EFFECT OF CLIMATE CHANGE ON THE SPATIO-TEMPORAL DISTRIBUTION OF THE MEDITERRANEAN FRUIT FLY *CERATITIS CAPITATA* WIEDEMANN (1824) IN ALGERIA

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ABSTRACT

This study was carried out in order to determine the initial distribution of Mediterranean fruit fly *Ceratitis capitata* Wiedemann (1824) (Diptera, Tephrididae) in Algeria, the area now occupied and assess the role of climate change in determining its current distribution. The various surveys and trapping of adults indicate that in addition to the coastal, sub-coastal and Argan regions, this fly is also present in oases. It is reported in all the traditional oases where fruit trees are intercropped with date palm. From the 2000s, the area occupied by this fruit fly increased and spread into provinces where it was not previously reported. Gradually, it increased in abundance and became an important pest. The climate data recorded in the province of Batna (Aurès Mountains, Saharan Atlas) indicate there has been a change in climate. The annual and monthly average temperatures and relative humidity for the period 2000–2018, in this province became more favourable for this fruit fly than in the period 1913–1937, in particular, during the months of March, April, October and November. The results also indicate that in orchards where there are several types of fruit, the numbers of this fly are higher than where mainly apples are grown.

Keywords: climate change; initial area; recently colonized area; Tephritidae

Introduction

The original distribution of the Mediterranean fruit fly, *Ceratitis capitata* Wiedemann (1824) (Diptera, Tephrididae), has always been a subject of controversy. However, the studies of Malacrida et al. (1992) and Baruffi et al. (1995), using molecular biology techniques, confirmed that it is native to sub-Saharan Africa. Its appearance in the Mediterranean basin is fairly well documented and dated. It was reported in Spain shortly after 1840, around Algiers in 1858, Italy in 1860 and Tunisia in 1885 (Piguet 1960). Between 1920–1930, it colonized almost all of its current distribution (Piguet 1960). This fruit fly is present in many countries in Africa, Central and South America, the Mediterranean Basin and Australia (Quilici 1997). In North Africa, it occurs along the coast and in sub-coastal areas from Tunisia to Morocco (Balachowsky and Mesnil 1935; IAEA 1995). Based on its extreme polyphagia, it is considered to be one of the most economically important pests in the world. In fact, its host range includes more than 360 species of plants (Liquido et al. 1991). In the Mediterranean basin, it is considered to be the most harmful pest, especially in Maghreb countries (Algeria, Libya, Morocco and Tunisia) (IAEA 1995). The financial loss due to this pest in these countries is estimated to be US $60–90 million per year, of which US $7–10 million per year is spent on insecticides (IAEA 1995). In addition, a survey conducted in Morocco, evaluated the annual losses caused by this fly on the main fruit and *Citrus* crops at 53 422 200 DH (Aboussaid et al. 2009). In Tunisia, Boulahia-Kheder and Jerraya (2009) also consider this pest as the most important of several types of fruit, in particular, *Citrus*, peaches, figs and prickly pears and Jerraya (2003), estimates that the losses would be 90% of production in the absence of chemical treatments.

In Algeria, this fly was reported for the first time in 1858 (Balachowsky and Mesnil 1935) and is a major problem for the production and export of fruit (Oukil et al. 2002). In northern Algeria, the presence of *C. capitata* has been confirmed in all the coastal provinces, in particular, in Algiers (Oukil et al. 2002), Blida (Dridi 1990; Oukil et al. 2002), Tizi Ouzou (Sadoud Ali-Ahmed et al. 2011; Bachi and Sadoud Ali-Ahmed 2017), Jijel (INPV 2019), Annaba (Boudjelida and Soltani 2011), Oran (Oukil et al. 2002) and Tlemcen (Settaoui et al. 2017). In southern Algeria (Sahara), Oukil et al. (2002) report collecting specimens of this fly from apricots and oranges grown in the oases Djanet and Ghardaia. According to Laamari et al. (2015), this fly is always associated with fruit in coastal regions. In the interior provinces, with a semi-arid climate (cold winter and hot and dry summer), this pest is unknown despite the presence of its favourite hosts. Laamari et al. (2015) add that due to the effect of climate change in Algeria, especially from the 2000s, the distribution of this pest has increased. In addition to apricots, peaches, figs and pomegranates, very significant losses are reported for apples grown mainly in the mountainous areas of Batna and Khenchela (Aurès Mountains, northeast of Algeria). The objective of this study is to determine the distribution of this fly in Algeria before and after the increase by means of

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surveys and trapping of adults. In addition, a comparison of climatic data from the province of Batna during 1913–1937 and 2000–2018 was carried out, in order to determine the reasons for the increase in the distribution of this fly.

