The Effect of Larval Diet on the Flight Capability of the Adult Moth Athetis lepigone (Möschler) (Lepidoptera: Noctuidae)

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The effect of larval diet on the flight capability of the adult moth *Athetis lepigone* (Möschler) (Lepidoptera: Noctuidae)

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Abstract

Athetis lepigone (Möschler) (Lepidoptera: Noctuidae) is a polyphagous insect which has caused severe damage to corn seedlings in recent yr in the summer corn region of China. It is suggested that this is a migrant species, which annually produces 4 different host-fed generations, but the discovery of its flight performance on each host has been elusive. The effects of 4 host plants—corn, peanut, soybean, and wheat—on the survival ratio of larvae and on the flight performance of *A. lepigone* moths were investigated under laboratory conditions. The results indicate that wheat was the comparatively preferred diet for larvae. The flight distance of *A. lepigone* moths increased from 1 d old to a peak level at 3 d and then declined after 4 d old within a 24 h limited flight time. The positive larval-nutrition relationship in terms of flight capability of *A. lepigone* moths also resulted in the furthest distance and longest duration from the preferred wheat. The maximum distance covered by a single individual fed on wheat for 24 h was 44.55 km. The max duration of an individual was 21.46 h. However, *A. lepigone* moths had a comparatively higher maximum immediate speed (max speed) when larvae fed on non-preferred host plants such as corn and peanut. The sex of the moths from different hosts had no effect on flight distance, duration, or max speed. There were 2 peaks in flight duration of all 3 to 4 d old tested moths, which meant 2 groups: short flight and long flight duration. The difference between hosts in terms of distance, duration, and max speed as previously mentioned occurred only in the long flight duration group. All these results enhance understanding of the seasonal population dynamics of this migratory moth in the agricultural ecosystem in China. They also have important implications for natural environments in terms of migration and outbreaks.

Key Words: *Athetis lepigone*; host preference; tethered flight; flight ability

Resumen

Athetis lepigone (Möschler) (Lepidoptera: Noctuidae) es un insecto polífago que ha causado graves daños a las plántulas de maíz en los últimos años en la región de maíz de verano de China. Se sugiere que esta es una especie migratoria, que anualmente produce 4 generaciones alimentadas por diferentes hospederos, pero ha eludido el descubrir el desempeño de vuelo en cada hospedero. Los efectos de 4 plantas hospederas—maíz, maní, soja, y trigo—en la tasa de sobrevivencia de las larvas y en el rendimiento de vuelo de las polillas. De *A. lepigone* fue investigado en condiciones de laboratorio. Los resultados indican que el trigo fue la dieta comparativamente preferida para las larvas. La distancia de vuelo de las polillas *A. lepigone* aumentó desde el primer día hasta un nivel máximo a los 3 días y luego disminuyó después de los 4 días dentro de un tiempo de vuelo limitado de 24 horas. La relación positiva larva-nutrición en términos de capacidad de vuelo de las polillas *A. lepigone* también resultó en la mayor distancia y mayor duración del trigo preferido. La distancia máxima recorrida por un solo individuo alimentado con trigo durante 24 h fue de 44,55 km. La duración máxima de un individuo fue de 21,46 h. Sin embargo, las polillas *A. lepigone* tenían una velocidad inmediata máxima comparativamente más alta (velocidad máxima) cuando las larvas se alimentaban de plantas hospederas no preferidas, como el maíz y el maní. El sexo de las polillas de diferentes hospederos tuvo ningún efecto sobre la distancia de vuelo, la duración o la velocidad máxima. Hubo 2 picos en la duración del vuelo de todas las polillas de 3 a 4 días de edad probadas, lo que significó 2 grupos: vuelo corto y vuelo largo. La diferencia entre los hospederos en términos de distancia, duración y velocidad máxima, como se mencionó anteriormente, ocurrió solo en el grupo de larga duración del vuelo. Todos estos resultados mejoran la comprensión de la dinámica de población estacional de esta polilla migratoria en el ecosistema agrícola en China. También tienen implicaciones importantes para los ambientes naturales en términos de migración y brotes de la polilla.

Palabras Claves: *Athetis lepigone*; preferencia de hospedero; vuelo atado; capacidad de vuelo

Athetis lepigone Möschler (Lepidoptera: Noctuidae) was first reported in peanut in Liaoning Province in China in 1999. It was first discovered that *A. lepigone* causes damage to maize crops in Anxing, Hebei Province in China in 2005 (Jiang & Xi 2006). In subsequent yr, an outbreak of this species quickly expanded and severe damage to summer maize crops occurred in the Huang-Huai-Hai Rivers Plain in

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China over an area of roughly 2.2 million ha in 2011(Shan et al. 2011; Wang et al. 2012). *Athetis lepigone* now is considered a significant pest of maize in China.

