Monoterpenes from larval frass of two Cerambycids as chemical cues for a parasitoid, *Dastarcus helophoroides*

Jian-Rong Wei\(^1\)*, Xi-Ping Lu\(^2\), Li Jiang\(^3\)

\(^1\)College of Life Sciences, Hebei University, Hebei Baoding, 071002, China
\(^2\)College of Plant Protection, Shandong Agricultural University, Shandong Taian, 271018, China
\(^3\)Taian Forestry Bureau, Shandong Taian, 271000, China

**Abstract**

*Anoplophora glabripennis* (Motsch.) (Coleoptera: Cerambycidae) is a destructive woodboring, attacking many species of deciduous hardwood trees. *Apriona swainsoni* (Hope) (Coleoptera: Cerambycidae) is a woodborer of *Sophora japonica* L. (Angiospermae: Fabaceae). *Dastarcus helophoroides* (Fairmaire) (Coleoptera: Bothrideridae) is an important natural enemy of both Cerambycid species in China. Kairomones for two populations of *D. helophoroides* that parasitize *A. glabripennis* and *A. swainsoni* respectively were studied. Based on identification and quantification of volatiles from larval frass produced by *A. glabripennis* and *A. swainsoni*, monoterpenes were selected to test their kairomonal activity to both populations of *D. helophoroides* adults using a Y-tube olfactometer. The results indicated that (S)-(−)-limonene served as a kairomone for the population of *D. helophoroides* parasitized *A. glabripennis*. α-pinene, (1R)(+)-α-pinene and (+)-β-pinene were attractive to the population of *D. helophoroides* parasitized *A. swainsoni*. The results provide information about the co-evolution of *D. helophoroides*, its host, and host-food trees.

**Keywords:** kairomone, olfactory response, parasitoid, tritrophic interactions, woodboring

**Correspondence:** a weijr@hbu.edu.cn, b lxp59@sda.edu.cn, c jiangli1986@163.com, *Corresponding author.

**Editor:** Brian Aukema was editor of this paper.

**Received:** 4 February 2012 **Accepted:** 29 July 2012

**Copyright:** This is an open access paper. We use the Creative Commons Attribution 3.0 license that permits unrestricted use, provided that the paper is properly attributed.

**ISSN:** 1536-2442 | Vol. 13, Number 59

**Cite this paper as:** Wei J-R, Lu X-P, Jiang L. 2013. Monoterpenes from larval frass of two Cerambycids as chemical cues for a parasitoid, *Dastarcus helophoroides*. *Journal of Insect Science* 13:59. Available online: [http://www.insectscience.org/13.59](http://www.insectscience.org/13.59)
Introduction

Apriona swainsoni (Hope) (Coleoptera: Cerambycidae) is a woodborer and a major threat to the historical and famous tree Sophora japonica L. (Angiospermae: Fabaceae), which is the civic tree in many cities in China (Tang and Liu 2000). Anoplophora glabripennis (Motsch.) (Coleoptera: Cerambycidae) is a serious wood-boring pest that infests many broad-leaved tree species in northern China (Gao and Li 2001; Hu et al. 2009). Both pests attack healthy trees and spend most of their life as larvae boring inside tree trunks and large branches, eventually causing mortality. In the late 1990s, A. glabripennis was discovered as an invasive pest in the United States, which prompted a major eradication effort (Nowak et al. 2001; Macleod et al. 2002; Hu et al. 2009). A. swainsoni is listed as a quarantine forest insect pest in some provinces in China (Tang and Liu 2000).

