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Monitoring and control of the date moth *Ectomyelois ceratoniae* (Lepidoptera: Pyralidae) in a citrus orchard in El Alia region (Bizerte, Tunisia)

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Abstract
In El Alia region damages caused by the date moth *Ectomyelois ceratoniae* in a citrus grove were reported since 2008. So, this study targeted to monitor this pest during three agricultural campaigns and to evaluate different treatments to control it. The results showed that this moth evolved in four to five generations according to the crop year and was active from April to early December. Besides, damages caused by this lepidoptera reached 50%. Moreover, only three tested treatments (Spinosad, Indoxacarb and Abamectin) could reduce this pest population, but the Spinosad was the highly effective substance.

Keywords: El Alia, citrus, date moth, Spinosad

1. Introduction
In Tunisia, the agricultural sector occupies an important place in the economy where the citrus sector revenues account for over 10% of gross domestic product [1]. The areas devoted to citrus fruits are mainly concentrated in Cap Bon region with more than 70% of the national citrus production where the Navel orange group constituted 30% of the total citrus production [2, 3].
Bizerte governorate is situated in the north of Tunisia and is essentially a cereal, fodder and vegetables crop production region [2]. Recently, citrus sector was developped in this locality. Indeed, it participated by 5% of the total national citrus production in 2020, where the Navel orange group represented 20% of the total citrus production in this governorate [3].
However, citrus cultivation is negatively affected by several enemies. In Tunisia, Navel oranges fruits are threatened by a lepidopteran pest known as the date moth, *Ectomyelois ceratoniae* (Zeller) (Lepidoptera: Pyralidae: Phyticitinae) since 2008 [4]. Its larvae bore into developing citrus fruits and feed on the pulp causing the necrosis of the main axis, a premature yellowing and abscission of the citrus fruit. In the Mediterranean bassin, this moth was initially known as a pest of stored commodities such as pods of the carob tree (Fabaceae: *Ceratonia siliqua*) and dates of the palm tree (Arecaceae: *Phoenix dactylifera*). Besides this pest is attacking various botanical families such as figs (Moraceae: *Ficus carica*) and pomegranates (Punicaceae: *Punica granatum*), moreover to host plants belonging to Anacardiaceae and Rosaceae families. Furthermore, in this latter area, Rutaceae fruits are widely infested by this pest, in fact, Serghiou (1983) [5] indicated the presence of this moth in citrus groves attacking grapefruits (*Citrus paradisi*) in Cyprus. While, in Egypt, *E. ceratoniae* was reported infesting oranges (*Citrus sinensis*) and grapefruits [6]. In addition, this pyralid is causing damages on the navel group of oranges in Turkey [7]. To control this moth, several biological management strategies were adapted thanks to essential oils mainly under controlled conditions [8, 9]. Besides to releases of Hymenoptera parasitoids recognized as natural enemies of *E. ceratoniae* belonging to the families of Braconidae (*Habrobracon hebetor*, *Phanerotoma ocuralis*) and Trichogrammatidae (*Trichogramma carverae*) in Tunisian palm dates, pomegranates and citrus orchards [10, 11, 12, 13].
Thus, this work aimed to study the flight periods of this pest. Besides, in the absence of active substances registered on the date moth on citrus, this work aimed to test different products registered on other lepidopteran pests, on the reduction of the date moth infestation rate in the Thomson orange orchard.

2. Materials and Methods

2.1 Experimental field

The experimental field (37°10'08"N, 10° 02' 08"E) was localized in "El Alia" (Bizerte governorate) and covered an area of 3.5 hectares. The citrus variety considered for this study was "Thomson Navel". The planting density was of 6m x 4 m conducted in drip irrigation system. The neighboring plot was planted with pomegranates.

2.2. Insect monitoring

The monitoring was carried from April 2nd, 2010, to December 6th 2012. Sex pheromone Delta traps (ISCA Technologies) were used at a density of two traps per hectare. A total of eight traps were installed in this field and pheromone capsules were replaced monthly.

2.3. Population structure and assessment of damages

In order to determine the population structure of *E. ceratoniae* and to evaluate the damages caused by this pest, a random sample of 20 fruits was brought back to the laboratory and examined under a binocular microscope (Leica® model MS5) weekly from August to December.

2.4. Applied treatments

Four active substances were applied in two repetitions on September 06th and October 10th, 2012 as indicated in (Tab. 1). The number of considered treated trees was 6 for each treatment. To evaluate the treatments efficacy, 20 fruits were randomly recuperated the day of the treatment's applications then 7, 14 and 21 days after.

The treatments' efficacies were calculated according to the Abbott's formula [14]: [(C-T)/C] x 100, with C: number of alive individuals in control, and T: number of alive individuals in treatments.