Athetis lepigone larvae drill deep into and eat young roots or stems, resulting in the wilting and later death of the corn plant. It also chews on corn pistil, causing yield loss of corn crops (Ma et al. 2012a). *Athetis lepigone* can produce up to 4 generations a yr in the Huang-Huai-Hai Rivers Plain in China. *Athetis lepigone* is a polyphagous insect and has been observed eating more than 30 species of plants from 13 different plant families (Shi et al. 2011; Ma et al. 2012b). The host plant of the first generation is mainly regional winter wheat. Wheat, corn, peanut, and soybean are the dominant local plants in the plain, and the insect pest's host preference is particularly for germinating wheat kernels (Liu et al. 2015). The moths of the first generation fly into corn fields, then the next generation causes the majority of the damage to the summer corn seedlings. Moths also fly into other fields and feed on many other summer crops such as peanut, soybean, and sweet potato, but the density of the population is lower (Wang et al. 2012; Xu et al. 2012; Li et al. 2013). This reduced density in non-maize fields may be caused by differences in host fitness of *A. lepigone* larvae between seedlings of different crops in field habitats (Liu et al. 2015).

A larger variety of hosts for insects may maintain the species' development, survival, and reproduction, and also may play a more consistent role in population expansion (Hasan & Ansari 2010, 2011). High quality host or preferred food that is ingested by larvae directly promotes adult reproductive output and quality for capital breeding species (Miller 2005; Thiéry & Moreau 2005; Luo et al. 2018). High survival and high reproductivity on a preferred host clearly results in a higher density of population for larva-derived nutrient in insect species. Examples include *Lobesia botrana* (Denis & Schiffermüller) (Lepidoptera: Tortricidae) (Moreau et al. 2006; Muller et al. 2015), *Cameraria ohridella* (Deschka & Dimić) (Lepidoptera: Gracillariidae) (Walczak et al. 2017), *Conogethes punctiferalis* (Guenée) (Lepidoptera: Crambidae) (Li et al. 2015; Du et al. 2016). Many studies also have stated that the nutritional condition of larvae is linked to flight performance (Sétamou et al. 2012). Poor condition of the host on which larvae feed results in a greater flight tendency in adults. For example for the beetle *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae), poor quality of larvae diet equals a stronger tendency to take off in order to locate a higher quality host (Fadamiro et al. 1996). Male *Malacosoma disstria* Hübner (Lepidoptera: Lasiocampidae) moths collected as eggs from high density populations produce longer flight distances because there is more competition for food (Evenden et al. 2015). Female *Spodoptera exempta* (Walker) (Lepidoptera: Noctuidae) moths also demonstrated longer flight distances when the larvae are of a higher density (Woodrow et al. 1987). Brown et al. (2017) showed that beetles emerging from the natural host were larger but flew shorter distances than beetles reared on less favorable substrates; smaller beetles fly longer distances. These examples mean that flight performance is strongly affected by poor quality of larvae diet. It has been shown that nutritional stress during development reduces flight distance and endurance of butterfly *Lycaena tityrus* (Poda) (Lepidoptera: Lycaenidae) adults (Reim et al. 2019) due to the larvae not having the capacity to store enough reserves for long distance flight in adulthood.

The species of *A. lepigone* has proved itself as a migrant species. There are 4 peaks (1 higher than the other 3) in populations which appear annually on an island in the center of the Bohai Sea in China, which means the moth must have crossed more than 40 km of ocean to arrive (Fu et al. 2014). It is assumed to be connected annually to the 4 adult peaks on the mainland detected by search light trap that is used mostly for high altitude flight insect species (Huang et al. 2017). These 4 population peaks are related directly to the agricultural ecosystem where the winter wheat matures and the regional Jun harvest occurs, and corn, peanut, and soybean are planted (Wang et al. 2012; Huang et al. 2017). There are many wheat seedlings in this summer crop field before spraying herbicide where seeds fell during the wheat harvest. In order to estimate the potential spread of different generations and to verify the consequential flight performance of different hosts mentioned above, a computer-monitored rotational flight mill was used to determine the effects of the larvae host on *A. lepigone* moth flight capacity under laboratory conditions. The present study aimed to (1) understand of the flight behavior of *A. lepigone* moths sourced from different hosts, and (2) verify the adult performance of larva-derived nutrient species of *A. lepigone* on larvae diet. This will lead us to comprehend the causes of outbreaks and help us to develop regional pest forecasting and management strategies.

Materials and Methods

HOST PLANTS

Four species of host plants: corn (*Zea mays* L. [Poaceae], variety 'Luodan 6'), wheat (*Triticum aestivum* L. [Poaceae], variety 'Luomai 24'), peanut (*Arachis hypogaea* L. [Fabaceae], variety 'Yuanza 9102'), and soybean (*Glycine max* (L.) Merr. [Fabaceae], variety 'Yudou 22') were used in the experiments. All 4 plants were cultivated in 40 L × 20 W × 20 H cm pots (Shenzhen Meinaijia Commodity Co., Ltd., Shenzhen, China) filled with compost and organic fertilizers, and put into a greenhouse free from insects and disease. The fresh plant seedlings of corn, wheat, peanut, and soybean were collected and cut into small pieces to feed the larvae, which is the same process used by Liu et al. (2015). The same plant materials were given to all larval stages throughout the development of *A. lepigone*.

INSECTS

Athetis lepigone used in the experiments were from a colony that originated from a population from which larvae were collected from a corn field near Luoyang, Henan Province in China (34.62N, 112.40E). One generation of the colony had been maintained on each host plant when the experiments began, and the eggs of the same moths were collected the morning after being laid, and were separated into 4 different hosts. Larvae were then hatched and reared in an artificial climate incubator (Jiangsu Jinyi Instrument Technology Co., Ltd., Changzhou, China) at a constant temperature of 24 °C, 70 to 80% RH, and 14:10 h (L:D) photoperiod (light period was from 6:00 AM to 8:00 PM) according to Li et al. (2013).

