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Japanese beetle lures used alone or combined with structurally related chemicals to trap NE China scarabs (Coleoptera: Scarabaeidae)

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ABSTRACT

Scarab beetles are agriculturally important worldwide, and as adults or larvae they may cause damage to the leaves, flowers, fruit, and roots of crops. Previous international studies showed that Japanese beetle (*Popillia japonica*, Newman) lures, and structurally related chemicals, can attract numerous scarabs. Based on those studies, season-long trials in grape, cabbage, corn and soybean fields were conducted in 2012–2013 in NE China. Tests determined the attractiveness of the Japanese beetle floral lure (phenethyl propionate:eugenol:geraniol, 3:7:3) and sex attractant (Japonilure), alone, combined, or in a mixture with either (Z)-3-hexen-1-ol, anethole = 1-methoxy-4-propenyl benzene or benzyl alcohol, to local Coleoptera. Furthermore, control efficacies based on leaf, ear, and silk damage, as well as reductions of adults on plants, and overwintering larvae, were also determined. Eleven scarab species, and four non-scarab species, were captured. The addition of other chemicals increased the attractiveness of the two Japanese beetle lures to scarabs such as *Potosia brevitarsis* (Lewis), *Oxycetonia jecunda* Faldermann, *Holotrichia diomphalia* Bates et al., *Popillia quadriguttata* (Fabricius), *Maladera verticalis* (Fairmaire), and *Metabolus impressifrons* Fairmaire, and the chrysomelid beetle *Chrysomela populi* L. The floral lure, and floral lure plus Japonilure baited traps resulted in >80% overwintering larvae and adult reductions in corn and cabbage fields, whereas the Japonilure traps gave similar results in the soybean fields. This indicates that the commercial Japanese beetle lure combination can be recommended for use by the Chinese farmers in the corn or soybean fields, and that the related chemicals can be used to increase the attractiveness of the Japanese beetle lures.

Introduction

Cultivated crops, including corn, soybean, vegetables and fruit, can be seriously damaged by the many species in the family Scarabaeidae. The most important scarabs in East-Asia are *Potosia* (*Liocola*) *brevitarsis* (Lewis), *Popillia quadriguttata* (Fabricius), *Holotrichia diomphalia* Bates et al., and *Anomala corpulenta* Motschulsky et al. (Sang, 1979; Reed et al., 1991; Wang et al., 1999; Lee et al., 2002; Hao and Ren, 2003; Oh et al., 2003; Chen and Li, 2011; Chen et al., 2013b, 2014). Scarabs as either adults, larvae, or both may cause damage. Beetle populations emerge in the fields at various times, and can continuously damage plants over the growing season. In addition, many of these pests (especially *Pop. quadriguttata*) are destructive to most parts of crop plants, including the roots, leaves, flowers, and fruit, (Luo and Zhang, 1981; Zhang et al., 1981; Tan et al., 1998; Wang, 2001; CABI, 2002; Wang and Zhen, 2006; Fang, 2007). Overall, scarabs can cause up to 20–30% in yield loss per year (Zhang et al., 1981; Qu et al., 1993; Wang, 2001; AQSIQ, 2003a,b; Australian Government, 2004; Fang, 2007; unpublished data, Chen et al., 2001; Chen et al., 2013a). In South Korea, *Pop. quadriguttata* is a major pest on golf courses where the adults feed on many ornamental plants and the larvae destroy the turfgrass roots (Reed et al., 1991; Lee et al., 2007).

Suppressing the scarab populations has been a major problem for growers trying to protect their crops and products. Traps baited with attractants can be an effective aid in adult scarab suppression, and a considerable body of knowledge has been accumulated based on a work with attractants for the Japanese beetle (*Pop. japonica* Newman) (Fleming, 1969; Hamilton et al., 1971; Chen et al., 2013b, 2014).

The female produced Japanese beetle sex attractant has been identified as (R.Z)-5-(1-decenyl) dihydro-2(3H)-furanone and commonly called Japonilure (Tumlinson et al., 1977). A sweet smelling “floral or food” lure containing three chemicals: 2-phenethyl propionate; eugenol; and geraniol (3:7:3) has been shown to be the most attractive to both sexes of Japanese beetles (Ladd and McGovern, 1980). Furthermore, the combination of Japonilure and the floral lure increased the

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captures of both males and females over the floral lure alone, and makes up the current survey and commercially available attractants (Klein et al., 1981, Ladd et al., 1981).

Numerous scarab beetles have been captured in the traps baited with Japanese beetle lures in the USA, South Africa, Japan, Korea, and China (see Chen et al. (2013b) for details). Furthermore, structurally related chemicals have shown attraction to several additional scarab species (Allsopp and Cherry, 1991; Cherry et al., 1996; Crocker et al., 1999; Williams et al., 2000; Toth et al., 2003; Chen and Li, 2011).

In previous studies (Chen et al., 2013b, 2014), and through preliminary field observations, Japanese beetle lures were shown to be particularly attractive to *Pop. quadriguttata* in NE China, and clearly provided damage reduction in soybean fields. Also in NE China, (Z)-3-hexen-1-ol and benzyl alcohol have shown attractiveness to *H. diomphalia*, *H. parallela* Motschulsky and *A. corpulenta* (Li et al., 2013) anethole was attractive to another *Anomala* species (*A. marginata* (Robinson)) in Florida, USA (Cherry et al., 1996), and anethole:eugenol was the standard Japanese beetle lure for many years (Fleming, 1969). Based on the above information, the traps baited with Japonilure and/or the Japanese beetle floral lure were utilized in 2012–2013 in various fields to determine the attraction of the chemicals to scarab species and to measure possible damage reductions. In addition, the three other scarab attractants noted above were individually added to the joint Japanese beetle lure to evaluate their potential as lures in NE China.

