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First report of *Adoxophyes orana* in northwestern Turkey: population fluctuation and damage on different host plants

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Abstract: This study reports the presence of the summer fruit tortrix moth, *Adoxophyes orana*, in pome and stone fruit orchards for the first time in northwestern Turkey. Based on growers' complaints about cosmetic damage to peach and pear fruits, pheromone traps were set up in mid-April of 2009 and 2010 to monitor the occurrence of the summer fruit tortrix moth. We conducted studies in conventional apple, pear, peach, and sweet cherry orchards in Bursa, northwestern Turkey. Moths caught in pheromone traps showed a trimodal flight pattern in all orchards. However, both moth emergence time and total flight period varied among host plants. The first moths were caught in peach and apple orchards on 13 May in 2009 and 3 May in 2010, corresponding to an average degree-day (DD) accumulation of 350–356 DD starting from 1 February. The 2nd and 3rd moth flights began in late June or early July (1003–1027 DD) and early August (1600–1690 DD), respectively. Moth captures continued until the end of September, lasting for an average of 2305 DD. The highest mean percentage leaf damage (9.3%) was found in sweet cherry orchards. However, neither sweet cherry nor apple fruits were injured in any way by *A. orana* larvae. Conversely, the mean percentage of fruit infested with larvae was 1.4% and 0.8% in peach and pear orchards, respectively. Because a level of fruit damage higher than 1% is considered the control threshold, *A. orana* is more likely to cause economic damage in peach and pear orchards in the near future.

Key words: *Adoxophyes orana*, degree-days, fruit orchard, new pest, summer fruit tortrix moth, Turkey

1. Introduction

The summer fruit tortrix moth, *Adoxophyes orana* (Fischer von Röslerstamm, 1834) (Lepidoptera: Tortricidae), is a polyphagous pest of pome and stone fruits in most of Europe and Asia. *A. orana* larvae have a strong preference for apples and pears in central and northern Europe (Barel, 1973; Charmillot and Brunner, 1990; Stamenkovic et al., 1999). However, they seem to change their preference to peaches and sweet cherries in southern Europe, where larval damage was more common in stone fruits (Savopoulou-Soultani et al., 1985).

A. orana can be considered the most damaging leaf roller species in Europe due to its wide range of host plants and high abundance during the summer (Kocourek and Stara, 2005). Since its introduction, it has established itself as a serious pest of apples in England and peaches in Greece (Savopoulou-Soultani et al., 1985; Cross, 1996).

The larvae may cause both direct and indirect damage by actively feeding on leaves, buds, flowers, shoots, and fruit. Indirect damage occurs when the larva feeds on young shoots and leaves that are stuck together. Leaf and

shoot damage usually has no economic impact unless leaf roller populations reach high density and completely defoliate host trees (Dickler, 1991). In contrast, larval feeding directly on fruit, especially in June and July, may result in crop losses varying from 10% to 82% in apples, peaches, and pears (de Jong et al., 1971; Whittle 1985; Stamenkovic and Pesic, 1998). Economic damage can exceed \$1,000,000, as reported in 33,000 ha of apples in the Netherlands in the late 1980s (de Jong et al., 1971; Whittle, 1985).

Fruit damage usually occurs in the spots where leaves are attached to fruit with a silken web of larvae. Larvae can also cause cosmetic damage to apple, peach, and pear fruits. Damaged fruits show a “gnawed” or misshapen appearance due to malformed skin. External damage may also present an opportunity for pathogens to infect, which further damages internal quality and/or reduces the shelf life of fruits (de Jong and Van Dieren, 1974; Whittle, 1985).

The summer fruit tortrix moth may produce 2–3 generations per year, depending on climatic factors, host plant availability, and presence of natural enemies

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(Cross et al., 1999). In much of Europe, 2 generations dominate in apple and pear orchards, but a partial third generation may occur in warmer years with extended growing seasons (de Jong and Van Dirren, 1974; Minks and de Jong, 1975, de Jong and Minks, 1981; Stamenkovic and Pesic, 1998). However, there are 3 generations of the summer fruit tortrix moth per year in peach orchards in Greece with a 1st flight in early May, a 2nd in July, and a 3rd in late August, spanning into September (Milonas and Savopoulou-Soultani, 2006).

Based on growers' complaints about external damage (a gnawed appearance) on peach and pear fruits, pheromone traps were set up in mid-April to monitor the presence of the summer fruit tortrix moth, which had been previously identified in the fall of 2008. To our knowledge, no previous field study has been conducted for monitoring this pest in Turkey. Therefore, the biology of the summer fruit tortrix moth and its potential impact on different host plants in Turkey is unknown.

The aims of this study were to detect the presence as well as to monitor the seasonal fluctuation of *A. orana* populations by using pheromone traps in conventional apple, pear, peach, and sweet cherry orchards in Bursa, northwestern Turkey, in 2009 and 2010. In addition, the relationship between moth catch data in pheromone traps and accumulated degree-days (DD) was examined. We also recorded larval damage to leaves and fruits.

