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Elaboration of a strategy to control the peach twig borer *Anarsia lineatella* Zeller in the Sefrou region in Morocco

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Abstract: Trapping by specific sex pheromones initiated in 2009 to monitor three pests, peach twig borer (*Anarsia lineatella*), oriental fruit moth (*Cydia molesta*) and plum fruit moth (*Grapholita funebrana*) revealed the greater importance of peach twig borer in comparison to the others. The results of monitoring the development of larval stages over time and the accumulated degree-days from biofix show that the pest develops five generations per year, one of which undergoes a diapause. In 2009 and 2010 chemical control based on tolerance threshold of 10 males/trap/2 weeks showed unsatisfactory results. With this method, the percentage of affected fruits increased from 6.8% in 2009 to 18.6% in 2010 despite the application of four treatments of organophosphate-based insecticides in 2009 and the application of four treatments in 2010 using active ingredients from different chemical families (pyrethroid, organophosphate and chlorinicotinyl). On the other hand, management of the peach twig borer by the degree-days method tested and planned on the basis of a bifenthrin treatment between 150 to 204 degree-days accumulated from biofix, gave interesting results where the percentage of affected fruits hardly exceeded 0.5% over the four years of study.

Key words: *Anarsia lineatella*, degree-days model, peach twig borer, tolerance threshold

Introduction

In Morocco, peach and nectarine rank 4th in terms of area planted with stone rosacea, after almond, apricot and plum. They occupy a privileged place within the core for Rosaceae for their fruits used as dessert. However, yields remain relatively low and hardly exceed 14 t · ha^{-1} (Anonymous 2012). This low yield is due to several factors both climatic and technical in nature. Among the technical challenges facing peach producers is the mismanagement of crop protection especially since this p each and nectarine are attacked by several pests and diseases, some of which are difficult to control and may cause substantial damage. Among these pests is the peach twig borer (*Anarsia lineatella* Zeller) which is very dangerous on peach, nectarine, apricot and almond in the Mediterranean countries (north and south) as well as in North America (Kehat *et al.* 1994). In California and northern Utah this multivoltine pest develops 3–4 generations per year and can have more than 4 generations in southern Utah causing significant economic losses for growers (Coates *et al.* 1989; Gencsoylu *et al.* 2006; Alston and Murray 2007; Damos and Savopoulou-Soultani 2007; Mamay *et al.* 2014). In Morocco this species which has been reported only in the Gharb region without noticeable impact on production (Hmimina 2008) is still unknown to growers. However, in the Sais region and the Middle Atlas, sexual trapping in peach and nectarine orchards in Meknes, El Hajeb, Sefrou and Imouzzer, confirmed the presence of this pest (Asfers and Sekkat 2009, unpublished data). Consequently, and to better understand the bio-ecology of this pest, sex pheromone traps specific for the insect were used to study the insect ecology with the final objective of guiding bio-chemical control interventions against the peach twig borer (*A. lineatella*).

One strategy involving sexual trapping is based on the degree-days model in which the planning of an insecticide application is determined by the sum of degree-days (DD) from biofix. In the case of the peach twig borer that amount is in the range of 150–204 DD and corresponds to 5 to 28% of the hatched eggs (Brunner and Rice 1984; Kehat *et al.* 1994; Kocourek *et al.* 1996; Alston and Murray 2007). Several authors reported that this model can be used for biological study and the prediction of the optimum spray period of several pests. Doganlar in 2008 found that the best control period of *Archips rosanus* (Linnaeus, 1758) is between 112.7 DD for males and 122.7 DD for females.

This study was conducted over a period of six years and its aim was to develop an effective control of the peach twig borer by comparing two strategies:

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1) the first was based on the use of an organophosphate applied at the threshold of 10 male insects/trap/2 weeks over 2 years;
2) the second was based on the use of pyrethroid molecules (bifenthrin) applied according to the degree-days method over a period of 4 years.

Materials and Methods

Trials were conducted at the Louata Agricultural Domain in the Sefrou region (33°53′27.9“N, 4°40′45.2″W) at an altitude between 500 and 772 meters above sea level.

