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Laboratory screening supports the selection of sesame (*Sesamum indicum*) to enhance *Anagrus* spp. parasitoids (Hymenoptera: Mymaridae) of rice planthoppers

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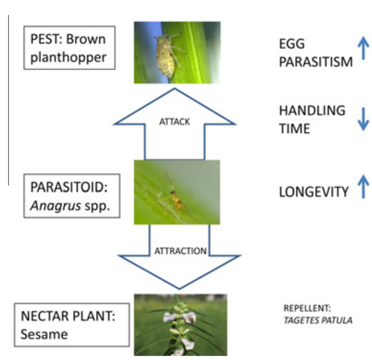
HIGHLIGHTS

- ▶ Little is known about how to promote biological control in rice crops.
- ▶ *Anagrus* spp. parasitoids are known to attack rice planthoppers, serious pests.
- ▶ Olfactometer studies showed which flowers attract and which repel two *Anagrus* spp.
- ▶ Sesame nectar improved longevity, fecundity and handling time in *Anagrus nilaparvatae*.
- ▶ Sesame sown on rice bunds could improve management of rice planthopers.

GRAPHICAL ABSTRACT



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ABSTRACT

Planthopper (Delphacidae) pests have broken out frequently in Asia over the last decade leading to interest in enhancing the impact of natural enemies by growing nectar plants on the bunds that border rice fields. Such targeted use of plant diversity is popular in other crop systems but there is a marked lack of information on the scope for its use in rice, particularly the important aspect of which plant species to use. This study used Y-tube olfactometer assays to measure the response of two important parasitoids of delphacid pests to candidate nectar plants. *Anagrus optabilis* exhibited significant attraction to the air from six of the seven plant species whilst *Anagrus nilaparvatae* appeared more selective, exhibiting attraction to only seven of the 23 plants screened and repulsion to one. *Sesamum indicum*, *Emilia sonchifolia*, and *Impatiens balsamena* were the only three plants attractive to both parasitoids. Laboratory longevity of adult female *A. nilaparvatae* and *A. optabilis* with access to sesame flowers was significantly greater than with access to sesame from which the flowers were removed plus water. Similarly, both parasitoids parasitized significantly more brown planthopper (*Nilaparvatae lugens*) eggs in the presence of sesame flowers. Handling time of *A. nilaparvatae* was reduced from 31.29 to 18.36 min by access to sesame nectar. Findings show that sesame has a marked beneficial effect on key parameters of *Anagrus* spp. and justifies further evaluation of its utility as a nectar plant to improve biological control in Asian rice systems.

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1. Introduction

Rice accounts for more than 65% of caloric intake in the low-income countries in tropical Asia and is the most important staple food worldwide (Peng and Hardy, 2001; Zeigler and Barclay, 2008). Rice planthoppers (Delphacidae), the brown planthopper (*Nilaparvata lugens* (Stål)), white-backed planthopper (*Sogatella furcifera* (Horváth)), and small brown planthopper *Laodelphax striatellus* (Fallén)), are amongst the most destructive insect pests of rice in Asia and outbreaks have occurred frequently in recent years (Cheng, 2009; Savary et al., 2012). In China alone an average of 26.7 million hectares were affected by these species in the seasons between 2005 and 2007 (Xia, 2008). Their impact is now so severe they are considered to be substantial threats to the world food security (Lou and Cheng, 2011).

Anagrus spp. parasitoids are important egg parasitoids of planthoppers in Asia (Gurr et al., 2011). Their parasitism incidence normally reaches about 10–70% in rice fields in China where *Anagrus nilaparvatae* (Pang et Wang) dominates (Yu et al., 2001). The same species is important also in Cambodia, India and Philippines (Chandra, 1979; Kalode, 1983; Preap et al., 2001). The congeneric, *Anagrus optabilis* (Perkins) is the dominant egg parasitoid of the green slender planthopper, *Saccharosydne procerus* Matsumura, which is the key insect pest of a perennial vegetable crop *Zizania caduciflora* L. often grown by rice farmers in adjacent fields in eastern China (Lu, 2003). This is relevant to rice because *A. optabilis* also attacks eggs of rice planthoppers so, whilst able to overwinter using *S. procerus* on its perennial host plant, it can move to nearby rice fields after spring to attack rice planthoppers (Zheng et al., 2003b). This phenomenon is important in non-tropical Asian rice systems where neither brown planthopper nor white-backed planthopper are able to overwinter so are unavailable as hosts for parasitoid survival.