2. Materials and methods

2.1. Species identification

In August 2008, field visits were made to commercial pear growers who suffered unidentified lepidopteran damage. Sweep net sampling was performed in combination with visual inspection for collecting the larvae and adults from the host. Using a sweep net, resting adult moths and larvae were collected. Specimens were brought back to the laboratory alive. Adult moths were pinned with

their wings spread, then dried and preserved in the Plant Protection Department collection of the Faculty of Agriculture at Uludağ University. *A. orana* larvae and adults were identified by Prof Bahattin Kovancı (Uludağ University, Turkey) using the identification keys of Bradley et al. (1973), Beeke and de Jong (1991), and Meijerman and Ulenberg (2000). Species identification was also confirmed by examining the genitalia (http://idtools.org/id/leps/tortai/Adoxophyes_orana.htm).

2.2. Experimental sites

Studies were carried out in apple, peach, pear, and sweet cherry orchards in İnegöl, Bursa (40°19'N, 29°06'E), northwestern Turkey, in 2009 and 2010. For each host plant, trials were set up in 2 separate orchards, each in a different location. Each orchard was 0.5 ha in size and consisted of the following fruit varieties:

a. Apple: Both orchards contained late-ripening *Malus domestica* Borkh. 'Granny Smith';

b. Peach: Orchard 1 contained early-ripening *Prunus persica* L. 'Dixired', while Orchard 2 was a mixed orchard including the late-ripening cultivars Glohaven and Redhaven;

c. Pear: Orchard 1 had early-ripening *Pyrus communis* L. 'Santa Maria', whereas Orchard 2 consisted of the late-ripening cultivar Marguerite Marillat;

d. Sweet cherry: Both orchards contained late-ripening *Prunus avium* L. 'Ziraat900'.

2.3. Flight monitoring

We used delta-type traps (Figure 1, Pherocon IIC Trap, Trécé Inc., Adair, OK, USA) baited with a 9:1 pheromone blend of (Z)-9-tetradecenyl acetate and (Z)-11-tetradecenyl acetate (Agrisense, Cardiff, UK) to determine the presence and seasonal population fluctuation of the male summer fruit tortrix moth (Figure 2, Minks and Voerman, 1973). Each year, 3 traps per orchard were placed approximately 1.5 m above the ground (Barel, 1973; Minks and de Jong, 1975; Hrudova, 2003) at a distance of 45 m from each



Figure 1. Monitoring adult male summer fruit tortrix moths using pheromone traps.

