Development and Fecundity Performance of Oriental Fruit Moth (Lepidoptera: Tortricidae) Reared on Shoots and Fruits of Peach and Pear in Different Seasons

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ABSTRACT The oriental fruit moth Grapholita molesta (Busck) is a globally important insect pest. In some parts of its geographic range, the oriental fruit moth shifts its attack from peach orchards to pear orchards late in the growing season. The phenological effects of host plants on the performance of the moth were evaluated by examining the development and fecundity of the moth reared on peach (Prunus persica variety “Shahong”) and pear (Pyrus bretshneideri variety “Dangshan Su”) collected at various times of the growing season under laboratory conditions. Results showed that the moth developed faster on shoots and fruits of peach than on those of pear. The preimaginal survival rate was the highest on peach shoots, and the moth could not survive on pear fruit collected on May 10. For both peach and pear, the boring rates of neonatal larvae were significantly higher on shoots than on fruits, and the pupal mass of females was significantly higher on fruits than on shoots. The boring rate increased with pear fruits growing during later days. Fecundity was significantly less on pear shoots than on the other plant materials. The results of this study suggest a possible host adaptation process in oriental fruit moth.

KEY WORDS Grapholita molesta, host plant, survival, development, fecundity

The availability of host plants is an important factor that determines the population dynamics of herbivorous insects (Ishihara and Ohgushi 2006, Naseri et al. 2009). The physical characteristics and chemical components of host plants affect the performance of herbivorous insects, including their development time, survival rate, and fecundity (Singh and Mullick 1997, Awmack and Leather 2002, Ishihara and Ohgushi 2006). These characteristics and components vary in different phenological periods (Mattson 1980, Drossopoulou et al. 1996, Hartley and Jones 1997, Bezemer and Mills 2001, Van Steenwyk et al. 2004). Previous studies showed that the phenology of host plants may influence the dynamics of pest populations, such as the larval survival of Cydia pomonella (L.) (Riedl et al. 1998, Bezemer and Mills 2001, Van Steenwyk et al. 2004), the seasonal dynamics of Halyomorpha halys (Stål) (Nielsen et al. 2011), and the survival or fitness of Choristoneura rosaceana (Harris) (Ostad et al. 1986) and Choristoneura fumiferana (Clemens) (Lawrence et al. 1997). For Grapholita molesta (Busck), the larvae feed at different sites on peaches and apples over the course of the growing season (Myers et al. 2007), and the larval survival was higher in ripening peach fruit than in green (Myers et al. 2006a).

G. molesta, oriental fruit moth, is an important insect pest on a global scale. It is widely distributed throughout temperate and subtropical regions of Asia, Europe, the Americas, Africa, and Australia (Rothschild and Vickers 1991, Najar-Rodriguez 2013a). It is also a quarantine pest that affects fruit export shipments among countries (Cichon et al. 2013). For example, oriental fruit moth is quarantine pest for Mexico of stone and pome fruit from the United States (Hansen 2002). It is considered to be an oligophagous species because nearly all of its host plants belong to the family Rosaceae, including many economically important tree fruit crops such as peach, apple, and pear (Rothschild and Vickers 1991, Natale et al. 1999, Myers et al. 2007, Najar-Rodriguez 2013b). The pest occurs three to six generations per year depending on the temperature and the location (Zhang 1980, Kanga et al. 1999, Kovanci and Walgenbach 2005, Puñero and Dorn 2007, Ahn et al. 2012). Populations show seasonal dynamics in host plant use at some parts of the geographic range of the moth (Najar-Rodriguez et al. 2013a, b). Larvae infest shoots of peach and apple in the early growing season (Myers et al. 2006a) and then shift to fruits in the mid-to-late season (Zhang 1980, Yang 1983, Puñero and Dorn 2009, Lu et al. 2012). Pear is the primary host late in the growing season (Lu et al. 2012). In Jiangsu, China, the first three generations of oriental fruit moth attack peach orchards, whereas the third generation starts to infest pear and apple orchards (Zhao et al. 1989). In eastern North America, larvae

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feed on growing shoots early in the season, whereas larvae feed directly on the fruit later in the season (Myers et al. 2006a).

