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Bioscience Research

Print ISSN: 1811-9506 Online ISSN: 2218-3973

Journal by Innovative Scientific Information & Services Network

RESEARCH ARTICLE BIOSCIENCE RESEARCH, 2020 17(4): 2750-2759. **OPEN ACCESS**

Determination of number, duration and annual generations of *Ceratitis capitata* (Diptera: Tephritidae) under field condition at Mitidja region, north Algeria

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The current study was conducted out over two successive years at Mitidja region, north Algeria, using sex pheromone traps (Trimedlure) to capture *Ceratitis capitata* male flies throughout 2016 and 2017 seasons. The aim of this study was to estimate number and of field generations and predict it occurrence in Mitidja. The results revealed that this insect had nine annually generations during both seasons in 2016 and 2017. Mean numbers of MFF adults for each generation were recorded, obtained data indicate that the first MFF male generation that occurred in winter seasons was the longest (111 days) but with lowest weakly mean number of population density of males (11.36 - 16.55 male in 2016 and 2017 respectively). Two generations took place in spring with an average duration of 35 days and an average weakly number of population density of 46.5 and 61.9 male in 2016 and 2017 respectively. The four generations that occurred in summer were the shorter (22 days) but with highest weakly mean population (242 and 271 male in 2016 and 2017 respectively. Two generations took place in autumn with an average duration of 45 days and an average weakly number of population density of 35 and 37.28 males in 2016 and 2017 respectively. Predicting of Mediterranean fruit fly *C. capitata* male annual peaks was carried out by studying the relations between the accumulated thermal heat units expressed as degree-days (DD'S) and the population fluctuation of male flies for the successive seasons. Obtained results revealed that number and duration of *C. capitata* generations coincide and agree with obtained results by applying day degree theory.

Keywords: Mediterranean fruit fly, *C. capitata*, annual generation, duration, degrees-day, predicting

INTRODUCTION

The Mediterranean fruit fly, *Ceratitis capitata* Wiedemann (Diptera: Tephritidae) is a highly polyphagous and the most destructive pest on fruits and vegetables worldwide. It infests over 400 plant species in tropical, subtropical and temperate regions (Liquido et al. 1991; Copeland, 2002). Originating from tropical Africa (De Meyer et al. 2002) has been transported extensively through trade (Karsten et al. 2013). Its highly adaptable nature is one of the factors that allowed it to become established throughout much of the world as an invasive species in many countries (Metcalf, 1995, De Mayer et al. 2008). The first report of this species in Algeria was made in 1858 (Bodenheimer, 1951). This pest found in coastal areas a diversification of fruit species and favorable climatic conditions and become the most injurious pest in fruit growing and the main obstacles to the production of healthy fruits and their export (Oukil et al. 2002).

Among climatic factors, temperature is the main ecological factor affecting insect growth and development, since it directly affects physiological processes and enzyme activity (Trudgill et al. 2005). Temperature is an important environmental factor affecting survival and developmental rates of fruit flies (Afia, 2007; Amin, 2008; Ghanim, 2009). Insect development depends on thermal requirements. Each insect species has an optimal temperature range for development limited by lower and upper thresholds (base temperature (Tb) and upper limit (Ts)). Below and above these temperature limits, development does not occur (Haddad et al. 1999). In the range between Tb and Ts, insects accumulate degree-days and are able to develop. From the practical aspect, accumulated thermal units have been used to predict the seasonal development and emergence of various insects (Eckenrode et al. 1975, Farag et al. 2009). Accumulated thermal units are used to predict the seasonal development and emergence of various insects (Farag et al. 2009).

The monitoring of *C. capitata* males was via McPhail traps baited with Trimedlure hung about 1.5m above the ground in the trees. The lure most commonly used for monitoring *C. capitata* populations is Trimedlure (TML) (Israely & Oman, 2005). TML is very efficient in detecting the earliest seasonal emergence of *C. capitata* males (Miranda et al. 2001) and has been used in attract-and-kill methods and in chemosterilization approaches (Navarro-Llopis et al. 2004). In countries where this pest is already established, traps baited with TML are used to monitor *C. capitate* populations and guide insecticide application decisions.

The aim of this study was to estimate number of field generations and predicting it occurrence in Mitidja in order to select the best time for the pest management. As the appearance of *Ceratitis capitata* varies from season to another, it can be predicted by The Thundered degree-days method.