Dastarcus helophoroides (Fairmaire) (Coleoptera: Bothrideridae) is an important ectoparasitoid of Cerambycid beetles and is distributed in most provinces of China (Qin and Gao 1988; Wang et al. 1996; Wei et al. 2009a), some areas of Japan (Tadahisa 2003), and Korea (Lim et al. 2012). Studies on this species have been conducted investigating its biology (Zhou et al. 1985; Qin and Gao 1988; Lei et al. 2003), behavior (Wei et al. 2008a), and mass-rearing techniques (Ogura et al. 1999; Wang et al. 1999; Shang et al. 2009). Adults are polyphagous, mainly feeding on corpses of other insects (Qin and Gao 1988); sometimes, they also attack live larvae of longhorned beetles (Wei et al. 2008a). During most of their lifetime, they stay motionless under the bark crevice or in the caves of trees. Eggs are laid on the outer surface of the bark near the host entrance hole, frass-extrusion hole, or around the host larvae tunnel walls (Qin and Gao 1988). Once hatched, first instar larvae have legs and can actively move to locate hosts, but their legs degenerate once parasitism has occurred. They pupate next to the host corpse. D. helophoroides lay eggs twice a year in the field (Qin and Gao 1988), but in the laboratory, females can lay eggs at 4 to 6 months intervals at 20–27°C regardless of the presence of a suitable host (Wei and Jiang 2011). The egg, larval, and pupal periods are respectively 12.7, 8.4, 25.6 days on average at 21 ± 1°C (Lei et al. 2003). Most adults can live over 3 years (Wei et al. 2007). They are tolerant of starvation and can live over 60 days without food or water (Wei et al. 2009a). Since the 1980s, D. helophoroides has been used as a biological agent to control A. glabripennis, Batocera horsfieldi (Hope), and Massicus raddei (Blessig) in China, and Monochamus alternatus Hope in Japan (Zhou et al. 1985; Qin and Gao 1988; Tadahisa 2003; Li et al. 2009; Wei et al. 2009b).

Some parasitoids and predators utilize specific chemical cues from the frass of herbivores as a host-finding strategy (Grégoire et al. 1991; Sullivan et al. 2000; Pettersson 2001; Chuche et al. 2006). There are three different populations of D. helophoroides in China that differ in their olfactory response to frass of different longhorned beetle species (Wei et al. 2009c). One population of D. helophoroides that parasitized larvae and pupae of A. glabripennis was attracted to the host larval frass from Salix babylonica L. (Malpighiales: Salicaceae) (Wei and Jiang 2011). Recent studies showed that a population of D. helophoroides that was collected on S. japonica was attracted to the larval frass of A. swainsoni (Lu et al. 2012). Wei et al. (2008b) reported that one of the populations of D. helophoroides that parasitizes M. raddei (Blessig) on Quercus
mongolicus Fisch. ex. Turcz in northern China uses larval frass of *M. raddei* as a major cue while searching for hosts, and the chiral monoterpenes \( (R)\)-\((+)-\)limonene is a kairomone of *M. raddei* for this population of *D. helophoroides*. Larval frass of *A. glabripennis* and *A. swainsoni* both release monoterpenes (Ding et al. 2009; Jiang et al. 2010). Therefore, we put forward a hypothesis that different populations of *D. helophoroides* might use similar monoterpenes as their kairomones when searching for their hosts.

The objectives of this study were to analyze monoterpenes and stereoisomers of chemicals released both from larval frass of *A. glabripennis* feeding on *S. babylonica* and larval frass of *A. swainsoni* feeding on *S. japonica*, and to test selected monoterpenes and their isomers against adults of related *D. helophoroides* populations to identify the unique kairomone that may aid *D. helophoroides* adults in searching for their hosts. The information gained will further the understanding of the co-evolution of this parasitoid, its host, and host tree, and will benefit the development and improvement of effective and sustainable biological control methods for two Cerambycid species management.

**Materials and Methods**

**Insects**

Adults of type G *D. helophoroides* were from a laboratory colony established from parasitized larvae and pupae of *A. glabripennis* collected from trunks of *S. babylonica* in Xian, Shaanxi province, China (latitude 34° 15’ N, longitude 108° 50’ E, altitude 450 m a.s.l.) in April 2006. Adults of type S *D. helophoroides* were from a laboratory colony established from parasitized larvae and pupae of *A. swainsoni* collected from trunks of *S. japonica* in Qufu city (latitude 35° 39’ N, longitude 117° 05’ E, altitude 150 m a.s.l.) during June 2008. Frass was collected from larvae tunneling in galleries by cutting off the outer bark of tree trunks and scooping frass into vials. Frass (about 120 g) from more than 30 heavily damaged trees was collected and mixed together in capped, clean glass bottles and kept at -20°C in the laboratory until tested.

**Host frass field collection**

Larval frass of *A. glabripennis* was collected from *S. babylonica* in Xian during May 2008. Larval frass of *A. swainsoni* was collected from *S. japonica* in Taian city, Shandong province (latitude 35° 50’ N, longitude 117° 05’ E, altitude 150 m a.s.l.) during June 2008. Frass was collected from larvae tunneling in galleries by cutting off the outer bark of tree trunks and scooping frass into vials. Frass (about 120 g) from more than 30 heavily damaged trees was collected and mixed together in capped, clean glass bottles and kept at -20°C in the laboratory until tested.