Table 1: Applied treatments in El Alia citrus field

Active substances	Doses (cc/hl)
Spinosad (240 SC)	50
Indoxacarb (150 SC)	60
Abamectin (EC)	60
Lufenuron +Fenoxycarb (105 EC)	200

2.5. Climatic data

The climatic data were given by the Tunisian Meteorological Institute. In El Alia, the lowest temperatures were recorded in January 2010 and February 2011 and 2012 with 12.1, 11 and 11 °C respectively. While the highest ones were recorded in July 2010 and 2011 and August 2012 with 26.6, 28.8 and 30 °C respectively.

Concerning the relative humidity averages, it ranged from 58 to 76, 56 to 75 and 65 to 82% in 2010, 2011 and 2012 respectively (Tab.2).

Table 2: Climatic conditions in El Alia (Average years 2010, 2011 and 2012)

	2010		2011		2012	
	T (°C)	RH (°/°)	T (°C)	RH (°/°)	T (°C)	RH (°/°)
January	12.1	76	11.9	74	14	79
February	12.6	71	11	73	11	79
March	14.2	71	12.9	73	14	82
April	16.3	76	16.5	69	17	81
May	19.3	65	19.6	65	20	74
June	22.7	63	23	62	26	68
July	26.6	61	26.8	56	28	68
August	26.5	58	26.6	56	30	65
September	24	63	25	65	26	73
October	20.6	66	20.5	67	23	79
November	16.6	70	17	74	19	79
December	13.3	71	13.8	75	15	73

T: Temperature °C, and RH: Relative Humidity (°/°).

2.6. Statistic analyses

Variables evaluated the control efficacy of insecticides. One-way ANOVA was used to determine the statistical difference among treatments at each sampling date, followed by Duncan's test. Results were considered significant at $p<0.05$. All statistical analyses were performed using SPSS v. 16.0 software.

3. Results and Discussion

3.1. Insect monitoring

The monitoring of the date moth during 3 agricultural campaigns is illustrated in (Fig.1). It was noticed, for the whole surveillance period that the first adult flights were recorded in April then 4 to 5 generations succeeded until the end of November where the most harmful ones were observed. The most important peaks reached an average of 2.25, 2 and 3.25 captured adults per trap on 15th October 2010, 20th October 2011 and 1st November 2012 respectively.

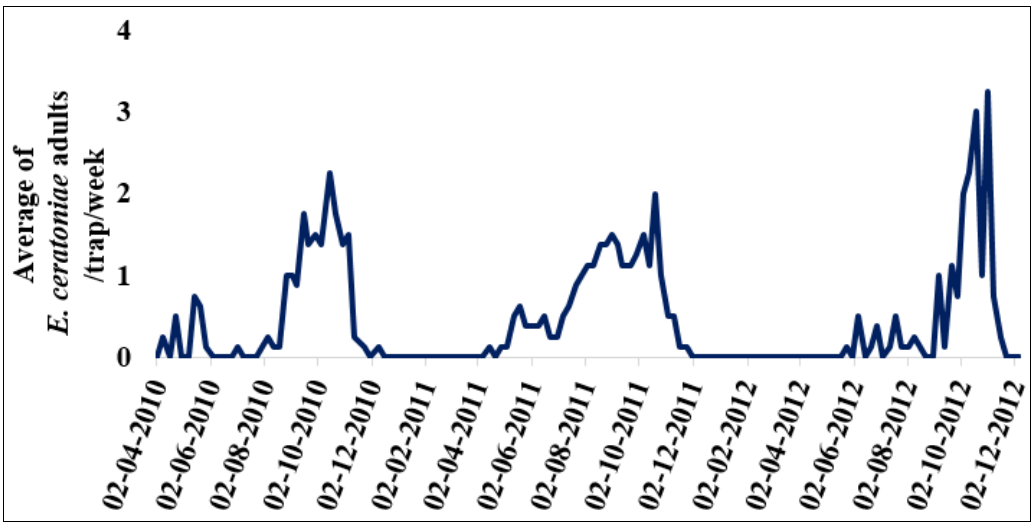

Fig 1: Average of the date moth adults/trap/week during 3 agricultural campaigns in El Alia citrus field

We also noted that the catch rates in peripheral traps, installed on the side of the neighbouring pomegranate plot, were more important than the further ones (Fig.2). In fact, the most important peaks were 3.5, 3.5 and 5.5 for the peripheral traps in 2010, 2011 and 2012 respectively whereas they don't exceed 2, 1.5 and 2.5 for the same dates in the further traps.