Relative importance of peach twig borer in the Sefrou area

The specific sexual pheromones to the peach twig borer (*A. lineatella*) [containing a mixture of 5 mg of (E)-5-decenyl acetate (E5-10Ac) and 1 mg of (E)-5-decenol (E5-10Oh)], the oriental fruit moth (*Cydia molesta* Busck) and the plum fruit moth (*Grapholita funebrana* Treitschke) (containing a 1 mg mixture of Z-8-dodecen-1-ol acetate, E-8-dodecen-1-ol acetate, Z-8-dodecen-1-ol), were installed in peach and nectarine orchards in June 2009 in the Sefrou area, to determine the relative importance of each pest. Meanwhile, the caterpillars infesting the fruits were identified using the criteria described by Balachawsky (1966).

Monitoring the flight activity of the peach twig borer

To monitor the flight activity of the peach twig borer, eight varieties of peach and nectarine were chosen for observation. These varieties were: Ryan Sun, Louata-Peach, Alexandra, Benedict, N123, N46-28, September Great and Rome Star. Their characteristics are shown in Table 1. The choice of these varieties is essentially based on the very lengthy harvest periods which start at the beginning of June and end in September, thus following the life cycle of the insect throughout the whole growing season.

A trapping network was installed on these varieties, using one trap per variety. Delta type traps were equipped with a capsule containing a specific sex pheromone to attract the males and a sticky plate to capture them. The traps were hung on branches at a height of 1.5 to 1.7 m in a shady spot. The traps were positioned with their main axis perpendicular to the direction of prevailing winds. After their installation in 2009, the position of the traps was not changed throughout the whole study period. However, pheromone capsules were replaced every 4 weeks and the sticky plates were renewed after catching 50 males or when they had lost their adhesive ability. Observations were conducted three times a week and captured males were counted and removed from the plates.

To determine the number of generations, a control of larval emergence was performed once a week on the young shoots and fruits. On shoots a control of larval emergence involved the observation of a sample of 100 trees taken randomly by variety. The detected larvae were counted and classified by stage. On fruits the control consisted of observing a sample of 1,000 fruits per variety from a total of 50 trees at the rate of 20 fruits per tree. Infested fruits were removed and the larvae were counted and classified by the larval stage.

Table 1. Characteristics of peach and nectarine varieties on which the bio-ecology of the peach twig borer was observed

Crop	Variety	Surface area [ha]	Year planted	Density [trees · ha^{-1}]	Harvest period
Peach	Alexandra	0.85	2005	1,333	early July
	Rome Star	2.47	2003	666	starting July 10
	Benedict	2.47	2003	666	starting July 15
	Louata-Peach	2.45	2005	666	starting August 20
	Ryan Sun	2.47	2003	666	starting August 15
Nectarine	N123	2.27	2009	555	late May
	N46-28	2.40	2009	555	starting June 10
	September Great	5.38	1997	740	starting September 15

Table 2. Active ingredients and time of their foliar application to control the peach twig borer using the tolerance threshold method

Year	Active ingredient (CP*)	Dose	Application date
2009	phosalone (Zolone)	200 g pc · hl^{-1}	26/03/2009
	phosmet (Imidan)	150 g pc · hl^{-1}	24/06/2009
	fenthion (Lebaycide)	100 g pc · hl^{-1}	08/07/2009
	phosalone (Zolone)	200 g pc · hl^{-1}	31/07/2009
2010	deltamethrin (Decis Expert)	7.5 cc pc · hl^{-1}	08/03/2010
	thiacloprid (Calypso)	25 cc pc · hl^{-1}	01/05/2010
	malathion (Malathion)	200 g pc · hl^{-1}	28/06/2010
	bifenthrin (Talstar)	40 cc pc · hl^{-1}	16/08/2010

*CP = Commercial product

Table 3. Dates of recorded biofix during the four years of study, and dates of chemical interventions [biofentrin (Talstar), 40 cc · hl^{-1}, with a spray volume of 1,000 to 1,200 l · ha^{-1}] as determined by the degree-day (DD) method in the Sefrou region for the four periods of 2011 to 2014

Year	Generation targeted	Treatment date at 150 to 204 DD
2011	1st biofix: 11 April, 2011 1st generation or spring generation	05 Mai, 2011
2012	3rd biofix: 14 July, 2012 Summer generation	28 July, 2012
2013	2nd biofix: 17 June, 2013 Summer generation	03 July, 2013
2014	1st biofix: 12 March, 2014 Spring generation	25 March, 2014

Evaluation of the control strategy based on the tolerance threshold in 2009 and 2010

This strategy required the application of an insecticide after the pest threshold exceeded 10 males/trap/2 weeks (Lichou *et al.* 1994). The active ingredients and application dates are detailed in Table 2.