The prime objective of these studies was to optimize the chemical attractants for several scarab pests, and to assess the potential of utilizing these chemicals to suppress the complex of scarabs in agricultural fields.

Materials and methods

Traps and lures

Tests were conducted at the Jilin Agricultural University experimental farms and campus at Changchun, Jilin Province, north-eastern China, in July–October, 2012 and June–October, 2013. During those times, Trécé Japanese beetle traps (Trécé, Inc., Adair, OK, USA), or laboratory made yellow bottle traps were used in separate tests. The lures consisted of 1 mg Japonilure in a rubber septum, 5 ml of the floral lure in a felt pad or high void polyethylene disk, or a combination of the joint lure, each in a separate solvent-resistant compartment on the lure pack (Chen et al., 2014).

Additional chemicals; (Z)-3-hexen-1-ol, anethole = 1-methoxy-4-propenyl benzene, and benzyl alcohol were obtained from Sigma-Aldrich (Changchun, China). All compounds were at least 95% pure as stated by the supplier. Five ml of each chemical was applied to the surface of a high void polyethylene disk held in a 3 cm dia. round Poly-con container (details in Klein and Edwards (1989)).

Trap layout — In both years, the traps were baited with the Japanese beetle floral lure and Japonilure, alone or together. In 2013 the traps with those three combinations of Japanese beetle lures and one of the three additional chemicals were used as noted above. In both years, tests were conducted at five locations: field corn; soybean field, cabbage, grapes and nearby apple orchard, hereafter referred to as grapes; and a poplar tree planting with an understory of grass, hereafter referred to as trees. Each location had three replicates of each lure treatment, with ca. 25 m between traps within a block ca. 100 m between blocks. The traps were randomized within a block, and secured to wooden poles so the upper edge of the funnel was about 75 cm above the ground. Lures were replaced every four weeks during the three or four month test periods.

Captured beetles — The traps were serviced every 2 days and captured insects were removed and taken back to the Agricultural Insects Research Laboratory at the Jilin Agricultural University, Changchun, where they were identified and counted. In addition, sex was established for *Pop. quadriguttata* beetles using the front tibial spur characteristic, which is similar to that of *Pop. japonica* (Fleming, 1972).

Attractiveness of lures versus natural hosts

Olfactometer testing

The attractiveness of the three combinations of Trécé lures were compared to fresh corn ear, corn silk, corn leaf, soybean leaf, and cabbage leaf in a laboratory olfactometer, similar to the one used in previous studies (Chen and Li, 2011). The primary difference here was that the choice chamber was separated into nine chambers by foam boards, where the attractants or host materials were randomly placed. Forty beetles of a scarab species were placed in the central chamber of each of the three olfactometers run at the same time. The beetles were collected from the traps and starved in the laboratory for ca. 3 days before bioassays. In addition, the beetles placed into the central chamber had a sex ratio of ca. 1:1. After ca. 30 min, the beetles in each choice chamber were removed, counted and recorded.

Host preference

The traps were placed in five locations noted above. Adult scarab captures in the various crops were assessed in both 2012 and 2013 by counting the beetles captured in each field, as well as the total captures from different fields. The ratios of the species captured in one host field to total captures of that species in all fields were used to indicate the host preference.

Evaluation of treatment efficacy

Treatment efficacy was determined from: (i) crop damage (leaf, ear, or silk damage); (ii) number of adults on host crops; and (iii) overwintering larvae populations. While the first two methods are good indicators that trapping was effective, the number of overwintering larvae is probably the best indication of treatment efficacy.

Crop damage assessment — Plant leaf and ear damage from scarab adults was assessed on 29 August 2012 and 26 August 2013, and silk damage was evaluated on 25 July 2012 and 28 July 2013 by randomly selecting 50 plants in each treatment plot. Damage values were as follows: 0 (no damage), 1 (up to 1% leaf/kernel/silk eaten), 2 (2–4% leaf/kernel/silk eaten), and 3 (4–6% leaf/kernel/silk eaten). Protection values were based on the damage value in the control minus the damage value in the treatments.

Evaluation of adults on foliage and overwintering larvae — The adults attracted to plants, but not into a trap, were counted and recorded by randomly selecting 50 plants in the treatment plots every 5 days from 2 July to 12th August 2012–2013. On 10, 20, and 30 October, overwintering larvae were assessed by digging 1.5 m^2 holes to a depth of ca. 30 cm in 10 randomly selected areas in the treated and non-treated field plots. The overwintering larvae from the soil were given a preliminary identification, counted and recorded. However, since the larvae could only be identified to the genus level at best using shapes on the last abdominal segment (pygidium) (Ping, 1988; Li et al., 1997), the larval data was pooled to establish differences between the host fields.

Data analysis

During the four month investigations, the trap captures were transformed by $\log(x + 1)$ to normalize the data, the insect counts were subjected to analysis of variance and the means were separated using Duncan's (1955) multiple range test. Since tests were conducted under similar conditions, and had high data homogeneity, replicates from various dates were pooled for an average.