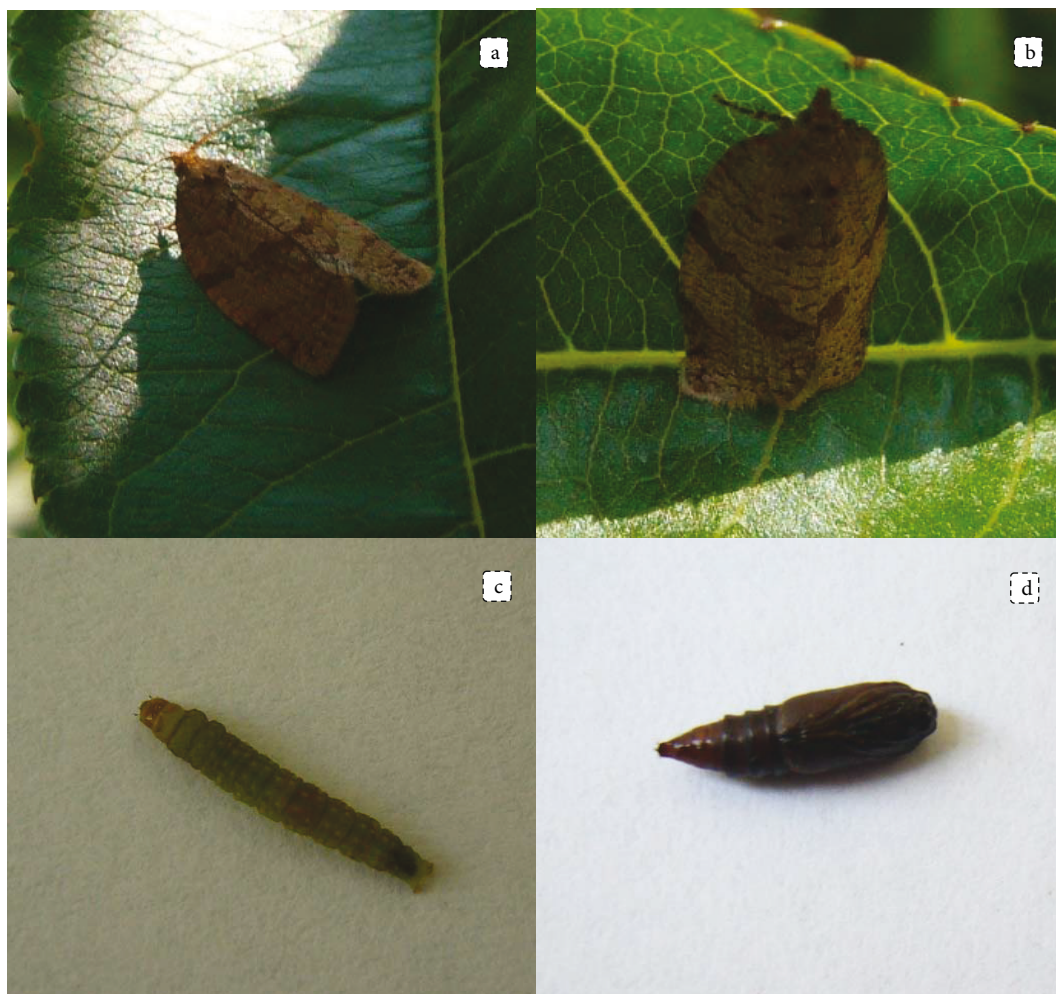


Figure 2. Different life stages of *Adoxophyes orana*: a) Adult male summer fruit tortrix moth; b) Adult female summer fruit tortrix moth; c) Mature larva; d) Pupa.

other to prevent interaction among the traps (Kraan and Deventer, 1982). In addition, one blank trap was used as a control in each orchard.

Traps were deployed on 15 April before night temperatures reached above 13–14 °C, the temperature threshold for adult flight activity (Whittle, 1985). They were checked daily until the first sustained fly captures occurred, and then adults were counted and removed from traps once a week. The pheromone lures and trap bottoms were changed every 6 weeks. At the end of the growing season, the traps were removed after 3 consecutive zero captures.

2.4. Fruit and leaf sampling

We assessed fruit damage at harvest time from July to early September because of the variation in ripening time among different fruits and varieties. At each location, 25 leaves and fruits per tree from 20 randomly selected trees were collected from the 4 sides (N, S, E, W) of a tree at

different canopy heights. Thus, a total of 500 leaf and fruit samples were taken per location. Fruits and leaves were examined for leaf roller damage. Larval damage was recorded by counting all damage types, including pitting (holes), scars, and live larva (Figures 2 and 3). Compared with other leaf rollers, *A. orana* larvae usually spin a leaf against a fruit and damage occurs at these hidden spots where they attach the leaf to the fruit. Larvae may cause superficial damage by leaving small holes in the fruit tissue due to sting-feeding. Additionally, extensive areas of damage and large holes may result from larval grazing on the fruit surface (Bylemans, 1997).

2.5. Insecticide treatments

In trial orchards, the number of insecticide treatments against other major insect pests varied between 2 and 4 per season.

Diflubenzuron (Dimilin 48 SC, Hektas, Turkey) was applied once at 100 mL in 500 L of water per ha to control