Rice is an annual crop so subject to high levels of disturbance from cultivation, seasonal inundation, transplanting, and harvesting as well as the abuse of pesticides and fertilizers, all of which can adversely affect natural enemies leading to low levels of biological control (Heong, 2009). Enhancement of biological control by habitat management (Landis et al., 2000) has been widely explored in many crop systems. The main goal of habitat management is to conserve natural enemies and enhance their performance by providing resources such as non-host foods which can be particularly important when hosts or prey are unavailable to natural enemies (Gurr, 2009), because foods such as nectar often have a great influence on the female parasitoid longevity, searching efficiency and parasitism (Mitsunaga et al., 2004, 2006; Rivero and Casas, 1999; Shearer and Atanassov, 2004; Jervis et al., 2004). In ecological engineering for pest management, habitat management approaches are used in a targeted manner whereby the benefits of candidate plants are evaluated to identify the right kinds of diversity to introduce into a farming system (Gurr et al., 2004). Despite the importance of rice in world agriculture and the fact that insect pests cause serious losses, surprisingly little information is available on the scope for ecological engineering to contribute to more sustainable pest management in this crop (Gurr et al., 2011). The only available study (published in Chinese) showed that longevity and parasitic ability of *A. nilaparvatae* was strongly improved by feeding from soybean flowers (Zheng et al., 2003a). Accordingly, the aim of this study was to study the behavioral and physiological response of *A. nilaparvatae* and *A. optabilis* to a range of potential nectar plant species that could be grown on the bunds surrounding rice fields. The rationale for plant selection was that each species is either a food, medicinal herb or ornamental crop of potential value as a secondary income source or a weed species that farmers could be advised to conserve when present on rice bunds.

2. Materials and methods

2.1. Plants

Seeds of the crop or medicinal herb species *Hibiscus esulentus* L. (Malvaceae), *Hibiscus coccineus* Walt. (Malvaceae), *Luffa cylindrical* [L.] Roem.) (Cucurbitaceae), *Glycine max* (L.) Merr. (Leguminosae), *Vernonia cinerea* (L.) Less. (Compositae), *Emilia sonchifolia* (L.) DC. (Compositae), *Trida procumbens* L. (Compositae), *Ipomoea nil* (Linnaeus) Roth (Convolvulaceae), *Eclipta prostrata* L. (Compositae) and the weeds *Ageratum conyzoides* L. (Compositae), *Mazus japonicus* (Thunb.) O.Kuntze. (Scrophulariaceae) and *Erigeron annuus* L. (Compositae), were collected from the Experimental Farm of Zhejiang Academy of Agricultural Sciences, in Hangzhou (30.2731° N, 120.1769° E), eastern China. Commercial seed was used of the medicinal herbs *Impatiens balsamena* L. (Balsaminaceae), *Tagetes erecta* L. (Compositae), *Tagetes patula* L. (Compositae), *Hydrangea macrophylla* (Thunb.) Ser. (Hydrangeaceae), *Cosmos sulphureus* Cav. (Compositae) (Beijing Namo Tech.-Trade Co. Ltd., Beijing) and the ornamental plants *Gazania rigens* L. (Compositae), *Portulaca grandiflora* Hook (Portulacaceae). Commercial young sprouts were used of the medicinal plant *Rosa chinensis* Jacquin (Rosaceae), and the multi-use plant *Canna indica* L. (Cannaceae) (Flower market, Hangzhou). Seeds of the crop plant *Sesamum indicum* L. (Pedaliaceae) (a landrace from Zhejiang province China) were collected from the field at Jinhua (29.0833° N, 119.6500° E). All seeds were sown in plastic pots (8 cm diameter, 6 cm height) filled with soil and thinned to two plants per plot at ten days after emergence and grown in a greenhouse (average temperature of 24.5 °C, 78% relative humidity). Plants had only natural light with day lengths ranging from 13.5–14 h.

2.2. Insects

Adults of brown planthopper were collected in rice fields of China National Rice Research Institute (CNRRI), Hangzhou, and cultured on a susceptible variety of rice (TN1) in a greenhouse with the aforementioned environmental conditions.