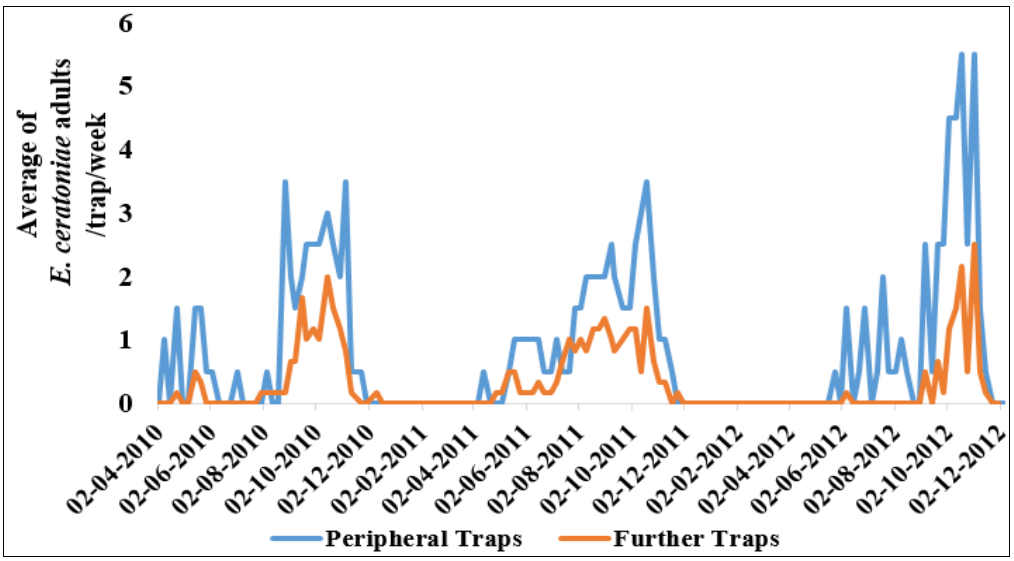

Fig 2: Comparison of *E. ceratoniae* adults average between peripheral and further traps during 3 agricultural campaigns in El Alia citrus field

This study revealed that the imagine population of the date moth is characterized by 4 to 5 flight periods from April to the end of November in El Alia citrus field. In Tunisia, previous studies demonstrated that *E. ceratoniae* evolved in four and five generations on pomegranate and palm date respectively [15, 16]. However, in Tunisian Thomson orange orchards situated in Morneg locality, it was demonstrated that the date moth flight periods ranged between 4 and 6, besides the most important peak was detected in October which corresponds to the last generation of the pest before overwintering and which coincides with orange's ripening period [17, 18, 12].

Furthermore, this study demonstrated the influence of the planted crop in the neighbouring plot in raising catch adult number in traps. This finding could be explained by the study of Hached *et al.*, (2020) [19] which demonstrated the absence of *E. ceratoniae* specimens' genetic specificity collected either from pomegranates or citrus. Thus, the plantation of these crops in neighbouring plots must be avoided.

These results showed that the flight periods of the date moth varied according to the host plant, the biotope, and the climatic conditions.

3.2. Population structure and assessment of damages

For 2011, the population structure on the fruits collected from trees was mostly composed with eggs and young larval stages (L1+L2+L3) from mid-August to early November (Fig 3). Then, since mid-November, the old larval stages (L4+ L5) were more abundant. Whereas chrysalids didn't exceed 10% on these fruits.

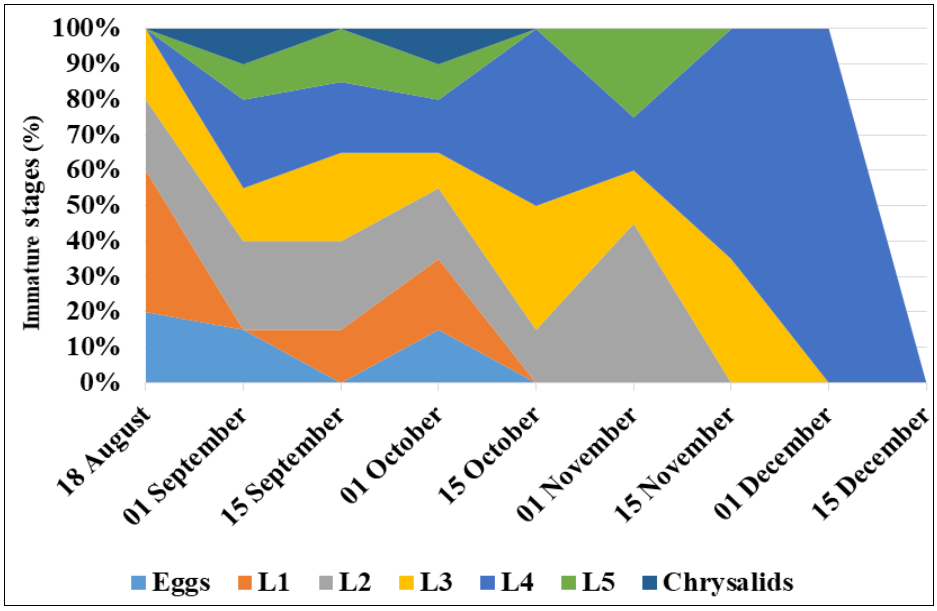

Fig 3: *E. ceratoniae* population structure on fruits collected from citrus trees in 2011

Regarding the fallen fruits (Fig 4), the absence of eggs was noticed for the whole surveillance period. The young larval stages were more abundant from mid-August to early November. Since that period, the old larval stages become more important. Whereas chrysalides were present during the whole surveillance period and became more abundant in Mid-December.