The developmental rate and survival of oriental fruit moth larvae differ between peach and apple, both on growing shoot and excised fruit, at various times of the season (Myers et al. 2006a, 2007). The larvae do not have the same physiological capability with respect to using peach, apple, and pear fruits as hosts (Najar-Rodriguez et al. 2013a). Few studies compare the development rate and population dynamics of the pest on different phenological periods of the host plant, especially on pear (Myers et al. 2006a). Whether the phenology of peach and pear influences the performance of the moth and results in a switch from peach to pear orchards late in the growing season remains unknown. Thus, it was hypothesized in this study that the switch of oriental fruit moth from peach to pear in the late growing season, especially after peach harvesting, might be caused by different performances of the pest on peach and pear at different phenological periods. The main objective of this study was to investigate the effects of shoots and fruits of peach and pear on the development time, survivorship, and reproduction of oriental fruit moth under laboratory conditions. These experiments are expected to enhance our understanding of the seasonal host switch from peach to pear, and these are prerequisite for developing efficient integrated management programs for controlling the pest.

Materials and Methods

Plant Materials. Shoots and fruits of 18-yr-old peach trees (Prunus persica (L.) variety “Shahong”) and 20-yr-old pear trees (Pyrus brunsvigleri Rehd variety “Dangshan Su”) were collected from Licun Village, Xingping, Shaanxi, China (34° 22′ 46″ N, 108° 31′ 47″ E) in 2014. The harvest dates of peach and pear fruits in Xingping were June 20 and September 1, respectively. The orchard was managed under a conventional pesticide management program. For arthropod pest and disease management, pesticides were used about once per month. Acetamiprid was used against aphis both in peach and pear orchards. Chlorpyrifos and cyhalothrin were used against mites, tortricid species, and oriental fruit moth in peach orchard according to previous records of occurrence dates of each generation (Zhao et al. 1989, Chen et al. 2011, Guo et al. 2013). Fruits at the first collecting date were not used in this study due to those being too small and these would become dehydrated long before the completion of larval development (Najar-Rodriguez 2013a), and replaced those with shoots which easily were infested with oriental fruit moth during the early growing season. In total, 400–500 shoots, 120–140 small fruits (<20 mm in diameter), 20–23 middle fruits (20–40 mm in diameter), or big fruits (>40 mm in diameter) were collected and used for evaluation of each plant material type. All the plant materials were collected in the day before each plant material evaluation, sealed in valve bag, and kept under 4°C.

Insect Colony. The oriental fruit moth used in the experiment was originally collected from infested stems of peach (P. persica) on May and June 2008 in Yangling, Shaanxi, China (34°16′49″N, 108°04′05″E). Larvae were reared in glass tubes with artificial food described by Du et al. (2010). The top of each glass tube was sealed with cotton to prevent escape of larvae and to provide a suitable site for pupation. When mature larvae emerged from artificial food, they would build their cocoons at the junction of the cotton and the inner wall of the glass tube. Once the pest emerged as adults, these adults were removed and placed into beakers (2,000 ml) covered with absorbent gauze. Three pieces of vegetable parchment (12 by 18 cm²) were placed in each beaker for egg laying, and 10% honey solution was provided for food. Oriental fruit moth was maintained at 25 ± 0.5°C, 70 ± 10% RH, and a photoperiod of 15:9 (L: D) h.

Development and Survival Rate of Immature Stages. Shoots and fruits were placed in covered transparent plastic containers (12 cm in diameter and 8 cm in height). The cut sections of shoots were wrapped with water-soaked cotton to maintain freshness. A hundred holes were made in the container cover using a #0 insect pin for aeration. Each container was filled with 3 shoots, 10 small fruits, 3 middle fruits, or 1 big fruit. In total, 32 containers with peach shoots, 83 containers with pear shoots, 8–14 containers with small or middle fruits, or 20–23 containers with big fruits were used for evaluation of each plant material type.

Eggs laid on the vegetable parchment were collected within 12 h from the colony, and the vegetable parchment was cut into pieces with one egg. Each egg paper was maintained on a Petri dish (6 cm in diameter and 1 cm in height) with water-soaked cotton to keep moist under the colony conditions. When eggs reached the black-head stage and hatched within 12 h, egg paper sheets were attached to the junction of the leaf petiole and shoot stem, the calyx end (pear) or stalk cavity (peach). Each egg was placed on each shoot or small fruit, and five eggs were placed on each middle or big fruit. More than 100 eggs were used on shoots of peach or pear collected on April 15; peach fruits collected on May 10 and June 15; and pear fruits collected on May 10, June 15, July 15, or August 15. All eggs were examined daily. The unhatched ones were removed to another container filled with the same plant materials to ensure consistency of development time of eggs in
the same container. Shoots were replaced every 3 d with new ones stored at 4°C. All the containers were maintained in a climate chamber under the same conditions as the colony and examined daily to record the hatch time and boring rate. The duration of egg stage was measured as the time from newly laid egg to hatching.