Material and Methods

Initial distribution area

In order to delimit the initial distribution of this fly in Algeria, the collection of fruit and trapping of adults was used in arid provinces where previously reported (Balachowsky and Mesnil 1935; Oukil et al. 2002) and in provinces with a semi-arid climate, where previously reported before the 2000s (Laamari et al. 2015).

The first part of this study was carried out during 1995–1997. During this period, fruit of *Prunus armeniaca* L., *P. domestica* L., *P. persica* L., *Ficus carica* L., *Pyrus communis* L., *Citrus sinensis* (L.), *Citrus reticulata* Blanco, *Citrus aurantium* L., *Punica granatum* L., *Eriobotrya japonica* (Thunb.), *Opuntia ficus-indica* L., *Malus communis* L., *Cydonia oblonga* Mill. and *Juglans regia* L., were collected and kept in cages until the adults emerged. This involved fruit collected from the oasis region (provinces of Biskra, El Oued, Ouargla and Ghardaïa) and provinces with a semi-arid climate (Tébessa, Oum El Bouaghi, Khenchela, Batna, M'sila, Laghouat and Djelfa).

In addition to collecting infested fruit, pheromone traps were set in two provinces. Four traps in two oases located at Guerara (province of Ghardaïa, Sahara) (32°49′09.68″N, 4°31′39.05″E, altitude: 296 m a.s.l.) during 1995–1997. These oases are characterized by very high catches. In addition to date palm, *Citrus*, fruit trees and vegetable crops, are grown there. During the same period, four traps were set in two apple orchards located at Ichemoul (province of Batna, Aurès Mountains, Saharan Atlas) (35°16′09.39″N, 6°26′41.05″E, altitude: 1203 m a.s.l.). The traps used are of type: AA-TRAP and the pheromone capsule was renewed every four weeks. The traps were checked once a week.

Recently colonized area

In order to delimit the area colonized by the Mediterranean fruit fly in Algeria in the 2000s, infested fruit was collected in the provinces where this fly did not previously occur. These are the provinces of Tébessa, Oum El Bouaghi, Khenchela, Batna, M'sila, Laghouat and Djelfa, located throughout the Saharan Atlas and characterized by a semi-arid climate. In addition, pheromone traps were set in two orchards in the province of Batna during 2014–2018. The first orchard was located at T'kout (35°7′44.30″N, 6°16′55.99″E, altitude: 934 m a.s.l.) and in which fig, apricot, pomegranate, peach, pear trees and prickly pear were cultivated. The second was located at Ichemoul (35°16′09.39″N, 6°26′41.05″E, altitude: 1203 m a.s.l.) in which there was mainly apple trees.

Effect of climate change

Among climatic factors, temperature and relative humidity are very important for the survival of the Mediterranean fly (Messenger and Flitters 1958; Shoukry and Hafez 1979; Delrio et al. 1986). Based on the requirements of the Mediterranean fruit fly, Bodenheimer (1951) delimits 4 zones: optimal (temperature 15–30 °C, relative humidity 75–85%), favourable (temperature 10–35 °C, relative humidity 60–90%), tolerance zone (temperature 2.5–40 °C, relative humidity 40–100%) and unfavourable (other values). Dajoz (1975) presents these zones graphically in the form of an eco-climagram for *C. capitata* (Fig. 1). If the annual or monthly average values of these climatic factors for a region is known then using an eco-climagram it is possible to determine the level of development of this fly. In order to assess the effect of climate change on changes in the distribution of *C. capitata* in Algeria, the data re-

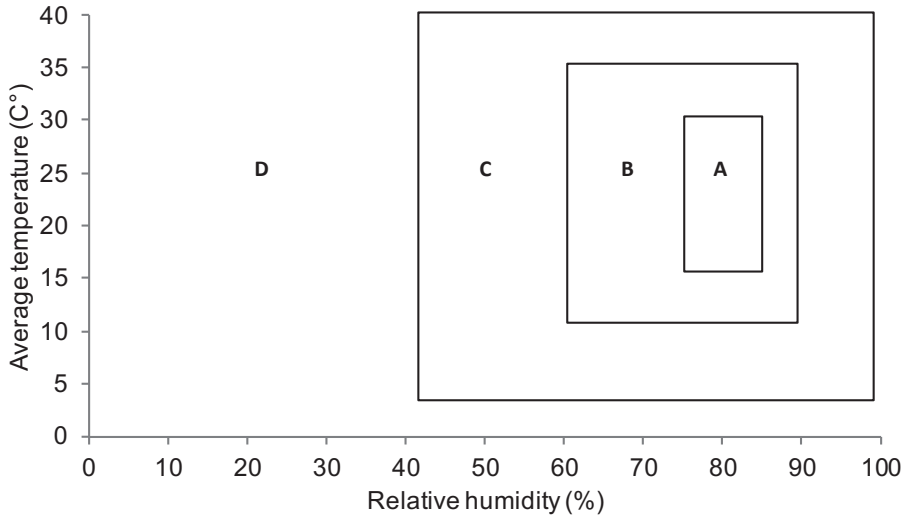

Fig. 1 Eco-climagram of *C. capitata* based on average temperature and relative humidity. A: Optimal zone, B: Favorable zone, C: Tolerable zone, D: Unfavorable zone (Dajoz, 1975).