Results

Traps and lures

Scarab species attraction in the field — During the 2012–2013 growing seasons, 11 agriculturally important scarab species, including *Pot.*

brevitarsis, *Oxycetonia jecunda* Faldermann, *H. diomphalia*, *H. parallela*, *A. corpulenta*, *Maladera orientalis* Motschulsky, *Pop. quadriguttata*, *Proagopertha lucidula* (Faldermann), *Maladera verticalis* (Fairmaire), and *Metabolus impressifrons* Fairmaire, *Pop. indigonacea* Motschuosky, were caught with all types of lure–traps (Table 1). Four other non-scarab genera: the red poplar leaf beetle, *Chrysomela populi* L., Chrysomelidae; the eastern pale clouded yellow butterfly *Colias erate* Esper, Pieridae; the imported cabbageworm, *Pieris rapae* L., Pieridae; and the brown marmorated stink bug, *Halyomorpha halys* Stal, Pentatomidae were also captured (Table 1).

With the floral lure traps, more (≧100) *Pot. brevitarsis*, *Pop. quadriguttata* and *O. jecunda* adults were caught than the other seven scarab species (Fig. 1a). One hundred or more *Pot. brevitarsis*, *Pro. lucidula* and *Pop. quadriguttata* were caught with the Japonilure plus floral lure (Fig. 1a). In the Japonilure alone traps, only *Pop. quadriguttata* was caught in numbers near 100 (Fig. 1a), but unusually high numbers of *Pro. lucidula*, and low numbers of *Pop. indigonacea*, were caught. In 2013, *Pop. quadriguttata*, *Pot. brevitarsis*, *O. jecunda*, *Pro. lucidula*, and *A. corpulenta* were caught in numbers exceeding 100 per trap in the combination of Japonilure and floral lure plus (Z)-3-hexen-1-ol traps (Fig. 1b). Similar numbers of the above scarab species, in addition to *H. parallela*, were also captured in the Japonilure, floral lure combination plus benzyl alcohol (Fig. 1b). Whereas, *Pop. quadriguttata*, *Pro. lucidula*, *Pot. brevitarsis*, and *Chr. populi* were caught in high numbers with the Japonilure, floral lure combination plus anethole traps (Fig. 1b).

Additive or inhibition — During the 2012–2013 growing season the traps with the Japonilure, floral lure combination captured significantly more *O. jecunda*, *Pro. lucidula* and *Met. impressifrons* than the traps containing Japonilure, or floral lure alone. The inhibition between the two lures was only shown when trapping *Pop. quadriguttata*. In that case, the traps baited with the floral lure alone, or the Japonilure and floral lure combination, caught significantly fewer *Pop. quadriguttata* adults than the Japonilure lure alone, which is in agreement with our previous study (Chen et al., 2013b). With the other seven scarab species, the Japonilure, floral lure combination catches were ca. equal to the floral lure alone, and significantly higher than the Japonilure alone (Table 1). Similar results were found with three of the four non-scarab species. The combination and floral lure alone were similar, and the Japonilure was less attractive. All three lures were similar for the stink bug probably indicating that the yellow color rather than the lures was responsible for the attraction.

Since the Japonilure, floral lure combination was not less attractive to the 11 scarab species than the floral lure or Japonilure SA lure alone, the combination and the three structurally related chemicals were tested during the 2013 growing season. The addition of (Z)-3-hexen-1-ol resulted in significantly higher captures of *Pro. brevitarsis*, *O. jecunda*, *H. diomphalia*, *Pop. quadriguttata*, *Mal. verticalis*, and *Met. impressifrons* than the two lure combination. The addition of 1-methoxy-4-propenyl benzene gave increased captures of *Pop. quadriguttata* and *Mal. verticalis*. The Japonilure, floral lure combination, with the addition of benzyl alcohol, caught more *O. jecunda*, *H. diomphalia*, *H. parallela*, *Pop. quadriguttata*, *Mal. verticalis*, and *Met. impressifrons* (Table 1). In 2013, only the addition of 1-methoxy-4-propenyl benzene significantly enhanced the attractiveness to the Lepidoptera *Col. erate* and *Pier. rapae* (Table 1).

Attractiveness of lures versus natural hosts

Ninety eight percent of the beetles responded to one of the treatments and moved to one of the choice chambers. There is a trend that significantly more adults of all the scarab species reached the floral lure and the Japonilure, floral lure combination than host plant parts with the exceptions of *O. jecunda* to the Japonilure, and *Pop. quadriguttata* to the floral lure or Japonilure, floral lure combination (Table 2). Furthermore, *Pop. quadriguttata* was significantly more attracted to Japonilure (34.9 ± 11.6) than the floral lure (16.5 ± 3.6) and the Japonilure, floral lure combination (14.3 ± 4.1). The floral lure and combination were equally attractive to all scarab species with the exception of *O. jecunda* (floral lure: 15.5 ± 3.7; combination: 36.6 ± 4.3). Compared to the chemical attractants, the host plants did not attract high numbers of beetles, except the soybean leaf which attracted 18.5% of *Pop. quadriguttata*, and the corn ear and silk, which both attracted more than 10% of *Pro. brevitarsis* and *O. jecunda*. None of the other host plant material attracted more than nine percent of the adults (Table 2), and the empty traps never captured more than an average of 5 beetles.

Table 1
Captures in traps baited with various chemicals, 2012–2013*.