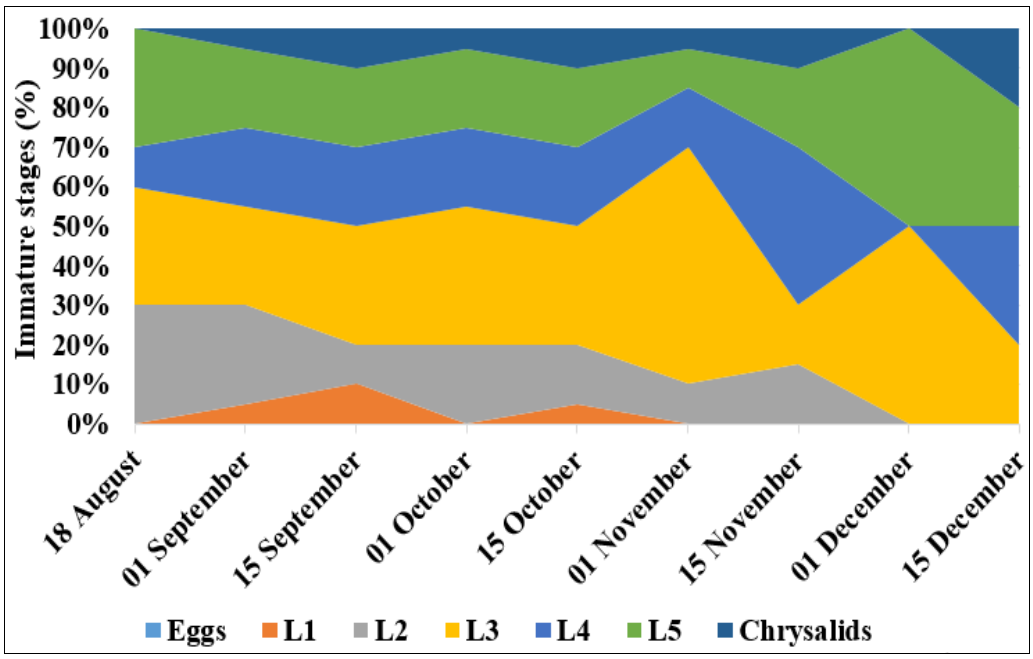

Fig 4: *E. ceratoniae* population structure on fruits collected from the field ground in 2011

Concerning *E. ceratoniae* infestation rate, it increased significatively since mid-August from 10 to 50% in mid-October for the fruits on trees. Whereas, on fallen fruits, the infestation rate raised considerably from 15% in mid-August to 80% in mid-November (Fig 5).

