Host preference and suitability of grasses for *Oebalus pugnax*

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Abstract

The rice stink bug, *Oebalus pugnax* (Fabricius) (Hemiptera: Pentatomidae: Carpocorini), though graminaceous, discriminates among its numerous host grass species. This could represent a feeding preference, it could be related to host suitability for growth and development. To clarify the role of host grass discrimination, two laboratory studies were conducted: (1) free-choice tests to evaluate preferences of *O. pugnax* among 11 wild host grass species found in three rice-producing counties of the central Mississippi Delta (MS, USA), and (2) no-choice tests to evaluate the impact of rice (*Oryza sativa* L.), junglerice (*Echinochloa colona* (L.) Link), and dallisgrass (*Paspalum dilatatum* Poir.) (all Poaceae), on the development of *O. pugnax* from second instar to adult. In the free-choice test, four experiments were conducted, each with four sets of host grass species and observed 1, 2, 4, 8, and 16 h after release in cages. Approximately 4 h was necessary for *O. pugnax* to settle on preferred host grasses. *Oebalus pugnax* showed a feeding preference for junglerice over all 10 other grass species. Bahiagrass, *Paspalum notatum* Fluegg, was the least preferred. The no-choice tests showed significant effect of host grass species on *O. pugnax* mean development time of nymphal survival to adults. Survival of nymphs was lower and mean development time was longer on dallisgrass compared to rice and junglerice. Knowledge of *O. pugnax* rate of growth and development on host grasses could be useful in the future development of rice integrated pest management strategies.

Introduction

The rice stink bug, *Oebalus pugnax* (Fabricius) (Hemiptera: Pentatomidae: Carpocorini), is an important pest of rice, *Oryza sativa* L. (Poaceae), in the southern USA because of its impact on grain quality and yield (Way, 2003). In general, phytophagous insects prefer to feed on host plants or plant structures that provide the greatest nutritional quality for development and reproduction (Scheirs et al., 2005; Molina & Trumper, 2012).

As a graminaceous feeder, *O. pugnax* feeds on a broad range of grass species. In a host survey of 2011 and 2012, 11 non-cultivated grass species were identified as important to *O. pugnax* in the central Mississippi Delta Region of the USA (Awuni, 2013). *Oebalus pugnax* densities were greater on some hosts than on others (Awuni, 2013). This may be a result of a feeding preference or it may come from some other basis. Regardless, the choice of host grass can impact the growth and development of both nymph and adult *O. pugnax*. Although temperature has been reported to have profound influence on the feeding performance of *O. pugnax* (Naresh & Smith, 1983; Rashid et al., 2005a), several authors have suggested that host plant availability constitutes the most important element for *O. pugnax* survival, reproduction, growth, and development (Douglas & Ingram, 1942; Ogden & Warren, 1962; Naresh & Smith, 1984; Rashid et al., 2005b).

In recent years, the dependence on herbicides to manage weeds in crop production has resulted in an increased...
occurrence of herbicide-resistant weeds (Bagavathiannan et al., 2013). In the mid-southern USA, herbicide resistance has been documented in three major host grass species of *O. pugnax*. They include Johnsongrass [*Sorghum halepense* (L.) Pers.; Riar et al. (2011)], Italian ryegrass [*Lolium multiflorum* Lam.; Dickson et al. (2011)], and *Echinochloa crus-galli* (L.) P. Beauv. (Allen et al., 1995). As a result, these grass species have become more abundant in and around agricultural areas and may influence the population dynamics of *O. pugnax* (Awuni, 2013). The availability and suitability of host grass species impact positively on the rate of growth, development, and reproduction of *O. pugnax* (McPherson & McPherson, 2000). Pentatomids such as the southern green stink bug, *Nezara viridula* (L.), and the redbanded stink bug, *Piezodorus guildinii* Westwood, have been reported to survive better and develop faster when provided early reproductive stage (*R3–R5*) soybean, *Glycine max* Merril, compared to later stages (*R6–R8*) (Fehr & Caviness, 1977; Panizzi & Alves, 1993; Molina & Trumper, 2012).