When a mature larva emerged from either a shoot or a fruit, it was transferred into a separate test tube (1.5 cm in diameter and 8 cm in height). The glass tube was sealed with cotton, and the larvae usually built their cocoons at the junction of the cotton and the inner walls of the glass tube. The larvae were continuously examined until pupation. After pupation, the pupae were withdrawn from the tubes and from their cocoons. The fresh mass and the sex of each newly formed pupa were recorded. Male pupae can be distinguished from female pupae due to the apparent presence of an additional posterior abdominal segment. Each pupa was then returned to the tube, which was examined daily for adult emergence. Duration of larval stage was measured as the time from hatching to emergence from either fruit or shoot, prepupal stage from emergence to pupation, pupal stage from pupation to adult emergence, and immature stage from egg to adult emergence.

**Longevity and Fecundity of Female Adult.** Newly emerged adults were transferred to transparent plastic containers (5 cm in diameter and 7 cm in height) in pairs that consisted of a female and a male. Containers were covered with plastic wrap that was poked 100 times using a #0 insect pin for aeration. The number of pairs of both sexes of moth tested for each host plant depended on the survival from the previous stage and ranged from 5 to 30 pairs. A cotton wick soaked in 10% honey solution was placed in each container to provide a carbohydrate source for adult feeding. The number of eggs was recorded as a daily routine, and each egg was marked with a short line outside the container using a marker pen until the female adult died. Data obtained from unmated females as indicated by the absence of a spermatophore were excluded from the analysis. The preoviposition period was defined as the number of days from adult emergence to the date on which the adult started to lay eggs. The oviposition period was the number of days between the day of starting to lay eggs of female adult and the day stopping to lay eggs. Longevity was recorded as the number of days between adult emergence and death. Fecundity was assessed as the number of eggs laid by each female during its lifespan.

**Statistical Analysis.** Differences in development time, survival rate, and fecundity of oriental fruit moth reared on different host plant materials were analyzed with one-way ANOVA, and means were separated using the Student–Newman–Keuls (S–N–K) test at \( \alpha = 0.05 \). All survival rates were transformed using arcsine square-root to normalize the means before the ANOVA was performed. The jackknife procedure was conducted to test the differences in population parameters (Meyer et al. 1996; Maia et al. 2000). A dendrogram of plant materials based on the life table parameters of oriental fruit moth reared on various plant materials was created after cluster analysis by Ward’s method using SPSS 16.0 statistical software (SPSS Inc., Chicago, IL).

**Results**

**Effects of Different Host Plant Materials on Development and Survival Rate of Oriental Fruit Moth.** Larvae could not survive on pear fruits collected on May 10 (Table 1). Significant differences were observed in duration of larval stage (\( F = 67.75; df = 6, 187; P < 0.0001 \)), prepupal stage (\( F = 9.46; df = 6, 186; P < 0.0001 \)), pupal stage (\( F = 5.73; df = 6, 174; P < 0.0001 \)), and immature stage (\( F = 62.78; df = 6, 174; P < 0.0001 \)) of oriental fruit moth reared on shoots and fruits of peach and pear collected at various times of the growing season. Durations of immature and larval stages of the pest reared on pear materials (25.23, 27.00, 27.60, and 31.20 d, respectively; 14.63, 12.67, 13.20, and 16.06 d, respectively) were significantly longer than durations of those on peach materials (22.66, 23.26, and 25.13 d, respectively; 9.37, 9.55, and 10.53, respectively). For peach, the duration of the immature stage was longer on fruits collected on June 15 (25.13 d) compared with that on shoots (22.66 d) and fruits collected May 10 (23.26 d). No significant difference was observed in the duration of larval stage of the moth reared on peach at different times of the growing season. For pear, durations of immature and larval stages were the longest on fruits collected on August 15 (31.20 and 16.06 d, respectively). The prepupal stage was significantly shorter on peach shoots (2.29 d) and fruits collected on May 10 (2.67 d) compared with that on pear fruits collected on August 15 (3.61 d). The pupal stage of the pest reared on peach fruits collected on June 15 (7.57 d) and that on pear fruits collected on August 15 (7.60 d) was significantly longer than that of the pest reared on pear shoots (6.77 d). No variation was observed in the duration of egg on different plant materials (\( F = 1.43; df = 7, 927; P = 0.19 \)).