A colony of *A. nilaparvatae* was initiated from 150 individuals trapped by exposing potted 45–60 day old TN1 rice plants bearing brown planthopper eggs to wild parasitoids in rice fields. Plants were then held in a growth cabinet (26 ± 1°C, 70–90% relative humidity and L12:D12 lighting) and covered individually with cylinders (60 cm tall, 9.5 cm diameter) constructed from transparent mylar with a 9 × 9 cm square port in the side covered by fine nylon mesh for ventilation. The tops of cylinders were open and the whole of each cylinder covered with a black cotton sleeve, tapering at the top to an inverted glass vial. Positively phototaxic adult parasitoids emerging from host eggs in the rice plants collected in the glass vials and were individually identified to species (Yu et al., 2001). Parasitoids were then introduced into mylar cages (15 cm diameter, 40 cm height) with 45–60 day old potted TN1 rice plants with eggs and gravid females of brown planthopper. Successive generations of *A. nilaparvatae* were cultured in a climate room (26 ± 1 °C, 70–90% relative humidity and L12:D12 lighting). The same number of *A. optabilis* was sourced and cultured in a similar manner except that the initial collection was from leaves of *Z. aquatica* bearing *S. procerus* eggs.

2.3. Response of Anagrus spp. to plant volatiles

Responses of *Anagrus* spp. females to odors from different plant flowers were measured using a Y-tube olfactometer (Lou et al., 2005). The olfactometer consisted of a Y-shaped glass tube of 1 cm diameter. The base and the two arms of the Y-tube were all

10 cm in length. Each arm was connected to an odor source (a glass box, 10 cm long, 10 cm wide and 30 cm high). Odor sources were either empty or had the base covered with excised flowers of a given plant species. Flowers were picked immediately before commencing assays each day and the cut end of each was embedded into a cotton wool swab soaked in distilled water. An airstream was generated and divided in two, and each secondary airstream was led through a flow meter, a tube with activated charcoal, a humidifier bottle, and one of the odor containers. Subsequently, the two airstreams were led through the two arms of the Y-tube olfactometer at 150 ml/min. The Y-tube olfactometer was placed in a box painted white with an artificial light source consisting of a single 40 W lamp placed above the arms of the Y tube. All bioassays were done between 9:00 and 15:00 in a climate room at (26 ± 1) °C. Adult female *A. nilaparvatae* within 8 h of eclosion were allowed to acclimatize to the laboratory for 30 min before use in assays. Wasps were introduced individually into the base tube of the olfactometer and observed. A choice was recorded if the parasitoid moved to a point mid-way along the length of one side arm of the olfactometer and did not return past this point for 10 s. If a parasitoid did not make a choice within 5 min, this was recorded as no response. Parasitoid individuals were used once only. Treatments were reversed on the olfactometer arms after five parasitoids were tested. The Y-tube was replaced with a clean assembly after every ten parasitoids. Flowers were renewed and clean odor bottles used after each twenty parasitoids. A total of 40 parasitoids were used for each two-way comparison of flower odor and clean air. Glassware was cleaned using acetone and rinsed with double-distilled water then dried at 60 °C. Logistical constraints precluded testing both parasitoids against all plant species and for additional studies of all attractive plants. Sesame was selected for the more detailed studies because it was attractive to both parasitoids and use in separate field studies showed it to have an indeterminate flowering phenology such that nectar was available for two months. It also proved agronomically well suited to growing on rice bunds and popular with farmers in pilot field studies.

2.4. Effect of sesame nectar on Anagrus spp. longevity

Female parasitoids that had emerged up to 4 h previously were placed individually into 50 ml glass vials and allocated to three treatments. A flower plus water treatment used freshly collected sesame flowers kept turgid by placing the cut end within water-soaked cotton wool. Flowers were renewed every 24 h. A piece of Parafilm (ca. 1 cm^2) with a 5 μL drop of distilled water was also placed into vials and the water renewed every 24 h. A water only treatment had the water-bearing Parafilm and water-soaked cotton wool. A control treatment had neither flower nor water. Vials were closed with gauze and laid out in a fully randomized design in a climate room at 26.0 ± 1 °C, 70–90% RH 12D: 12L. Parasitoid survival was recorded at 2 h intervals until all died.