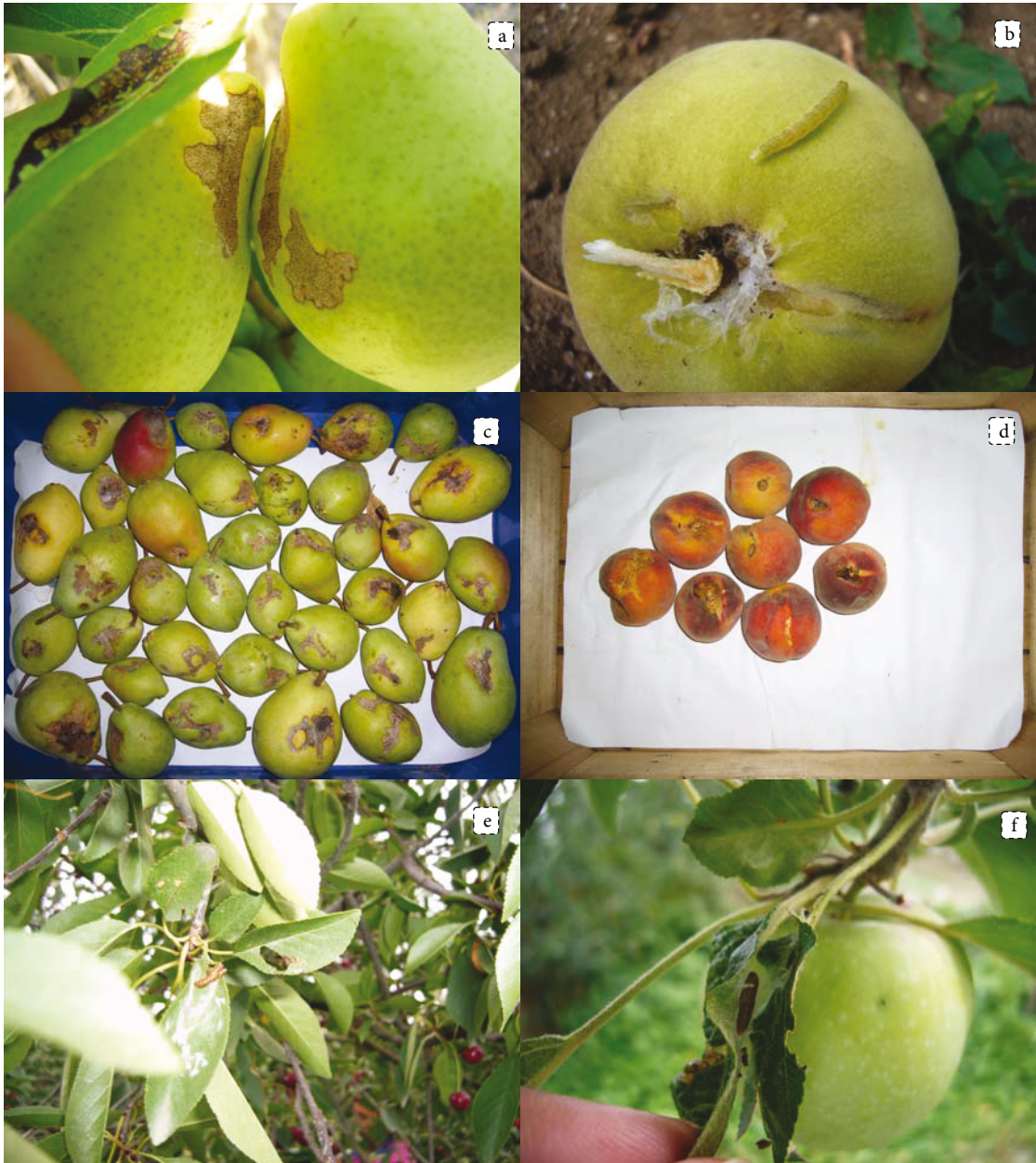


Figure 3. Damage by larva of *Adoxophyes orana*: a) Leaf and fruit damage to pear; b) Larva and fruit damage to peach; c) Gnawed pear epidermis; d) Gnawed peach epidermis; e) Leaf damage to sweet cherries; f) Pupa hidden under apple leaves.

codling moth, *Cydia pomonella* L., eggs and larvae in early May in apple and pear orchards. In apple orchards, 3 subsequent applications with chlorpyrifos-ethyl (Dursban 48 EC, Dow Agrosiences, Turkey) were made at 750 mL in 500 L of water per ha in mid-July and early and late August to control second generation codling moth adults. In the same period, spinetoram (Delegate 25 WG, Dow Agrosiences, Turkey) was applied twice at a rate of 200 g in 500 L of water per ha in pear orchards to control both codling moth and pear psylla.

Peach orchards were sprayed with Phosalone (Balance 35 EC, Hektas, Turkey) at 1000 mL in 500 L of water per ha against the first generation Oriental fruit moth, *Grapholita molesta* Busck, in late April. Second and third generation moths were treated with Thiacloprid at 100 mL in 500 L of water per ha in early July and early August, respectively.

In sweet cherries, only 2 applications of thiacloprid were made against the European cherry fruit fly, *Rhagoletis cerasi* L., in late May and mid-June.

2.6. Meteorological data

The meteorological data were obtained from the station located in the town center of İnegöl, Bursa. The station was located as far as 3–5 km from the study sites.

2.7. Data analysis

DD were calculated based on Baskerville and Emin's equation (1969):

$$DD = \sum_{i=m}^n \frac{T_{\max} + T_{\min}}{2} - T_b$$

where DD stands for daily degree-days, T_{\max} and T_{\min} for high and low daily temperature, and T_b for the lowest temperature of the insect developmental threshold. DD above a developmental threshold of 7.2 °C were accumulated from 1 February, when Milonas and Savopoulou-Soultani (2006) report that larval diapause development is completed. Based on previous studies, we adopted a developmental threshold of 7.2 °C to calculate DD (Charmillot and Megevand, 1983; Milonas and Savopoulou-Soultani, 2000; Damos and Savopoulou-Soultani, 2010). Figure 4 gives the average temperature data for each biweekly period of each trial season (2009–2010) in İnegöl, Bursa, Turkey.

Statistical analysis was carried out using analysis of variance (ANOVA) (JMP, version 7: SAS Institute Cary, NC, USA, 2007). Trap counts were transformed using [square root ($x + 1$)] before ANOVA. Likewise, data for the mean percentage of fruit damage were arcsine square-root transformed prior to statistical analysis. If there were significant interaction effects, LSMEANS comparisons were used to identify these effects. Fisher's protected LSD test was used to compare means ($P = 0.05$).

3. Results

3.1. Detection and monitoring of moth flight activity in pome and stone fruits

In this study, the presence of the summer fruit tortrix moth in pome and stone fruits was detected for the first time in northwestern Turkey. A total of 1504 moths were captured in pheromone traps during a 2-year study period. However, total moth catches varied significantly among the years, with 285 and 1219 moths captured over the 2009 and 2010 seasons, respectively ($F = 9$; d.f. = 1, 1232; $P = 0.002$).

Significant differences were found among weekly captures of moths in all orchards in 2009 ($F = 10.92$; d.f. = 17, 432; $P < 0.01$) and 2010 ($F = 11.37$; d.f. = 20, 504; $P < 0.01$). When averaged across orchards, moth captures reached a peak in 20 May, 8 July, and 19 August in 2009. Similarly, moths displayed a well-defined trimodal flight pattern in 2010 with peaks on 10 May, 5 July, and 16 August (Figures 5a and 5b).