DEVELOPMENT, SURVIVAL RATE, AND PUPAL WEIGHT

Each group of 20 larvae was housed in a 15 L × 5 W × 8 H cm plastic container (Xinxiang Chahua Plastic Industry Co., Ltd., Xinxiang, China), and larval feces were filtered by an arched metal wire screen. Stale food was replaced with fresh small pieces of leaves, which were cut from 4 host plants every d. There were 40 plastic containers of 20 larvae per treatment. Four containers of 20 larvae were sampled continuously for survival numbers every d when the larvae had developed into late instars, pupae, and moths. All the sampled larvae were weighed when they developed into pupae (Mettler Toledo ME204, Zurich, Switzerland). Then pupae from all containers were placed in Petri dishes (20 cm diam) divided by host, and moth emergence was checked every morning. Between 1 and 5 pairs of the newly emerged adults were then placed in a 40 L × 40 W × 30 H cm net cage (Zhongyi Plastic Technology Co., Ltd., Chengdu, China) and provided with a 5% honey solution (v/v). They were allowed to mate freely. Moths that emerged on different d from different hosts were fed separately in different cages.

FLIGHT CAPACITY

All the moths tested were healthy with no wing damage. In order to determine which age of moths was the strongest, moths at different stages (1–7 d old) were tethered on flight mills for 24 h. The ovary development stage of female moths was assessed by dissection after 24 h of limited flight as in Li et al. (2012). We found the strongest moths were 3 to 4 d old. Subsequently, 217 female and male *A. lepigone* moths were selected randomly from the cage with different hosts at 3 to 4 d old and tethered to flight mills to determine whether there were host-differentials in flight performance. Flight tests were conducted on a 32-channel rotational flight mill system (Hebi Jiaduo Science Industry Trade Co., Ltd., Hebi, China), as described in previous studies (Jiang et al. 2010; Jones et al. 2016; Yang et al. 2017). The method of the flight tests was performed as in Jiang et al. (2010). The moths were first lightly anaesthetized and the tether loop was attached to the dorsal side of the moth. The other side of the tether was attached to the arm of the flight mill system with a band. Flight parameters, including distance (sum of distance covered by all flights), duration (sum of duration of all flights), and maximum immediate speed (max speed) were recorded automatically by software from Jiaduo Co., Henan, China. After a 24 h-limited flight time, the ovaries of female moths were dissected and classified into 5 development levels, as described by Li et al. (2013). The flight tests were performed in a climate chamber, and data logging began at 8:00 PM and terminated at 8:00 PM the next day, a 24-h L:D cycle. Temperature and humidity of the climate chamber were maintained at the same conditions as the rearing conditions (24 °C, 70–80% RH, 14:10 h [L:D] photoperiod); each flight treatment began at dusk (8:00 PM).

STATISTICAL ANALYSIS

Larval, pupal, and eclosion survival of *A. lepigone* were recorded as the percentages that survived from newly emerged larvae into late instars, late instars into pupae, and pupae into adult eclosion, respectively. The effects of larval nutrition on survival and flight performance were evaluated using R version 3.5.3 (R Core Team 2019) for all statistical analyses. The flight distances and flight duration values were log-transformed to achieve normality. The 'lme4' package was used to construct a generalized linear mixed model (Bates et al. 2014). The relationship between the 3 variables (the development survival, body weight and moth flight parameters, and the explanatory variables) were explored using a restricted maximum likelihood approach using the 'lmerTest' package to estimate *P*-values for the fixed effects, and Kenward-Roger method for degrees of freedom (Kuznetsova et al. 2017). Tukey-Kramer groupings for comparing differences in the least-squares means were used if the explanatory variables had significant effects (Kuznetsova et al. 2017). In terms of larval and pupal survival percentages, or pupal weight, the model considered the host as fixed effects, and the repetitions of the treatment as random effects. For the flight parameters of different moth ages, the model considered age and sex as fixed effects. In terms of flight parameters of different hosts, the model considered host and sex as fixed effects, whereas the date the insect was flown and the mill channels were treated as random effects (Jones et al. 2015).

Results

The host plant affected the larval survival rates of *A. lepigone* ($F_{3,9}$ = 166.03; $P < 0.001$). Nearly all larvae survived to late instars when reared on soybean leaves (95 ± 0.9%), whereas those fed on corn seedlings had the lowest larval survival (65 ± 2.04%). Larvae fed on wheat and peanut survived in comparatively high percentages (85 ± 2.04% and 73.32 ± 1.17%, respectively). Moreover, host plants also affected the pupal survival ($F_{3,9}$ = 59.385; $P < 0.001$), and eclosion survival ($F_{3,9}$ = 52.433; $P < 0.001$) (Fig. 1A). Nearly all late instars survived to pupae and to moths when reared on soybean (pupal = 98.23 ± 1.25%; eclosion = 94.6 ± 0.07%) and wheat (pupal = 92.13 ± 1.40%; eclosion =