Apart from their toxicity profile and the adverse effects on the beneficial fauna, the use in 2009 of the organophosphate active ingredients aimed to verify their effectiveness in a rational control program against the peach twig borer as well as to check for any occurrence of resistance to these active ingredients that are irrationally used by growers in the study region.

In contrast, in 2010, we tested organophosphate molecules together with other active ingredients belonging to different chemical families such as the neonicotinoids (thiacloprid, Calypso) and synthetic pyrethroids (deltamethrin, Decis Expert; bifenthrin, Talstar) to assess the reaction of the pest to these newly introduced chemical families in the control program.

Evaluation of the control strategy based on the degree-day method of 2011 to 2014

To minimize the treatments targeting the peach twig borer, we used heat summation based on degree-days. This method assumes that for a given pest to complete its life cycle, it must accumulate a sum of temperatures called the sum of degree-days (DD). Different formulas are available to calculate that amount. In this study we used the following formula (McMaster and Wilhelm 1997):

$$\text{Daily value DD} = \frac{(T_{max} + T_{min})}{2} - T_0,$$

where: T_{max} = the maximum daily air temperature; T_{min} = the minimum daily air temperature; T_0 = low temperature threshold below which the insect does not develop (for *A. lineatella* is 10°C).

The peach twig borer can complete its life cycle from egg to egg when the amount of accumulative degree-days is 582 (Alston and Murray 2007). It is in this context that this strategy is proposed to evaluate the application of an insecticide at an accumulative 150–204 DD corresponding to an egg hatching rate of about 5 to 28% (Alston and Murray 2007). Each year, one pest generation is considered to test the effectiveness of this method.

The biofix corresponds to the day of the year when the first two individuals of the pest are caught by the traps for at least two successive nights. From this date we began to count the number of DD accumulated. Table 3 summarizes the biofix dates and the intervention periods.

Temperature readings to calculate degree-days were taken daily from a thermometer (min/max liquid thermometer –40/+50 of the Tr brand) placed in the farmyard 200 to 800 m from the test plots.

Results

Relative importance of the peach twig borer in the Sefrou region

In 2009, the trapping of the three suspected species gave the results presented in Figure 1. It is clear from Figure 1 that only traps that were specific to the peach twig borer recorded catches. No catches were recorded in the traps of the other two species. In addition, inspection of the caterpillar revealed that it was indeed the peach twig borer, which must be the sole source of the damage observed on stone fruits in the region. There was a total of 584 catches between June 18 and August 27 with an average of 28.75 males/trap/week, which far exceeds the threshold of 10 males/trap/2 weeks. The flight curve is characterized by two distinct waves that could match two summer generations.

Flight patterns of the peach twig borer in the Sefrou region

In 2010, the results of trapping adult male peach twig borers by the network of pheromone traps installed in the peach orchards towards the end of March are presented in Figure 2.

The flight curve during this season was characterized by four more or less distinct peaks. The first flight occurred between 16 and 21 April and the second between 25 and 30 June. Two other flight peaks can be suspected respectively between 06 and 13 August and between

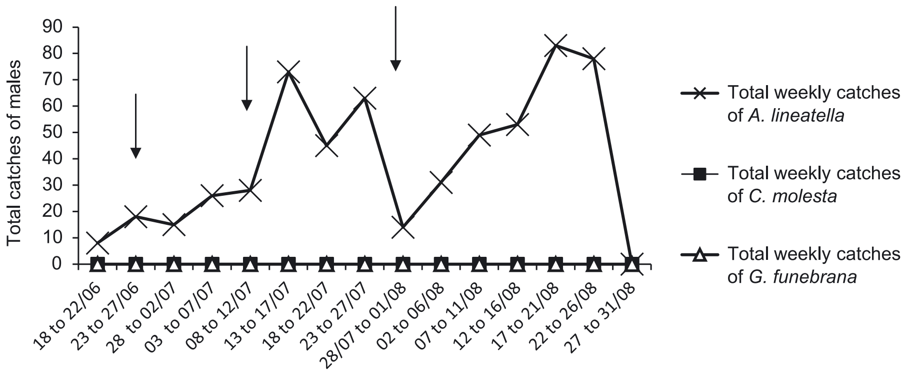


Fig. 1. Total weekly catches of male *Anarsia lineatella*, *Cydia molesta* and *Grapholita funebrana* in 2009 (mean catches of *A. lineatella*: 28.75 males/trap/week, 0 males/trap/week for *C. molesta* and *G. funebrana*; the arrows indicate a pesticide application)

