fly, *Bactrocera zonata* (Saunders) (Diptera: Tephritidae), under laboratory conditions. J. Entomol., 14: 160-167.
5. Woods, B., I.B. Lacey, C.A. Brockway and C.P. Johnstone, 2005. Hosts of Mediterranean fruit fly *Ceratitis capitata* (Wiedemann) (Diptera: Tephritidae) from Broome and the Broome Peninsula, Western Australia. Aust. J. Entomol., 44: 437-441.
6. Khalil, A.A., S.M. Abolmaaty, M.K. Hassanein, M.M. El-Mtewally and S.A. Moustafa, 2010. Degree-days units and expected generation numbers of peach fruit fly *Bactrocera zonata* (Saunders) (Diptera: Tephritidae) under climate change in Egypt. Egypt. Acad. J. Biol. Sci. A. Entomol., 3: 11-19.
7. Saeed, M., T. Ahmad, M. Alam, L.A. Al-Shuraym and N. Ahmed *et al*., 2022. Preference and performance of peach fruit fly (*Bactrocera zonata*) and melon fruit fly (*Bactrocera cucurbitae*) under laboratory conditions. Saudi J. Biol. Sci., 29: 2402-2408.
8. Papadopoulos, N.T., B.I. Katsoyannos, J.R. Carey and N.A. Kouloussis, 2001. Seasonal and annual occurrence of the Mediterranean fruit fly (Diptera: Tephritidae) in Northern Greece. Ann. Entomol. Soc. Am., 94: 41-50.
9. El-Gendy, I.R., 2012. Elevation of attraction efficiency of jackson trap on peach fruit fly, *Bactrocera zonata* (Saunders). Int. J. Agric. Res., 7: 223-230.
10. El-Gendy, I.R., 2012. Evaluating attractency of some protein derivatives for the Mediterranean fruit fly, *Ceratitis capitata* (Wiedmann) and the peach fruit fly, *Bactrocera zonata* (Saunders). Int. J. Agric. Res., 7: 185-194.
11. Ali, M.A., 2016. Effect of temperature on the development and survival of immature stages of the peach fruit fly, *Bactrocera zonata* (Saunders) (Diptera: Tephritidae). Afr. J. Agric. Res., 11: 3375-3381.
12. Collier, T. and N. Manoukis, 2018. Evaluation of predicted medfly (*Ceratitis capitata*) quarantine length in the United States utilizing degree-day and agent-based models. F1000Research, Vol. 6. 10.12688/f1000research.12817.2.
13. Radonjić, S., M. Čizmović and R. Pereira, 2013. Population dynamics of the Mediterranean fruit fly in Montenegro. Int. J. Insect. Sci., Vol. 5. 10.4137/IJIS.S12964.
14. Papadopoulos, N.T., B.I. Katsoyannos and D. Nestle, 2003. Spatial autocorrelation analysis of a *Ceratitis capitata* (Diptera: Tephritidae) adult population in a mixed deciduous fruit orchard in Northern Greece. Environ. Entomol., 32: 319-326.
15. El-Gendy, I.R. and J.A. Villanueva-Jimenez, 2021. Does fruit phenology influence trap-capture and emergence of *Ceratitis capitata* and *Bactrocera zonata* in commercial hosts? Fruits, 76: 303-309.
16. de Villiers, M., A. Manrakhan, P. Addison and V. Hattingh, 2013. The distribution, relative abundance and seasonal phenology of *Ceratitis capitata*, *Ceratitis rosa* and *Ceratitis cosyra* (Diptera: Tephritidae) in South Africa. Environ. Entomol., 42: 831-840.

SUPPLEMENTARY MATERIALS

Table S1: Correlation coefficients between trapped MFF and PFF on tested hosts in the El-Beheira Governorate in Egypt during the 2019-020 season

		Coefficients					
		2019			2020		
Fruit species	Host	r	Se (±)	p-value	r	Se (±)	p-value
MFF	Plum	0.71	0.06	0.000***	0.51	0.069	0.000***
	Apple	0.91	0.04	0.000***	0.72	0.056	0.000***
	Mango	0.59	0.06	0.000***	0.54	0.068	0.000***
	Navel orange	0.36	0.08	0.000***	0.29	0.077	0.002***
PFF	Plum	0.55	0.07	0.000***	-0.16	0.079	0.052^{ns}
	Apple	0.69	0.06	0.000***	0.018	0.08	0.83^{ns}
	Mango	0.62	0.063	0.000***	0.65	0.06	0.000***
	Navel orange	0.74	0.05	0.000***	0.82	0.05	0.000***

MFF: Mediterreanan fruit fly, PFF: Peach fruit fly, r: Correlation coefficient, Se: Standard error, ns: Non significant and ***High significant

Table S2: Correlation coefficients between trapped MFF and PFF sexes and abiotic factors on tested hosts during 2019 season at El-Beheira Governorate, Egypt