**Monoterpenes collection and quantification**

Samples of *A. glabripennis* larval frass (15 g) and *A. swainsoni* larval frass (15 g) were aerated separately in a clean, glass conical flask (300 mL) with an air entrance (inner diameter: 0.3 cm) at the bottom and a vent (inner diameter: 0.3 cm) at the top (diameter: 2.5 cm). The vent was connected by 10 cm Teflon tubing to a Porapak Q trap (200 mg in a glass tube, 80–100 mesh; Waters Associates Inc., www.waters.com) (Wei et al. 2008b). Pure nitrogen (99.999%), warmed to 26°C by passing through an electric thermostat, was directed through the bottom entrance of the
flask and subsequently purged headspace volatiles into the trap that was connected to the vent on the top of the flask with a Teflon tube. For each frass sample, there were three replicates. Before samples were run, each clean, empty conical flask was aerated using heated nitrogen (about 26º C) for 10 min to reduce potential contamination. The flow rate of nitrogen was 100 mL/min, and the samples were aerated for 4 hours. Volatiles trapped in Porapak Q were rinsed with 200 µl dichloromethane, and 2 µg of internal standard (heptyl acetate) was added for quantification analysis.

The configuration and quantification of monoterpenes in the extracts were analyzed by gas chromatographic enantiomer separation on a chiral column (Cyclosil-B, 30 m × 0.25 mm × 0.25 µm; Agilent, www.agilent.com) equipped on an Agilent 7890 GC with an FID detector. The carrier gas was pure nitrogen, and the injector temperature was 220º C. The column temperature was programmed at 45º C for 1 min, increased at 1.5º C/min to 72º C, held for 6 min, then increased at 6º C/min to 120º C and 10º C/min to 220º C, and held for 10 min. Injections of 1 µl of each extract were made. The different synthetic monoterpenes identified (Ding et al. 2009; Jiang et al. 2010) were also injected to compare their retention times with peaks in extracts. Quantification of each compound in the extracts was determined by comparing to the internal standard.

Olfactory responses of *Dastarcus helophoroides* adult to synthetic monoterpenes

All commercially available monoterpenes and their isomers identified in frass were evaluated to identify behaviorally active components that may serve as kairomones for type G and type S *D. helophoroides*. The orientational responses of *D. helophoroides* adults to different odor sources were tested using a Y-tube olfactometer. The bioassay setting and procedure were as described in Wei et al. (2008b; 2011). The beetles were challenged with synthetic compounds in an odor dispenser at one arm and a blank control at the other arm of the Y-tube olfactometer. A special odor dispenser was designed to control the amount of chemical released. It consisted of a polymerase chain reaction tube (0.5 mL, Eppendorf, www.eppendorf.com) containing 10 µl of each undiluted synthetic compound, with two large holes (diameter: 0.49 ± 0.10 mm) and two small holes (diameter: 0.22 ± 0.05 mm) made by puncturing the wall with a needle, that was inserted into a centrifuge tube (2.0 mL, Eppendorf, Corp.) with two holes (diameter: 1.11 ± 0.02 mm) made by puncturing the wall with a needle. Both the polymerase chain reaction tube and the centrifuge tube were capped tightly (Wei et al. 2008b). Dispensers were replaced with fresh ones every day to ensure consistent release rate throughout the entire experiment. The average release rates of different monoterpenes were 20–30 µg/hr by weighed odor dispensers each day.

Insects were introduced into the release chamber individually. Observations were taken 30 min after introduction to note whether the insect had made a choice (traveled at least to the midpoint of one of the arms or already dropped into one of the glass containers). Beetles that did not respond within 30 min (stayed in the release chamber or did not reach to the midpoint of the arms) were excluded from data analysis. Individual beetles were tested only once. At least 30 adults should respond per treatment for statistical analysis. Connections between the odor source containers and olfactometer arms were exchanged after every 5 beetles tested in order to exclude directional bias in beetle choices. After each experiment, the olfactometer was disconnected from the containers and thoroughly washed with a de-
Tables and statistical analysis

A Wilcoxon test (Two-Related-Sample Test of Nonparametric Tests) was used to determine the differences in the responses of *D. helophoroides* adults in the olfactometer bioassays. The release rates of different compounds (i.e., the amount of a compound (ng) being released per hr per g of material) were compared with a One-Way ANOVA after square-root transformation, and was followed by multiple comparisons with Tukey’s tests. All statistical analyses were carried out by SPSS software (IBM, [http://www-01.ibm.com/software/analytics/spss/](http://www-01.ibm.com/software/analytics/spss/)) using a *p*-level of 0.05.