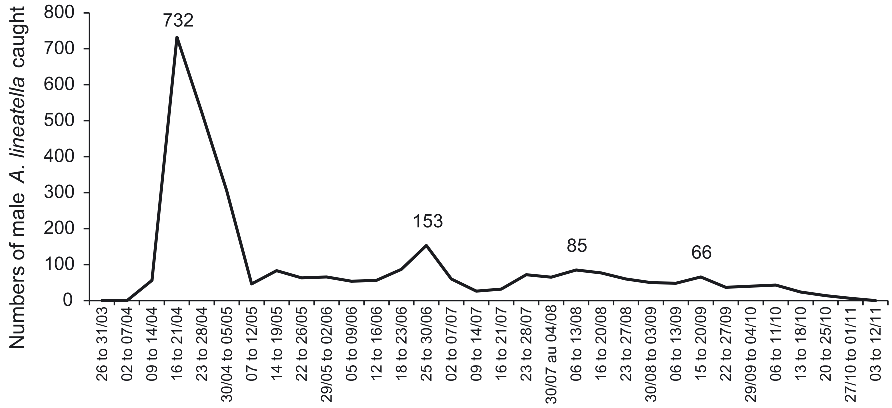


Fig. 2. Number of male *Anarsia lineatella* caught during the 2010 growing season in the Sefrou region

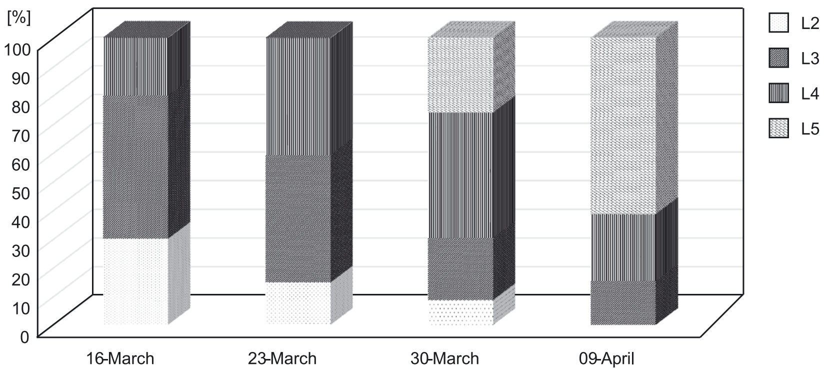


Fig. 3. Percentages of L2, L3, L4 and L5 larval populations of *Anarsia lineatella* in 2010

15 and 20 September. Monitoring the larval population shows that diapausing individuals of the 2nd larval stage began to appear around the last ten days of February through March, thus triggering the lifting of the winter diapause. Thereafter, the development of L2, L3, L4 and L5 larval populations is shown in Figure 3.

The first individuals coming out of diapause do not give rise to older larvae until a month after coming out of diapause. Also, no larva of the diapausing generation is observed beyond the month of March. Thus, spring and summer non-diapausing larvae are responsible for the detrimental damage toshoots andfruits. Their development is illustrated in Figure 4.

An analysis of the development of larval stages during the summer highlights the presence of three summer generations from the first ten days of June to September with an apparent overlap between the three generations. A summer–autumn 4th generation occurs towards the second ten days of September. Ultimately, this pest has four flight waves from five generations, one of which occurs in the spring and the other four in the summer. The 5th generation is partial and consists mainly of diapausing individuals. The accumulation of degree-days from