MATERIALS AND METHODS

Mean numbers of the MFF *Ceratitis capitata* male's flies on six host fruit plants (Loquat, Citrus, Apricot, Pear, Peach, fig) during period from January to December of 2016 and 2017 were pooled together and illustrated graphically to determine the duration, number of annual generation by trap in the hosts at Mitidja region through the two successive seasons of 2016 and 2017.

Presentation of the study sites

The trials were conducted during period from Jan. to December of 2016 and 2017 in 7 fruit orchards in Mitidja (North Algeria). The characteristics of the orchards are shown in Table 1.

Table 1: General information on orchards used in this study

Orchards	Coordinates	Altitude	Superficie	Variétés
Loquat	(36.17 N, 3.15 E)	20 m	0.5 ha	NI.
Citrus	(36°55 N, 2°55 E)	50 m	2.71 ha	Clementine, Valencia late Navelate, Washington navel, Thomson navel, Navelina, New hall navel, Navelate.
Lemon	(36°43 N, 36°49 E)	25m	2 ha	Eureka.
Fig	(36°55 N, 2°55 E)	50 m	1.76 ha	Thamourth, Ajenjar.
Apricot	(36°50N, 2°87 E)	188 m	2 ha	Bulida.
Peach	(36°31 N, 2°46 E)	620 m	2 ha	Redhaven.
Pear	(36°31 N, 2°46 E)	620 m	2 ha	Santa maria.

NI : undetermined

Trapping devices for monitoring C. capitata.

In order to follow the fluctuation of the population of *C. capitata* in the orchards, we used McPhail type traps baited with trimedlure at the rate of 1 traps suspended in the middle of the orchard. These traps are installed in orchards from fruit formation to harvest. On the tree, the trap is suspended at the middle layer of the foliage, near the prevailing winds. The catch records have a frequency of 10 days and the attractants are renewed every 28 days.

Data Recording:

Obtained mean numbers of MFF males were recorded from the monitored pheromone traps. On the other hand records of daily means of maximum and minimum temperature as well as relative humidity of the years of study (2016 and 2017) were obtained from El- Metrological Station of Dar el Beida. The mean numbers of the MFF male's flies on tested hosts during period from Jan. to December of 2016, 2017 were pooled together and illustrated graphically to determine the duration, number of annual generation by trap in the three hosts in Mitidja through the two successive seasons of 2016 and 2017.

Estimation Number and Duration of Annual Generations of MFF:

Two different mains of MFF annual generation calculation were concerned during current study as follow:

Estimation of annual generation depending on thermal constant and day degree:

The first main depend on determination of *Ceratitis capitata* accumulated daily thermal units by transforming recorded daily maximum, minimum temperature and threshold of development (zero of development) of MFF to Daily Degree units (DDU) by applying following formula.

DDU = (Max. Temp. + Min. Temp.)/2 – Threshold of Development Temp (t0).

Then estimation number and duration of *C. capitata* annual generations could be possible in the field by using calculated value of Thermal constant of *C. capitata* developments (C) and applying following formula according to Jasic (1975).

Number of Generations = Σ (D.D.U) / C

Estimated Values of threshold of development (zero of development) (t0) and Thermal constant (C) of *C. capitata* to develop from egg to adult were 12.4°C (Muñiz & Zalom, 1997) and 260 °D (Duyck and Quilici, 2002).

Estimation of annual generations according to Audemard and Milaire (1975) and Iacob (1977):

The second main suggested by Audemard and Millaire (1975) and emended by Iacob (1977), which depended on weekly mean captured numbers of MFF males by pheromone traps. Those mean numbers of MFF males were accumulated along the tested year and arranged, and then illustrated graphically on semigaussian paper (scale gausses). Whether, the number and duration of annual field generations could be detected.

RESULTS

Results of using two different mains of calculation for annual generation of *C. capitata* were shown in Tables (2), (3) and graphically illustrated in Figures (1) and (2).Obtained data declared that *C. capitata* has nine generations along year. The longest generation duration observed in winter, while the shortest were in summer seasons.

Predicting of *C. capitata* annual generation peaks using heat unit accumulation:

Under climate conditions of 2016 and 2017 number, duration and approximated dates of annual generations were estimated depending on values of threshold of development (t_0= 12.4°C (Muñiz & Zalom, 1997) and Thermal constant (C) of *C. capitata* to develop from egg to adult (260 thermal units according to and Duyck & Quilici, 2002) and presented in Table (2) and (3).

Data in Table (2) revealed that *C. capitata* has nine field generations on orchards along both two experimental years of 2016 and 2017. These generations and their duration could be detected as follows. The first generation was the longest and occurred in winter season (128 and 129 days in 2016 and 2017, respectively).