2.5. Effect of sesame nectar on Anagrus spp. parasitism

Potted rice plants bearing brown planthopper eggs were prepared as follows. A 1.5 cm diameter hole was cut in the base of plastic cups (7 cm diameter, 9 cm high). Cups were then inverted and placed over 35 day old rice plants with the top of one plant protruding through the hole of each cup. Three gravid brown planthoppers were inserted through the hole such that they were able to feed on the base of the plant inside the plastic cup. They were prevented from escaping by sealing the hole with cotton wool. After two days, the planthoppers were removed and a freshly collected sesame flower and a newly emerged male and female parasitoid introduced. The same set up without the sesame flower was used as the control. Parasitoids were removed after 24 h and the number of planthopper eggs, both parasitized and non-parasitized, were counted using a dissecting microscope. Treatments were replicated 30 times and arranged in a fully randomized design in a growth chamber maintained at 26 ± 1 °C, 70–90% RH and 12D: 12L.

2.6. Effect of sesame nectar on Anagrus spp. functional response

Potted rice plants bearing brown planthopper eggs were prepared as described above but differing densities of brown planthoppers (2, 4, 6, 8, 10 or 16 per cage) were used to give a range of host egg densities. A newly emerged male and female *A. nilaparvate* was introduced into each cup and parasitism assessed after 24 h as described above. This experiment was replicated eight times in a fully randomized design.

2.7. Statistical treatments

Olfactometer choice data and parasitism data were arcsine transformed to normalize values and means compared with compared with *t*-tests. One-way ANOVA was used to test for treatment effects on *Anagrus* spp. Longevity and the Tukey post hoc test applied. The non-parametric estimation of survival used the Kaplan–Meier analysis. Functional response data were modeled using Michael Marquardt method by Royama (1971) and Rogers (1972):

$$Np = Nt[1 - exp(-aTPt/(1 + aThNt))] \tag{1}$$

where Np is the number of hosts parasitized by each female in one day, Nt is host density, a is search effect (instantaneous attack rate), *T* is the total search period (24 h), *P* is parasitoid density, and Th is the time of processing. The coefficient of determination was represented as a fitted curve. All statistical tests were performed using SPSS. Statistical v18.0.0.

3. Results

3.1. Response of Anagrus spp. to plant volatiles

A. optabilis was significantly attracted by the volatiles from *S. indicum*, *I. balsamena*, *E. sonchifolia*, *H. coccinus*, *T. procumbens* and *H. esculentus*, but not to *V. cinerea* (Fig. 1A). In contrast, *A. nilaparvatae* appeared more selective in being attracted to only seven of the 23 plant species it was tested with (Fig. 1B). These included the first three species mentioned above, *V. cinerea* and *L. cylindrica*, *R. chinensis*, *M. japonicus*. Further, *A. nilaparvatae* was significantly repelled by *T. patula.*

3.2. Effect of sesame nectar on Anagrus spp. longevity

Adult female longevity of *A. nilaparvatae* was significantly ($df_{treatment} = 2$, $df_{total} = 170$, $F = 52.704$, $P < 0.001$) greater in the presence of flowers with mean survival over 28 h, contrasting to less than 18hr in the water treatment. For *A. optabilis* also there was a significant ($df_{treatment} = 2$, $df_{total} = 139$, $F = 114.440$, $P < 0.001$) increase in longevity in the flower treatment (Table 1). Kalpan Meyer analyses reflected these trends with some *A. nilaparvatae* surviving for up to 80 h and some *A. optabilis* for 60 h when allowed access to sesame nectar, whilst maximum survival was around half these values in other treatments (Fig. 2).

3.3. Effect of sesame nectar on Anagrus spp. parasitism

The mean number of brown planthopper eggs on the plants to which *A. nilaparvatae* and *A. optabilis* were exposed did not differ significantly ($t = -0.629$, df = 37, $P = 0.533$ and $t = -0.670$, df = 36, $P = 0.507$, respectively) between treatments (Table 2). Parasitism