Significant differences were observed in the preimaginal survival rate (\( F = 7, 16; df = 55.60; P < 0.0001 \)) and longevity (\( F = 106.84; df = 7, 16; P < 0.0001 \)) of oriental fruit moth reared on pear fruits (1.78, 8.77, 12.89 and 74.45, respectively) increased with pear fruits growing during later days. Exiting rate was significantly lower on pear shoots (7.42 %) and pear fruits collected on May 10 (0 %) and the highest for peach shoots (64.21 %). The mating rate of neonatal larvae was significantly different (\( F = 106.84; df = 7, 16; P < 0.0001 \)), with the highest rate observed on shoots of peach (92.22%) and pear (90.00%). The mating rate of neonatal larvae reared on pear fruits (1.78, 8.77, 12.89 and 74.45, respectively) increased with pear fruits growing during later days. Exiting rate was significantly lower on pear shoots (7.42 %) and pear fruits collected on May 10 (0 %) and the highest for peach shoots (64.21 %). The mating rate of neonatal larvae was significantly different (\( F = 106.84; df = 7, 16; P < 0.0001 \)), with the highest rate observed on shoots of peach (92.22%) and pear (90.00%). The mating rate of neonatal larvae reared on pear fruits (1.78, 8.77, 12.89 and 74.45, respectively) increased with pear fruits growing during later days. Exiting rate was significantly lower on pear shoots (7.42 %) and pear fruits collected on May 10 (0 %) and the highest for peach shoots (64.21 %). The mating rate of neonatal larvae was significantly different (\( F = 106.84; df = 7, 16; P < 0.0001 \)), with the highest rate observed on shoots of peach (92.22%) and pear (90.00%).
The study by Myers showed significant effects of different plant materials on development time, survival rate, and fecundity of the pest. Peach fruits collected on May 10, and pear shoots. Cluster B consisted of peach fruits collected on June 15, July 15, and August 15, and pear shoots collected on August 15, and pear shoots (Fig. 2).

**Discussion**

Because oriental fruit moth shifted its attack from the peach tree to the pear fruit late in the growing season, mainly after peach harvest (Zhao 1989, Natale et al. 2003, Il’ichev et al. 2007), the performance of oriental fruit moth reared on peach and pear materials collected at various times of the growing season was compared. Significant differences were found in the effects of different plant materials on development time, survival rate, and fecundity of the pest. Peach serves as the primary host of oriental fruit moth, and apple and pear are considered as secondary hosts (Rice et al. 1972, Rothschild and Vickers 1991). The larvae infest shoots of peach and apple, among others, in the early growing season and then shift to fruits in the mid-to-late season (Zhang 1980, Yang 1983, Piñero and Dorn 2009, Lu et al. 2012). Host plants in the present study significantly affected the development time, survival rate, and fecundity of the moth. Duration of the immature stage was significantly shorter on peach than on pear (Table 1). This result is similar to that of Myers et al. (2007) and Najar-Rodriguez et al. (2013a), who

### Table 1. Durations (d ± SE) of each stage of oriental fruit moth reared on shoots and fruits of peach and pear collected at various times of the growing season under laboratory conditions