In 2016 season, the first one began from January to early May, while the second one stared from the 8th of May till the first week of June then the 3rd generation is started until the end of June. The fourth generation took place from the end of June and the last week of July and lasted 23 days. The fifth one was from end of July to early August while the sixth generation was from the first week of to the end of august and lasted 20 days. The seventh generation was the shortest duration (14 days) and occurred from end of august to first week of September. The eighth generation was from the 9th of September to the 18th of October. The last generation that was the ninth was from 19th October to 2nd and December and lasted 45 days.

2017 season

At the second season, 2017, the first generation lasted 129 days and began from February to the 9th of May, while the second one stared from early May till the 9th of June and lasted 31 days. The 3rd was from 10th of June to early July and lasted 22 days. The fourth generation was from early July to 19th of July and lasted 18 days. The fifth one was from the of July to early August while the sixth generation was from the first week of to the end of 20th of July to the 6th of August and lasted 18 days. The sixth generation was the shortest duration (16 days) and occurred from early august to the last week of August. The seventh generation was from end of August to 18th of September and lasted 27 days. The eighth generation lasted 24 days and was from the 19th of September to the 12th of October. The last generation that was the ninth was from 13th October to 23th of November and lasted 42 days.

Estimation annual generation according to Audemard and milaire (1975) and Jacob (1977):

2016 season

Seasonal fluctuation of MFF males in Mitidja was recorded during two consecutive years (2016-2017).The population activity was expected to be consist of several consecutive and overlapping. So, formula suggested by Audemard and Millaire (1975) and Iacob (1977) was applied.

Results in Figure (1) and table (4) revealed that, *C. capitata* had nine seasonal generations during 2016 season, the first generation occurred between early January to late - April and lasted for about 111 days. The 2nd generation was from late April to end May. The 3rd generation occurred between end of May to end of June and lasted 31 days. The 4th generation was from end of June to the 20th of July and lasted 20 days. The 5th generation was from 20th of July to the 10th of August. Then, from 10th of August to end of August for the 6th generation. The 7th generation occurred between end of August and end of September. The 8th generation was from last September to 10th of November. The last generation occupied the period from 10th of November to end of December.

Mean numbers of MFF adults for each generation were recorded, that highest values (268 251, 218and 231 adult / trap/ week) observed in fourth ,fifth , sixth and seventh generation in summer season, while lowest numbers (11.36 adults / trap/ week) were recorded during the first generation in winter season (Table 4).

2017 season

Figure (2) and table (5) also indicate 9 generations for *C. capitata* during 2017 season; the first generation was observed from 1st January to mid-April and lasted 107 days. The 2nd generation began from 17th of April to 27 May and lasted 40 days. The 3rd generation started from late May to late of June and lasted 30days. The 4th generation was from and of June to end of July. The 5th generation was from end of July to early August and lasted 11days. The sixth one was from early of August to late of the same month and lasted 20 days. The 7th generation was from late of August to late of September. The 8th generation was from late of September to early of November. The last generation was observed from mid-November to late of December.

Table 2: Number and duration of Annual generations of *C. capitata* along 2016 season in Mitidja, estimated depending on thermal constant and day degree according to Richmond (1983).

				Generation period		
Month	**Average T° (t)**	**rate of (G)**	**Generation**	**Duration (day)**	**From**	**to**
January	12,8	0,048	1st	128	01-janv	07-may
February	13,7	0,145	2nd	31	08-may	08-juin
March	14,4	0,238	3rd	21	09-juin	29-juin
April	15,6	0,369	4th	23	30-juin	22-juil
May	19,7	0,87	5th	14	23-juil	05-aug
June	24,4	1,385	6th	20	6-aug	29-aug
July	26,9	1,729	7th	16	30-aug	08-sept
August	28,4	1,908	8th	40	09-sept	18-oct
September	23,5	1,281	9th	45	19-oct	02-dec
October	19,4	0,835	/	/	/	/
November	14,6	0,254	/	/	/	/
December	13,1	0,083	/	/	/	/
Average	18,87	0.76	/	/	/	/

Table 3: Number and duration of Annual generations of *C. capitata* along 2017 season in Mitidja, estimated depending on thermal constant and day degree according to Richmond (1983).