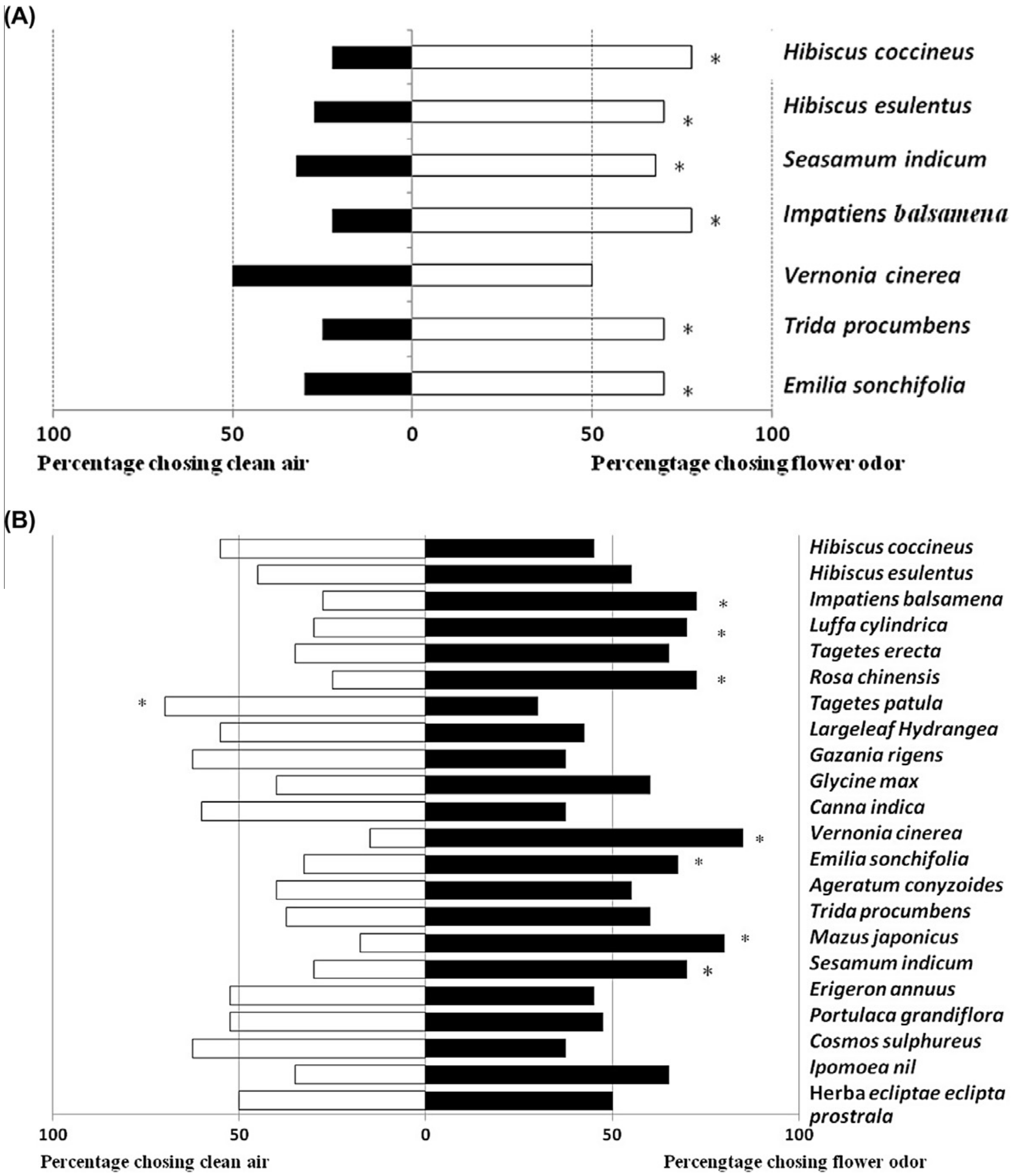

Fig. 1. Percentage of food-deprived parasitoid adults choosing flower odors or clean air in a Y-tube olfactometer. (A) *A. optabilis*; (B) *A. nilaparvate.* Asterisks indicate a significant deviation from random choice (preference or repellency) (test on two-tail binomial distribution; $P < 0.05$).

Table 1
Effect of sesame flowers on female longevity of *Anagrus* spp.