Species	Mean ± SE per block per year								
	2012–2013				2013				
	Chemicals tested			$F_{(2,42)}$ value/ addition	SA + FL + chemicals tested				$F_{(3,48)}$ value/ addition
	FL	SA	SA + FL		SA + FL[a]	Hexen[b]	Anethole[c]	Benzyl[d]	
Scarabs									
Potosia (Liocola) brevitarsis	137.2 ± 14.3a	21.2 ± 7.3b	135.6 ± 12.1a	113.2/n-s	105.2 ± 32.6b	185.2 ± 15.2a	98.2 ± 14.1b	112.3 ± 9.6b	133.4/++
Oxycetonia jecunda	102.2 ± 11.5b	11.3 ± 4.2b	122.3 ± 13.5a	88.4/+	87.5 ± 3.4c	157.5 ± 13.4a	57.3 ± 6.8d	103.5 ± 8.9b	104.6/++
Holotrichia diomphalia	17.3 ± 2.2a	2.2 ± 0.5b	15.6 ± 2.1a	98.8/n-s	22.3 ± 3.4c	41.4 ± 5.8a	9.5 ± 1.6d	39.8 ± 5.3a	178.7/++
Holotrichia parallela	57.2 ± 21.2a	6.6 ± 9.3b	65.6 ± 31.2a	163.2/n-s	82.2 ± 16.7b	72.2 ± 26.7b	52.5 ± 13.3c	112.2 ± 23.5a	126.7+
Anomala corpulenta	82.2 ± 22.3a	13.4 ± 5.9b	79.4 ± 16.3a	63.5/n-s	107.3 ± 13.2a	121.3 ± 18.1a	46.4 ± 10.9b	125.2 ± 25.2a	165.6/n-s
Maladera orientalis	37.7 ± 5.9a	11.2 ± 6.5b	34.3 ± 6.6a	79.9/n-s	57.3 ± 2.8a	17.5 ± 3.6b	47.7 ± 3.6a	55.2 ± 8.9a	33.6/n-s
Popillia quadriguttata	103.3 ± 15.3b	124.2 ± 52.1a	104.2 ± 42.5b	103.8/n-s	173.4 ± 16.8b	202.8 ± 33.1a	196.9 ± 25.3a	188.4 ± 21.3a	299/+++
Proagopertha lucidula	87.2 ± 4.3b	61.2 ± 23.4c	105.6 ± 25.7a	188.5/+	123.7 ± 24.2a	153.5 ± 11.6a	109.9 ± 15.3b	108.8 ± 13.6b	117.7/+
Maladera verticalis	27.4 ± 4.4a	5.5 ± 1.4b	31.3 ± 4.8a	34.6/n-s	48.9 ± 10.6c	56.9 ± 9.3b	77.4 ± 9.7b	55.8 ± 13.1b	146.7/+
Metabolusimpressifrons	17.2 ± 4.3b	5.2 ± 2.1c	25.6 ± 8.2a	131.6/+	35.9 ± 8.8b	47.3 ± 12.3a	28.9 ± 6.5b	45.2 ± 10.8a	33.6/++
Popillia indigonacea	33.5 ± 8.7a	5.5 ± 1.6b	33.8 ± 2.4a	221.4/n-s	52.1 ± 13.5a	33.9 ± 8.7b	55.3 ± 7.9a	37.8 ± 14.6b	13.8/n-s
Non-scarabs									
Chrysomela populi	47.2 ± 9.7a	1.4 ± 0.3b	45.6 ± 8.3a	10.7/n-s	77.5 ± 13.3b	98.2 ± 21.4a	54.2 ± 15.8c	48.5 ± 12.6c	17.8/n-s
Colias erate poliographus	6.2 ± 2.1a	1.2 ± 0.3b	5.8 ± 1.7a	98.7/n-s	7.9 ± 2.6b	6.5 ± 2.6b	22.4 ± 2.6a	13.3 ± 1.8b	76.9/+
Pieris rapae	5.2 ± 1.3a	2.2 ± 0.6b	5.6 ± 1.1a	65.5/n-s	8.8 ± 1.9b	5.9 ± 2.1b	17.3 ± 1.8a	12.1 ± 3.3b	38.9/+
Halyomorpha halys	3.2 ± 1.3a	2.6 ± 0.7a	4.6 ± 1.3a	1.1/n-s	7.3 ± 2.1a	6.6 ± 2.2a	5.8 ± 1.8a	5.7 ± 1.9	1.8/n-s

a: no addition chemicals added; b:+(Z)-3-hexen-1-ol; c:+1-methoxy-4-propenyl benzene; d:+benzyl alcohol. +: positive addition; ++: two chemicals provide positive addition; +++: three chemicals provided positive addition; n-s: no positive addition. FL: 2-phenethyl propionate:eugenol:geraniol (3:7:3); SA: Japonilure: (R.Z)-5-(1-decenyl) dihydro-2(3H)-furanone. * Means in a row for each year with the same letters are not significantly different with LSD test (0.001).