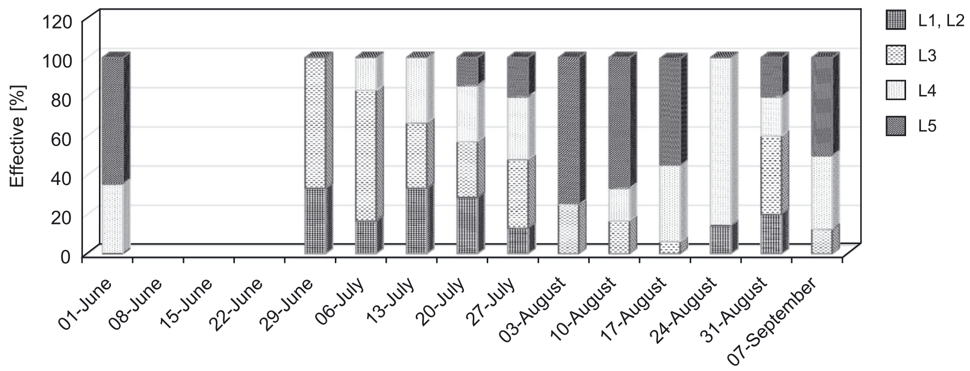
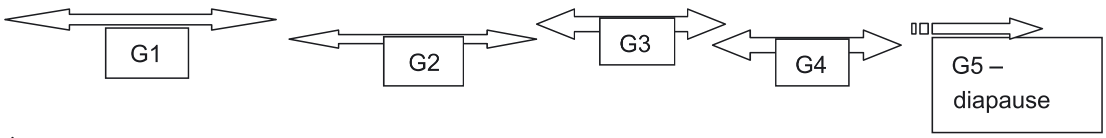


Fig. 4. Development of the spring and summer larval stages of *Anarsia lineatella* in the trial orchard plots in 2010

Table 4. Dates of biofixes calculated by cumulating degree-days during the 2010 growing season at the Louata Agricultural domain in the Sefrou region

Month	April	May	June	July	August	September	October
Biofix day	12/4 first biofix		07/6 2nd biofix	13/7 3rd biofix	08/8 4th biofix	06/9 5th biofix	



G1–G5 – generations

the first biofixon April 12th reveals the presence of four additional biofixes corresponding to five generations as shown in Table 4.

Evaluation of the peach twig borer control using the tolerance threshold during the 2009 and 2010 growing seasons

Damage on peach and nectarine varieties observed in 2009 is presented in Figure 5. It can be seen that the damage was very important and that after each treatment it substantially decreased, but resumed increasing two weeks later. The average percentage of damage was close to 6.8% with a maximum of 10% recorded during the week of July 28 to August 1, which appears to be related to the drastic increase of insect catches during the week from 23 to 27 of July.

In 2010, there were four treatments targeted at the larvae of peach twig borer (*A. lineatella*). The 1st one, deltamethrin, targeted the larvae coming out of diapause. The 2nd one, thiacloprid, targeted the spring generation. The 3rd and the 4th ones, respectively malathion and bifenthrin, targeted the summer generation. The infestation rate of peaches and nectarines by *A. lineatella* in 2010 is depicted in Figure 6.

It can be noted that pest pressure was very high and damage continued to increase despite the insecticide applications. The average damage reached 18.6% of all varieties throughout the whole growing season. These results illustrate that the strategy based on the tolerance threshold has its limits in the case of this pest. Indeed, trap catches and fruit damage were not controlled throughout the growing season despite the treatments applied. This can be explained by a possible adaptation of the summer

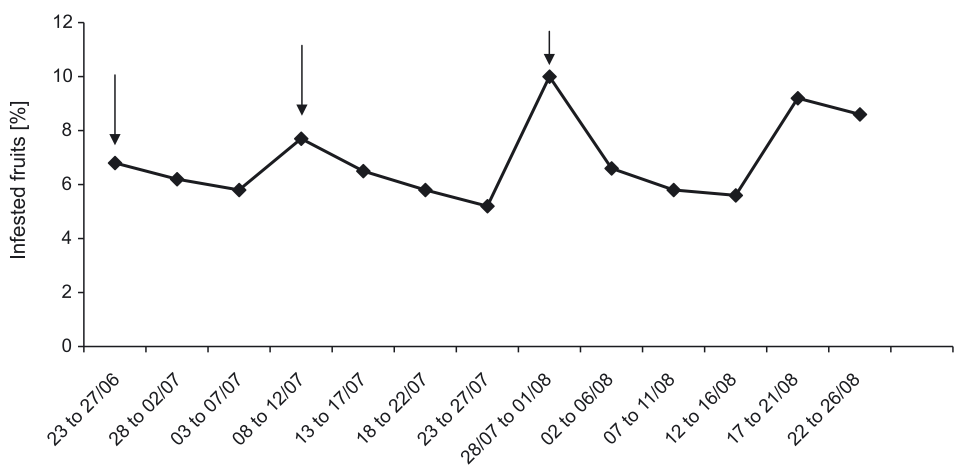


Fig. 5. Percentage of peaches and nectarines infested by *Anarsia lineatella* in 2009 (the arrows indicate a pesticide application)