					Generation period	
Month	Average T° (t)	Rate of (G)	Generation	Duration (day)	From	to
January	10,3	0	/			
February	13,7	0,14	1st	129	1-feb	09-may
March	14,4	0,24	2nd	31	10-may	09-juin
April	15,6	0,37	3rd	22	10-juin	01-juil
May	19,7	0,87	4th	18	02-july	19-juil
June	24,4	1,38	5th	18	20-juil	6-aug
July	26,9	1,73	6th	16	7-aug	22-aug
August	28,4	1,91	7th	27	23-aug	18-sept
September	23,5	1,28	8th	24	19-sept	12-oct
October	18,7	0,75	9th	42	13-oct	23-nov
November	13,6	0,14	/	/	/	/
December	10,9	0	/	/	/	/
Average	18,34	0.73	/	/	/	/

Table 4: Estimated numbers and durations of annual generations for *C. capitata* adults and associated average weekly mean numbers of adults Mitidja during 2016 season, according to Audemard and Milaire (1975) and Iacob (1977).

	Approximated date of occurrence			
No. Generation	From	to	Generation duration (days)	Average of weekly numbers in specific generation
1st	January, 1st	April, 20th	111	11.36
2nd	April, 20th	May, 30th	41	46
3th	May, 30th	June, 30th	31	47
4th	June, 30th	July, 20th	20	268
5th	July, 20th	August, 10th	21	251
6th	August, 10th	August, 30th	20	218
7th	August, 30th	September, 30th	31	231
8th	September, 30th	November, 10th	41	55
9th	November, 10th	December, 30th	50	15

Table 5: Estimated numbers and durations of annual generations for *C. capitata* adults and associated average weekly mean numbers of adults Mitidja, according to Audemard and Milaire (1975) and Iacob (1977).

	Approximated date of occurrence			
No. Generation	From	to	Generation duration (day)	Average of weekly numbers in specific generation
1st	January, 1st	April, 17th	107	16.55
2nd	April, 17th	May, 27th	40	53.8
3th	May, 27th	June, 27th	30	70
4th	June, 27th	July, 27th	30	185.33
5th	July, 27th	August, 7th	11	350.67
6th	August, 7th	Auguste, 27th	20	246.67
7th	Auguste, 27th	September, 27th	30	304.75
8th	September, 27th	November, 7 th	40	50.40
9th	November, 7 th	December, 27th	50	24.17

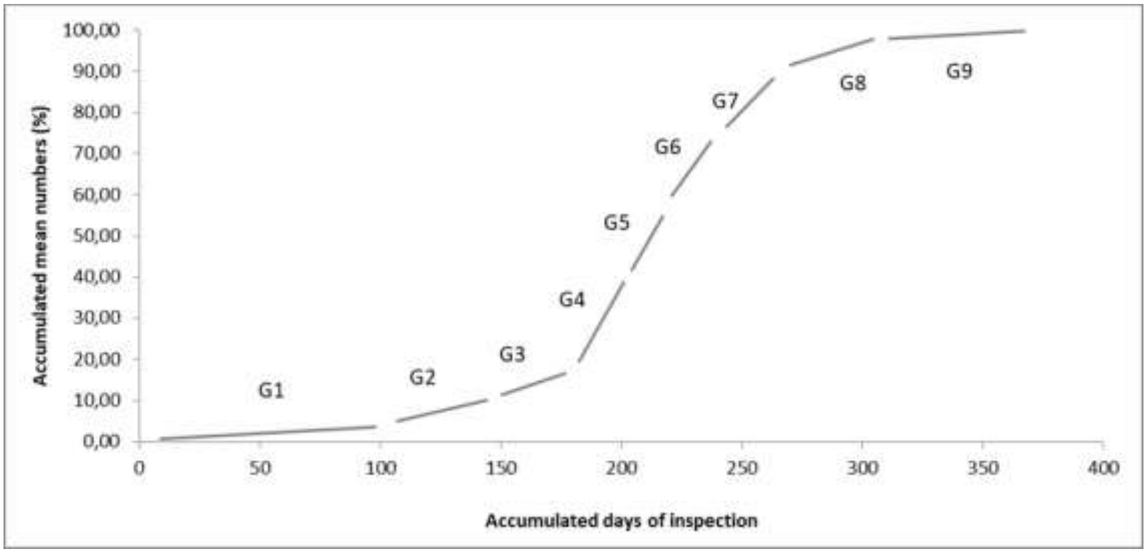

Figure 1: Numbers of *C. capitata* field generations, according to Audemard and milaire (1975) and Iacob (1977) method at fruit orchards in Mitidja region, 2016.