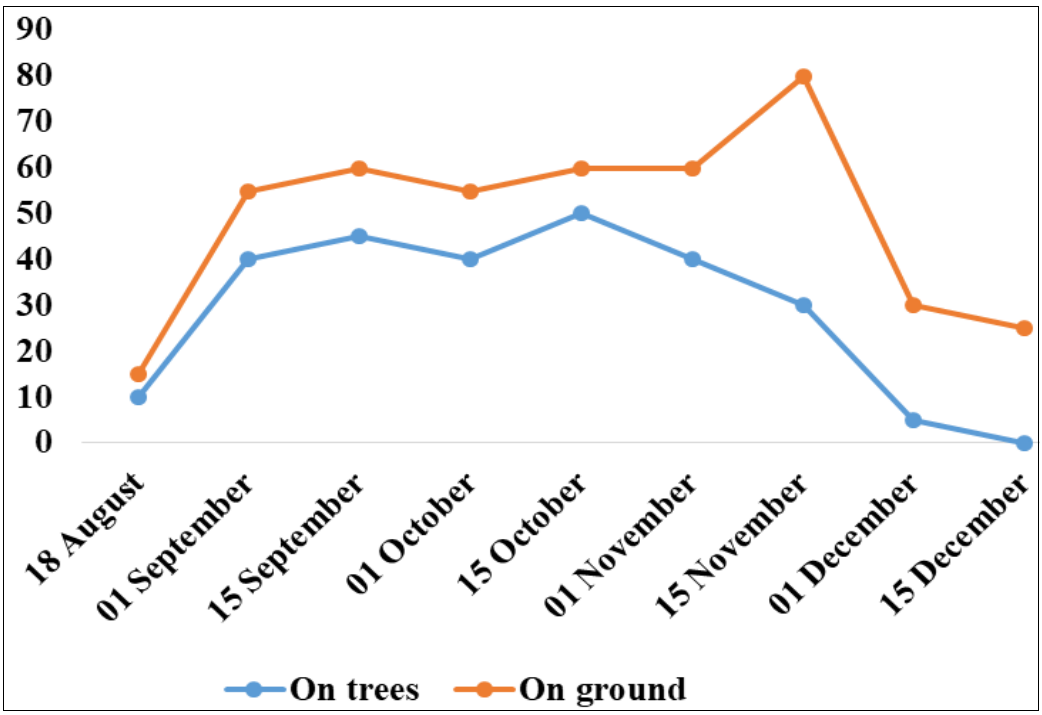

Fig 5: *E. ceratoniae* infestation rates on fruits collected from the citrus trees and fallen ones on the ground from mid-August to mid December 2011

For 2012, the population structure of *E. ceratoniae* on citrus fruits collected from trees showed that eggs and young larval stages (L1+L2+L3) were more abundant from mid-August to mid-October. Since that period, the percentage of old larval stages (L4+L5) and chrysalids became more important and reached 30% in early November (Fig 6).

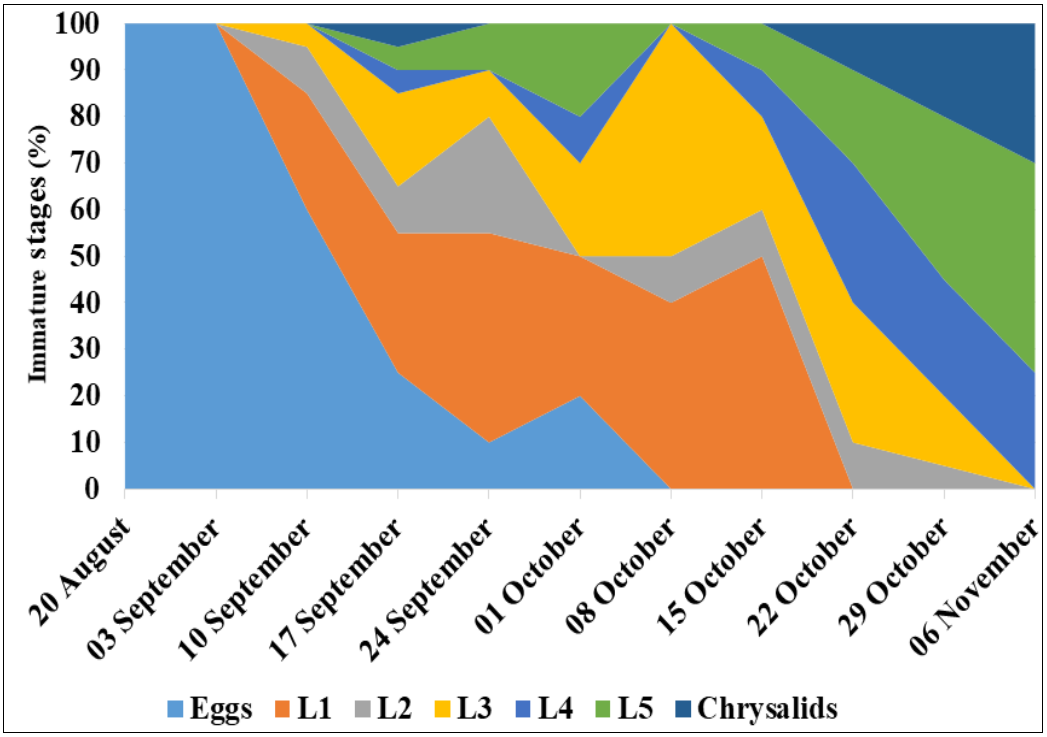

Fig 6: *E. ceratoniae* population structure on fruits collected from citrus trees in 2012

The (Fig 7) showed that the attacked fruits collected from the field ground didn't shelter eggs for the whole surveillance period, whereas the percentage of young larval stages was more important from mid-August to the first week of October. However, the old larval stages were abundant and their percentage ranged between 40 and 70% from the first week of September to the first week of November. Besides, the nymphal stage percentage was more important since the end of October to reach 30% on the first week of November.