<table>
<thead>
<tr>
<th>Plant materials</th>
<th>Collection date</th>
<th>Egg</th>
<th>Larva</th>
<th>Prepupa</th>
<th>Pupa</th>
<th>Immature stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peach shoot</td>
<td>April 15</td>
<td>3.62 ± 0.03a</td>
<td>9.37 ± 0.19d</td>
<td>2.29 ± 0.11b</td>
<td>7.07 ± 0.08ab</td>
<td>22.66 ± 0.23d</td>
</tr>
<tr>
<td>Peach fruit</td>
<td>May 10</td>
<td>3.71 ± 0.02a</td>
<td>9.55 ± 0.21d</td>
<td>2.67 ± 0.11b</td>
<td>7.03 ± 0.14ab</td>
<td>23.26 ± 0.37b</td>
</tr>
<tr>
<td>May 10</td>
<td>June 15</td>
<td>3.63 ± 0.03a</td>
<td>10.53 ± 0.38c</td>
<td>3.12 ± 0.13ab</td>
<td>7.57 ± 0.10a</td>
<td>25.13 ± 0.40c</td>
</tr>
<tr>
<td>Pear shoot</td>
<td>April 15</td>
<td>3.67 ± 0.02a</td>
<td>14.63 ± 0.50b</td>
<td>3.00 ± 0.16ab</td>
<td>6.77 ± 0.17b</td>
<td>28.23 ± 0.41b</td>
</tr>
<tr>
<td>Pear fruit</td>
<td>May 10</td>
<td>3.66 ± 0.03a</td>
<td>12.67 ± 0.33c</td>
<td>3.00 ± 0.26ab</td>
<td>7.33 ± 0.21ab</td>
<td>27.60 ± 0.36b</td>
</tr>
<tr>
<td>May 10</td>
<td>June 15</td>
<td>3.69 ± 0.03a</td>
<td>13.2 ± 0.33c</td>
<td>3.10 ± 0.10ab</td>
<td>7.30 ± 0.15ab</td>
<td>27.60 ± 0.43b</td>
</tr>
<tr>
<td>July 15</td>
<td>3.63 ± 0.02a</td>
<td>16.06 ± 0.43c</td>
<td>3.61 ± 0.24ab</td>
<td>7.60 ± 0.10a</td>
<td>31.20 ± 0.53a</td>
<td></td>
</tr>
<tr>
<td>August 15</td>
<td>3.66 ± 0.01a</td>
<td>16.06 ± 0.43c</td>
<td>3.61 ± 0.24ab</td>
<td>7.60 ± 0.10a</td>
<td>31.20 ± 0.53a</td>
<td></td>
</tr>
</tbody>
</table>

Values within the same column followed by different letters are significantly different (S–N–K, \( P < 0.05 \)).

### Table 2. Survival rate (% ± SE) of each stage of oriental fruit moth reared on shoots and fruits of peach and pear collected at various times of the growing season

<table>
<thead>
<tr>
<th>Plant materials</th>
<th>Collection date</th>
<th>Hatching rate</th>
<th>Boring rate</th>
<th>Exiting rate</th>
<th>Pupation rate</th>
<th>Emergence rate</th>
<th>Preimaginal survival rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peach shoot</td>
<td>April 15</td>
<td>94.76 ± 1.38a</td>
<td>92.22 ± 1.16a</td>
<td>76.81 ± 3.22a</td>
<td>100.00 ± 0.00a</td>
<td>97.10 ± 5.72ab</td>
<td>64.21 ± 5.55a</td>
</tr>
<tr>
<td>Peach fruit</td>
<td>May 10</td>
<td>95.52 ± 2.21a</td>
<td>43.24 ± 2.98c</td>
<td>55.78 ± 2.45a</td>
<td>100.00 ± 0.00a</td>
<td>94.21 ± 5.84ab</td>
<td>22.21 ± 3.12b</td>
</tr>
<tr>
<td>May 10</td>
<td>June 15</td>
<td>95.18 ± 5.25a</td>
<td>45.63 ± 3.06b</td>
<td>76.78 ± 6.96a</td>
<td>100.00 ± 0.00a</td>
<td>86.47 ± 4.07ab</td>
<td>29.88 ± 4.90b</td>
</tr>
<tr>
<td>Pear shoot</td>
<td>April 15</td>
<td>96.00 ± 0.55a</td>
<td>90.00 ± 1.39a</td>
<td>7.42 ± 0.62b</td>
<td>100.00 ± 0.00a</td>
<td>81.11 ± 0.52b</td>
<td>5.20 ± 0.52c</td>
</tr>
<tr>
<td>Pear fruit</td>
<td>May 10</td>
<td>94.18 ± 2.60a</td>
<td>1.78 ± 3.13e</td>
<td>0.00 ± 0.00c</td>
<td>100.00 ± 0.00a</td>
<td>0.00 ± 0.00d</td>
<td>0.00 ± 0.00d</td>
</tr>
<tr>
<td>May 10</td>
<td>June 15</td>
<td>95.39 ± 1.27a</td>
<td>8.77 ± 1.80b</td>
<td>72.22 ± 13.67a</td>
<td>100.00 ± 0.00a</td>
<td>100.00 ± 0.00a</td>
<td>5.36 ± 1.1c</td>
</tr>
<tr>
<td>July 15</td>
<td>94.50 ± 1.57a</td>
<td>12.89 ± 2.00d</td>
<td>76.67 ± 13.06a</td>
<td>100.00 ± 0.00a</td>
<td>100.00 ± 0.00a</td>
<td>8.81 ± 1.01c</td>
<td>25.60 ± 4.64b</td>
</tr>
<tr>
<td>August 15</td>
<td>94.28 ± 0.21a</td>
<td>74.45 ± 3.19b</td>
<td>43.40 ± 1.92a</td>
<td>97.43 ± 5.37a</td>
<td>97.23 ± 5.58ab</td>
<td>28.54 ± 6.49ab</td>
<td></td>
</tr>
</tbody>
</table>