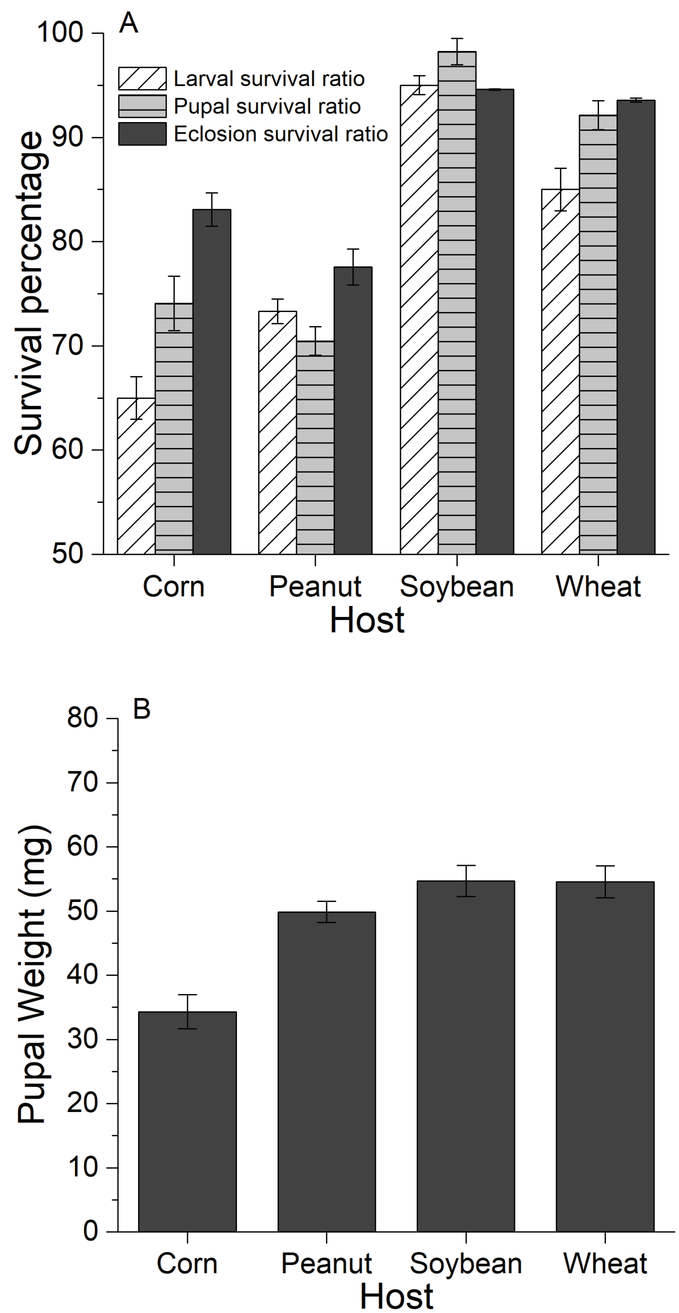
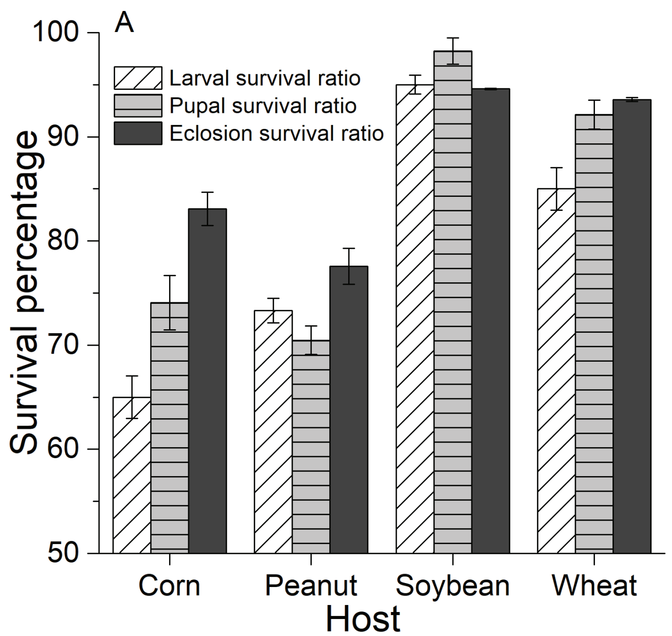


Fig. 1. Performance of *Athetis lepigone* reared on different host plants in developmental survival (A) and pupal weight (B).

93.58 ± 0.19%). Larvae fed corn (pupal = 74.08 ± 2.63%; eclosion = 83.1 ± 1.60%) and peanut (pupal = 70.47 ± 1.39%; eclosion = 77.58 ± 1.72%) survived to pupae and to moths in statistically equivalent percentages (Fig. 1A). The host also affected pupal weight ($F_{3,39}$ = 16.354; P < 0.001). Those fed corn seedlings had the lowest weight (34.31 ± 2.66 mg). The pupal weight of insects reared on soybean, peanut, and wheat were not significantly different from each another (Fig. 1B).