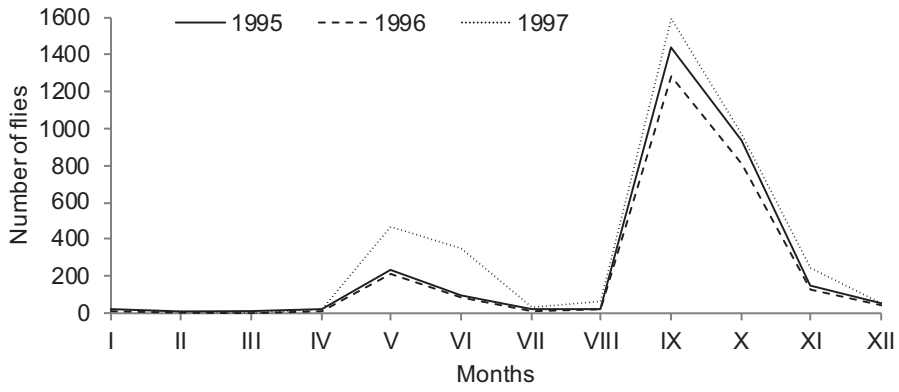

Fig. 2 Evolution of the average monthly number of *C. capitata* flies in the traps installed in the locality of Guerara (Provience of Ghardaia) during 1995–1997 (average per trap).

Fig. 3 Initial distribution of *C. capitata* in Algeria. Administrative code of the province: 07 Biskra, 09 Bilda, 13 Tlemcen, 15 Tizi Ouzou, 16 Algiers, 18 Jijel, 23 Annaba, 30 Ouargla, 31 Oran, 37 Tindouf, 39 El Oued, 47 Ghardaia, 51 Ouled Djellal, 55 Touggourt, 56 Djanet, 57 El M'ghaier, 58 El Meniaa.

corded in the province of Batna during 1913–1937 and 2000–2018, were compared. The first period is the earliest for which climatic data is available for Algeria (Seltzer 1946). The second period coincides with the occurrence of this fruit fly in this province. It should be noted that Batna is known as one of the coldest provinces in Algeria. It is part of the mountainous region of Aurès, where the cultivation of fruit trees is very old and most orchards are located at altitudes above 1000 m a.s.l.

Results

Initial distribution

The results obtained in 1995–1997 revealed that the Mediterranean fruit fly was present in all oases, where polyculture was practiced (Table 1). In addition to fruit trees and *Citrus*, melon was severely infested, but no other Cucurbitaceae or Solanaceae. In the provinces located throughout the Saharan Atlas, this pest was completely

Table 1 Crops infested with *C. capitata* during 1995–1997 in the regions of oases and the Saharan Atlas.

Regions	Oases	Saharan Atlas
Provinces	Ghardaïa, El Oued, Biskra, Ouargla, Djanet, Ouled Djellal, Touggourt, El M'Ghaier, El Meniaa	Tébessa, Oum El Bouaghi, Khenchela, Batna, M'sila, Laghouat and Djelfa
Infested plants	*Eriobotrya japonica* (Thunb.), *Prunus armeniaca* L., *Ficus carica* L., *Pyrus communis* L., *Citrus sinensis* (L.), *Citrus reticulata* Blanco, *Citrus aurantium* L., *Punica granatum* L., *Cucumis melo* L.	No infestation
Uninfested plants	*Phoenix dactylifera* L.	

Table 2 Annual average number of *C. capitata* in pheromone traps installed in the provinces of Ghardaïa and Batna during 1995–1997.

Regions	Oases			Saharan Atlas		
Provinces	Ghardaïa			Batna		
Localities	Guerara			Ichemoul		
Years	1995	1996	1997	1995	1996	1997
Average number of flies per trap	3003	2630	3840	0	0	0

absent. The pheromone traps set during 1995–1997 at Guerara (province of Ghardaïa), confirmed the presence of this fly in the Algerian oases and an annual average of 3840 flies / trap was recorded in 1997 (Table 2). It should be noted that this fly is present in this oasis throughout the year and is most active during the months of September (1596 flies) and October (965 flies) (Fig. 2). However, the pheromone traps set during the same period, at Ichemoul (province of Batna), caught no fruit flies (Tables 1 and 2). On the basis of these results and those already obtained by other authors in coastal, sub-coastal regions and natural stands of *A. spinosa*, the initial distribution area of the Mediterranean fruit fly in Algeria was delimited (Fig. 3).