Results

Quantification of monoterpenes released from larval frass of *A. glabripennis* and *A. swainsoni*

Analysis of enantiomeric composition of volatiles trapped in Porapak Q from larval frass of *A. glabripennis* and *A. swainsoni* indicated that different isomers of some monoterpenes were present (Table 1). In most cases, the release rates (ng/hr/g) of both isomers of α-pinene were significantly higher than those of other compounds in the extracts of larval frass. γ-Terpinene was not found in the extract sample of *A. glabripennis* larval frass. (+)-β-pinene released from larval frass of *A. swainsoni* reached 52.29 ng/hr for each gram of larval frass (Table 1), though its release rate was not significantly higher than that of other monoterpenes except for two isomers of α-pinene. The average release rates of monoterpenes from larval frass of *A. swainsoni* were higher than those from larval frass of *A. glabripennis* (Table 1).

Olfactory responses of *D. helophoroides* adults to synthetic monoterpenes

Table 1. Release rate (ng/hr/g) of monoterpenes from larval frass of *Anaplophora glabripennis* or *Apriona swainsoni*.

| Compounds        | *A. glabripennis* | *A. swainsoni* |
|------------------|------------------|----------------|
| (S)-(−)-α-pinene | 25.44 ± 3.30 b   | 122.29 ± 47.70 ab |
| (IR)-(−)-α-pinene| 71.51 ± 14.79 a  | 493.58 ± 213.75 a |
| (+)-camphene     | 1.54 ± 0.24 c    | 7.51 ± 1.15 b    |
| (−)-camphene     | Not found        | Not found        |
| (+)-β-pinene     | 7.07 ± 1.03 c    | 52.29 ± 4.32 b   |
| (−)-β-pinene     | 2.40 ± 0.44 c    | 15.1 ± 7.19 b    |
| Δ-3-carene       | 2.67 ± 0.09 c    | 14.23 ± 4.97 b   |
| (S)-(−)-limonene | 1.12 ± 0.10 c    | 6.00 ± 1.58 b    |
| (R)-(−)-limonene | 3.05 ± 1.70 c    | 13.4 ± 5.57 b    |
| γ-terpinene      | Not found        | 4.40 ± 1.30 b    |

*Mean ± SE. Different lower case letters within a column indicate significant difference at *p* < 0.05 among different compounds (Tukey’s test, one-way ANOVA)
A total of 11 identified monoterpenes, including different isomers, were tested for attractiveness to type G and type S adults of *D. helophoroides* in the Y-tube olfactometer. For type G *D. helophoroides*, only (S)-(−)-limonene attracted significantly more *D. helophoroides* than the control (Z = -2.77; p < 0.01) (Figure 1). All of the other monoterpenes were not significantly different from the control in attractiveness to this population of *D. helophoroides*.

For type S *D. helophoroides* adults, α-pinene, (1R)-(−)-α-pinene, and (+)-β-pinene attracted significantly more adults than the control (Z = -3.64, p < 0.001; Z = -2.03, p < 0.05; Z = -3.93, p < 0.001, respectively) in the Y-tube olfactometer (Figure 2). Other monoterpenes were not attractive to this population of *D. helophoroides* in the Y-tube olfactometer.

**Discussion**

**Monoterpenes as kairomones of different populations of *D. helophoroides***

Most plants can release monoterpenes when attacked by insect pest (Luik et al. 1999; Chen et al. 2002; Iason et al. 2011). Many species of Coleopteran use tree terpenes as kairomones or pheromones (Byers 1992; Hobson et al. 1993; Allison et al. 2001, 2004; Thoss and Byers 2006). For instance, the volatile monoterpenes are often found serving as major attractants of Cerambycids (Allison et al. 2004), bark beetles (Byers 1992; Hobson et al. 1993; Allison et al. 2001, 2004; Thoss and Byers 2006), and a pine weevil (Nordlander 1990; 1991), or as major chemical cues for natural enemies searching for pine herbivores (Pettersson 2001; Mumm and Hilker 2006). The present study showed that two populations of *D. helophoroides* adults also used terpenes as kairomones to look for their potential hosts.