Treatment	Longevity (hr) (mean ± SE)	
	A. nilaparvatae	*A. optabilis*
Flower + water	28.64 ± 1.84a*	23.74 ± 1.84a
Water	17.95 ± 1.07b	17.61 ± 0.83b
Control	6.86 ± 0.28c	5.30 ± 0.18c

* Means within a column followed by differing letters are differ significantly at $P < 0.05$.

level by *A. nilaparvatae* in the presence of sesame flowers significantly ($t = 2.99$, df = 37, $P = 0.005$) exceeded the value for parasitoids in the water control (12.29 versus 7.68 percent). Similarly, realized parasitism for *A. optabilis* was significantly ($t = 3.490$, df = 36, $P = 0.001$) enhanced by sesame (14.12 versus 9.34 percent) (Table 2).

3.4. Effect of sesame nectar on Anagrus spp. functional response

Functional response curves for *A. nilaparvate* showed a clear effect of sesame (Fig. 3). Whilst the instantaneous attack rate of *A. nilaparvate* with sesame flowers was lower than that without flowers, processing time was much shorter with sesame ($Th = 0.012749$ d, (18.36 min)) than without ($Th = 0.021726$ d, (31.29 min)).

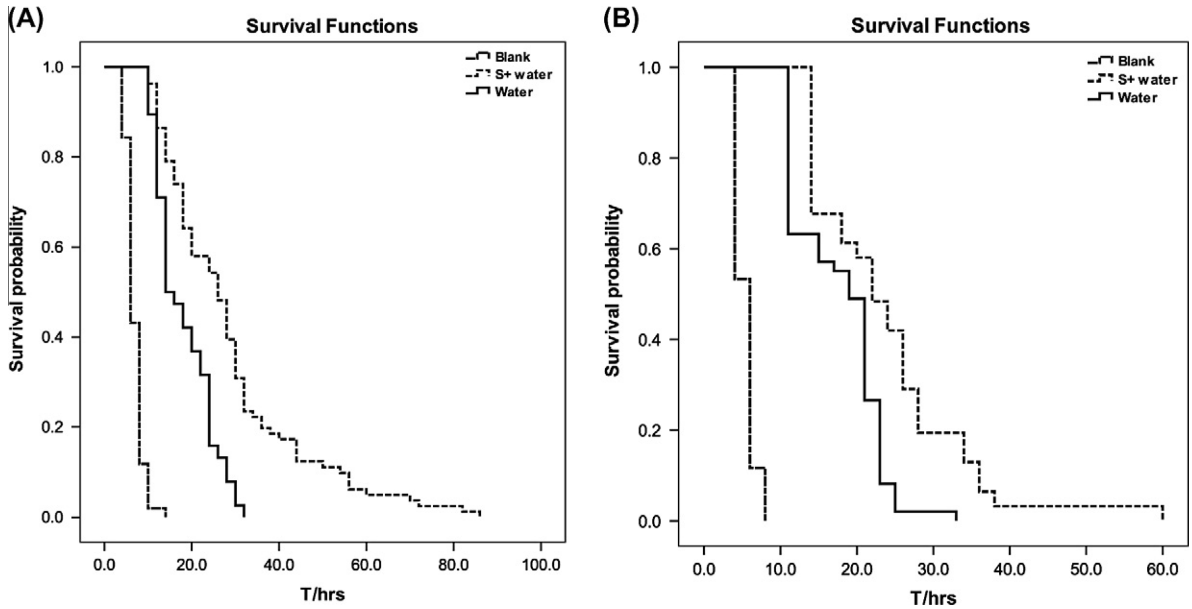

Fig. 2. Effect of sesame flowers on the survival of parasitoid adults. (A) *A. optabilis*; (B) *A. nilaparvate*.

Table 2
Effects of sesame flowers on realized parasitism of *Anagrus* spp.

Treatment	*A. nilaparvatae*		*A. optabilis*	
	Host eggs present per plant	Parasitized eggs per plant	Host eggs present per plant	Parasitized eggs per plant
Flower	174.35 ± 14.59a	21.43 ± 2.12a	168.72 ± 10.19a	23.83 ± 1.63a
Control	187.25 ± 12.79a	14.38 ± 1.05b	178.30 ± 9.99a	16.65 ± 1.29b

Values are mean ± SE. Means within a column followed by differing letters are differ significantly at $P < 0.05$.