The flight distance of *A. lepigone* moths increased from 1 d old to a peak level at 3 d, then declined after 4 d old within a 24 h limited flight (Fig. 2A). There were no differences in flight distance and max speed between the ages (distance = $F_{1,10.277}$ = 0.0823l; P = 0.7799; max speed = $F_{1,9.298}$ = 0.4815l; P = 0.5047), and sexes (distance = $F_{1,203.255}$ =1.4438l; P = 0.2309; max speed = $F_{1,204.373}$ = 1.221; P = 0.2705) of the moths (Fig. 2B). However, considering 1 and 2 d old moths as young, and 3 and 4 d old moths together as middle aged, and 5 d plus as old, the middle aged moths flew a greater distance (distance = $F_{2,7.376}$ = 7.3978; P = 0.01727) than the young (1–2 d old) and old (over 5 d old) moths with no relation to sex ($F_{2,201.675}$ = 0.0276; P = 0.86813). But still there was no difference with the max speed between the 3 combined age groups (max speed = $F_{2,7.379}$ = 1.2889; P = 0.3311) and sex (max speed = $F_{2,201.708}$ = 0.5957; P = 0.4411). The females were filtered as subset data to explore the association of ovary development on the total distance flown using the flight date and mill channels as a random effect variable. This demonstrated that there were no differences in distance ($F_{1,12.262}$ =0.1252; P = 0.7295) and max speed ($F_{1,10.542}$ = 0.095; P = 0.7639) between different ovary development stages (Fig. 3).

The results of testing 3 to 4 d old *A. lepigone* moths, which fed on the 4 hosts with the same mills are illustrated in Figure 4A. Most individuals flew a short distance, but there were many moths that fed on wheat that flew a long distance. The maximum distance covered by a



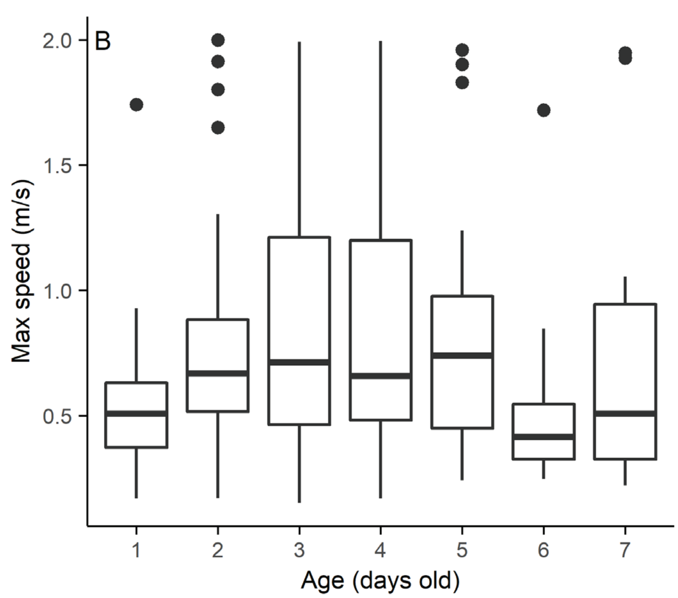


Fig. 2. Flight distance (A) and max speed (B) of *Athetis lepigone* moths at different ages after eclosion.

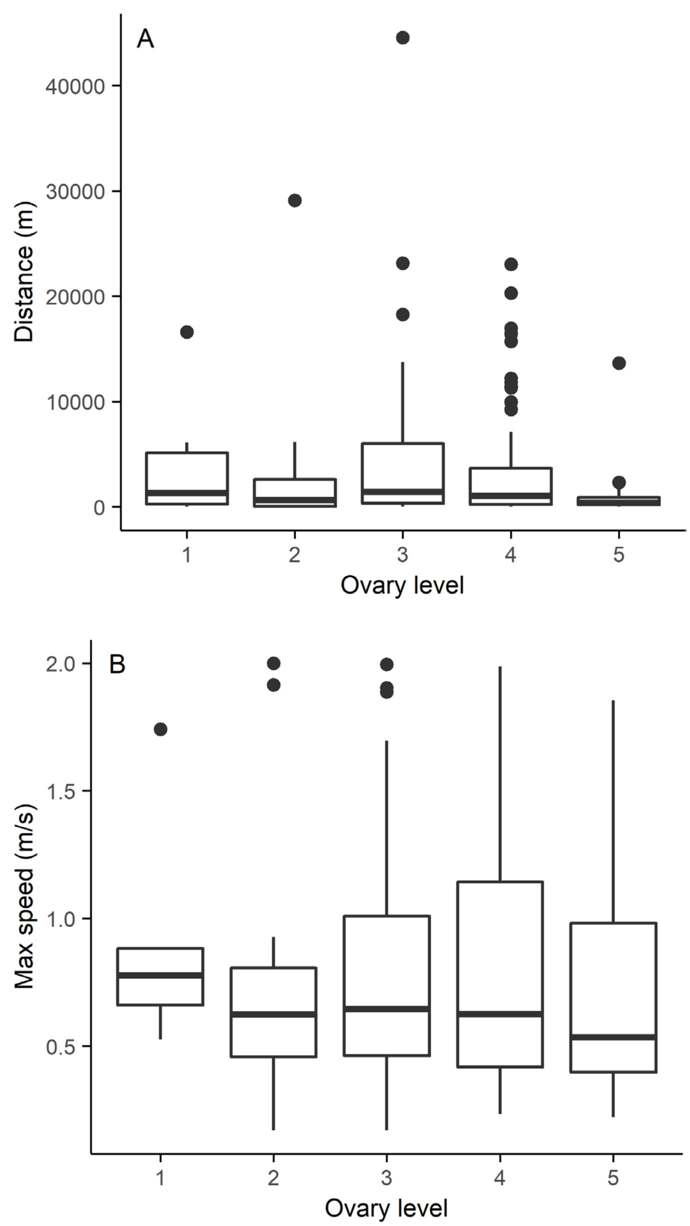


Fig. 3. Flight distance (A) and max speed (B) of *Athetis lepigone* females at different stages of ovary development described in Li et al. (2012).