The highest peak catches of moths occurred in peach orchards on 20 May in 2009. Likewise, peach orchards had the highest peak catches, with 30 moths per trap, on 10 May in 2010. Moth numbers showed a similar trend in pear and sweet cherry orchards in both years and reached a peak in mid-August. In contrast, peak moth catches in apple orchards did not show a consistent pattern, with the highest catches recorded on 15 July in 2009 and 16 August in 2010.

However, both moth emergence time and total flight period varied among host plants. The first moths were caught in peach orchards on 13 May in 2009 and 3 May in 2010 (Figures 5a and 5b), corresponding to an average degree-days (DD) accumulation of 350–356 DD starting from 1 February (Figures 6a and 6b). A delayed appearance of moths at 385 DD was seen in pear and sweet cherry orchards in 2009, but moth captures revealed

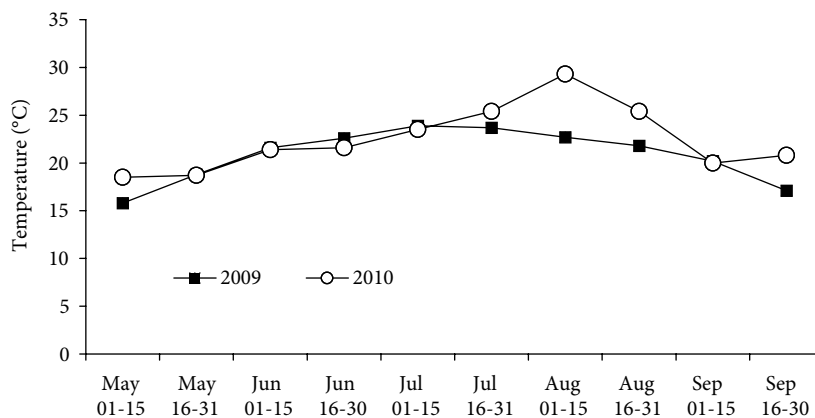


Figure 4. Average temperature data for each biweekly period of each trial season (2009–2010) in İnegöl, Bursa, Turkey.