Recently colonized area

In the 2000s, the first appearance of the Mediterranean fruit fly is reported in the provinces located throughout the Saharan Atlas. The infested fruit was apricot, peach, fig, pear, pomegranate, prickly pear and apple (Golden Delicious) (Table 3). The pheromone traps set in the province of Batna during 2014–2018, confirmed the presence there of this pest. Despite annual variations, the numbers caught are considered to be very large, especially in the orchard at T'kout. At this locality 9479 flies / trap was recorded in 2015 (Table 4). A maximum of 4450 flies / trap was recorded in August, or about 1113 flies per week or 36 flies per day (Fig. 4). In the apple orchard at Ichemoul, this fly was less abundant than that recorded in the previous locality. The overall number did not exceed 354 flies per trap in 2018 (Table 4). About 85% of this number was caught in September (123 flies) and October (179 flies), which coincides with the maturity of the apples (Golden delicious) (Fig. 5). The results obtained in the 2000s were used to determine the area recently colonized by the Mediterranean fruit fly in Algeria (Fig. 6).

Effect of climate change

Comparison of the climatic data from the Batna meteorological station for the periods 1913–1937 and 2000–2018, revealed marked differences (Figs 4, 5 and 6). The average annual temperature was 1.5 °C higher in the second period, while precipitation decreased by 80 mm. Relative humidity also increased by 10.5%. Based on the annual average temperature and relative humidity, the eco-climagram of this fly in province of Batna changed from a zone of tolerance (1913–1937) towards

Table 3 Crops infested with *C. capitata* in the provinces located throughout the Saharan Atlas from the 2000s.

Region	Saharan Atlas
Provinces	Tébessa, Oum El Bouaghi, Khenchela, Batna, M'sila, Laghouat et Djelfa
Infested plants	*Prunus armeniaca* L., *Prunus persica* L., *Ficus carica* L., *Pyrus communis* L., *Punica granatum* L., *Opuntia ficus-indica* L., *Malus communis* L. variety Golden Delicious and occasionally the variety Royal Gala
Uninfested plants	*Malus communis* (L.) variété Starkrimson, *Cydonia oblonga* Mill., *Prunus domestica* L., *Juglans regia* L.

Table 4 Number of *C. capitata* in pheromone traps installed in the province of Batna during the period 2014–2018.

Region	Saharan Atlas									
Province	Batna									
Localities	T'kout					Ichemoul				
Years	2014	2015	2016	2017	2018	2014	2015	2016	2017	2018
Average number of flies per trap	8435	9479	5894	6509	7750	302	274	240	261	354

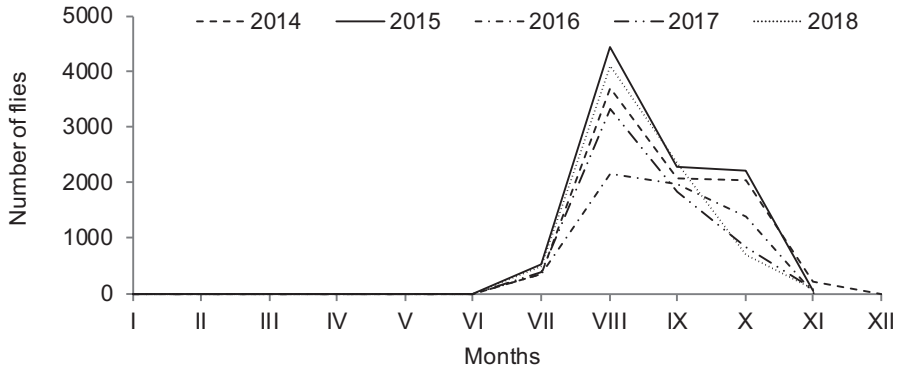

Fig. 4 Evolution of the average monthly of *C. capitata* in the traps installed in the locality of T'kout (Province of Batna) during the period 2014–2018 (average per trap).

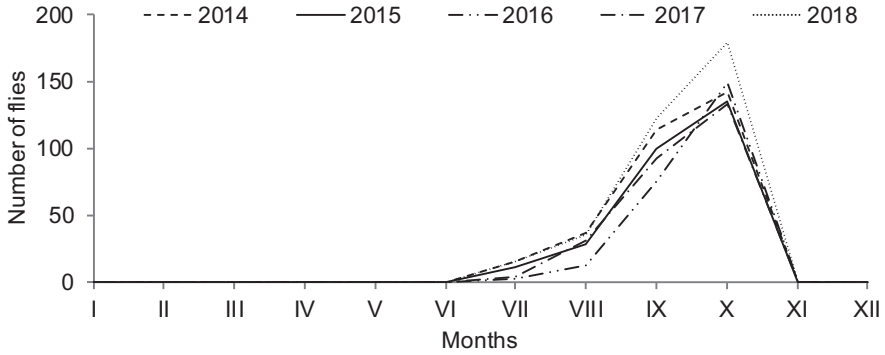

Fig. 5 Evolution of the average monthly numbers of *C. capitata* in the traps installed in the locality of Ichemoul (Province of Batna) during the period 2014–2018 (average per trap).