Molina & Trumper (2012) noted that food selection of herbivorous insects is influenced by chemistry of the host plant. Because plants vary in chemical composition and concentration, even within the same plant species (Schoonhoven et al., 2005), the likelihood of a particular food item being chosen if offered on an equal scale with other similar food types can vary (Johnson, 1980). The feeding activity of *O. pugnax* changes depending on the type and developmental stage of host grass species, with grasses being most attractive at the flowering and seed formation stages (Odglen & Warren, 1962). Several grass species have been identified as hosts of *O. pugnax* (Odglen & Warren, 1962). Rice has been reported as the most preferred host among the broad spectrum of cultivated and non-cultivated host grasses studied (Odglen & Warren, 1962). Narsh & Smith (1983) conducted a feeding preference study with *O. pugnax* and reported vasesgrass, *Paspalum urvillei* Steud., as the most preferred host over 10 other grasses. Rashid et al. (2005b) conducted an experiment on feeding preference, fecundity, and egg hatch of *O. pugnax* and reported that rice and barnyardgrass, *Echinochloa crus-galli* (L.) P. Beauv., were most preferred over three other food sources. Tindall et al. (2004) observed greater densities of *O. pugnax* in rice plots infested with barnyardgrass compared to infestations with other host grasses.

Knowledge of host preference among these host grasses is important to understanding the population dynamics and movement of *O. pugnax* into rice fields. Cueto et al. (2001) noted that feeding preference experiments are the most appropriate methods for assessing food suitability.

This study specifically evaluated (1) the preference of *O. pugnax* in free-choice tests on 11 host grass species identified in and around the central Mississippi Delta Region, and (2) the mean development time and survival of *O. pugnax* second instars to adults in no-choice test on rice, dallisgrass (*Paspalum dilatatum* Poir.), and junglerice [*Echinochloa colona* (L.) Link].

### Materials and methods

#### Study area and insect source

These experiments were conducted under laboratory conditions at the Delta Research and Extension Center (DREC; Stoneville, MS, USA), from May to July, 2012. *Oebalus pugnax* adults were collected from naturally occurring populations on heading wild host grasses in and around Washington County, MS, with a 38-cm-diameter sweep net (BioQuip Products, Rancho Dominguez, CA, USA). *Oebalus pugnax* were sorted after every 10 sweeps, placed in 30 × 30 × 30-cm Bugdorm cages (BioQuip), and transported to the laboratory. Prior to the test, *O. pugnax* were maintained in Bugdorm cages on a 10% (wt/vol) sugar solution for a 12-h period at 25 ± 2 °C, 60 ± 5% r.h., and L14:D10 photoperiod. Bioassays included males and females tested separately.

#### Host plants in a free-choice test

The 11 host grass species evaluated in this study were identified in a host survey during 2011 and 2012 across Washington, Bolivar, and Sunflower counties in the central Mississippi Delta (Awuni, 2013). They included: Johnsongrass, Italian ryegrass, dallisgrass, crabgrass spp. (*Digitaria* spp.), prairie cupgrass (*Eriochloa contracta* Hitchc.), bahiagrass (*Paspalum notatum* Flueggé), yellow foxtail (*Setaria pumila* (Poir.) Roem. & Schult.), southwestern cupgrass (*Eriochloa acuminata* J. Presl Kunth), broadleaf signalgrass [*Urochloa platyphilla* (Munro ex C. Wright) R.D. Webster], browntop millet [*Urochloa ramosa* (L.) Nguyen], and junglerice.

All grasses were collected from wild populations from different ecological niches within the landscape. All of the tested grasses may not survive well in flooded rice fields. However, barnyardgrass and broadleaf signalgrass have been documented as season-long pests in rice fields with potential yield loss of up to 32% in flooded rice (Smith, 1988). Host grasses were identified according to Bryson & DeFelice (2009) and with confirmation from the resident weed scientist. Host grasses were divided into four test groups based on the time of the season when panicles were available. Four separate choice tests were done based on host plant groups. Each test group consisted of three host grass species plus junglerice. Junglerice was included across all test groups as a standard control, because it was the most abundant host and supported relatively high
densities of *O. pugnax* in the 2011 and 2012 host surveys (Awuni, 2013). In addition, *Echinochloa* spp. has been reported as the most preferred over other uncultivated host grasses (Odglen & Warren, 1962; Naresh & Smith, 1984; Rashid et al., 2005b).