Some herbivores and natural enemies show chiral specificity in responses to host plant semiochemicals (Miller et al. 1996; Wibe et al. 1998; Allison et al. 2001; Erbilgin and Raffa 2001; Mozuraitis et al. 2002; Hull et al. 2004). Hobson et al. (1993) found that *Dendroctonus valens* LeConte is strongly affected by the enantiomeric composition of monoterpenes. Also, the natural enemies of *Ips pini* (Say), *Thanasimus dubius* (F.), and *Platysoma cylindrica* (Paykull) are known to prefer different optical isomers of ipsdienol (Raffa and Klepzig 1989; Raffa and Dahlsten 1995). The results of our study showed that two populations of *D. helophoroides* used different chiral monoterpenes as kairomones. This result suggests that (S)-(−)-limonene is an important component of the attractant kairomone for type G *D. helophoroides* adults searching for
A. glabripennis. (R)-(+-)limonene and limonene were not attractive to this population, which indicates that type G D. helophoroides specializes on the (S)-(-) isomer. For type S D. helophoroides, adults were attracted to three monoterpenes.

**Specialization of different populations of D. helophoroides on kairomone**

The ancestors of both type G and type S populations were collected from different ecological niches, as they parasitized different hosts on different host tree species in different places. Since this parasitoid lives in caves and is a less-active species (Wang et al 1996; Wei et al. 2008a), it is possible that they have adapted to different ecological environments and developed into different populations after long years of evolving with their own host species and host tree species (Kester and Barbosa 1991; Magalhães et al. 2007). Tree species certainly influence the frass volatiles of woodborers (Wei et al. 2011).

All tested adults from both types of populations were fifth generation. Because every generation of D. helophoroides was developed from the first batch of eggs laid by adults of the new generation, the fifth generation was reached after two years of rearing. The results showed that both populations retained their differences in olfactory response to chemical cues, even though both were reared from the same species of substitute host in laboratory. Therefore, both populations were specializing on the kairomones relative to their respective hosts.

Adults of type S D. helophoroides were attracted to more than one compound, which indicated that the type S population might be more original than other D. helophoroides populations, since this population is less specialized on chemical signals and can respond to more compounds, or it is a mixed population, which might respond to more Cerambycid species. Therefore, it is necessary to test the olfactory response of type S D. helophoroides to frass odors of different longhorned beetle species in the future.

For more distinct discrimination of different populations of D. helophoroides, genetic relationships of different populations need to be studied (Vaughn and Antolin 1998). Furthermore, whether the different populations are geographically distinct or overlapping needs to be clarified.

**Generalist or specialist**

From the concept of species, D. helophoroides is referred to as a generalist or a polyphagous parasitoid because it can parasitize many Cerambycid species (Qin and Gao 1988; Wang et al. 1996). However, there exist different populations of D. helophoroides in nature, and they specialize on their own hosts and host tree species, so D. helophoroides might be referred to more accurately as a “habitat specialist” or “host specialist” (Jermy 1988; Gaston 1990; Wei et al. 2009c).

**The release rates of chemicals from larval frass and selected compounds tested in bioassay**

The average release rates of monoterpenes from larval frass of A. swainsoni were higher than that from larval frass of A. glabripennis (Table 1). However, since the monoterpenes exist in almost every plant species and plant extract, and the results from the olfactory test showed that different populations of D. helophoroides specialize on different monoterpenes when tested using similar release rates in the laboratory, comparison of quantities of monoterpenes between larval frass from two Cerambycids might not have real meaning.
The mixtures of different monoterpenes were not tested for either *D. helophoroides* population, since the release rates of different monoterpenes from the mixture were difficult to control in order to comply with the natural release rates or ratios of different monoterpenes in the larval frass of longhorned beetles.

**Kairomone used as an attractant in the field**

*D. helophoroides* is a cave beetle (Wang et al. 1996), so it is difficult to find in the field. Because the longevity of adults breeding in the laboratory decreased after several generations of rearing, it is necessary to develop some attractant to lure and trap *D. helophoroides* in the field in order to collect enough wild individuals to establish a new colony to mass rear. Based on the results in this study, kairomones can be used as attractants to lure *D. helophoroides* adults.