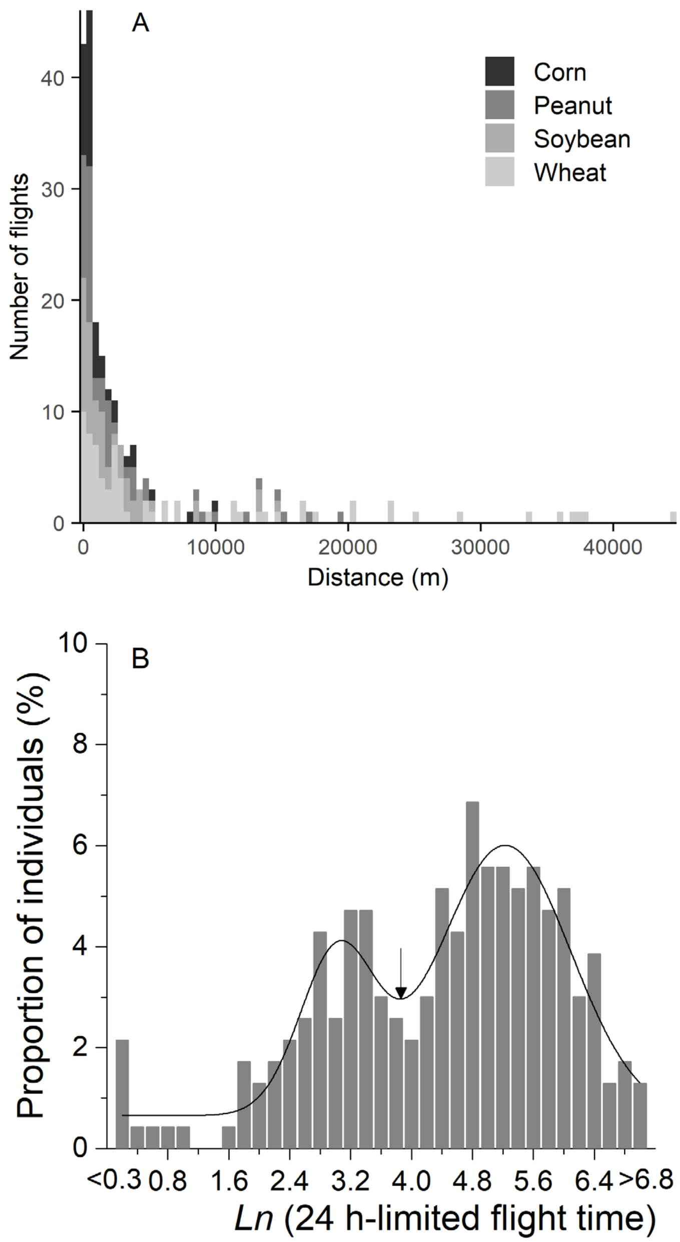


Fig. 4. Frequency distribution of flight distance (A) and duration (B) of *Athetis lepigone* moths. The arrow shown in (B) shows the threshold flight time of 44.7 min that differentiates the short and long flight populations.

single individual during the 24 h period was 44.55 km. The max duration of an individual was up to 21.46 h (1,287.627 min) (Table 1). There was strong evidence for host differences in terms of distance ($F_{3,11.432}$ = 6.162; P = 0.018) (Fig. 5A). Adult moths from wheat flew the furthest mean distance (mean distance = 8.175 km) and highest mean duration (mean duration = 40.342 min), which were significantly higher than the corn (Z = 6.158; P < 0.001) and soybean (Z = 3.004; P = 0.010). However, moths fed on corn and peanut had comparatively higher max speed ($F_{3,11.432}$ = 6.162; P = 0.009), with the mean values for corn as 1.037 ± 0.096 m per s, and peanut as 1.12 ± 0.086 m per s, compared to the mean values for wheat (0.811 ± 0.054 m per s) (Fig. 5B), with no evidence that the sex of the moths from the 4 hosts had any effect on max speed. The duration of flight also was significantly affected by the hosts ($F_{3,36.236}$ = 13.197; P < 0.001). After filtering the data for female moths as a subset, we found that the ovary development status did not affect the flight distance ($F_{1,5.571}$ = 2.234; P = 0.138), max speed ($F_{1,5.571}$ = 0.152; P = 0.698), or duration ($F_{1,5.571}$ = 0.339; P = 0.562), but female flight distance ($F_{3,87.9}$ = 3.823; P = 0.012) and duration ($F_{3,87.9}$ = 4.351; P = 0.006) were affected by the type of host plant. Moreover, there was bimodal distribution in the flight duration of all 3 to 4 d old individuals treated in this study, which indicated that there appeared to be a population polarization of 2 groups, those of short flight and long flight duration (Fig. 4B). The duration of 44.7 min was the threshold. The shorter duration population was 36.4% (n = 71) and the longer duration population was 63.6% (n = 146) of total individuals. There was strong evidence for host differentiation in terms of distance ($F_{3,13.846}$ = 4.555; P = 0.021), duration ($F_{3,11.822}$ = 5.802; P = 0.011), and max speed ($F_{3,11.822}$ = 5.1989; P = 0.016) for the longer duration population; it appeared that there was no difference by sex for these flight parameters. Similarly, flight parameters of the longer flight duration population that fed on the preferred wheat showed a significantly longer distance (wheat, soybean = Z = 3.053; P = 0.0136) and duration (wheat, corn = Z = 2.671; P = 0.0454; wheat, soybean = Z = 2.596; P = 0.0481). However, there were no differences in flight parameters of different hosts and different sex for the short flight duration population.