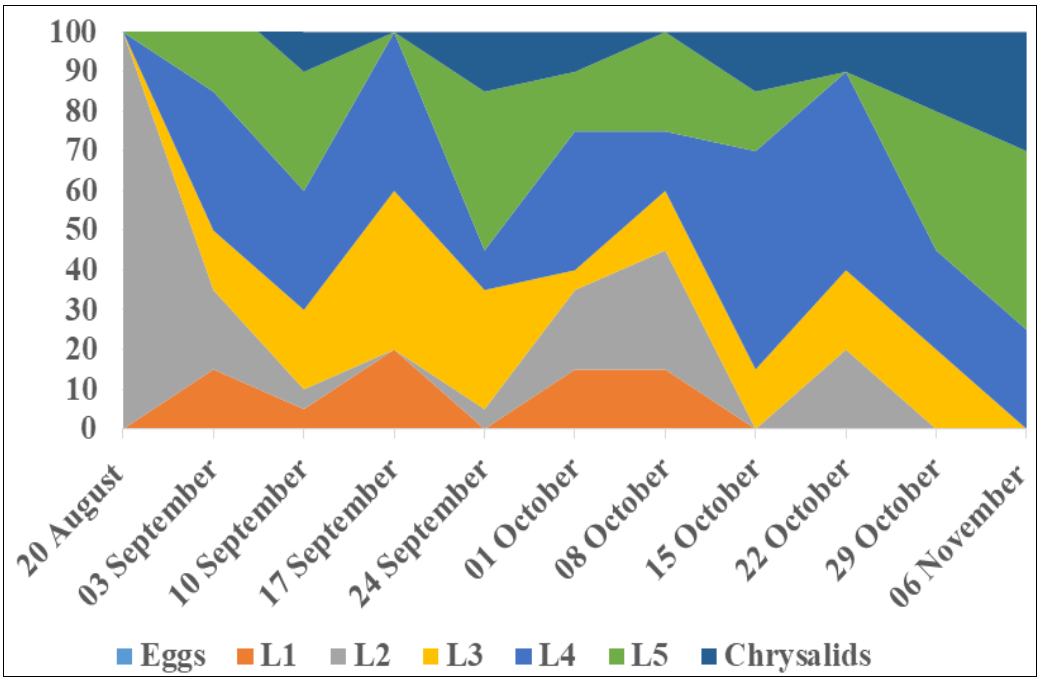

Fig 7: *E. ceratoniae* population structure on fruits collected from the field ground in 2012

The (Fig 8) showed that *E. ceratoniae* infestation rate increased significatively for the fruits on trees from 0 on August 20th to 30% on September 10th, October 22^{nd,} and November 6th. However, on the fallen fruits, the infestation rate increased considerably from 5% on August 20th to 45, 50 and 50% on September 24th, October 22nd and November 15th respectively.

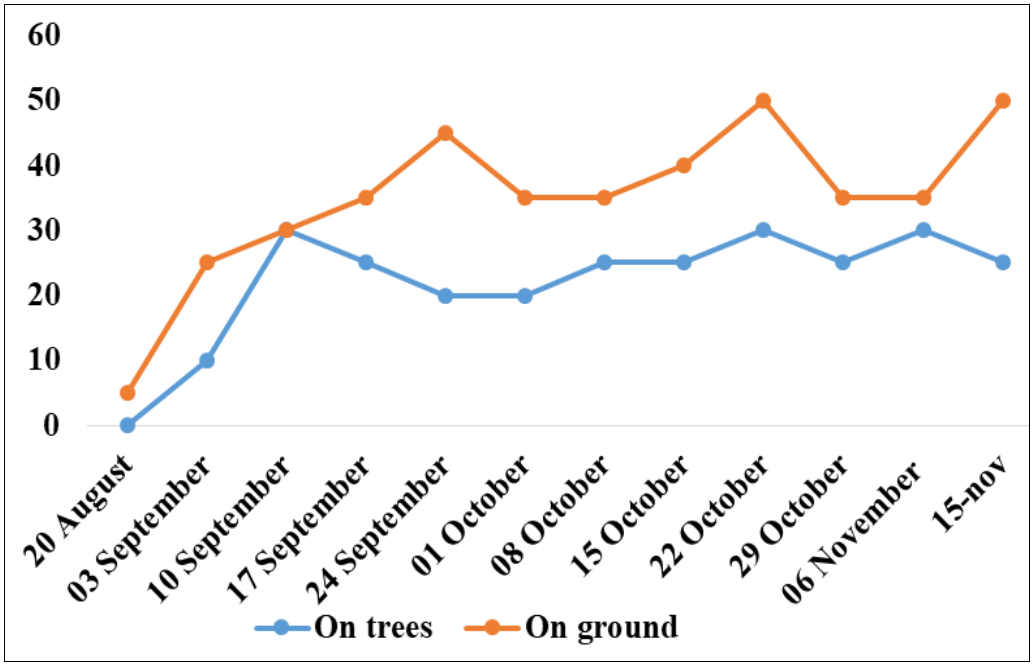

Fig 8: *E. ceratoniae* infestation rates on fruits collected from the citrus trees and fallen ones on the ground from mid -August to mid-November 2012

The determination of *E. ceratoniae* population structure and infestation rates for 2011 and 2012 revealed that, the fruit attacks started from August for both years and increased significatively to mid-November. The infestation rates become more important after the attacks of the most voracious generations.