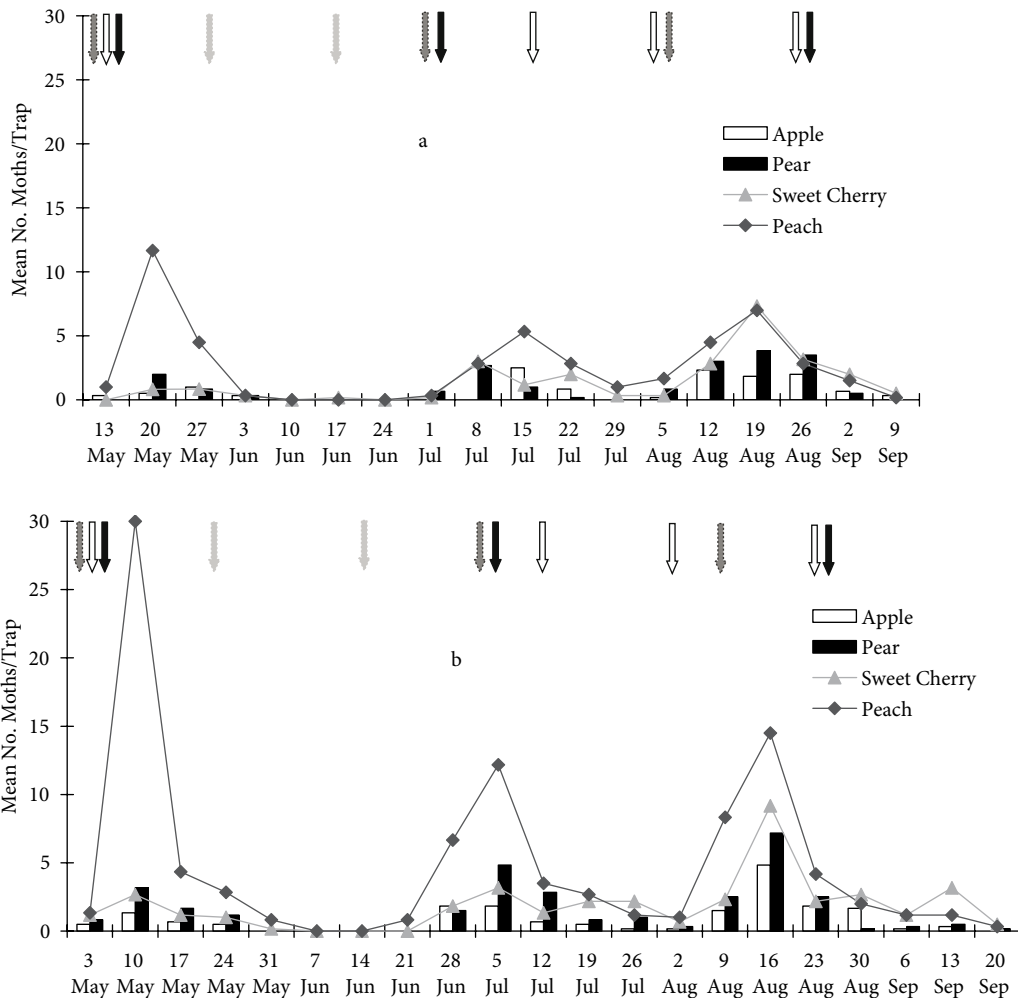


Figure 5. Mean weekly catch of *Adoxophyes orana* adults per trap in apple, pear, peach and sweet cherry orchards in 2009 (a) and 2010 (b) in Bursa, Turkey. Arrows in different colors for each orchard indicate insecticide treatment against other pests.

a well-synchronized adult emergence in all orchards in 2010. The 2nd and 3rd moth flights began in late June or early July (1003–1027 DD) and early August (1600–1690 DD), respectively. Moth captures continued until the end of September, and total flight period lasted for 2305 DD when averaged over host plants and years.

Moth populations significantly varied between the 2 orchards containing the same host plant ($F = 3.90$; d.f. = 3, 1232, $P < 0.01$). In pear and peach orchards, significantly more moths were caught in late-ripening varieties compared with early-ripening varieties, although both varieties were treated with the same insecticides.

3.2. Leaf and fruit damage in pome and stone fruits

Leaf damage by *A. orana* larvae varied from 2.4% to 11.2% (Table). Damage assessments showed that there were significant differences in mean percentage leaf damage between years ($F = 30.4$; d.f. = 1, 32; $P < 0.01$). Significantly

more larval damage was found on leaves in 2010 (7.6%) than in 2009 (4.3%). The sweet cherry leaves sustained the highest mean percentage damage (9.3%).

As seen in the Table, fruit damage was low ($< 1.5\%$) and consistent between years ($F = 0.57$; d.f. = 1, 14; $P = 0.46$). However, neither sweet cherry nor apple fruits sustained any larval damage. The mean percentages of fruits infested with larvae were 1.4% and 0.8% in peach and pear orchards, respectively. In peach and pear orchards, damage levels did not differ significantly between early- and late-ripening varieties ($F = 1.05$; d.f. = 1, 14; $P = 0.32$).

4. Discussion

This study reports the presence of the summer fruit tortrix moth in pome and stone fruit orchards for the first time in northwestern Turkey. The importation of new peach seedlings, which have been used as rootstocks, from