Test groups were: (1) junglerice, Johnsongrass, ryegrass, and dallisgrass, tested on 11 May 2012; (2) junglerice, crabgrass spp., prairie cupgrass, and bahiagrass, tested on 15 June 2012; (3) junglerice, yellow foxtail, southwestern cupgrass, and broadleaf signalgrass, tested on 26 June 2012; and (4) junglerice, crabgrass spp., dallisgrass, and brown-top millet, tested on 22 July 2012. Panicles of each host grass species were excised, prepared, and offered simultaneously in rearing cages (30 × 30 × 30 cm). The cages were made from white plastic polypropylene with good visibility on all side panels suitable for insect observation. Three of the cage side panels were made from 16 × 24-mesh plastic screens, and the fourth side panel provided easy access from a 16-cm diameter opening with a nylon sleeve. Host preference was determined by the number of individual *O. pugnax* adults that were found on a host at the time of observation. Each trial lasted 16 h, arranged in a randomized complete block design with five replicates and with repeated observations of *O. pugnax* adults at 1, 2, 4, 8, and 16 h after release. The most suitable and preferred host should retain the most *O. pugnax* adults (Velasco & Walter, 1992). Preference was expressed as number of *O. pugnax* adults found on a host at each observation time.

Bioassays were prepared by excising panicles to include 2–3 cm of the main stem and the entire panicle. Five excised panicles were mounted in a capped 37.0-ml clear Solo plastic cup (T125 0090 Solo Cup, Highland Park, IL, USA) through holes (4–5 mm diameter) created at the center of each plastic lid. Solo cups were filled with water to reduce desiccation of the plant material. Panicles were then assigned at random to one of the four corners of each cage. Five *O. pugnax* adults were placed on sterile Petri dishes (5 × 90 mm) (The Scientific Company, Denver, CO, USA) at the center of each cage as released points. Male and female *O. pugnax* adults were tested separately in five replicates, with each cage being a replicate. Cages were left undisturbed during and after each period of observation.

**Nymphal development in a no-choice test**

*Oebalus pugnax* second instars were evaluated for survival and development rate to adulthood on rice, junglerice, and dallisgrass in a no-choice test. Junglerice and dallisgrass were chosen because both were previously reported as the most preferred wild hosts for *O. pugnax* (Odglen & Warren, 1962; Naresh & Smith, 1984), and were common throughout the study area. These two host grass species were compared to rice, which is widely accepted as the most preferred host of *O. pugnax*. Second instars were used because first instars do not feed (Bowling, 1979). In addition, first instars are delicate and may suffer high mortality when disturbed. Nymphs were raised from egg masses laid within a 24-h period from a laboratory colony. The eggs were placed in a sterile Petri dish with a moist cotton ball to hatch. Eggs hatched within 4 days after incubation and left two additional days to second instars (Naresh & Smith, 1983) before being used in the experiment. Prepared panicles were mounted in plastic cups (T125 0090 Solo Cup) that contained water to minimize desiccation of the panicles. A plastic cup contained five prepared panicles of each host grass species to be tested. Plastic cups with prepared panicles were placed in 3.8-l cardboard containers (16.5 cm diameter × 16 cm deep; Ridgid Paper Tube, Wayne, NJ, USA). A fine paint brush was used to introduce batches of 15 individual *O. pugnax* second instars gently onto each host grass species that was placed at the center of each container. The nymphs were then reared to adulthood. The containers were covered with white polyester netting to prevent *O. pugnax* escape (61 × 51 cm) (BioQuip Products). A moist cotton ball was placed in a Petri dish and placed in the rearing containers to provide humidity. This experiment was arranged in a randomized complete block design in four replications with three host grass species. The same containers were used throughout the experiment, but cleaned twice weekly. The containers were placed in a rearing chamber and maintained at 25 ± 1 °C, 60 ± 5% r.h., and L14:D10 photocyte, and monitored daily to record time to adult and mortality. Any *O. pugnax* nymph that molted into an adult was removed from the test arena and the day recorded until all had developed into adults. Dead nymphs were recorded and discarded.