We also noted that fallen fruits didn't shelter the pest eggs whereas the old larvae and chrysalids were more abundant comparing to the fruits on trees. This result suggested that *E. ceratoniae* female lay its eggs only on fruits on trees, after hatching the larva will complete its development to the pupal stage inside the fruit either still attached to the tree or mostly fallen on the ground.

Moreover, this study indicated that the infestation rate caused by *E. ceratoniae* reached 30 to 50% on fruits on trees according to the crop year. Further studies indicated that this rate ranged from 16 to 80% in Cap Bon and Morneg region [20, 12].

3.4. Treatments efficacy

Four treatments were tested in El Alia field. During the first application, only three tested treatments (Spinosad, Indoxacarb and Abamectin) proved their efficacy to control the date moth in the citrus field (Fig. 9). In fact, the Spinosad seemed the most perform ant to control this pest with about 90% efficacy after one week from the first application. This efficacy decreased significantly after 3 weeks to reach 40%. However, the combined product based on Lufenuron + Fenoxycarb exerted the weakest effect with a maximum of 20% of efficacy after 3 weeks of application. Whereas Abamectin and Indoxacarb showed maximum effectiveness after 3 weeks of application with 80 and 60% respectively. Statistical analyses confirmed the significant difference between 'Lufenuron + Fenoxycarb' and the other applied treatments with (P=0.007, F=8.745).

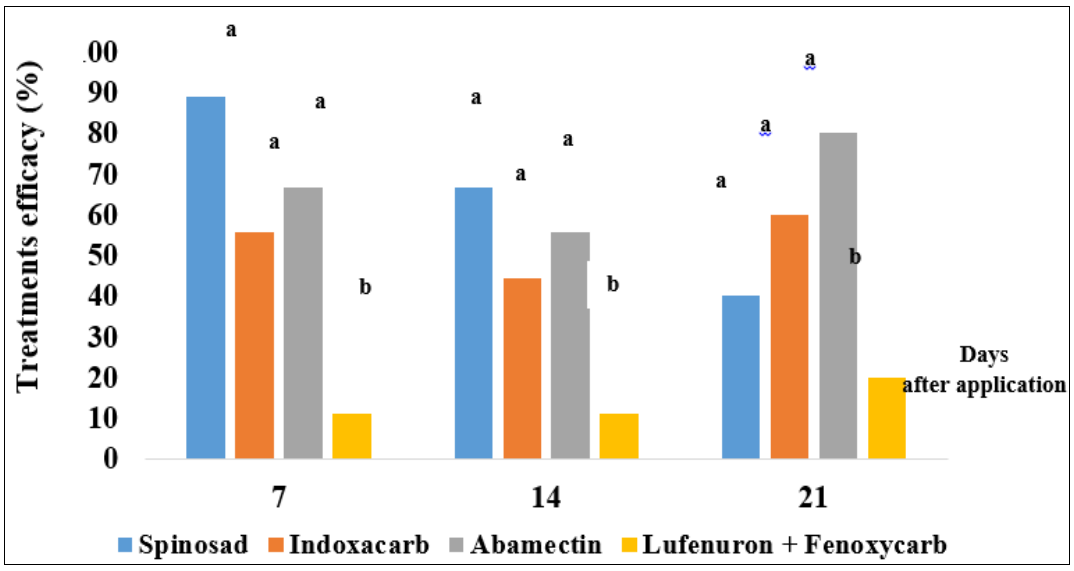

Fig 9: Treatments efficacy to control the date moth in the citrus field during the first application on September 2012

During the second application (Fig.10), the most important rates recorded for Spinosad, Abamectin and Indoxacarb with 80, 70 and 60% respectively after 14 days of treatment. Whereas the combined product bases on 'Lufenuron+ Fenoxycarb' was only 20% effective. The lowest efficacies were obtained after 21 days of treatments for the three first ones, however Lufenuron+ Fenoxycarb recorded its highest efficacy rate with 44.44%. Statistical analyses confirmed the significant difference between the applied treatments with (P=0.078, F=3.321).