Values within the same columns followed by different letters are significantly different (S–N–K, \( P < 0.05 \)). All analyses were conducted on arcsine-transformed data.
found that larvae develop faster on peach than on apple on both shoots and fruits. Zhang (1980) and Yang et al. (2003) considered that larvae mainly feed on shoots of peach, apple, and pear during the first two generations. Yang (1983) and Rice et al. (1972) found that larvae infested leaf petioles and shoots of pear, and the infestation characteristics retained similarity to those on peach shoots except that the feeding sites of pear shoots became black, which was consistent with the observation of this study. Fewer studies were conducted to investigate the performance of oriental fruit moth reared on pear shoots. In the present study, fecundity of adults from larvae reared on pear shoots was significantly lower than that of adults reared on other materials (Table 3). No significant difference was observed in adult fecundity and pupal mass of females.

Table 3. Fecundity of female adult of oriental fruit moth reared on shoots and fruits of peach and pear collected at various times of the growing season

<table>
<thead>
<tr>
<th>Plant materials</th>
<th>Collection date</th>
<th>Pupal mass (mg)</th>
<th>Preovipositive period (d)</th>
<th>Ovipositive period (d)</th>
<th>Fecundity</th>
<th>Longevity (d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peach shoot</td>
<td>April 15</td>
<td>8.38 ± 0.45b</td>
<td>6.91 ± 0.65a</td>
<td>17.59 ± 1.35a</td>
<td>145.04 ± 14.20a</td>
<td>24.23 ± 1.26a</td>
</tr>
<tr>
<td>Peach fruit</td>
<td>May 10</td>
<td>10.95 ± 0.44a</td>
<td>3.83 ± 0.53ab</td>
<td>17.16 ± 0.59a</td>
<td>160.36 ± 16.72a</td>
<td>21.31 ± 2.08a</td>
</tr>
<tr>
<td></td>
<td>June 15</td>
<td>13.39 ± 0.61a</td>
<td>3.67 ± 0.47ab</td>
<td>16.25 ± 1.99a</td>
<td>227.92 ± 23.85a</td>
<td>21.83 ± 2.75a</td>
</tr>
<tr>
<td>Pear shoot</td>
<td>April 15</td>
<td>6.48 ± 0.47b</td>
<td>3.25 ± 0.25b</td>
<td>12.50 ± 1.04a</td>
<td>37.50 ± 5.14b</td>
<td>15.75 ± 0.85a</td>
</tr>
<tr>
<td>Pear fruit</td>
<td>May 10</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>June 15</td>
<td>12.87 ± 1.59a</td>
<td>3.33 ± 0.88b</td>
<td>14.33 ± 2.33a</td>
<td>128.67 ± 27.47a</td>
<td>21.33 ± 3.18a</td>
</tr>
<tr>
<td></td>
<td>July 15</td>
<td>12.90 ± 1.22a</td>
<td>4.20 ± 0.49ab</td>
<td>15.80 ± 2.50a</td>
<td>214.40 ± 26.49a</td>
<td>20.20 ± 2.33a</td>
</tr>
<tr>
<td></td>
<td>August 15</td>
<td>11.56 ± 0.54a</td>
<td>4.80 ± 0.43ab</td>
<td>20.80 ± 1.47a</td>
<td>178.80 ± 19.05a</td>
<td>25.60 ± 1.57a</td>
</tr>
</tbody>
</table>

Values within the same columns followed by different letters are significantly different (S–N–K, P < 0.05).