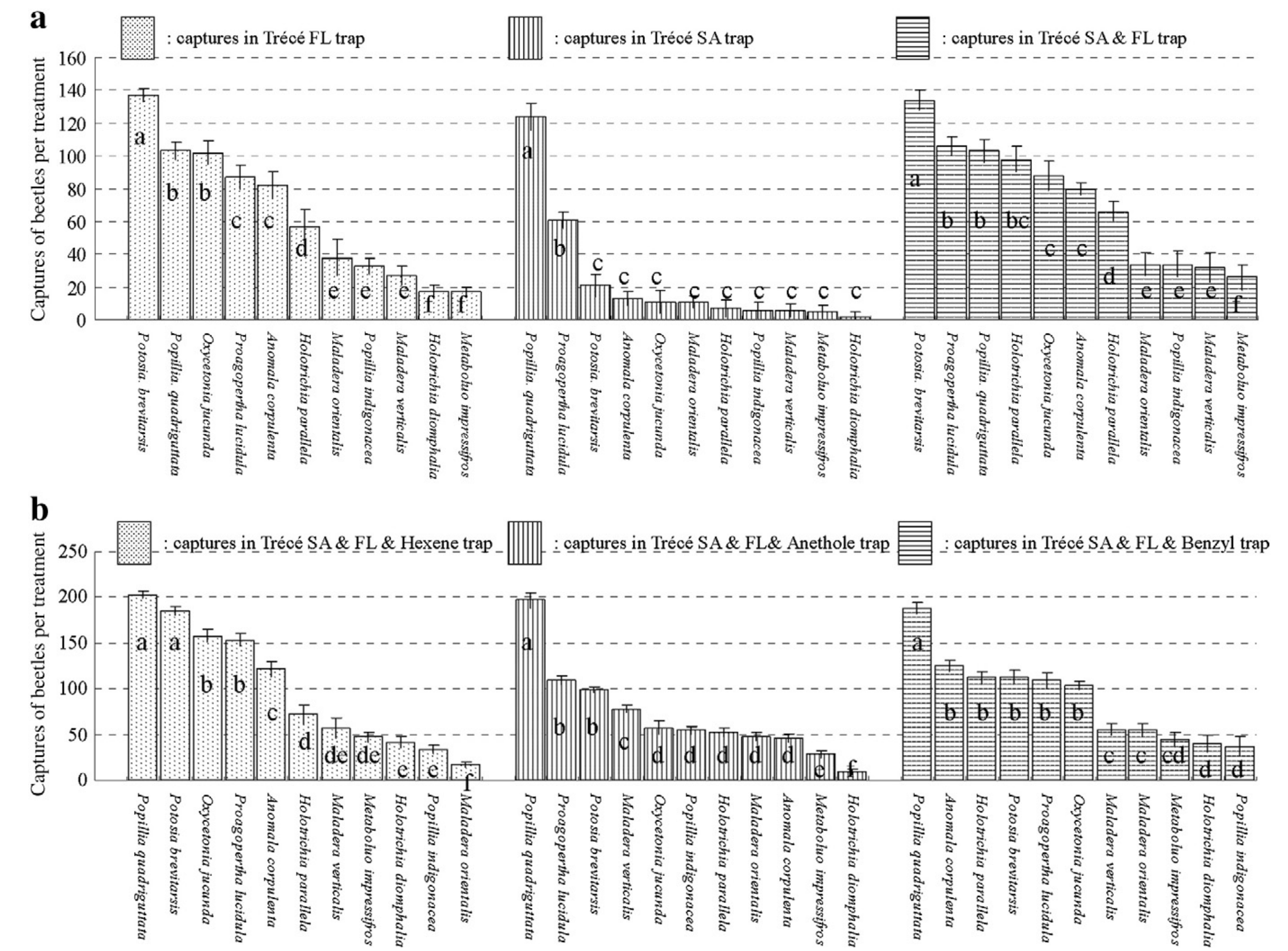

Fig. 1. a Captures of scarab beetles with Japanese beetle lures. b Captures of scarab beetles with Japanese beetle lures plus related chemicals. Means followed by the same letter are not significantly different, Duncan's (1955) multiple range test.

Host preference

The captures of male beetles showed a uniform trend in both 2012 and 2013. Significantly more *Pro. brevitarsis*, *O. jecunda*, *H. parallela*, and *Met. impressifrons* were caught in the corn field than the other 7 scarab species (Fig. 2). In the soybean field, significantly more *Pop. quadriguttata*, *Pop. indigonacea* and *Met. impressifrons* were caught, and more *Mal. verticalis*, *Pro. lucidula* and *Mal. orientalis* were found in the grapes than were other scarabs. Fewer of the 11 scarab species were caught in the cabbage or area with trees (Fig. 2).

Table 2
Mean percentage (±S.E.) of various scarab adult beetles that reached attractants versus various hosts in an olfactometer trial—2013[a].