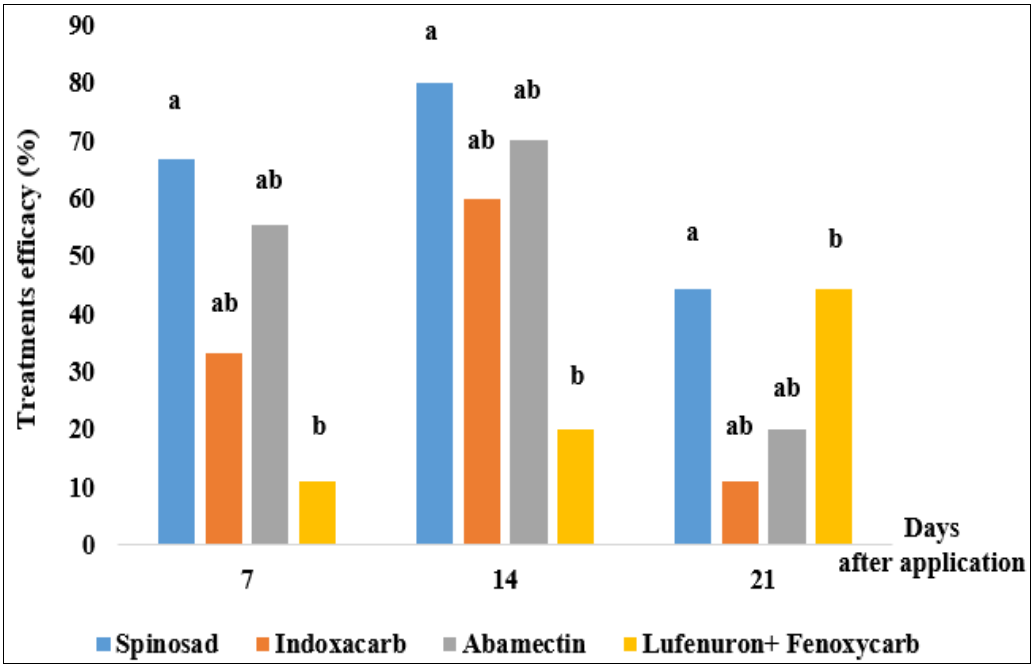

Fig 10: Treatments efficacy to control the date moth in the citrus field during the second application on October 2012

The different treatments tested to control *E. ceratoniae* in the citrus field proved their efficiencies to decrease this pest infestation rate where the Spinosad was the most perform ant with 88.9% after one week of its application. This active ingredient acts by contact at all stages of the insect life, including eggs, larvae and adults. Eggs need to be sprayed directly, but larvae and adults can be effectively affected by contact with treated surfaces.This result corroborate with the study of Hached *et al.*, (2018) [4] who demonstrated the Spinosad efficacy to control *E. ceratoniae* attacking Thomson orange fruits with 61.5% after one week of its application. Furthermore, Khoualdia *et al.*, (2002) [21] confirmed that Spinosad treatment at low doses was able to reduce the date moth infestation rate in Tunisian palm groves from 7% for the control to 2% for the treated ones. Besides, in Syrian pomegranate orchards, Spinosad resulted in a 70.2% *E. ceratoniae* infestation reduction [22].

The active substance indoxacarb acts by ingestion and contact. In this study, its maximum efficacy was 60% and was obtained after 3 and 2 weeks of application for the first and the second treatments respectively. In further studies, this insecticide recorded 48.8% of efficacy on *E. ceratoniae* in Syrian pomegranate orchards [22]. Tested on other lepidopteran pests, this product provides effective control on *Helicoverpa armigera*, *Spodoptera exigua*, *S. littoralis*, *Earias spp*. and *Pectinophora gossypiella* that attack cotton at all growth stages [23]. Besides, Indoxacarb proved its efficacy to control the caterpillars of soybean pests *Helicoverpa armigera* and *Chrysodeixis includens* [24].

Regarding abamectin, this ingredient acts by ingestion and contact. Its maximum efficacy to control the date moth in this study was 80% and was obtained after 3 weeks of application. In previous studies, this insecticide proved its efficacy with 28.6% after 14 days of application on *E. ceratoniae* infesting Thomson oranges [4]. This different performance can be explained by the initial infestation rate influence in the field. Tested on other lepidopteran pest, it caused a dramatic decrease in fecundity and inhibition of mating frequency on bollworm adults *Helicoverpa zea* [25].

The combined insecticide based on two active ingredients, lufenuron and fenoxycarb with ovicidal and larvicidal effects showed a low efficacy in the control of *E. ceratoniae* which didn't exceed 45% in this study. This result does not corroborate with the studies of Charmillot *et al.*, (2006) [26] and Dolzhenko &Dolzhenko (2017) [27] which proved the efficacy of this insecticide to control grape worms *Eupoecilia ambiguella* and *Lobesia botrana* besides to the larval population of codling moth *Cydia pomonella.*

4. Conclusion

This study revealed that *E. ceratoniae* evolved in four to five generations in Tunisian citrus orchards from April to late November- early December. Furthermore, being a concealed feeder insect, its control within orchards by sprays must target the wandering stages of the pest and it can be realised thanks to Spinosad and Abamectin which proved their efficiencies to control this pest as demonstrated by this work.

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