Table 4. Life table parameters of oriental fruit moth reared on different plant materials

<table>
<thead>
<tr>
<th>Plant materials</th>
<th>Collection date</th>
<th>Net reproductive rate (R0)</th>
<th>Mean generation time (T)</th>
<th>Intrinsic rate of natural increase (r)&lt;sub&gt;m&lt;/sub&gt;</th>
<th>Finite rate of increase (k)</th>
<th>Doubling time (DT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peach shoot</td>
<td>April 15</td>
<td>93.10 ± 9.12a</td>
<td>34.14 ± 1.15b</td>
<td>0.1327 ± 0.0063a</td>
<td>1.1419 ± 0.0071a</td>
<td>5.21 ± 0.25c</td>
</tr>
<tr>
<td></td>
<td>May 10</td>
<td>35.51 ± 3.70bcd</td>
<td>32.67 ± 0.84d</td>
<td>0.1094 ± 0.0042ab</td>
<td>1.1156 ± 0.0047ab</td>
<td>6.33 ± 0.24c</td>
</tr>
<tr>
<td></td>
<td>June 15</td>
<td>64.45 ± 7.23ab</td>
<td>33.16 ± 1.50b</td>
<td>0.1255 ± 0.0061a</td>
<td>1.1336 ± 0.0069a</td>
<td>5.51 ± 0.29c</td>
</tr>
<tr>
<td>Pear shoot</td>
<td>April 15</td>
<td>1.95 ± 0.27d</td>
<td>35.84 ± 1.01b</td>
<td>0.0190 ± 0.0035d</td>
<td>1.0192 ± 0.0036d</td>
<td>35.07 ± 7.55a</td>
</tr>
<tr>
<td></td>
<td>May 10</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>June 15</td>
<td>7.16 ± 1.53d</td>
<td>35.95 ± 1.37b</td>
<td>0.0552 ± 0.0087c</td>
<td>1.0567 ± 0.0083c</td>
<td>12.29 ± 1.92b</td>
</tr>
<tr>
<td></td>
<td>July 15</td>
<td>19.88 ± 2.75cd</td>
<td>35.24 ± 0.70b</td>
<td>0.0620 ± 0.0051b</td>
<td>1.0857 ± 0.0056b</td>
<td>8.12 ± 0.49c</td>
</tr>
<tr>
<td></td>
<td>August 15</td>
<td>50.82 ± 5.40bc</td>
<td>43.04 ± 1.00a</td>
<td>0.0913 ± 0.0039b</td>
<td>1.0956 ± 0.0043b</td>
<td>7.58 ± 0.33c</td>
</tr>
</tbody>
</table>

Values within the same columns followed by different letters are significantly different (S–N–K, P < 0.05).
between peach and pear fruits (Table 3). This is inconsistent with Najar-Rodriguez et al. (2013a) that females laid significantly fewer eggs when reared on pear fruits than when reared on peach fruits, and newly emerged female pupae from larvae reared on peach fruits were significantly lighter than those from larvae reared on pear fruits. Such inconsistency might be caused by use of different plant materials. Pear (Pyrus communis variety “Harrow Sweet”) was used in Najar-Rodriguez et al.’s research (2013a), while pear (P. bretshneideri variety “Dangshan Su”) was used in this study. Several studies indicate that pupal weight and fecundity of lepidopteran pests are influenced by host plants, and pupal weight is positively correlated with fecundity (Cisneros and Barnes 1974, Robison et al. 1998, Asaro and Berisford 2001, Azidah and Sofian-Azirun 2006, Najar-Rodriguez et al. 2013a). In the present study, fecundity increased with female pupal weight (Table 3).