Traps/lure	Percentage of scarab species* (±S.E.)										
	Potosia brevitarsis	*Oxycetonia jecunda*	*Holotrichia diomphalia*	*Holotrichiaparallela*	*Anomala corpulenta*	*Maladera orientalis*	*Popillia . quadriguttata*	*Proagopertha lucidula*	*Maladera verticalis*	*Metaboluo impressifros*	*Popillia indigonacea*
FL	27.2 ± 5.5a	15.5 ± 3.7b	27.4 ± 3.9a	33.2 ± 12.3a	38.4 ± a	35.4 ± 5.5a	16.5 ± 3.6b	27.9 ± 6.6a	28.9 ± 5.6a	31.5 ± 7.7a	22.7 ± 8.5a
SA	6.6 ± 2.1c	6.3 ± 1.9c	3.9 ± 1.1c	2.7 ± 0.9c	4.1 ± b	3.1 ± 0.8c	34.9 ± 11.6a	27.5 ± 2.1a	12.1 ± 3.3b	9.6 ± 3.8b	6.6 ± 1.3b
FL& SA	28.3 ± 6.3a	36.6 ± 4.3a	29.4 ± 6.5a	38.3 ± 8.8a	32.4 ± a	41.2 ± 6.2a	14.3 ± 4.1b	27.2 ± 12.4a	32.3 ± 11.9a	33.4 ± 11.5a	24.2 ± 7.6a
Corn leaf	7.6 ± 2.2c	5.2 ± 1.9c	8.2 ± 3.3b	9.3 ± 3.2b	4.2 ± b	2.4 ± 1.1c	2.1 ± 0.9c	4.2 ± 1.5b	4.1 ± 1.2c	3.2 ± 0.4b	1.9 ± 0.7b
Soybean leaf	1.6 ± 0.3d	1.9 ± 0.7d	7.9 ± 2.2b	1.3 ± 0.3c	5.5 ± b	5.2 ± 1.3c	18.5 ± 7.3b	3.3 ± 1.2b	3.2 ± 1.1c	3.6 ± 0.9b	28.1 ± 8.3a
Corn ear	11.1 ± 2.4b	13.8 ± 2.7b	8.8 ± 1.7b	4.2 ± 1.5c	4.2 ± b	3.4 ± 1.9c	2.2 ± 0.8c	3.1 ± 2.5b	5.8 ± 2.3c	5.8 ± 1.8b	3.6 ± 1.1b
Corn silk	11.5 ± 2.7b	13.2 ± 3.1b	6.3 ± 2.1b	3.5 ± 1.1c	5.4 ± b	3.0 ± 1.4c	3.6 ± 0.9c	1.1 ± 0.3b	6.5 ± 2c	5.9 ± 2.1b	4.5 ± 1.5b
Cabbage leaf	3.3 ± 0.9d	4.7 ± 1..4c	4.6 ± 0.9c	3.8 ± 2.1c	2.7 ± b	3.5 ± 1.7c	3.8 ± 1.3c	1.3 ± 0.7b	3.7 ± 6c	3.1 ± 0.9b	3.3 ± 0.7b
Control	2.8 ± 1.2d	2.8 ± 1.2d	3.5 ± 0.8c	3.7 ± 1.4c	3.1 ± b	2.8 ± 1.1c	4.1 ± 1.2c	2.4 ± 0.7b	3.4 ± 1.8c	3.9 ± 1.7b	5.1 ± 2.3b
$F_{(9.18)}$	132.6	178.8	67.3	33.7	13.8	168.9	225.9	356.8	135.5	337.8	35.8

* : Percentage = number of beetles reaching a tested attractant/(100 − number of beetles reaching all attractants and control) %.
[a] Means with the same letters in a column are not significantly different at level 0.001 with LSD test. FL: 2-phenethyl propionate:eugenol:geraniol (3:7:3); SA: Japonilure: (R,Z)-5-(1-decenyl) dihydro-2(3H)-furanone.

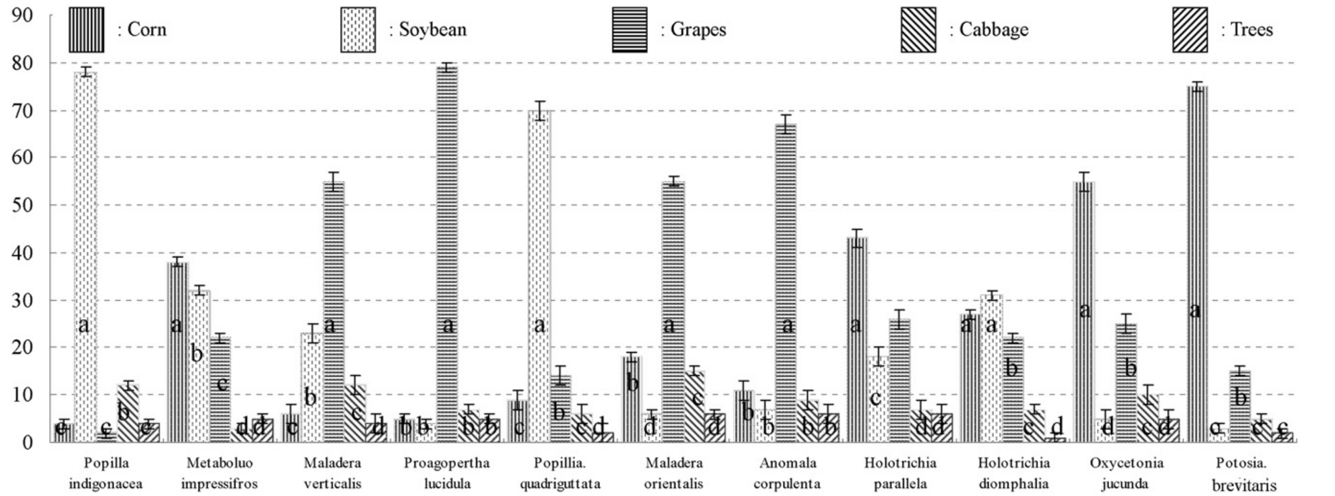

Fig. 2. Percent of total scarab beetles captured at various agricultural sites — 2012–2013. Means followed by the same letter are not significantly different, Duncan's (1955) multiple range test.