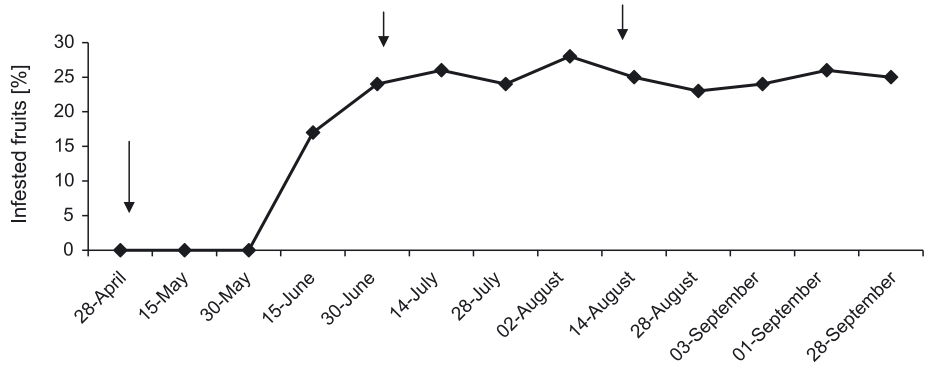


Fig. 6. Percentage of peaches and nectarines infested by *Anarsia lineatella* in 2010 (the arrows indicate a pesticide application)

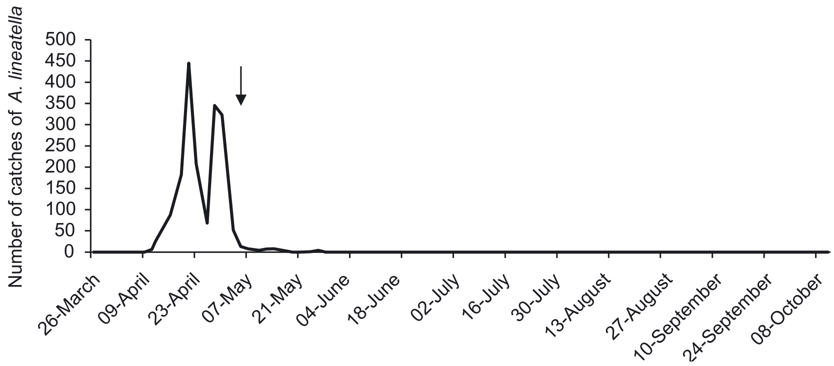


Fig. 7. The number of spring generation male *Anarsia lineatella* caught in traps and the effect of bifenthrin treatment applied according to the degree-days in 2011 (the arrows indicate a bifenthrin treatment)

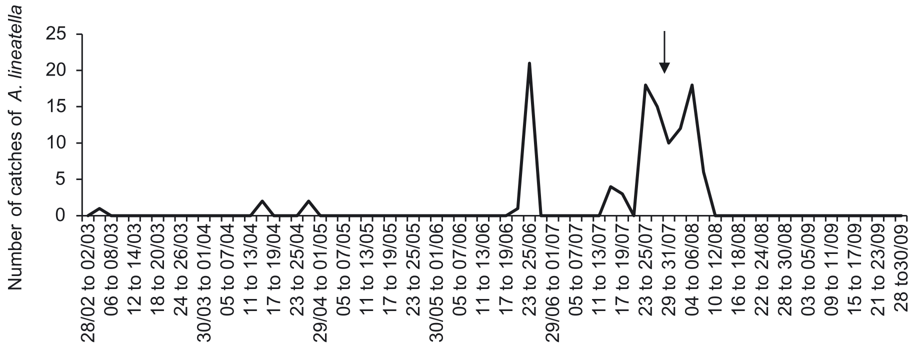


Fig. 8. Catches of 2nd summer generation *Anarsia lineatella* males and the effect of a bifenthrin treatment according to the degree-days method in 2012 (the arrows indicate a bifenthrin treatment)

generations of this pest to the organophosphates, and by the very high level of the pest population occurring in the orchards during this year.

The degree-days method for elaborating a pest management strategy for the control of the peach twig borer in the Sefrou region

This method proposes an insecticide treatment between 150 and 204 DD calculated from the biofix, which corresponds to a rate of pest egg hatching between 5 and 28%.

Results of 2011

Figure 7 illustrates the results of trap catches of the spring generation in 2011 and the effect of one application of bifenthrine targeting primarily the spring generation. Before treatment, a high pest pressure was recorded, with catches amounting to 1,789 male insects during a 2 month trapping period, corresponding to 223.6 males/week or the equivalent of 31 males/trap/week, with negligible damage to the shoots. After applying the treatment no catches were recorded and no damage on fruits or shoots was observed.