In both the free-choice and no-choice tests, panicles of wild grass species were collected between flowering and soft dough stages. Rice panicles were collected during the milk stage determined by pressing rice kernels between the thumb and index finger. Panicles were replaced twice weekly.

**Data analysis**

In the free-choice study, initial analysis examined the role of sex of *O. pugnax* in determining host feeding preference. Because it was not a significant factor, sex was included in the model as a random effect. All analyses were conducted by test with a repeated measure statement to determine feeding time and host preference. Two separate analyses were conducted. In the first analysis, all *O. pugnax* were included and the cage was considered one of the
possible hosts. In the second analysis, only *O. pugnax* observed on panicles were included. Each test was statistically evaluated and an overall statistical ranking was evaluated relative to junglerice. A pooled relative statistical preference rating from all experiments was then compared with junglerice on a common preference rating of all host grass species. In the free-choice analyses, post-release time (h), host grass, and their interactions were included in the model as fixed effects. The replication by *O. pugnax* sex was included as a random effect.

In the no-choice study, nymphal survival to adulthood was evaluated by expressing the number of *O. pugnax* second instars that survived to adulthood as a percentage of the initial number of second instars tested per host. The mean development time (MDT, days) of *O. pugnax* second instars reared to adulthood was evaluated using the formula proposed by Eddy & Amatobi (2003):

$$\text{MDT} = \frac{X_1Y_1 + X_2Y_2 + X_3Y_3 + \ldots + X_nY_n}{\text{Total no. nymphs that turned adult}}$$

where \(X\) = no. nymphs that turned adult per day, \(Y\) = no. days from the start of experiment, and 1, 2, and \(n\) are the first, second, and last day of experiment, respectively.

Analysis of variance (ANOVA) was applied to detect mean differences among host plants. Means and standard errors were calculated by LSMEANS and separated according to Fisher’s Protected Least Significance Difference (LSD) (\(\alpha = 0.05\)).

**Results**

**Host plant preference in free-choice test**

Preference of *O. pugnax* among the 11 host grass species was not significantly influenced by the sex*host*post-release time (h) interaction in any of the four tests: \(F_{12,160} = 0.14–0.47, P = 0.93–1.0\). The main effect of sex was not significant in the four tests: \(F_{1,160} = 0.03–2.96, P = 0.09–0.85\). Therefore, sex was moved to being a random effect in the model and the data were re-analyzed. There was a significant post-release time*host grass interaction for all four tests when *O. pugnax* adults found on cage walls were included in the analysis as a possible host: \(F_{16,80} = 2.24–7.86, all P<0.01\). Because all four tests followed the same pattern of results, the data were combined for re-analysis. There was a significant host*post-release time interaction of the combined test analysis (\(F_{3,309} = 51.14, P<0.01\)).

When *O. pugnax* found on cage walls were excluded from the final analysis, there was no significant post-release time*host grass interaction in any test: \(F_{12,64} = 0.55–1.12, P = 0.36–0.87\). The effect of post-release time on *O. pugnax* adults was significant when averaged across host grasses in test 1, as more adults were found on host grasses at higher post-release time (\(F_{4,64} = 3.02, P = 0.02\) (Table 1). The number of *O. pugnax* adults observed across post-release time was greater on junglerice compared with Johnsongrass and ryegrass (\(F_{3,16} = 3.67, P = 0.03\) (Table 1). There was no difference in overall host preference averaged across post-release time between dallisgrass and junglerice (Table 1).

In test 2, post-release time was not significant for the average number of *O. pugnax* adults observed across host grasses (\(F_{4,64} = 1.54, P = 0.20\). The average number of *O. pugnax* adults was higher on junglerice compared with bahiagrass and prairie cupgrass, but not different from the number on crabgrass (\(F_{3,16} = 4.39, P = 0.02\) (Table 2).