Control efficacy

During the 2012 growing season, significant differences ($P < 0.05$) were found in the number of adults on leaves, number of overwinter larvae, and leaf damage in soybean, corn and cabbage fields trapped with different lures (Table 3). In addition, the trap captures and the overwintering larvae also differed significantly between fields (Fig. 2). With all three lures, reductions in overwintering larval populations were significant in all three crop fields. There was also a significant decrease in adults on foliage, ear damage and silk damage in the corn fields (Table 3). The Japonilure, floral lure combination treatment, and the floral lure traps were superior with significant reduction of adults on leaves (corn field: 89.7%, 85.6%; cabbage field: 53.3%, 55.6%), reduction of overwintering larvae (corn field: 91.3%, 90.6%; cabbage field: 88.9%, 83.3%), ear damage in corn (89.9%, 91.3%), and silk damage in those same fields (92.3%, 89.7%). However, Japonilure traps were the best in the soybean field (adults on foliage: 62.5%; overwintering larvae: 75.6%), while the Japonilure, floral lure combination traps still provided 78.9% overwintering larvae reduction (Table 3). The damage to the plant parts showed a trend with both beetles on leaves and overwintering larval populations. In 2013, most control parameters increased, especially the reduction of leaf damage in all types of crop fields. Control of leaf damage in soybean fields reached 55.4% with the combination lure traps and 55.2% and 58.5% in corn fields with the floral lure or combination traps. For the ear and silk damage in the corn field, the floral lure and combination traps gave the best control (ear damage: 89.9%, 91.3%; silk damage: 92.3%, 89.7%). The adults on plants were reduced 85.4% and 84.3% in the corn field with the floral lure or combination traps, and the Japonilure traps gave a 75.4% adult reduction in the soybean field where both *Popillia* species were prevalent. The highest reductions of overwintering larvae were found in the corn and cabbage fields with the floral lure and combination traps (corn field: 89.9%, 90.6%; cabbage field: 88.9%, 86.9%), while the Japonilure and combination traps gave the highest larval reduction in the soybean field (83.8%, 86.5%) (Table 3).

In 2012–2013, over 70% overwintering larvae control was obtained in the corn and soybean fields, and ca. 60% control was seen in the cabbage field with the three types of lure/traps and combination lure plus either (Z)-3-hexen-1-ol, 1-methoxy-4-propenyl benzene, or benzyl alcohol baited traps. This correlates well with scarab adult catches, where over 80 scarab adults were caught per trap in corn and soybean fields (Figs. 3a, b).

Discussion

Field trials showed that *Pop. quadriguttata*, *Pro. brevitarsis*, *O. jecunda*, *H. diomphalia*, *Pop. indigonacea*, *A. corpulenta*, *Mal. orientalis*, and *H. morosa* were captured by Japonilure, floral lure and the combination of both in Japanese beetle traps. This information fits with previous

Table 3
Control efficacy of total of scarab populations in fields treated by various lure traps: 2012/2013.

Parameter	Mean control efficacy*: 2012/2013											
	Soybean				Corn				Cabbage			
	Lure type				Lure type				Lure type			
	Floral lure	Japonilure	Combination	$F_{(2,147)}$ value	Floral lure	Japonilure	Combination	$F_{(2,147)}$ value	Floral lure	Japonilure	Combination	$F_{(2,147)}$ value
LD	[a] 69.3a/39.3b	33.5b/42.2b	72.3a/55.4a	192.3/73.6	nt/55.2a	nt/32.1b	nt/58.5a	nt/23.6	36.3a/27.6a	19.6b/21.7a	42.5a/39.9a	135.4/159.2
ED	nt[b]	nt	nt		89.9a/84.3a	35.2b/39.3b	91.3a/88.6a	19.6/123.7	nt	nt	nt	
SD	nt	nt	nt		92.3a/88.7a	28.4b/31.2b	89.7a/88.6a	112.5/139.8	nt	nt	nt	
AP	38.3b/47.2b	625a/75.4a	32.2b/47.9b	88.7/162.5	89.7a/85.4a	26.5b/29.1b	85.6a/84.3a	257.3/177.6	53.3a/48.9a	21.4b/29.9b	55.6a/56.7a	18.9/33.6
OL	39.6b/47.4b	75.6a/83.8a	78.9a/86.5a	133.6/98.9	91.3a/89.9a	23.3b/37.3b	90.6a/92.5a	18.9/154.6	88.9a/87.5a	23.3b/17.3b	83.3a/86.9aa	156.3/178.9

Note: LD = Leaf damage, ED = Ear damage, SD = Silk damage, AP = Adults on plants, OL = Overwintering larvae.
LD/ED/AP/OL control efficacy = (LD/ED/AP/OL rank in control- LD/ED/AP/OL rank in treatments)/LD/ED/AP/OL rank in control;
* Means in a row followed by the same letter are not significantly different; Duncan's multiple range tests (0.001).
[a] 2012 data/2013 data.
[b] nt = no treatment.

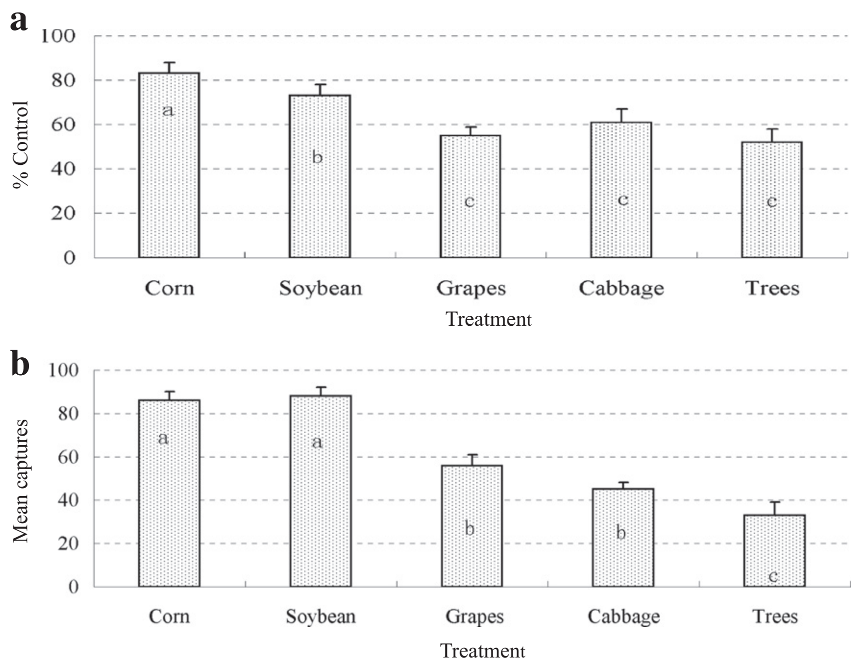

Fig. 3. a. Overwintering white grub control in various agricultural fields. b. Scarab beetle captures per trap in various agricultural fields. Means followed by the same letter are not significantly different, Duncan's (1955) multiple range test.