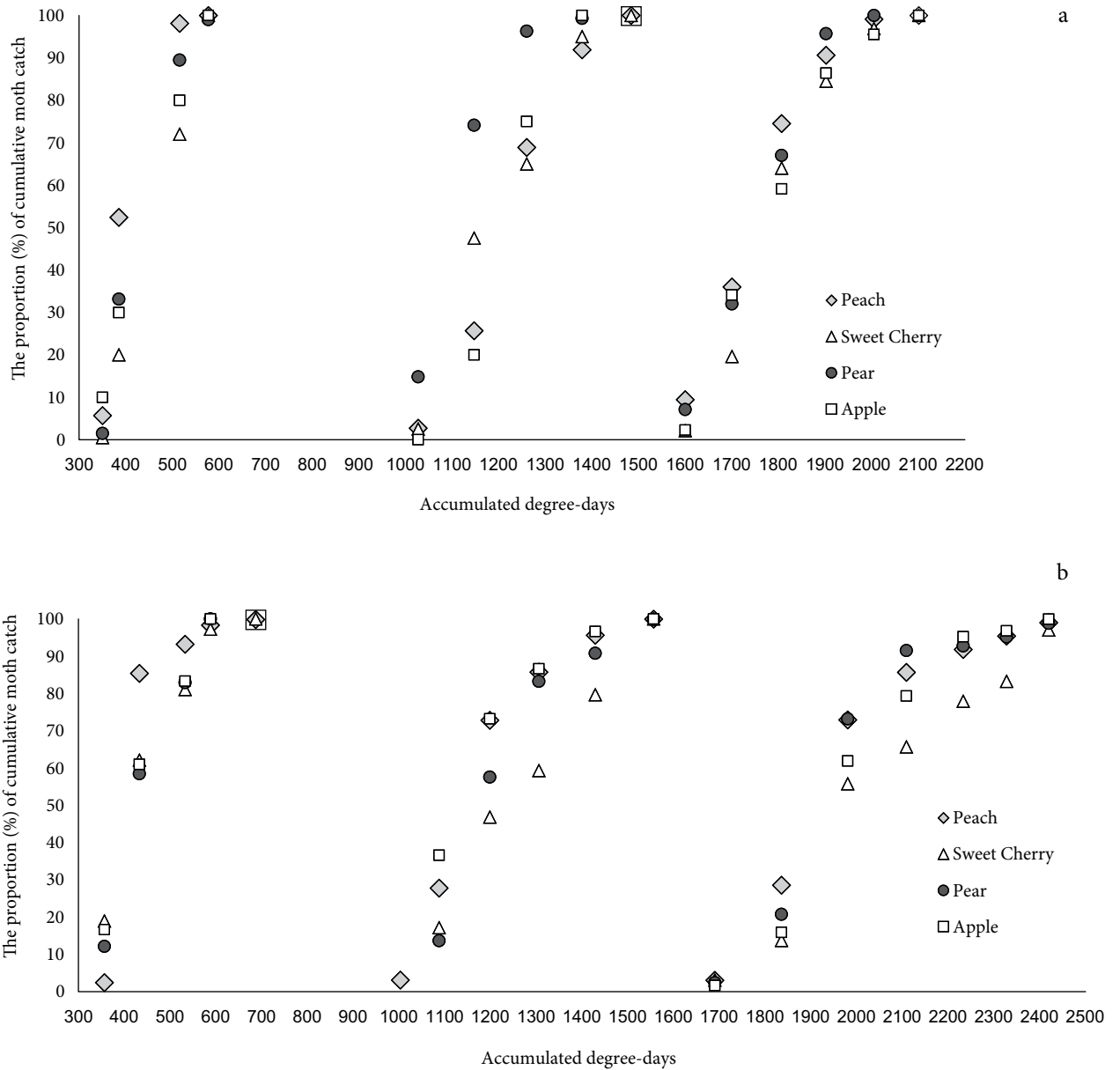


Figure 6. The proportion (%) of cumulative male moths caught in pheromone traps during the 1st, 2nd, and 3rd flight of *Adoxophyes orana* in 2009 (a) and in 2010 (b) in Bursa, Turkey. The y-axis represents cumulative percentage of moths captured in apple, pear, peach, and sweet cherry orchards corresponding to accumulated degree-days shown on the x-axis.

Table. Mean percentage leaf and fruit damage by *Adoxophyes orana* larvae averaged across 2 different locations in 2009 and 2010 in Bursa, Turkey.

Orchard	Leaf Damage		Fruit Damage	
	2009	2010	2009	2010
Apple	2.4%	6.6%	0.0%	0.0%
Peach	4.4%	7.8%	0.7%	2.0%
Pear	2.8%	4.8%	0.8%	0.7%
Sweet cherry	7.4%	11.2%	0.0%	0.0%

Greece and Italy may account for the introduction of this invasive pest to Bursa Province. Leaves and fruits can carry *A. orana* larvae during transport. For this reason, domestic quarantine regulations are needed to prevent the introduction of *A. orana* into other regions of Turkey.

Pheromone traps have proved effective in detecting the presence and monitoring the seasonal population fluctuation of *A. orana* in pome and stone fruit orchards. In fact, pheromone-baited traps were successfully used in a broad-scale regional survey for *A. orana* in apple orchards in eastern Germany (Dickler, 1982), and South Korea (Goh et al., 1984). Following this study, a regional survey program for *A. orana* based on pheromone trapping may be initiated by representatives of the provincial agricultural directorates in Turkey.

When averaged over all orchards, moth catches showed 3 flight peaks in early or mid-May, early July, and mid-August. With the exception of the third flight, moth flight trends are similar to those of northern Greece. The last moths were recorded during September in Turkey (Figures 2a and 2b), whereas moth flights can extend well into October in Greece (Savopoulou-Soultani et al., 1985). During warmer years in northern Greece, Savopoulou-Soultani and Hatzivassiliadis (1991) even reported a 4th moth flight in November. This extra generation of *A. orana* may occur in hot, humid regions of Turkey if this invasive pest spreads to the south. The climatic conditions in Bursa did not favor a 4th flight, although 2010 was warmer than 2009 (Figure 1).

The use of DD accumulations may serve as a complementary tool to trapping for predicting adult emergence time (Damos and Savopoulou-Soultani, 2010). The relationship between temperature data and moth catches in 2009 was examined to see whether average first spring emergence times could be predicted in 2010. We did not attempt to construct a general DD model due to the need to further monitor data collected over a long period of time.

DD calculations in 2009 coincided with the first 2 moth emergence periods in 2010. In 2009 and 2010, the 1st flight period began at 350 and 356 DD and the 2nd at 1027 and 1003 DD, respectively (Figures 3a and 3b). The 3rd moth flight was delayed from 1600 DD in 2009 to 1690 DD in 2010. The delayed appearance of a summer generation of moths in 2010 may have been caused by higher temperatures exceeding the upper larval development threshold of 30 °C in August (Milonas and Savopoulou-Soultani, 2000). Apart from the 3rd flight, our findings are similar to those of Damos and Savopoulou-Soultani (2010) in Greece, who recorded 50% moth emergence of the 1st, 2nd, and 3rd generations of *A. orana* at 406, 1260, and 2141 DD in peach orchards. The difference between the 3rd flight periods in Turkey and Greece is the extended

moth emergence pattern lasting through October in peach orchards in Greece.