In test 3, the average number of *O. pugnax* adults was higher at 8 and 16 h post-release compared to 1 and 2 h (\(F_{4,64} = 5.75, P<0.01\) (Table 3). However, there was no difference among host grasses on the average number of *O. pugnax* observed across post-release times (\(F_{3,16} = 1.44, P = 0.27\).

In test 4, post-release time had no significant effect on the average number of *O. pugnax* adults observed on host grasses (\(F_{4,64} = 2.37, P = 0.06\) (Table 4). There was,

| Table 1 | Mean (± SEM) number of *Oebalus pugnax* adults observed on various grass hosts at 1–16 h after release (test 1) |
|---|---|
| **Host** | **Time of observation after release (h)** |
| | 1 | 2 | 4 | 8 | 16 | Mean |
| Junglerice | 1.3 ± 0.21 | 1.3 ± 0.26 | 1.7 ± 0.21 | 1.6 ± 0.27 | 1.6 ± 0.27 | 1.5 ± 0.20A |
| Dallisgrass | 1.1 ± 0.28 | 1.2 ± 0.33 | 1.3 ± 0.33 | 1.4 ± 0.37 | 1.4 ± 0.37 | 1.3 ± 0.20AB |
| Italian ryegrass | 0.4 ± 0.22 | 0.5 ± 0.22 | 1.1 ± 0.28 | 1.1 ± 0.28 | 1.2 ± 0.29 | 0.9 ± 0.20BC |
| Johnsongrass | 0.5 ± 0.17 | 0.7 ± 0.15 | 0.7 ± 0.26 | 0.7 ± 0.21 | 0.7 ± 0.21 | 0.7 ± 0.20C |
| Mean | 0.8 ± 0.13c | 0.9 ± 0.13bc | 1.2 ± 0.14a | 1.2 ± 0.13ab | 1.3 ± 0.13a |

Means within a row followed by the same lower case letter or within a column followed by the same uppercase letter are not significantly different (Fisher’s LSD: P>0.05).
Table 2  Mean (± SEM) number of Oebalus pugnax adults observed on various grass hosts at 1–16 h after release (test 2)

| Host                | 1       | 2       | 4       | 8       | 16      | Mean   |
|---------------------|---------|---------|---------|---------|---------|--------|
| Junglerice          | 1.2 ± 0.29 | 1.0 ± 0.33 | 1.5 ± 0.22 | 1.4 ± 0.22 | 1.7 ± 0.26 | 1.4 ± 0.16A |
| Crabgrass           | 0.8 ± 0.25 | 1.1 ± 0.38 | 1.1 ± 0.23 | 1.1 ± 0.10 | 1.2 ± 0.20 | 1.1 ± 0.16AB |
| Prairie cupgrass    | 0.4 ± 0.16 | 0.7 ± 0.26 | 1.1 ± 0.38 | 1.1 ± 0.23 | 0.9 ± 0.28 | 0.8 ± 0.16B |
| Bahiagrass          | 0.7 ± 0.15 | 0.7 ± 0.21 | 0.6 ± 0.16 | 0.7 ± 0.21 | 0.6 ± 0.27 | 0.7 ± 0.16B |
| Mean                | 0.8 ± 0.12a | 0.9 ± 0.14a | 1.1 ± 0.14a | 1.1 ± 0.14a | 1.1 ± 0.14a | 1.1 ± 0.14a |

Means within a row followed by the same lower case letter or within a column followed by the same uppercase letter are not significantly different (Fisher’s LSD: P>0.05).