Results of 2012

In 2012, the generation targeted was the 2nd summer generation. The choice of this generation was due to the low catches recorded for the spring generation and the first summer generation whose catches seem to be influenced by the strategy of the previous year. Figure 8 shows the number of catches of this generation before and after the bifenthrin treatment applied on July 28.

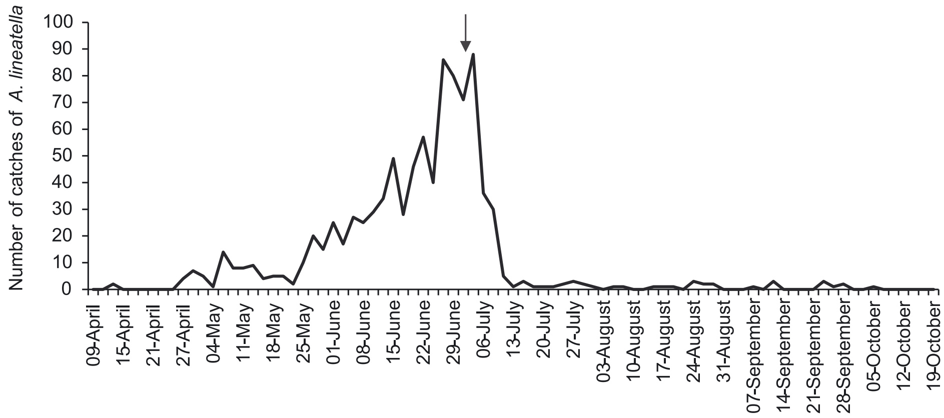


Fig. 9. Catches of the 1st summer generation of *Anarsia lineatella* males and the effect of a bifenthrin treatment planned according to the degree-days method in 2013 (the arrows indicate a bifenthrin treatment)

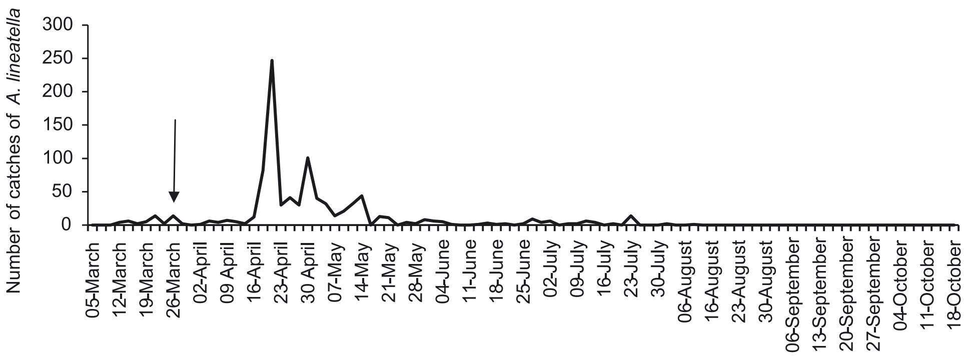


Fig. 10. Development of catches of male *Anarsia lineatella* and the effect of a bifenthrin treatment, timed according to the degree-days method in 2014 (the arrows indicate a bifenthrin treatment)

Before applying the treatment a total of 67 catches were recorded in 8 traps installed in different varieties, and no damage was observed on shoots or fruits. Ten days after the chemical treatment, the traps captured 46 males. However, no damage was observed. Thereafter, neither catches nor damage were observed. The effectiveness of this treatment is attributable first to the good timing of the treatment, and second to the lengthy persistence of bifenthrin lasting 3 to 4 weeks.

Results of 2013

In 2013, the first summer generation was targeted. Figure 9 shows the development of the actual catches of this generation before and after the application of bifenthrin on July 3rd.

Before applying the treatment, pheromone traps captured a total of 247 individuals with no significant damage on shoots and fruits. After the chemical treatment, trap catches were very sporadic and scarcely exceeded 21 individuals for the rest of the experiment. As for the percent damage, it was zero until the leaves had fallen from the trees.

Results of 2014

In 2014, the 1st generation or spring generation was targeted. Figure 10 shows the actual catches of this generation before and after the application of a bifenthrine treatment on March 25.