After (R)-(+)
- Limonene was found as a kairomone of *M. raddei* (Wei et al. 2008b) to a population of *D. helophoroides*, (R)-(+)
- limonene was used as a lure to trap the *D. helophoroides* adults in the field in order to collect enough wild individuals to establish a new colony to mass rear. However, only a few *D. helophoroides* adults were captured on average in each trap. Therefore, there could be other compounds also acting as chemical cues to attract *D. helophoroides* adults. A similar phenomenon could also be happening in two populations of *D. helophoroides* parasitizing *A. glabripennis* and *A. swainsoni*. On the other hand, the monoterpenes might be too volatile as an attractant of *D. helophoroides*, or there may be other environmental factors that also influence the behavior of insect (Hunter 2002). Further field trap experiments should be conducted based on controlled volatile ratios.

**Acknowledgements**

This work was supported by the National Natural Science Foundation of China (No: 30771738), funds from the Research Institute of Forest Ecology, Environment and Protection, Chinese Academy of Forestry (No: CAFRIF200703), and the Natural Science Foundation of Shandong Province (No: Y2008D37). The authors gratefully acknowledge Dr. Deepa Pureswaran in Laurentian Forestry Centre, Canadian Forest Service, for improving the language. Thanks also to Professor Zhong-Qi Yang at the Research Institute of Forest Ecology, Environment and Protection, Chinese Academy of Forestry, for his support on the research.

**References**

Allison JD, Borden JH, Seybold SJ. 2004. A review of the chemical ecology of the Cerambycidae (Coleoptera). *Chemoecology* 14: 123–150.

Allison JD, Borden JH, McIntosh RL, de Groot P, Gries R. 2001. Kairomonal response by four *Monochamus* species (Coleoptera: Cerambycidae) to bark beetle pheromones. *Journal of Chemical Ecology* 27: 633–646.

Byers JA. 1992. Attraction of bark beetle, *Tomicus piniperda*, *Hylurgops palliates* and *Trypodendron domesticus* and other insects to short-chain alcohols and monoterpenes. *Journal of Chemical Ecology* 18: 2385–2402.
Chen Z, Kolb TE, Clancy KM. 2002. The role of monoterpenes in resistance of Douglas fir to western spruce budworm defoliation. *Journal of Chemical Ecology* 28(5): 897–920.

Chuche J, Xuéreb A, Thiéry D. 2006. Attraction of *Dibrachys cavus* (Hymenoptera: Pteromalidae) to its host frass volatiles. *Journal of Chemical Ecology* 32: 2721–2731.

Ding BF, Wei JR, Zhao JX, Yang ZQ. 2009. Characterization of the volatile fraction emitted by larval frass of *Anoplophora glabripennis* feeding *Salix babylonica* Linn. or *Salix × aureo-pendula*. *Journal of Environmental Entomology* 31(3): 209–213 (In Chinese with English summary).

Erbilgin N, Raffa KF. 2001. Modulation of predator attraction to pheromones of two prey species by stereochemistry of plant volatiles. *Oecologia* 127: 444–453.

Gao RT, Li GH. 2001. Review and prospect of research on *Anoplophora glabripennis* in China. *Entomological Knowledge* 38(4): 252–258 (In Chinese with English summary).

Gaston KJ. 1990. Patterns in the geographical ranges of species. *Biological Review* 65: 105–129.

Grégoire JC, Baisler M, Drumont A, Dahlsten DL, Meyer H, Francke W. 1991. Volatile compounds in the larval frass of *Dendroctonus valens* and *Dendroctonus micans* (Coleoptera: Scolytidae) in relation to oviposition by the predator, *Rhizophagus grandis* (Coleoptera: Rhizopogaidae). *Journal of Chemical Ecology* 17(10): 2003–2020.

Hobson KR, Wood DL, Cool LG, White PR, Ohtsuka T, Kubo I, Zavarin E. 1993. Chiral specificity in responses by the bark beetle *Dendroctonus valens* to host kairomones. *Journal of Chemical Ecology* 19: 1837–1847.

Hu JF, Angeli S, Schuetz S, Luo YQ, Hajek AE. 2009. Ecology and management of exotic and endemic Asian longhorned beetle *Anoplophora glabripennis*. *Agricultural and Forest Entomology* 11: 359–375.

Hunter MD. 2002. A breath of fresh air: beyond laboratory studies of plant volatile-natural enemy interactions. *Agricultural and Forest Entomology* 4: 81–86.

Hull CD, Cunningham JP, Moore CJ, Zalucki MP, Cribb BW. 2004. Discrepancy between antennal and behavioral responses for enantiomers of α-pinene: electrophysiology and behavior of *Helicoverpa armigera* (Lepidoptera). *Journal of Chemical Ecology* 30(10): 2071–2084.