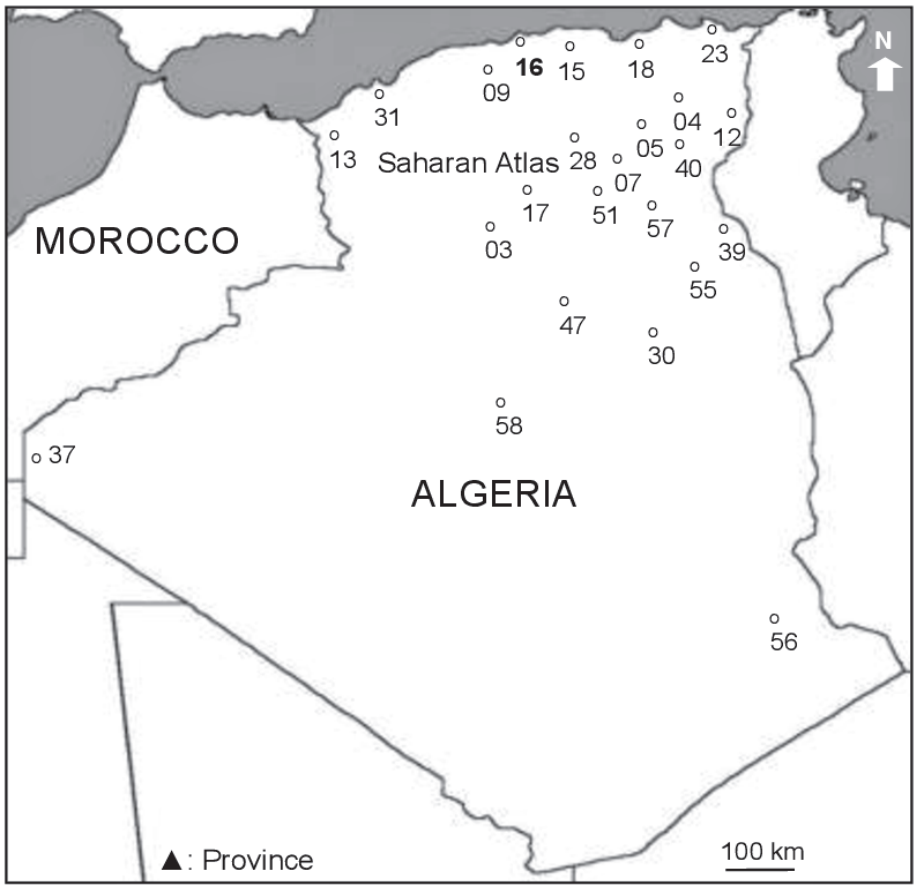

Fig. 6 New distribution area of *C. capitata* in Algeria. Administrative code of the province: 03 Laghouat, 04 Oum El Bouaghi, 05 Batna, 07 Biskra, 09 Bilda, 12 Tébessa, 13 Tlemcen, 15 Tizi Ouzou, 16 Algiers, 17 Djelfa, 18 Jijel, 23 Annaba, 28 Msila, 30 Ouargla, 31 Oran, 37 Tindouf, 39 El Oued, 40 Khenchela, 47 Ghardaia, 51 Ouled Djellal, 55 Touggourt, 56 Djanet, 57 El M'ghaier, 58 El Meniaa.

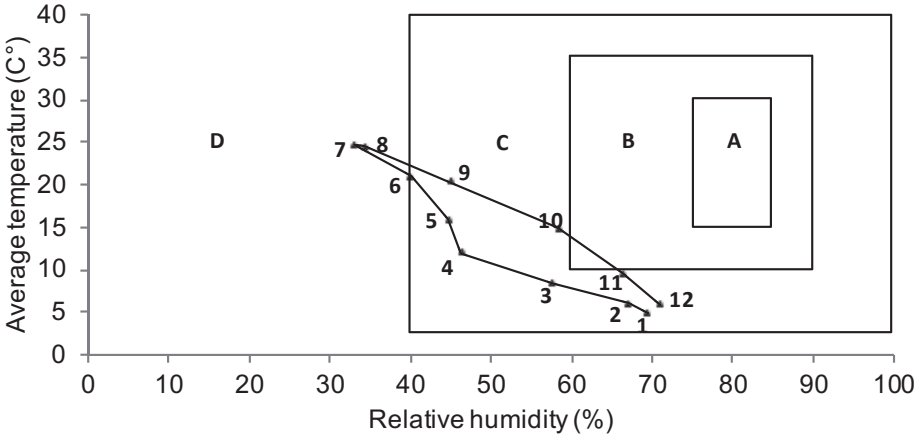

Fig. 7 Location of monthly average temperature and relative humidity values for Batna during 1913–1937 in the eco-climagram of *C. capitata*. A: Optimal zone, B: Favorable zone, C: Tolerable zone, D: Unfavorable zone, 1, 2, 3 … months.