studies (Reed et al., 1991; Chen et al., 2013b, 2014). In addition, Lee et al. (2007) also reported the successful captures of *Pop. quadriguttata* with the Japonilure, floral lure combination. Here, the captures of four scarabs *H. parallela*, *Pot. lucidula*, *Mal. verticalis*, *Met. impressifrons*, and two other families (*Chr. populi*, Chrysomeladiae and *Ha. halys*, Pentatomidae) were recorded for the first time with those traps. The attraction of the red poplar leaf beetle is interesting since little is known about the attractants for Chrysomeladiae beetles. There is a great interest recently in *Ha. halys* in the USA, but it appears that the attraction was to the yellow color of the traps rather than the lures. Among the scarabs, *Pro. brevitarsis* and *Pop. quadriguttata* have gradually become increasingly important agricultural pests in the corn and soybean fields, respectively, and have received recent attention (Chen and Li, 2011; Chen et al., 2013b, 2014). More importantly, *H. diomphalia*, *H. morosa*, *Pot. lucidula*, *O. jecunda*, and *A. corpulenta* have also been reported as agricultural pests, and need additional attention from the scientists. In the past, nearly all these scarabs were suppressed by chemical controls, but the ideal efficacies could not be obtained. Clearly, capturing all these scarab species with a commercially available lure combination can provide the farmers with another potential control tool. Due to the lower financial and environmental costs of lures and traps, these provide the farmers with a choice other than the chemical controls which have elicited more and more concerns from the consumers and environmental health agencies.

In previous studies, trapping of *Pro. brevitarsis* and *Pop. quadriguttata* provided the possibility of considerable control (Chen and Li, 2011; Chen et al., 2013b), and additional research on mass trapping *Pop. quadriguttata* also has been encouraging during the 2012–2013 soybean growing seasons (Chen et al., 2014). However, control of a single pest species will not really reduce or eliminate pest damage, since a complex of scarab species simultaneously appears in agricultural crops, and several of them can play an important role in causing plant damage. This requires making it clear just what the host preferences of various scarabs are, and developing pest control techniques which can suppress a majority of the pest complex in certain agricultural crops.

This is the first record of the host preference of various Chinese scarabs in both field trials and a controlled laboratory olfactometer test. The results of the field trials on host preference showed that *Pro. brevitarsis*, *O. jecunda* and *H. parallela* were present in higher numbers in corn, *Pop. quadriguttata* and *Pop. indigonacea*, were highly associated with soybean plants, and *Mal. verticalis*, *Pot. lucidula* and *Mal. orientalis* were found primarily in grapes. However, *Met. impressifrons* were commonly found in both corn and soybean. High captures of a particular beetle may be due to the number of that species present in the total environment. But, all of those field observations trend positively with the olfactometer trials. These basic data will provide information on which scarab species to expect most commonly in which fields, and if the Japanese beetle lures will allow an early detection and a timely warning to farmers in the future. Consequently, proper control tactics can successfully be employed based on the host preference and monitoring data.

This is the first data indicating that a commercial combination of a sex and food lure can be used to trap a complex of scarab species in various field crops. Sex pheromones have been utilized as an effective tactic against several Lepidoptera and Coleoptera species such as *Chilo suppressalis* (Walker), *Pot. brevitarsis* and *Popillia* spp. (Klein and Edwards, 1989; Stelinski et al., 2008; Witzgall et al., 2008; Chen and Li, 2011; Chen and Klein, 2012). In addition, when co-releasing pheromones and volatile plant chemicals (kairomones), a significant synergism for trapping captures or mating disruption may be expected (Klein et al., 1981; Ladd et al., 1981; Knight et al., 2012). This is based on food or aggregative lures being attractive to both sexes (Hulcr et al., 2011). Here, attractiveness to various scarab species with Japonilure and the floral attractant released alone or in combination showed that the combination, or floral lure alone, was much more attractive than Japonilure alone to all scarab species except *Pop. quadriguttata*, whose males were highly attracted to the *Pop. japonica* pheromone. On the other hand, *Pop. indigonacea* was not attracted to that pheromone. Additional work is needed on the true pheromones in the *Popillia* species. The results here indicate a good possibility for mass trapping a complex of scarab species in various host fields. Actually, increased captures were obtained by combining the joint Japanese beetle lure with (Z)-3-hexen-1-ol, anethole, or benzyl alcohol for several scarab species in the NE China complex. However, those three chemicals also inhibited captures by the Japanese beetle lures. Clearly, these and other chemicals should be added to the Japanese beetle lures, with and without geraniol, for additional testing in Asia. The % damage reductions obtained here must be evaluated to make sure they are closely related to the commonly accepted economic thresholds for the crops in question, and area wide placement of traps could increase the reduction in damage. These questions should be the objective of scarab studies in the future.

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