Table 3  Mean (± SEM) number of Oebalus pugnax adults observed on various grass hosts at 1–16 h after release (test 3)

| Host                | 1       | 2       | 4       | 8       | 16      | Mean   |
|---------------------|---------|---------|---------|---------|---------|--------|
| Junglerice          | 0.9 ± 0.38 | 1.0 ± 0.39 | 1.1 ± 0.30 | 1.5 ± 0.40 | 1.7 ± 0.42 | 1.3 ± 0.29A |
| Southwestern cupgrass | 0.6 ± 0.22 | 0.7 ± 0.26 | 1.2 ± 0.29 | 1.0 ± 0.30 | 1.1 ± 0.28 | 0.9 ± 0.29A |
| Broadleaf signalgrass | 0.3 ± 0.15 | 0.5 ± 0.22 | 0.5 ± 0.27 | 0.9 ± 0.41 | 0.9 ± 0.41 | 0.6 ± 0.29A |
| Yellow foxtail      | 0.3 ± 0.21 | 0.5 ± 0.27 | 0.6 ± 0.34 | 0.6 ± 0.31 | 0.8 ± 0.29 | 0.6 ± 0.29A |
| Mean                | 0.5 ± 0.16d | 0.7 ± 0.17cd | 0.8 ± 0.17bc | 1.0 ± 0.17ab | 1.2 ± 0.16a | 1.2 ± 0.16a |

Means within a row followed by the same lower case letter or within a column followed by the same uppercase letter are not significantly different (Fisher’s LSD: P>0.05).

Table 4  Mean (± SEM) number of Oebalus pugnax adults observed on various grass hosts at 1–16 h after release (test 4)

| Host                | 1       | 2       | 4       | 8       | 16      | Mean   |
|---------------------|---------|---------|---------|---------|---------|--------|
| Junglerice          | 0.9 ± 0.18 | 1.3 ± 0.26 | 1.6 ± 0.34 | 1.7 ± 0.21 | 1.6 ± 0.16 | 1.4 ± 0.15A |
| Dallisgrass         | 0.7 ± 0.21 | 1.0 ± 0.26 | 1.1 ± 0.23 | 1.2 ± 0.29 | 1.1 ± 0.23 | 1.0 ± 0.15AB |
| Crabgrass           | 0.7 ± 0.21 | 0.4 ± 0.16 | 0.8 ± 0.29 | 1.0 ± 0.30 | 1.0 ± 0.26 | 0.8 ± 0.15BC |
| Browntop millet     | 0.5 ± 0.22 | 0.3 ± 0.21 | 0.5 ± 0.17 | 0.4 ± 0.16 | 0.8 ± 0.29 | 0.5 ± 0.15C |
| Mean                | 0.7 ± 0.12a | 0.8 ± 0.12a | 1.0 ± 0.12a | 1.1 ± 0.12a | 1.1 ± 0.12a | 1.1 ± 0.12a |

Means within a row followed by the same lower case letter or within a column followed by the same uppercase letter are not significantly different (Fisher’s LSD: P>0.05).

however, a significant effect of host grasses on the average number of O. pugnax adults observed across post-release times (F3,16 = 6.61, P<0.01). The number of O. pugnax adults was greater on junglerice compared with crabgrass and browntop millet, but was not different from the number on dallisgrass (Table 4). Based on O. pugnax host preference, the 10 host grasses were evaluated as a percentage of junglerice (=100%, the most preferred host) across the four tests and ranked relative to junglerice as the standard control (Table 5).

Table 5  Mean (± SEM) number of Oebalus pugnax adults observed on various grass hosts at 1–16 h after release (test 5)

| Host                | 1       | 2       | 4       | 8       | 16      | Mean   |
|---------------------|---------|---------|---------|---------|---------|--------|
| Junglerice          | 0.9 ± 0.38 | 1.0 ± 0.39 | 1.1 ± 0.30 | 1.5 ± 0.40 | 1.7 ± 0.42 | 1.3 ± 0.29A |
| Southwestern cupgrass | 0.6 ± 0.22 | 0.7 ± 0.26 | 1.2 ± 0.29 | 1.0 ± 0.30 | 1.1 ± 0.28 | 0.9 ± 0.29A |
| Broadleaf signalgrass | 0.3 ± 0.15 | 0.5 ± 0.22 | 0.5 ± 0.27 | 0.9 ± 0.41 | 0.9 ± 0.41 | 0.6 ± 0.29A |
| Yellow foxtail      | 0.3 ± 0.21 | 0.5 ± 0.27 | 0.6 ± 0.34 | 0.6 ± 0.31 | 0.8 ± 0.29 | 0.6 ± 0.29A |
| Mean                | 0.5 ± 0.16d | 0.7 ± 0.17cd | 0.8 ± 0.17bc | 1.0 ± 0.17ab | 1.2 ± 0.16a | 1.2 ± 0.16a |

Means within a row followed by the same lower case letter or within a column followed by the same uppercase letter are not significantly different (Fisher’s LSD: P>0.05).