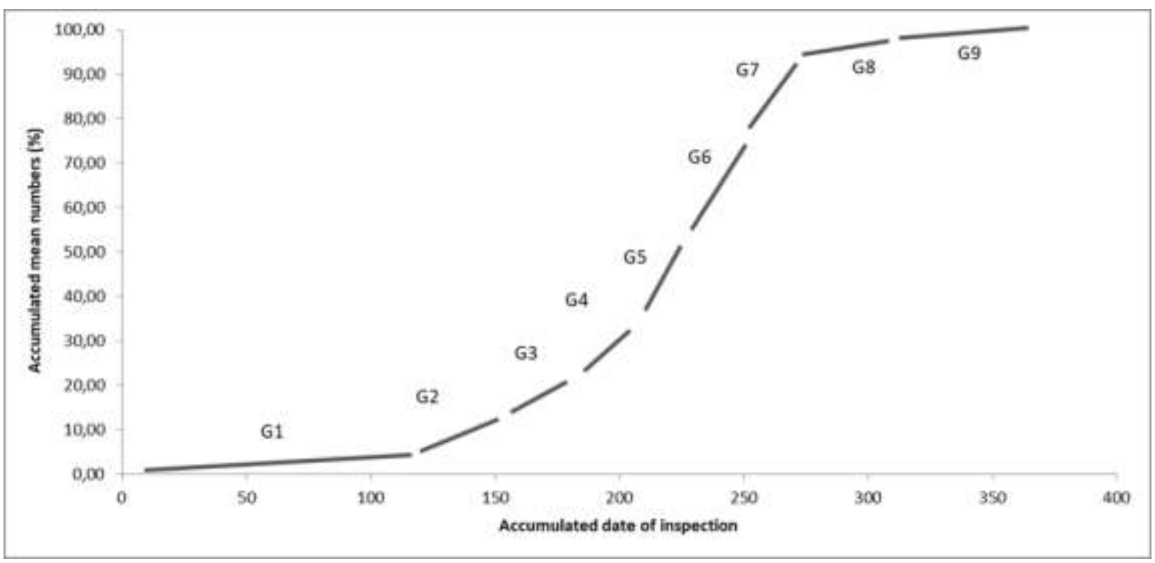

Figure 2: Numbers of *C. capitata* field generations, according to Audemard and milaire (1975) and Iacob (1977) method at Mitidja region, 2017.

Mean numbers of MFF adults for each generation were recorded, that highest values (185.33, 350.67, 246 and 304 adult / trap/ week) observed in fourth ,fifth , sixth and seventh generation in summer season, while lowest numbers (16.55 adults / trap/ week) were recorded during the first generation in winter season (Table 5)As presented in figure (1), (2) and table (4) and (5); nine annual generations were observed also along a year in both years of study, male mean numbers in all recorded generation were estimated. All obtained data reflected that the first MFF male generation of winter seasons was the longest but with lowest mean number of population density of males (11.36 – 16.55 male/ generation in 2016 and 2017 respectively), while the generations occurred in summer was shorter but with more population.

Dates and duration of all estimated generations were paralleled also with obtained results of applying of day degree. Obtained data are presented in Table (2) and(3) and graphically illustrated in Figures (1) and (2). These results revealed that number and duration of *C. capitata* generations coincide and agree with obtained results by applying day degree theory.

DISCUSSION

Insects as poikilothermic animals change their activity visibly depending on the temperature of the surrounding environment (Bale et al. 2002; Menéndez, 2007). There is a threshold temperature for each insect. Insects have an optimum temperature range in which they will grow rapidly. Then, there is maximum temperature (termed upper cutoff) above which development stops. These values are used to predicting insect activity and appearance of symptoms during the growing season. Indeed, accumulated thermal units have been used to predict the seasonal development and emergence of various insects (Sevacherian et al. 1977; Farag et al. 2009; Salama et al. 2015) and provide a valuable tool for insect pest control, in forecasting infestations monitoring and timing of insecticide applications (Zalom et al. 1983).

The climate change certainly affects the status of abundance of insets in the field and high temperature in the future may thus increase the damage on crops; by increasing the number of generations. According to Zalom et al. (1983) the rate of insect development is based on the accumulation of heat measured in physiological rather than chronological time, the number of generations per year is mainly determined by temperature. This is how several generations can succeed each other during the year. Data obtained in the present investigation can help in predicting *C. capitata* annual generations and expected times of frequency of annual generations in the field under current climate depending on the accumulated thermal requirements.