Iason GR, O’Reilly-Wapstra JM, Brewer MJ, Summers RW, Moore BD. 2011. Do multiple herbivores maintain chemical diversity of Scots pine monoterpenes? *Philosophical Transactions of the Royal Society* B 366: 1337–1345.

Jermy T. 1988. Can predation lead to narrow food specialization in phytophagous insects? *Ecology* 68: 902–904.

Jiang L, Wei JR, Qiao LQ, Lu XP. 2010. Analysis of volatiles emitted from larval frass of *Apriona swainsoni* (Coleoptera: Cerambycidae) by solid-phase microextraction and GC-MS techniques. *Journal of Environmental Entomology* 32(3): 357–362 (In Chinese with English Abstract).

Kester KM, Barbosa P. 1991. Behavioral and ecological constraints imposed by plants on...
insect parasitoids: implications for biological control. *Biological Control* 1(2): 94–106

Lei Q, Li ML, Yang ZQ. 2003. A study on biological feature of *Dastarcus longulus*. *Journal of Northwest Sci-tech University of Agriculture and Forestry* (Natural Science Edition) 31(2): 62–66 (In Chinese with English summary).

Li JQ, Yang ZQ, Zhang YL, Mei ZX, Zhang YR, Wang XY. 2009. Biological control of *Batocera horsfieldi* (Coleoptera: Cerambycidae) by releasing its parasitoid *Dastarcus helophoroides* (Coleoptera: Bothrideridae). *Scientia Silvae Sinicae* 45(9): 94–100 (In Chinese with English summary).

Lim J, Oh H, Park S, Koh S, Lee S. 2012. First record of the family Bothrideridae (Coleoptera) in Korea represented by the wood-boring beetle ectoparasite, *Dastarcus helophoroides*. *Journal of Asia-Pacific Entomology* 15(2): 273–275

Luik A, Ochsner P, Jensen TS. 1999. Olfactory responses of seed wasps *Megastigmus pinus* Parfitt and *Megastigmus rafni* Hoffmeyer (Hym., Torymidae) to host-tree odours and some monoterpenes. *Journal of Applied Entomology* 123(9): 561–567.

Lu XP, Jiang L, Wei JR. 2012. Behavioral bioassay of *Dastarcus helophoroides* (Fairmaire) (Coleoptera: Zopheridae) adults searching for *Apriona swainsoni* (Hope) (Coleoptera: Cerambycidae). *Chinese Journal of Biological Control* 28(4): 594-598 (In Chinese with English summary).

Macleod A, Evans HF, Baker RHA. 2002. An analysis of pest risk from an Asian longhorn beetle (*Anoplophora glabripennis*) to hard-wood trees in the European community. *Crop Protection* 21: 635–645.

Mgalhães S, Forbes MR, Skoracka A, Osakabe M, Chevillon C, McCoy KD. 2007. Host race formation in the Acari. *Experimental and Applied Acarology* 42: 225–238

Miller DR, Borden JH, Slessor KN. 1996. Enantiospecific pheromone production and response profiles for populations of pine engraver, *Ips pine* (Say) (Coleoptera: Scolytidae), in British Columbia. *Journal of Chemical Ecology* 22(11): 2157–2172.

Mozuraitis R, Stranden M, Ramirez MI, Borg-Karlson AK, Mustaparta H. 2002. (-)-Germacrene D increases attraction and oviposition by the tobacco budworm moth *Heliothis virescens*. *Chemical Senses* 27: 505–509.

Mumm R, Hilker M. 2006. Direct and indirect chemical defence of pine against folivorous insects. *Trends in plant science* 11(7): 351–358.

Nordlander G. 1990. Limonene inhibits attraction to α-pinene in the pine weevils *Hyllobius abietis* and *H. pinastri*. *Journal of Chemical Ecology* 16: 1307–1320.

Nordlander G. 1991. Host finding in the pine weevil *Hyllobius abietis*: effects of conifer volatiles and added limonene. *Entomologia Experimentalis et Applicata* 59(3): 229–237.

Nowak DJ, Pasek JE, Sequeira RA, Crane DE, Mastro VC. 2001. Potential effect of *Anoplophora glabripennis* (Coleoptera: Cerambycidae) on urban trees in the United States. *Journal of Economic Entomology* 94(1): 116–122.
Pettersson EM. 2001. Volatile attractants for three Pteromalid parasitoids attacking concealed spruce bark beetles. *Chemoecology* 11: 89–95.