Discussion

Flight capacity was tested using flight mills under laboratory conditions, and the research provided insights into hosts that affect flight behavior of *A. lepigone*. Middle aged (3–4 d old) adult individuals flew the greatest distance, which showed adult *A. lepigone* generally have a strong flight capacity (Zheng et al. 2014). A strong flight ability in migrant populations occurs when there is a low level of ovary development because of trade-offs between migration and reproduction, according to Rankin and Burchsted (1992), and Lorenz (2007), but this research showed that with high quality nutrition, flight was not affected by the development of ovaries, similar to conclusions by Fu et al. (2014) for *A. lepigone* species. This study demonstrates that wheat was the preferred host for *A. lepigone* with the highest survival rate, similar to conclusions by Liu et al. (2015). Wheat-fed *A. lepigone* exhibited stronger flight capacity than moths fed on corn, peanut, or soybean. This leads to understanding longer migration when moths feed on wheat in a field, because most larvae in the first generation in spring

Table 1. Flight parameters of 3 to 4 d old *Athetis lepigone* reared on different hosts.

		Distance (m)		Duration (min)		Max speed (m per s)	
Food	Numbers	Maximum	Mean ± SE	Maximum	Mean ± SE	Maximum	Mean ± SE
Corn	40 (21)	10107.760	1360.718 ± 342.994 b	429.201	80.5731 ± 14.489 b	1.993	1.037 ± 0.096 b
Peanut	73 (32)	19269.900	3293.513 ± 689.740 b	651.923	141.1847 ± 22.478 b	1.995	1.12 ± 0.086 a
Soybean	52 (27)	14490.280	2420.561 ± 478.092 b	726.185	153.871 ± 21.252 b	1.854	0.672 ± 0.053 c
Wheat	52 (22)	44553.440	8174.952 ± 1332.708 a	1287.627	296.788 ± 37.572 a	1.966	0.811 ± 0.054 c

Same column with different characters mean significant difference. Numbers within brackets were females.

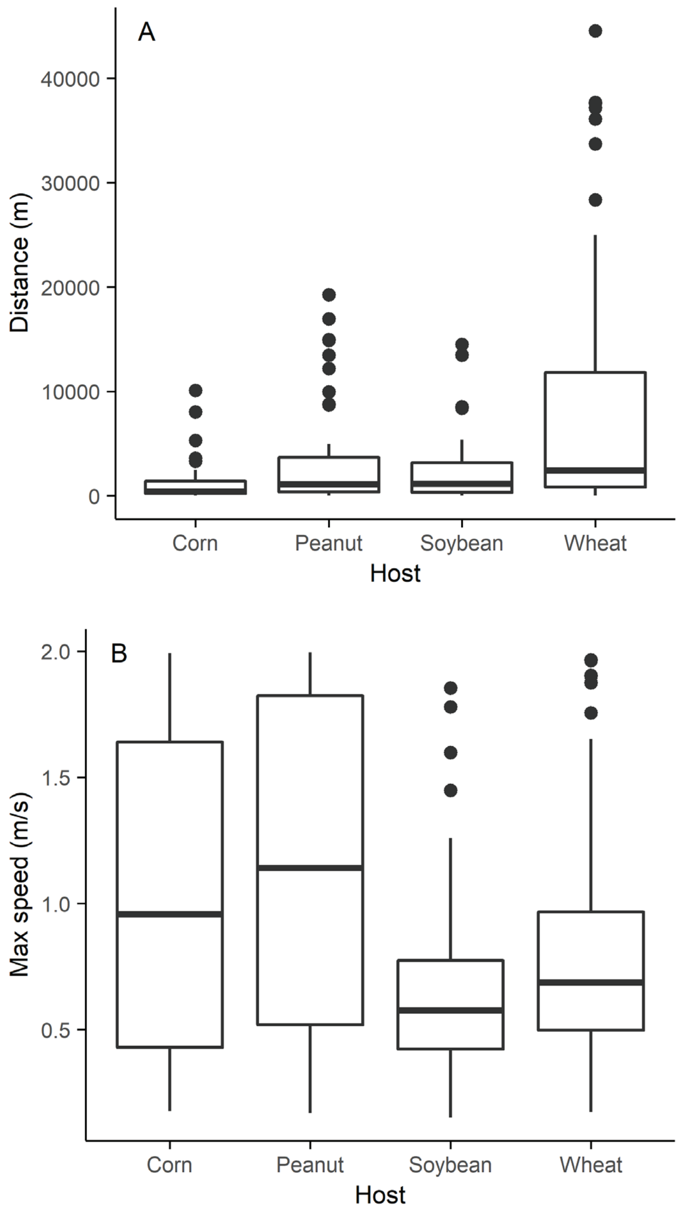


Fig. 5. Flight distance (A) and max speed (B) of 3 to 4 d old *Athetis lepigone* moths with different host plants.