Nymphal development in no-choice test

Survival of O. pugnax nymphs reared from second instar to adult was impacted by host grass (F2,237 = 41.19, P<0.01) (Figure 1). Oebalus pugnax nymphs survived better when reared to adults on rice compared with junglerice and dallisgrass (Figure 1). Survival was also better on junglerice than on dallisgrass. The mean developmental time of O. pugnax reared from second instars to adults was significantly shorter for nymphs reared on rice than on dallisgrass or junglerice (F2,8 = 7.60, P<0.01) (Figure 2). Development time was shorter on junglerice than on dallisgrass (Figure 2).

Discussion

Studies on feeding preference are common in the ecological literature. Compared to other pentatomids, limited host preference studies have been conducted on
O. pugnax. Naresh & Smith (1984) conducted host preference studies on O. pugnax with 11 host grasses and observed that the number of adults doubled from 1 to 6 h after release across host grasses. In this study, ca. 80% of O. pugnax adults had settled across host grasses by 4 h after release.

Researchers have cited rice as the most preferred host for O. pugnax among the cultivated and non-cultivated species for both nymphal development and adult reproduction (Webb, 1920; Bowling, 1963). Studies among wild host grasses have reported O. pugnax preference for vaseygrass (Douglas & Ingram, 1942; Naresh & Smith, 1984) or barnyardgrass (Odgen & Warren, 1962; Rashid et al., 2005b). In the choice tests in this study, there was a clear and consistent preference of adult O. pugnax for junglerice over all other wild hosts. However, vaseygrass and barnyardgrass were not tested because the grasses were either not available or were not major host species within the study area. Because barnyardgrass and junglerice are both in the Echinochloa genus, it is possible that both host grasses are similarly suitable for O. pugnax. Rice was not included in the choice tests, but survival and development on rice exceeded that on junglerice.

This study demonstrated that not all host grasses supported individuals of O. pugnax equally. Oebalus pugnax preferentially moved to some host grass species more than others. Singh et al. (2006) showed that different volatiles are produced from different host grass species resulting from O. pugnax feeding injury. This may help to explain why O. pugnax could be found in abundance on one host grass species relative to others.

The no-choice test demonstrated that rice was a more suitable host over junglerice and dallisgrass, consistent with previous observations. Nymphal survival was higher and mean development time shorter when reared on rice. Rashid et al. (2005b) reported longer mean development time of O. pugnax reared on dallisgrass compared to rice flour diet and barnyardgrass. Hamm (2011) reported shorter mean development time and greater body weight when nymphs were reared from first instars to adults on rice than on barnyardgrass or Amazon sprangletop, Leptochloa paniceoides (J. Presl) Hitchc. Aside from host plants also temperature can impact O. pugnax development. Nymphs have been reported to survive better at 30 °C when fed grain sorghum, Sorghum bicolor (L.), compared

| Host            | Test | % relative preference | Rank preference |
|-----------------|------|-----------------------|-----------------|
| Junglerice      | 1,2,3,4 | 100\(^1\)             | 1               |
| Dallgrass       | 1,4  | 77\(^1\)              | 2               |
| Ryegrass        | 1    | 76                    | 3               |
| Southwestern    | 3    | 69                    | 4               |
| Rice            | 2,4  | 63\(^1\)              | 5               |
| Crabgrass       | 2    | 53                    | 6               |
| Yellow foxtail  | 3    | 46                    | 7               |
| Broadleaf       | 3    | 46                    | 7               |
| signalgrass     | 1    | 41                    | 9               |
| Johnsongrass    | 4    | 36                    | 10              |
| Browntop millet | 4    | 35                    | 11              |

\(^1\)Average of all tests.