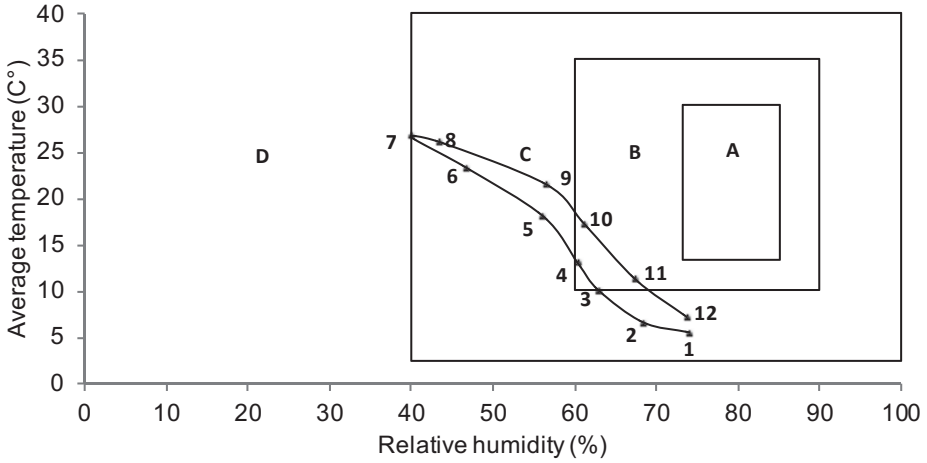

Fig. 8 Location of monthly average temperature and relative humidity values for Batna during 2000–2018 in the eco-climagram of *C. capitata*. A: Optimal zone, B: Favorable zone, C: Tolerable zone, D: Unfavorable zone, 1, 2, 3 … months.

favourable (2000–2018), especially in March, April, October and November (Figs 7 and 8).

Discussion

According to Balachowsky and Mesnil (1935); Oukil (1995); Sadoud-Ali Ahmed et al. (2011) and Settaoui et al. (2017), the Mediterranean fruit fly occurs in the coastal and sub-coastal region in Algeria, where the climatic and nutritional conditions are favourable for its proliferation. In these regions, with a Mediterranean climate, it attacks mainly oranges, mandarins, peaches, apricots, figs and medlars and it can complete up to 6 generations per year (Balachowsky and Mesnil 1935). In the Sahara, this fly is also present at the Algerian-Moroccan border where it infests the Argan tree (*Argania spinosa* L.), which is its natural host (Zhar et al. 2013). In Tunisia, this fly is reported occurring in oases by Ben Chaaban et al. (2018) and in Algeria for the first time. Its damage to 9 crops was reported in different provinces surveyed during 1995–1997. Very large numbers were also caught by pheromone traps in 1997 in a traditional oasis at Guerara (Ghardaïa). Despite the hot and dry climate of the Sahara, this pest occurs in these oases, where the microclimate is favourable for its development. It is even reported in the province of El Oued on *Capsicum annuum* cultivated in glasshouses (Mostefaoui et al. 2020). In addition, the different crops in these oases mature at different times, which enables this pest to reproduce continuously. Date palm, in particular, the variety Deglet Nour the main variety grown in these regions was not attacked. During the same period, this pest was not recorded during surveys and trapping in the provinces throughout the Saharan Atlas. Apparently, the semi-arid climate, characterized by a cold winter and a hot and dry summer in these provinces was unfavourable for this fly at that time.

From the 2000s, the first cases of fruit infestations by this pest were reported in provinces in the Saharan Atlas and have become increasingly important. Surveys and trapping, confirmed that this pest had spread into provinces in the Saharan Atlas and was infesting 7 types of fruit in all the provinces surveyed. The infestation can affect the whole production if it is harvested when the fruit is mature. In the Batna and Khenchela provinces, if the apples (Golden Delicious) are not stored in cold rooms,