		Coefficient											
		Plum			Apple			Mango			Navel orange		
Species	Abiotic factors	r	Se (±)	p-value	R	Se (±)	p-value	r	Se (±)	p-value	r	Se (±)	p-value
MMFF	T° (max)	0.60	0.06	0.000***	0.64	0.06	0.000***	0.60	0.06	0.000***	0.25	0.08	0.002**
	T° (mim)	0.64	0.06	0.000***	0.68	0.06	0.000***	0.72	0.05	0.000***	0.37	0.07	0.000***
	RH (%)	-0.04	0.08	0.6^{ns}	-0.05	0.08	0.5^{ns}	0.04	0.08	0.59^{ns}	0.13	0.08	0.09^{ns}
MPFF	T° (max)	0.42	0.07	0.000***	0.67	0.06	0.000***	0.63	0.06	0.000***	0.21	0.08	0.009**
	T° (mim)	0.48	0.07	0.000***	0.68	0.06	0.000***	0.77	0.05	0.000***	0.37	0.07	0.000***
	RH (%)	-0.02	0.08	0.77^{ns}	-0.02	0.08	0.01*	0.12	0.08	0.14^{ns}	0.14	0.08	0.08^{ns}
FMFF	T° (max)	0.47	0.07	0.000***	0.61	0.06	0.000***	0.59	0.06	0.000***	-0.15	0.08	0.06^{ns}
	T° (mim)	0.55	0.06	0.000***	0.63	0.06	0.000***	0.68	0.06	0.000***	0.003	0.08	0.97^{ns}
	RH (%)	0.11	0.08	0.16^{ns}	-0.08	0.08	0.32^{ns}	0.03	0.08	0.69^{ns}	0.39	0.07	0.000***
FPFF	T° (max)	0.48	0.07	0.000***	0.44	0.07	0.000***	0.60	0.06	0.000***	0.12	0.08	0.13^{ns}
	T° (mim)	0.52	0.06	0.000***	0.52	0.07	0.000***	0.69	0.06	0.000***	0.26	0.07	0.001**
	RH (%)	-0.03	0.08	0.72^{ns}	-0.02	0.08	0.74^{ns}	0.06	0.08	0.45^{ns}	0.19	0.08	0.018*

r: Correlation coefficient, Se (±): Standard error, MMFF: Mediterranean fruit fly males, FMFF: Mediterranean fruit fly females, MPFF: Peach fruit fly males, FPFF: Peach fruit fly females, T°(mim): Minimum temperature, T°(max): Maximum temperature, RH (%): Relative humidity, ns: Non significant, *Low significant, **Medium significant and ***High significant

Table S3: Correlation coefficients between weekly mean number of trapped males and females of MFF and PFF and abiotic factors on tested hosts during 2020 season at El-Beheira Governorate, Egypt

		Coefficient											
		Plum			Apple			Mango			Navel orange		
Species	Abiotic factors	r	Se (±)	p-value	R	Se (±)	p-value	r	Se (±)	p-value	r	Se (±)	p-value
MMFF	T° (max)	0.66	0.06	0.000***	0.55	0.07	0.000***	0.53	0.07	0.000***	0.56	0.06	0.000***
	T° (mim)	0.60	0.06	0.000***	0.53	0.06	0.000***	0.63	0.06	0.000***	0.58	0.06	0.000***
	RH (%)	-0.47	0.07	0.000***	-0.50	0.07	0.000***	-0.53	0.07	0.000***	-0.68	0.05	0.000***
MPFF	T° (max)	0.33	0.08	0.000***	0.14	0.07	0.07^{ns}	0.67	0.06	0.000***	0.09	0.08	0.12^{ns}
	T° (min)	0.38	0.07	0.000***	0.20	0.07	0.012*	0.78	0.05	0.000***	0.18	0.07	0.023*
	RH (%)	-0.39	0.07	0.000***	-0.35	0.08	0.000***	-0.75	0.05	0.000***	-0.29	0.08	0.000***
FMFF	T° (max)	0.47	0.07	0.000***	0.62	0.06	0.000***	0.58	0.07	0.000***	-0.11	0.07	0.15^{ns}
	T° (min)	0.50	0.07	0.000***	0.66	0.06	0.000***	0.59	0.06	0.000***	0.03	0.06	0.12^{ns}
	RH (%)	-0.43	0.08	0.000***	-0.58	0.07	0.000***	-0.53	0.07	0.000***	-0.23	0.08	0.005***
FPFF	T° (max)	0.52	0.07	0.000***	0.43	0.07	0.000***	0.67	0.06	0.000***	0.09	0.08	0.22^{ns}
	T° (min)	0.55	0.06	0.000***	0.46	0.07	0.000***	0.74	0.05	0.000***	0.22	0.08	0.005**
	RH (%)	-0.48	0.07	0.000***	-0.38	0.07	0.000***	-0.67	0.06	0.000***	-0.36	0.07	0.000***

r: Correlation coefficient, Se (±): Standard error, MMFF: Mediterranean fruit fly males, FMFF: Mediterranean fruit fly females, MPFF: Peach fruit fly males, FPFF: Peach fruit fly females, T° (mim): Minimum temperature, T° (max): Maximum temperature, RH (%): Relative humidity, ns: Non significant, *Low significant, **Medium significant and ***High significant

Table S4: Accumulated degree days and generation number of MFF, *C. capitata* and PFF, *B. zonata*, in orchards through 2019 and 2020 seasons at El-Beheira Governorate, Egypt

		ADD		Number of generation/year	
Host	Seasons	PFF	MFF	PFF	MFF
Mango	2019	2492	1785	5.11	5.165
	2020	2507	2142	5.14	6.16
	Mean	2500	1963	5.13	5.66
Citrus	2019	1626	1480	3.33	4.28
	2020	1873	1438	3.84	4.16
	Mean	1750	1459	3.59	4.22
Apple	2019	1622	1789	3.33	5.17
	2020	1534	1768	3.14	5.11
	Mean	1574	1779	3.23	5.14
Plum	2019	1858	1655	3.00	4.67
	2020	1861	1757	3.81	5.08
General mean		1860	1706	3.81	4.94

MMFF: Mediterranean fruit fly, MFF: Mediterranean fruit fly, PFF: Peach fruit fly and ADD: Accumulated-degree-days