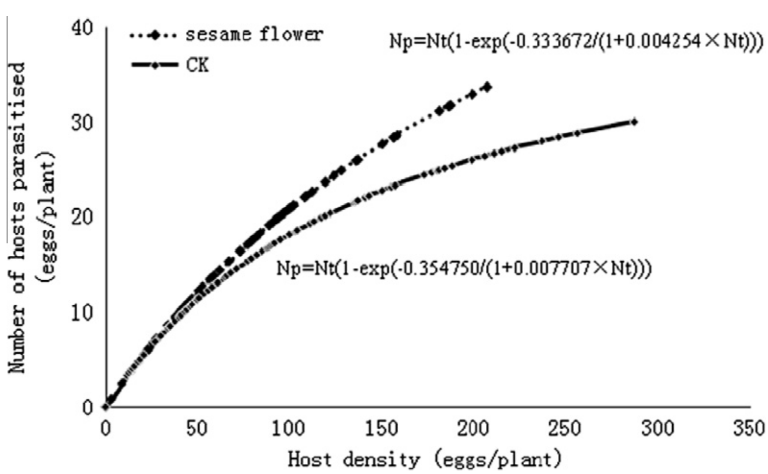

Fig. 3. The influence of sesame flower on the functional response of *A. nilaparvate*.

4. Discussion

Adult nutrition is a critical issue for the performance of parasitoids in biological control programs. The present results illustrate the fundamental importance of knowledge of the response of target parasitoids to candidate plants in ecological engineering programs. *Anagrus nilaparvate*, a species acknowledged to be an important parasitoid of brown planthopper and other planthopper pests of rice in Asia, was repelled by *T. patula* and attracted to seven of the 23 candidate plants. A second important species, *A. optabilis*, was less selective but of the six plant species to which it was attracted only three were also attractive to *A. nilaparvate*. The broader range of plants to which *A. optibalis* was attracted may reflect the wider geographical distribution and host range of this species compared with *A. nilaparvartae*. Whilst the latter species attacks hosts in the genera *Nilaparvata*, *Laodelphax*, *Sogatella* and *Toya* in China, Cambodia, India and Philippines, *A. optibalis* attacks hosts in several additional genera (*Nephotettix*, *Saccharosydne* and *Tagosodes*) and, though not reported from Cambodia or the Philippines has been reported from China, India, Japan, Thailand, Vietnam, Sri Lanka and Malaysia (Chandra, 1979; Kalode, 1983; Preap et al., 2001; Lu, 2003; Gurr et al., 2011).

The practical significance of such information in guiding nectar plant choice is recognised for plants likely to be used in Europe and North America (Wäckers and van Rijn, 2012) but the present findings constitute the first demonstration of its operation for a set of plants relevant to rice in Asian systems and the first concrete guidance on plants that are suitable for use on rice bunds. This is critical to the future use of ecological engineering in rice because identifying the right kind of diversity is more important than providing vegetation diversity *per se* (Olson and Wäckers, 2007).

On the basis of olfactometer tests, *S. indicum*, *E. sonchifolia*, and *I. balsamena* all appeared potentially suitable for supporting *A. optabilis* and *A. nilaparvate* to the extent that adults were attracted to the odors of these flowers. Factors that influence insect behavior are innate preference, previous experience and associative learning (Krugner et al., 2008). The inexperienced, food-deprived, newly-enclosed parasitic wasps used in the present study were exhibiting attraction based on innate preference alone. Though field responses could extend to other plant species on the basis of experience or learning, selection of nectar plants that are innately preferred is particularly important for *Anagrus* species that live for only 1–2 days.

Plant odor is known to play a pivotal role in nectar feeding of natural enemies (Bianchi and Wäckers, 2008). Sucrose has no odor and is not attractive to parasitoids; rather, the odor of nectars is responsible for attraction (Röse et al., 2006) though wider factors including flower shape and color are also important (Johanowicz and Mitchell, 2000). Thus, parasitoid performance is not necessarily enhanced by the presence of flowers (Wäckers and van Rijn, 2012). This was illustrated in a study in which individuals of the parasitoid *Meteorus autographae* collected from cotton fields bordered by botanically-diverse bird conservation strips were found to be starving. In contrast, parasitoids from cotton bordered by Cahaba white vetch flowers had threefold higher energy reserves (Olson and Wäckers, 2007).