this pest can destroy the entire harvest. Laamari et al. (2015) report that attacks by this fly in recently infested provinces (Batna and Khenchela) have reached alarming levels of an average of 10 larvae per fruit. During mild years, this fly can infest orchards located at 1600m. On the other varieties of apple attacks are very rare (Royal Gala) or not recorded (Starkrimson). Pomegranate and fig are the most affected. It is very rare to find an uninfected pomegranate in the market. All preserved fruit take one to two days to mummify. Pomegranate and fig are the most affected. It is very rare to find uninfected pomegranates in the market as their mummification takes a few days. In addition, the numbers of this fly caught in traps placed in the province of Batna were very high, in particular at T'kout. In this orchard there are several types of fruit. The number of individuals per trap in this orchard exceeded those reported by Sadoud-Ali Ahmed et al. (2011) (4590 flies) and Settaoui et al. (2017) (781 flies) in the coastal regions and in the traditional oasis at Guerara (3838 flies). In addition to suitable hosts that mature at different times, the presence of *Opuntia* at the edges of this orchard have enabled this fly to thrive. The fruit of *Opuntia* can be exploited by this fly (reservoir host) when other suitable fruit is not available. In Tunisia, Jerraya (2003) where *Opuntia* is abundant this fly reproduces continuously. In the orchard at Ichemoul, where there are only apple trees, the numbers of this fly caught by traps were lower. Apparently, at this locality, the absence of hosts that can harbour this fly during the period prior to the maturity of the apples is responsible for the lower abundance of this pest there than at the first orchard. These results are used to define the distribution of this fly in Algeria in the 2000s.

In order to understand the reasons for the change in the behaviour of this fly, the climatic data for the province of Batna was analysed. Comparison of the old (1913–1937) and recent (2000–2018) climatic data revealed a marked increase in the temperature and decrease in precipitation in this province. Despite this, the relative humidity has increased. It may be that the increase in cultivated and irrigated areas, construction of new dams and storage of water in basins has contributed to the increase in humidity in summer and autumn over the last few years. Based on the eco-climagram proposed by Dajoz (1975) the annual average values of temperature and relative humidity for the years 1913–1937, indicate that the province of Batna was a tolerance zone for development of this fly. The monthly data for these two climatic parameters for the months of June, July and August were in the unfavourable zone. Conversely, the data for the years 2000–2018 placed the province of Batna in the favourable zone especially in the months of March, April, October and November. If during the first two months, the fly resumes activity after winter diapause, the other two months coincide with the maturity of late varieties of apple, fig and all varieties of pomegranate. In addition to the increase in the area reserved for arboriculture, it is clear that the change in climate that has occurred in these provinces in the Saharan Atlas has favoured the spread of this pest. In the provinces recently infested with this pest, farmers cannot control it. The oviposition by this pest generally goes unnoticed and it is only after harvesting that its presence becomes apparent. It continues to seriously threaten fruit production in these regions.

Conclusion

The rearing of this pest from infested fruit and the sexual trapping of adults, started in 1995 in Algeria and initially confirmed the presence of *C. capitata* in the oasis region and absence in the provinces in the interior, located in the Saharan Atlas. In addition, the second part of the study started in the 2000s, just after the reports of the first cases of infestation of fruit in other provinces, confirmed that the distribution of this fly in Algeria had changed. It spread into the Saharan Atlas region, where the climate is semi-arid. The pheromone traps set in the province of Batna during the years 2014–2018 highlighted the abundance there of this fly, especially in orchards where there several types of fruit were grown rather than a single species (apple tree). The meteorological data for this province revealed that the climate was warmer and drier in 2000–2018. In order to assess the effect of this change in climate, the annual and monthly average values of temperatures and relative humidity were plotted on the eco-climagram for this fly. The results revealed that compared with the old data (1913–1937) this province became more favourable for the development of this fly in 2000–2018, in particular, during the months of March, April, October and November.

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REFERENCES

Aboussaid H, El Messoussi S, Oufdou K (2009) Activité insecticide d'une souche marocaine de *Bacillus thuringiensis* sur la mouche méditerranéenne: *Ceratitis capitata* (Wied.) (Diptera: Tephritidae). Afr Sci. doi: 10.4314/afsci.v5i1.61719.

Bachi K, Sadoud- Ali Ahmed D (2017) Effect of citrusessential oils on the larvae evolution of *Ceratitis capitata* Wied. 1824 (Diptera: Tephritidae). Biosci Res 14: 686–693.

Balachowsky AS, Mesnil L (1935) Les insectes nuisibles aux plantes cultivées. Busson, Paris.

Baruffi L, Damiani G, Guglielmino CR, Bandi C, Malacrida AR, Gasperi G (1995) Polymorphism within and between populations of *Ceratitis capitata*: Comparison between RAPD and multilocus enzyme electrophoresis data. Heredity 74: 425–437.

Ben Chaaban S, Mahjoubi K, Ben Maachia S, Nasr N (2018) Evaluation de la lutte intégrée basée sur le système de piégeage de masse Cera Trap® et Moskisan® contre *Ceratitis capitata* (Diptera: Tephritidae) sur agrumes dans les oasis Tunisiennes. J New Sci 57: 3707–3715.

Bodenheimer FS (1951) The Mediterranean fruit fly (*C. capitata* Wied.). In: Junk W (ed) Citrus Entomology in the Middle East. Gravenhage, Netherlands, pp 1–43.