Based on our data, the average life cycle duration during one year from January to December 2016 was 37.55 days and the number of annual generations was nine with an average of 0.76 generation per month when the average annual temperature was 18.88ºC. For 2017 season, the average life cycle duration during one year was 36.33 days and the number of annual generations was nine with an average of 0.73 generation per month when the average annual temperature was 18.34ºC.

Our results reveal the occurrence of one generation during the winter which coincides with the maturation of different citrus varieties, this generation was the longest but with lowest number of population density of males.

Two generations took place in spring with an average duration of 35 days and an average of weekly number of 46.5 and 61.9 male / generation in 2016 and 2017 respectively. These two generations coincide with the maturation of Medlars, late verities of citrus, peaches.

The four generations that occurred in summer were the shorter (22 days) but with highest weakly mean number (242 and 271 male in 2016 and 2017 respectively. A multitude of host fruit is offered to the flies of these generations (Late peaches, plums, pears, cherries, figs ...).

Two generations took place in autumn with an average duration of 45 days and an average weakly number of population densities of 35 and 37.28 males in 2016 and 2017 respectively. These generations coincide with the ripening of fig fruits, prickly pears, quinces, and early varieties of citrus fruits.

The flight of adults of *C. capitata* is observed throughout the year in Mitidja with different densities of *C. capitata* populations which depend on the presence and diversity of host plants. Indeed, tephritid distribution and abundance depend on several abiotic factors (e.g., temperature, relative humidity, rainfall) and several biotic factors (e.g., host plants, natural enemies) (Vayssières et al. 2008).Weather conditions, temporal patterns of host fruit availability, and crop sanitation practices are all factors that can contribute to annual variations in *C. capitata* populations (Israely et al. 1997; De Villiers et al. 2013). The number of annual generations varies greatly depending on the availability of host fruit. According to Ali ahmed Saadoudi (2011), the population density of *C. capitata* depends on the presence and diversity of the host plants, climatic conditions as well as the geographical location of the orchards compared to neighboring orchards.

Oukil (1995) states that *C. capitata* develops up to 6 generations per year in Algeria. However, its complete development is very variable for the same region and depends on climatic factors, particularly temperature, as well as on the fruit species on which the eggs are laid (Khoury, 1998; Ramade, 2003). The development, survival and reproduction of fruit flies are also influenced by the species and quality of hosts, especially at the larval stage. Carey (1984) reported that larval development of *C. capitata* increased from 1 week in favorable hosts such as mango and tomato to more than 3 weeks in quinces. Kamala and Abraham (2002) noticed that the developmental time of *B. dorsalis* varies with the host fruit species. Compared with the artificial diet, the development of larva is slow in natural hosts, because of the quick depletion of food material due to faster ripening and subsequent spoilage of fruit (Kamala and Abraham, 2002).

Predicting of Mediterranean fruit fly, *C. capitata* annual generation peaks in the field were carried out by studying the relationship between the accumulated thermal heat units expressed as degree-days (DD's)and the population fluctuations of *C. capitata* males flies during the pe riod from early January to late December of 2016 and 2017.when comparison between the expected peaks as calculated required heat accumulation) and the observed ones (that occurred in the field) for each generation throughout two successive seasons of 2016 and 2017; We expect a total of about 9 generations *C. capitata.* Dates and duration of all estimated generations were paralleled also with obtained results of applying of day degree. These results revealed that number and duration of *C. capitata* generations coincide and agree with obtained results by applying day degree theory. Per previous results, it is worth noting to mention that it is better expected for good prediction that the period between expected dates and actual observed dates should be short as possible and it is preferable that the prospective peak took place before the actual one.

CONCLUSION

The importance of the Mediterranean fruit fly, *Ceratitis capitata* is linked to several factors, it attacks high value-added crops and fruits about to ripen. In Algeria, this pest evolves on different fruit species with a period of maturity which succeeds over time, such as citrus fruits, apricots, peaches and figs. The data obtained during these investigations are important to know more about the biology of *C. capitata* in our region and estimate the expected frequencies of annual generations in our region of study for proper insect management.

CONFLICT OF INTEREST

The authors declared that present study was performed in absence of any conflict of interest.

ACKNOWLEGEMENT

The authors thank the editors and reviewers for their valuable comments on this manuscript.

AUTHOR CONTRIBUTIONS

SC designed and performed the experiments and also wrote the manuscript. KB corrected language and revised manuscript. AB supervised the work. All authors read and approved the final version.

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