Qin XX, Gao RT. 1988. Studies on bionomics and application of *Dastarcus longulus* Sharp. *Entomological Knowledge* 25(2): 109–112 (in Chinese).

Raffa KF, Dahlsten DL. 1995. Differential response among natural enemies and prey to bark beetle pheromones. *Oecologia* 102: 17–23.

Raffa KF, Klepzig KD. 1989. Chiral escape of bark beetles from predators responding to a bark beetle pheromone. *Oecologia* 80: 566–569.

Sullivan BT, Pettersson EM, Seltmann KC, Berisford CW. 2000. Attraction of the bark beetle parasitoid *Roptrocus xylophagorum* (Hymenoptera: Pteromalidae) to host-associated olfactory cues. *Environmental Entomology* 29(6): 1136–1151.

Tang YP, Liu GH. 2000. Study on forecast of ovipositing occurrence time of *Apriona swainsoni*. *Scientia Silvae Sinicae* 36(6): 86–89 (In Chinese).

Thoss V, Byers JA. 2006. Monoterpene chemodiversity of ponderosa pine in relation to herbivore and bark beetle colonization. *Chemoecology* 16: 51–58.

Tadahisa U. 2003. Preliminary release experiments in laboratory and outdoor cages of *Dastarcus helophoroides* (Fairmaire) (Coleoptera: Bothrideridae) for biological control of *Monochamus alternatus* Hope (Coleoptera: Cerambycidae). *Bulletin of the Forestry and Forest Products Research Institute* 2(4): 255–262.

Vaughn TT, Antolin MF. 1998. Population genetics of an opportunistic parasitoid in an agricultural landscape. *Heredity* 80: 152–162.

Wang XM, Ren GD, Ma F. 1996. Classification position of *Dastarcus helophoroides* and its applied prospects. *Acta Agri Boreali-occidentalis Sin* 5(2): 75–78 (In Chinese with English summary).

Wei JR, Jiang L. 2011. Olfactory response of *Dastarcus helophoroides* (Coleoptera: Bothrideridae) to larval frass of *Anoplophora glabripennis* (Coleoptera: Cerambycidae) on different host tree species. *Biocontrol Science and Technology* 21(11): 1263–1272.

Wei JR, Yang ZQ, Ma JH, Tang H. 2007. Progress on the research of *Dastarcus helophoroides*. *Forest Pest and Disease* 26(3): 23–25 (In Chinese with English summary).

Wei JR, Yang ZQ, Tang H, Du JW. 2008a. Behavior of a cerambycid parasitoid beetle *Dastarcus helophoroides*. *Scientia Silvae Sinicae* 44(7): 50–55 (In Chinese with English summary).

Wei JR, Yang ZQ, Hao HL, Du JW. 2008b. (R)-(++)-limonene, kairomone for *Dastarcus helophoroides* (Fairmaire), a natural enemy of longhorned beetles. *Agricultural and Forest Entomology* 10(4): 323–330.

Wei JR, Yang ZQ, Niu YL, Zhao HB, Tang H. 2009a. Distribution and ecological biology of *Dastarcus helophoroides*. *Forest Pest and Disease* 28(1): 16–18 (In Chinese with English Abstract).
Wei JR, Yang ZQ, Wang PY, Sun XG, Sun LG. 2009b. Control of Massicus raddei (Blessig) (Coleoptera: Cerambycidae) by parasitic beetle Dastarcus helophoroides Sharp (Coleoptera: Bothrideridae). Chinese Journal of Biological Control 25(3): 285–287 (In Chinese with English Abstract).

Wei JR, Yang ZQ, Poland TM, Du JW. 2009c. Parasitism and olfactory responses of Dastarcus helophoroides (Coleoptera: Bothrideridae) to different Cerambycidae hosts. Biocontrol 54(6): 733–742.

Wibe A, Borg-Karlson AK, Persson M, Norin T, Mustaparta H. 1998. Enantiomeric composition of monoterpenes hydrocarbons in some conifers and receptor neuron discrimination of α-pinene and limonene enantiomers in the pine weevil, Hylobius abietis. Journal of Chemical Ecology 24(2): 237–287.

Zhou JX, Lu XZ, Lu YZ. 1985. Reports on introducing Dastarcus longulus Sharp to control Anoplophora nobilis Ganglbauer. Entomological Knowledge 2(22): 84–86 (In Chinese).