consume wheat (Xu et al. 2012; Huang et al. 2017). The adults of the first generation need to migrate successfully to a new location when the wheat matures, when the regional Jun harvest occurs. Extensive wheat seeds generally are left after machine harvest and germinate again in the crop field. Those optimal germinating wheat kernels are the exact preferred host plant for the new migrants, and this triggers a huge peak in population of the second generation. The host preference and strong flight capacity perfectly explains the massive population of the next generation in the middle of Jul (Zhang et al. 2013; Huang et al. 2017). If there were no residual germinating wheat kernels in corn fields, the corn seedlings would be severely damaged by *A. lepigone* (Han et al. 2013; Chen et al. 2015). This strong flight capability after feeding on wheat produces a more comprehensive understanding of the low density of the first generation to the successful high density of the second generation of *A. lepigone*. After Jul a lower population density appears, suggesting the possible reason is that the hosts may not be the preference at that time because the crops are mostly soybean, peanut, and corn. However great the effect of the host is on the population dynamics of this species, other variables such as temperature (Li et al. 2013), humidity (Huang et al. 2017), predators and migration (Zhang et al. 2013), and cycle of the crops (Jiang et al. 2011; Wang et al. 2012) also are vital to understand the behavior of *A. lepigone*.

Diet during development consistently affects flight performance of adult *A. lepigone*. Larvae fed on wheat have a high survival rate when developing into later instars, pupae, and moths. This research shows a host preference of the polyphagous insects. The diet does not result in a gain in pupae weight, but produces the longest distance and duration performance during a 24 h limited flight time, and ultimately the potential dispersal ability. In contrast, larvae fed on corn, soybean, and peanut plants resulted in moths that performed comparatively worse. In similar research, food stress for *L. tityrus* individuals during development also results in diminished flight performance and negative exploratory behavior of moths (Reim et al. 2019). Fruit flies with poor food sources with heat stress showed decreased flight distance and duration of adults (Wang et al. 2009). This study also suggests that *A. lepigone* fed on the comparatively non-preferred hosts like corn and peanut showed lower survival during development. These non-preferred host plants also have detrimental consequences on flight distance and duration, but triggered a maximum immediate speed, which suggests a gain in power to escape quickly but is limited in terms of fuel reservation. Saastamoinen (2010) documented that food stress during development increased the thorax ratio and flight performance of the butterfly *Bicyclus anynana* (Butler) (Lepidoptera: Nymphalidae). Poor larval nutrition indeed increased investment in flight capability for potential dispersal, like the white butterfly, *Pieris rapae* (L.) (Lepidoptera: Pieridae) (Jaumann & Snell-Rood 2019) and the moth species *Speyeria mormonia* (Boisduval) (Lepidoptera: Nymphalidae) (Boggs & Niitepõld 2016). Larval development under poor conditions would result in more investment in proportionally larger flight muscles, wing area, or thorax mass of potential flight capacity, but long distance flights or flight durations require more nutrition and also are related to other variables such as age, mates, and oviposition (Center & Dray 2010; Jiang et al. 2010; Wone et al. 2018; Irvin & Hoddle 2020). There are many exceptive species, poor diet for the larvae of the beetle *Batocera rufomaculata* (De Geer) (Coleoptera: Cerambycidae) could result in a bigger thorax ratio, but long-distance flight could replenish reserves in adult feeding, and did not depend on nutrient reservation in the larval phase (Brown et al. 2017). Moreover, the flight distance or duration also will correlate with environment factors and intrinsic properties of species. Different populations performed different flight distances, which could divide populations into long distance migrants distinct from short distance non-migrants (Jones et al. 2015).

There is much research documenting the classification of the migrant populations from non-migrant ones by flight duration (McAnelly & Rankin 1986; Kent & Rankin 2001; Menz et al. 2019). The long/short duration populations of *A. lepigone* moths could be defined into migrants/non-migrants with the 44.7 min per 24 h boundary in this research, where the flight duration of all 3 to 4 d old moths showed bimodal distribution. This host differentiation occurred only in the *A. lepigone* population with a longer duration of flight time. This implied that those moths may be more selective in terms of food due to intrinsic selection because it possibly is easier to trigger an internal escape mechanism with bigger thorax muscles and wing area, for example, and in the meantime, to regulate the reproduction strategy. This suggests that the *A. lepigone* population has evolved to produce a survival mechanism when the regional Jun harvest occurs, and a strong flight capacity in order to fly to new places successfully. However, further studies are necessary to investigate this more thoroughly.

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