Boudjelida H, Soltani N (2011) Pathogenicity of *Metarhizium anisopliae* (Metsch) on *Ceratitis capitata* L. (Diptera: Tephritidae). Ann Biol Res 2: 104–110.

Boulahia-Kheder S, Jerraya A (2009) Premiers résultats sur la capture de masse en tant que moyen alternatif de lutte contre la mouche méditerranéenne des fruits *Ceratitis capitata* (Diptera: Tephritidae) en Tunisie. Ann INRAT 82: 168–180.

Dajoz R (1975) Précis d'écologie. Dunod, Paris.

Delrio G, Conti B, Crovetti A (1986) Effect of abiotic factors on *Ceratitis capitata* (Wied.) (Diptera: Tephritidae). Egg development under constant temperatures. In: Proceedings of the of the CEC/IOLB 'ad-hoc meeting Hamburg'. 23 August 1984.

Dridi B (1990) Etude de quelques aspects de la biologie de la mouche méditerranéenne des fruits *Ceratitis capitata* Wiedmann (Diptera, Trypetidae). Différence entre souche d'élevage et population sauvage provenant d'Algérie. PhD thesis, Aix-Provence University, Marseille.

IAEA (1995) Economic evaluation of damage caused by, and methods of control of, the Mediterranean fruit fly in the Maghreb. An analysis covering three control options, including the sterile insect technique. IAEA, Vienna, Austria.

INPV (2019) Bulletins agricoles: Cératite des agrumes (*Ceratitis capitata*). INPV, Constantine, Algérie.

Jerraya A (2003) Principaux nuisibles aux plantes cultivées et des denrées stockées en Afrique du Nord. Climat Pub, Tunis, Tunisie.

Laamari M, Mahmoudi R, Talbi Y (2015) *Ceratitis capitata*: une nouvelle menace pour le pommier en Algérie. Bulletin OEPP/EPPO Bulletin 45: 207–208.

Liquido NJ, Shinoda LA, Cunningham RT (1991) Host plants of Mediterranean fruit fly: an annotated world review. Ann Entomol Soc Am 77: 1–52.

Malacrida A, Guglielmino CR, Gasperi G, Baruffi L, Milani R (1992) Spatial and temporal differentiation in colonizing populations of *Ceratitis capitata*. Heredity 69: 101–111.

Messenger PS, Flitter NE (1958) Effect of constant temperature environments on the egg stage of three species of Hawaii a fruit flies. Ann Entomol Soc Am 51: 109–119.

Mostefaoui O, Sekour M, Balmès V, Benhalima-Kamel M (2020) Emergence de *Ceratitis capitata* (Diptera: Tephritidae) sur culture protégée du piment (Solanaceae) en zone subsaharienne. Bulletin OEPP/EPPO Bulletin 50: 572–575.

Oukil S (1995) Effet des insecticides et des radiations ionisantes en relation avec la variabilité de *Ceratitis capitata* (Diptera: Trypetidae). PhD thesis, d'Aix-en Provence University, Marseille.

Oukil S, Bues R, Toubon JF, Quilici S (2002) Allozyme polymorphism in populations of *Ceratitis capitata* from Algeria, the northwestern Mediterranean coast and Reunion Island. Fruits 57: 183–191.

Piguet P (1960) Les ennemis animaux des agrumes en Afrique du Nord. Société Shell, Algérie.

Quilici S (1997) La mouche méditerranéenne des fruits ou cératite, *Ceratitis (Ceratitis) capitata* (Wiedmann) (Diptera: Tephritidae), nom anglais: Mediterranean fruit fly. Fiches techniques sur les ravageurs des cultures dans l'océan indien. CIRAD, Montpellier.

Sadoud Ali-Ahmed D, Soltani N, Kellouche A, Sadoudi R (2011) Fluctuating populations of *Ceratitis capitata* Wied. 1824 (Diptera; Trypetidae) in Kabylian orchards using various traps. Int J Agri Sci 1: 75–84.

Seltzer P (1946) Le climat de l'Algérie. Carbonel, Alger.

Settaoui S, Taibi A, Hammadi F, Doumandji S (2017) Infestation des agrumes par la mouche méditerranéenne des fruits *Ceratitis capitata* (Wiedemann, 1824) (Diptera, Trypetidae) à Tlemcen, Algérie. A J Arid Environ 7: 102–110.

Shoukry A, Hafez M (1979) Studies on the biology of Mediterranean fruit fly, *Ceratitis capitata*. Entomol Exp Appl 26: 33–39.

Zhar N, Naamani K, El Keroumi A, Baaziz M (2013) Recherche sur quelques aspects de réaction de défense de l'Arganier à l'attaque par *Ceratitis capitata*. In: Acte du 2ème Séminaire International de l'Arganier, Agadir, Maroc, pp 95–98.