Before applying the treatment there were 50 individuals captured in pheromone traps without any noticeable damage. Four weeks after the treatment, a total of 633 males were caught in 8 traps, while thereafter, the catches were less intense totaling 222 males for the rest of the season. As for the damage to fruit, it was of the order of 0.5%.

Results of four years trials

Table 5 summarizes the results obtained during the 4 years of study both in terms of catches in pheromone traps of male peach twig borers as well as in terms of damage to fruit, after the adoption of the degree-day model which has proven its effectiveness in controlling this pest.

Development of fruit damage over the 6 year study

Figure 11 shows the development of fruit damage caused by the peach twig borer on peach and nectarine in the Sefrou region during the 6 year study. It is clear from this figure that fruit damage was very high during the first two years, varying from 6.8% in 2009 to 18.6% in 2010, and almost nil between 2011 and 2013. However, in 2014 a very small percentage of infested fruits was recorded but barely exceeded 0.5%. It can be concluded that the degree-day model has been effective in controlling the

Table 5. Pheromone traps cumulative captures of males of peach twig borer (*Anarsia lineatella)* and percentage of fruits infested by *A. lineatella,* before and after the application of a bifenthrin treatment positioned according to the degree-day method

Year	Before treatment		After treatment	
	cumulative captures in pheromone traps	% of fruits infested	cumulative captures in pheromone traps	% of fruits infested
2011	1,789	0	0	0
2012	67	0	46	0
2013	247	0	21	0
2014	50	0	855	0.5

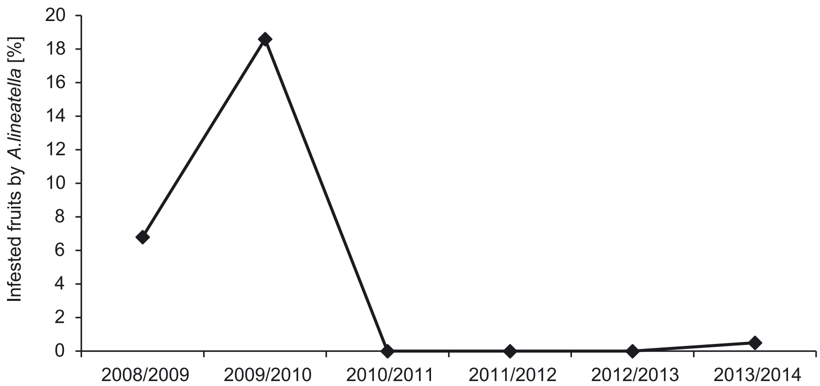


Fig. 11. Fruit damage caused by *Anarsia lineatella* on peach and nectarine in the Sefrou region during the 6 year study (2008 to 2014)

peach twig borer, especially as this model has made it possible to substitute organophosphate molecules with synthetic pyrethroids that are degradable in nature.

Discussion and Conclusions

Until 2008 in Morocco, the peach twig borer was thought to be present only in the Gharb region (Hmimina 2008). However, trapping by specific sex pheromones detected the insect in the Sais region and allowed us to study its main biological features.

In the Sefrou region this insect develops five generations per year, one of which diapauses. As in southern Utah (Alston and Murray 2007), the lifting of diapause usually occurs around the last 10 days of February and depending on the year, the first biofix occurs between March and the second week of April. In northern Greece the first flights were observed from early May to early June in Veria and from late May to mid-June in Velvendos (Damos and Savopoulou-Soultani 2007). The same result was found by Mamay *et al.* in 2014 in Şanlıurfa province (Turkey).

Chemical control tests based on the degree-days method helped reduce damage and insecticide applications directed against this pest. Indeed, the infestation rate never exceeded 0.5% and insecticide applications went down from four to only one. Similar results were reported by Brunner and Rice (1984), Kehat *et al.* (1994), Kocourek *et al.* (1996) and Alston and Murray (2007).

These results can be of great use for the control of this pest that continues to cause significant damage to the stone fruit in the Sais region and the Middle Atlas. In addition, these findings will help reduce the impact of chemical compounds on the environment and strengthen the auxiliary fauna weakened by earlier pesticide applications.

However, this study involved only the region of Sais and should be extended to other regions over several years to confirm the validity and the application of these results on a larger scale.

It is also important to note that despite the effectiveness of bifenthrin against this pest, this molecule has an adverse toxicological profile to the auxiliary fauna; and therefore it is recommended that future trials should be conducted using substitute molecules, especially those of the new generation that are environmentally friendly.

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