Table 5 Relative preference (%) and preference ranking of Oebalus pugnax among host grasses tested in four separate tests

Figure 1 Mean (+ SEM) percentage survival of Oebalus pugnax nymphs reared from second instar to adult on rice, junglerice, and dallisgrass. Means capped with different letters are significantly different (Fisher’s LSD: P<0.05).

Figure 2 Mean (+ SEM) development time of Oebalus pugnax nymphs reared from second instar to adult on rice, junglerice, and dallisgrass. Means capped with different letters are significantly different (Fisher’s LSD: P<0.05).
to rice (Naresh & Smith, 1983). In a previous experiment, development times ranged from 17 to 37 days at 21 to 29 °C, respectively (Rashid et al., 2005a). Similarly, in the current experiment the mean development times from second instar to adult at 25 ± 1 °C were 17, 18, and 20 days on rice, junglerice, and dallgrass, respectively.

Due to easy application, high efficiency, and relatively low cost compared to alternative methods, rice growers depend on herbicides application for weed control (Pingali et al., 1997). Despite these advantages, indiscriminate application of herbicides may adversely impact the environment and non-target organisms, as well as lead to resistant weeds (Johnson & Mortimer, 2005). Herbicide resistance has been reported in three major host grass species fed on by O. pugnax in the mid-southern USA where rice is primarily cultivated: Echinochloa spp., Johnsongrass, and ryegrass. The preference of O. pugnax for junglerice over other wild grasses as observed in this study, and barnyardgrass reported earlier (Rashid et al., 2005b), emphasizes the importance of Echinochloa spp. control as a key component of O. pugnax management. In Mississippi, Echinochloa spp. can be found in flooded, muddy, and warm conditions closely associated with rice fields. Echinochloa spp. at the seedling stage are not easily distinguishable from rice and, therefore, can be a challenge to rice growers in timely weed control decisions especially in broadcast seeded rice (Chauhan & Abuhgo, 2012). Preference of O. pugnax for Echinochloa spp. over other wild hosts could lead to infestation in rice fields. Most of the less-preferred host grasses grow on marginal lands away from rice fields, but Echinochloa spp. grow best in direct-seeded rice fields. Barnyardgrass or junglerice growing in and around commercial rice fields become potential sources of attraction to O. pugnax when these grasses begin to head ahead of rice. Espino et al. (2008) reported higher densities of O. pugnax sampled along 9 m rice field borders. Barnyardgrass growing in close association with rice has also been reported to increase densities of O. pugnax four-fold in rice fields (Tindall et al., 2004).

In the central Mississippi Delta, ryegrass was the most predominant host grass species during early spring that supported the survival, reproduction, and development of O. pugnax from overwintering (Awuni, 2013). Glyphosate-resistant ryegrass in the central Mississippi Delta (Bond & Eubank, 2012) could be a key component in O. pugnax management because of its role in population buildup from spring into summer.

Rice growers in the mid-south have been encouraged to approach pest problems via integrated management (IPM). The development of any IPM strategy requires grower knowledge of the life history and habitat of the target pest. For example, rice fields in close proximity to pastures, sorghum fields, et cetera, may be pre-disposed to O. pugnax infestation. Even before planting, a careful evaluation of the field environment would have to be assessed. Removal of these host grasses at early stages in and around rice production fields mechanically, physically, or by chemical means could minimize O. pugnax infestations in rice fields. Furthermore, timely herbicide and flood application to control weeds in rice production fields could prevent early attraction of O. pugnax into rice fields.

In conclusion, this study provides a hierarchical host preference of O. pugnax among the principal host grasses identified in and around the Mississippi rice production area. Managing the growth and abundance of these host grasses around rice fields may reduce O. pugnax populations, which may reduce the need for pesticide use in rice, thereby reduce pesticide resistance, and reduce yield losses and the incidence of pecky rice in commercial rice fields. Further study is recommended to examine the dispersal ability of O. pugnax and an efficient and effective strategy of herbicide use in rice, aimed at preserving the long-term mid-southern US rice production systems.

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