The phenology of the host affects growth, survival rate, and fecundity of herbivores and influences population dynamics. For example, the larvae of C. rosaceana developmental rates are faster and survival rates are higher earlier in the season (Onstad et al. 1986). The seasonal variation and larval survival in C. pomonella infestation is affected by changes in fruit maturity (Van Steenwyk et al. 2004). In Plagiodera versicolora (Laicharting), the total number of eggs laid late in the season is significantly fewer than that laid early in the season (Ishihara and Olgushi 2006). In the present study, for both peach and pear, the duration of immature stage of the moth reared on fruits collected later was significantly longer than the duration of those collected early (Table 1). The boring rate of neonatal larvae and survival rate of immature stages of the pest reared on pear fruits increased with pear fruits growing during later days (Table 2). The stone cell content of pear (P. bretshneideri variety “Dangshan Su”) was highest in the seventh week after flowering, which was the first date the pear fruit was collected in this study and subsequently decreased with increased weeks (Liu et al. 2006, Nie et al. 2009). Because the fruit hardness has a positive relationship with the stone cell content (Liu et al. 2011), it was concluded in this study that the boring rate was greatly affected by the hardness of fruit. This result is supported by VanSteenwyk (2004), who reported that as the fruit grows and stone cells break down, the pears become more suitable for infestation, and a greater percentage of C. pomonella larvae complete their development. Lower boring rate of neonatal larvae on peach fruit may be caused by the long and dense hair, which would make the penetration of peach fruit more difficult for larvae (Lei et al. 2012).

Cluster analysis indicated that based on the comparative life table parameters of oriental fruit moth, the different plant materials fell into two distinct groups: A (pear fruit picked on June 15 and July 15, peach fruit picked on May 10, and pear shoot) and B (peach fruit picked on June 15, pear fruit picked on August 15, and peach shoot; Fig. 2). The grouping with each cluster may be caused by a high level of physiological similarity of plant materials (Naseri et al. 2009, Razmjou et al. 2014). Life table parameters are important in measuring the population growth capacity of insects under specified conditions. The combined results of life table parameters and cluster analysis showed that cluster A plant materials, which included more unsusceptible host plant materials with lower survival rate, less fecundity, and longer development time of the moth,
were unsuitable, and cluster B host plant materials, which included more susceptible host plant materials with higher survival rate, shorter development time, and greater fecundity of the moth, were suitable. This is consistent with the switch of oriental fruit moth from peach to pear in the late growing season, especially after peach harvesting (Zhao et al. 1989; Lu et al. 2012, Najar-Rodríguez 2013a, b).

Shoots and fruits of peach and pear collected in this study at various times of the growing season significantly affected development time, survival rate, and fecundity of oriental fruit moth. In the natural environment, the switch of the moth from peach orchard to pear orchard is related to the different performance caused by different diets of the larvae and volatile blends emitted by the host plant in the process of host location. Najar-Rodríguez et al. (2013b) found that female moths are attracted to volatiles from peach twigs collected during the early growing season and pear twigs during the late fruiting stage. This result is consistent with that of the present study, which showed that the performance of the moths was higher on peach shoot, peach fruit collected on June 15, and pear fruit collected on August 15. This result supports the hypothesis of oviposition preference—offspring performance that females choose a host plant on which their larvae perform best (Wiklund 1981; Liu et al. 2010, 2011). Therefore, the switch of the moth from peach to pear late in the growing season, especially after peach harvest, may be caused by the combined preference of the moth and offspring performance on peach and pear at different phenological periods. Peach was the primary host of the moth, and apple and pear were considered as secondary hosts. After peach harvest, the larvae did not survive on the peach shoot (Dustan 1961) and shifted to attack pear. The switch is an adaptation in the coevolution progress between the pest and its hosts.

Understanding the relationship between the life history of oriental fruit moth and the species and phenological periods of host plants not only improves the accuracy of forecasting the population dynamics but also contributes to practical applications for integrated pest management programs. High performance of oriental fruit moth was observed on peach shoot, peach fruit collected on June 15, and pear fruit collected on August 15 in this study. This finding emphasizes that timely and effective control measures should be considered to reduce the total population in peach orchards given that some larvae in orchards may develop in drop fruits caused by pest damage or horticultural measures, such as early thinning. Shoots used in this study were replaced every 3 d, and their influence would lessen if excised shoots were used. This study explicitly illustrated the relationship between the performance of oriental fruit moth and the phenology of the host plants, which could be a reference for making efficient integrated pest management in controlling such pest. Future studies should be conducted under field conditions by using growing shoots and fruits and wild populations to evaluate the exact effects of various host plant materials on the pest. The mechanisms that are responsible for different performance of the pest grown on host plants of different phenological periods should also be investigated.

Acknowledgments

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