Identifying flower types suitable for the enhancement of *Anagrus* in rice is, therefore, important and the olfactometer tests of attraction constitute one step towards this goal. More detailed studies of longevity and parasitism are required to confirm that attractive nectar is actually accessible within the flower, of nutritional value and results in enhanced biological control activity. *S. indicum*, sesame, was selected for such further study based on other criteria that are important in nectar plant choice (Gurr et al., 1998).

Sesame is known to flower indeterminately so provides nectar over a period of around 60 days (PZ, personal observation). Further, sesame is agronomically compatible with rice in many parts of Asia were it is considered a valuable crop. The latter factor means that its use on the bunds around rice fields to provide nectar to parasitoids would have the additional benefit of providing farmers with a secondary crop. Labor for hand sowing and harvesting is not a major constraint in many Asian countries, so sesame cultivation in the long narrow confines of bunds is practicable, indeed other crops such as soybean are commonly grown on bunds in some areas (Gurr et al., 2012). Though soybean is known from Chinese studies to benefit *A. nilaparvate* (Zheng et al., 2003a), duration of flowering is short and nectar availability may be limited. In the study by Zheng et al. (2003a,b), longevity of *A. nilaparvatae* on soybean nectar was 2.18 days. This is considerably longer that the equivalent value for sesame in the present study, a little over 28 h but we do not believe the two studies are directly comparable. Longevity of the wasps in the control treatment of Zheng et al. (2003a,b) was over one day yet less than 7 h in the present study. It is likely that experimental conditions in the two studies are responsible for these large differences. In the case of fecundity of these wasps, Zheng et al. (2003a,b) report a value of 18.11 eggs parasitized in the soy nectar treatment. This is quite close to the 21.43 recorded for sesame nectar in the present study. Notwithstanding the possible benefits of soybean nectar, that of sesame was pursued in the more detailed studies because soybean plants flower for only ca 10 days. This compares with two months for sesame (with an indeterminate flowering pattern) allowing it to make nectar available to natural enemies for a longer period of the rice growing season. Combining these factors with the fact that the flowers of sesame were attractive to adults of both parasitoid species suggests that it is likely to be superior to soybean and the other plants as a nectar source for small, short-lived wasps such as *Anagrus* spp.

Though sesame is regarded as largely self – pollinating (Kinman and Martin, 1954), it is considered by apiarists to be a nectar and pollen plant for bees (McGregor, 1976) and the flowers are known to attract various other insects (Langham, 1941). Sesame nectar contains amino acids (Bahadur et al., 1986) and the sugars sucrose, glucose and fructose in the ratio of 70.6:28.8:0.6 (Freeman et al., 1991). Sucrose-rich nectars are generally considered typical of bee-pollinated flowers (Baker and Baker, 1983) and are fed upon readily by a wide range of parasitoid hymenoptera (Wäckers, 2005).

The issue of identifying flowering plants that provide plant-derived foods for parasitic and predatory natural enemies whilst denying benefit to herbivores is well recognized (Wäckers et al., 2007; Winkler et al., 2009). The aim is to select selective food plants which maximize the benefits to natural enemies but minimize any benefits to pests (Evans et al., 2009). Whilst the nectar of sesame is likely to be accessible to most Hymenoptera, the deep corolla of sesame flowers may preclude feeding by larger adult Lepidoptera, including major pests. Further, moths' probosci may not be long enough to access nectaries that are located at the base of the long tubular flowers (Abdalsalam and Al-Shebani, 2010) though further studies are required to confirm this.

Nectar can prolong the longevity and enhance parasitic ability of many kinds of parasitic natural enemies (Kugimiya et al., 2010). When there is a food shortage, synovigenic female parasitoids may mature fewer eggs whilst proovigeneic species will reabsorb mature eggs and redirect energy into host seeking and survival (Rivero and Casas, 1999). In the case of proovigeneic parasitoids such as *Anagrus*, starvation can, therefore, reduce fecundity both directly and by reducing the chance that the individual will survive long enough to locate sufficient hosts to realize its reproductive potential. The present study provides important information to guide the current interest in ecological engineering in rice. Three plant species attractive to two important parasitoids of rice plant hoppers have been identified from a wider group of 27 candidate plants. Amongst these is sesame, a plant that significantly increased survival and release fecundity to *A. nilaparvate* and that also offers the practical advantages of long-blooming and value as a secondary crop.

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