In western Serbia, Stamenkovic et al. (1999) reported 2 moth flight periods, the first occurring between late May and early July, and the second from early August to mid-September in apple orchards. In the same period, 3 moth flights occur in Turkey. The variation in the total number of seasonal moth flights could be explained by warmer temperatures and longer photoperiods in southern Europe than in central and northern Europe. When day length falls below a critical photoperiod of 12 h, diapause is induced in the 3rd instar larvae (Ankersmit, 1968). This critical photoperiod is reached around late September in southern England (Cross, 1997). For this reason, a partial 3rd generation may occur in central and northern Europe if the fall temperatures are warm enough, but emerging larvae may not be able to enter diapause and die as a result (Barel, 1973; Berlinger and Ankersmit, 1976; Charmillot and Brunner, 1989, 1990; Stamenkovic et al., 1999; Kocourek and Stara, 2005). However, biotic factors (e.g., host plant quality) rather than abiotic factors may also play a role in larval facultative diapause (Beck, 1980).

Another difference between northern and southern *A. orana* populations appears to be the preference for the host plant. *A. orana* larvae have a strong preference for apples and pears in central and northern Europe (Barel, 1973; Charmillot and Brunner, 1990; Stamenkovic et al., 1999). However, they seem to change their preference to peaches and sweet cherries in southern Europe, where larval damage was more common in stone fruits (Savopoulou-Soultani et al., 1985). The occurrence of high leaf and fruit damage in sweet cherries and peaches in Turkey, respectively, confirms the importance of stone fruits as alternative hosts to pome fruits.

Milonas and Savopoulou-Soultani (2004) claim that the populations collected from peaches and sweet cherries are a new host race strain of *A. orana* larvae. This strain had a weaker diapause intensity compared with populations collected from apples in central Europe. In line with this finding, peach orchards had the highest peak catches in the spring in both years (Figure 4). The young flower buds of the early blooming peaches, which flower about 7–10 days before pears, 14–17 days before apples, and 17–20 days before late-ripening cherries, may provide a ready source of food for post-diapause larvae of *A. orana*.

Fruit damage by summer fruit tortrix moth larvae in early- and late-ripening pear varieties supports the assumption of moth dispersal to pome fruits. In a diverse mixed-orchard environment, both larval oligophagy for Rosaceous plants and their phenological adaptation to the chemical quality and ripening time of other host plants may be held responsible for host switch in *A. orana* adults to pear and apple fruits in late season (Kovanci and Kovanci,

2006). A damage survey conducted in apple orchards by Cross (1997) also revealed that most fruit damage, reaching an average of 2%, was done near harvest time.

Summer-generation larvae primarily cause damage to fruits, while overwintering larvae can attack the buds, flowers, young leaves, and shoots in spring (de Jong and Beeke, 1976). Although no fruit damage was detected in the apple and sweet cherry orchards, the mean percentage of fruits infested with larvae reached 0.8% and 1.4% in pear and peach orchards, respectively. As far as the economic threshold of <1% fruits damaged at harvest is concerned, even lower levels of fruit damage in peach and pear orchards are considered to be of economic importance (de Jong and van Dieren, 1974; de Jong, 1980; Cross, 1997).

It is important to note that monitoring studies for *A. orana* were conducted in sprayed orchards. Unfortunately, it was not possible to find abandoned or unsprayed orchards. For this reason, sprays may have eliminated some proportion of the pest population, especially in summer when it is difficult to distinguish the flight periods. The absence of fruit damage by *A. orana* larvae in apple and sweet cherry orchards could also be attributed to Chlorpyrifos and Thiacloprid treatments, respectively. For example, Chlorpyrifos was found to reduce the numbers of *A. orana* larvae significantly when compared with the untreated control in England (Cross, 1997). Furthermore, Thiacloprid is registered for use against *A. orana* in Poland thanks to its good larvicidal activity on tortricid pests (Pluciennik and Olszak, 2010).

Insecticide spray schedules can also be determined using moth captures in pheromone traps. Both the moth capture and damage data in peach orchards support the

economic threshold of 5–10 moths/trap/week suggested by Minks and de Jong (1975) in apple orchards in the Netherlands. However, in some cases, moth captures in pheromone traps may be poorly correlated with the subsequent damage. In Switzerland, no significant fruit damage was reported even though weekly moth captures exceeded 20–40 moths (Charmillot and Brunner, 1989). Hence, visual inspection for larvae could be useful before making control decisions (Pralja et al., 1992).

In conclusion, the summer fruit tortrix moth is more likely to cause economic damage in peach and pear orchards in Turkey in the near future. In order to prevent the spread of this invasive pest into other regions, domestic quarantine of the areas that are under imminent threat of infestation should be implemented quickly within the framework of an emergency pest response program. This program may be composed of integrated pest management tools such as cultural, bio-technical, biological, and chemical control (Neumann et al., 1997; Mingyan et al., 2009; Pluciennik and Olszak, 2010). Kocourek and Stara (2005) suggested that a single insecticide application per generation in apples may provide satisfactory control, but this management approach needs to be tested in other tree fruit species in future studies. Moreover, it is important to understand the biology and ecology of *A. orana* populations in pome and stone fruits in a mixed-orchard environment in order to achieve a desired control level.

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