

# Methodology for determining susceptibility of rough rice to *Rhyzopertha dominica* and *Sitotroga cerealella*

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**Abstract** Varieties of rough rice, *Oryza sativa* (L.), were obtained from different sources in the south-central United States and evaluated for susceptibility to the lesser grain borer, *Rhyzopertha dominica* (Fab.), and the Angoumois grain moth, *Sitotroga cerealella* (Olivier), in laboratory studies. Adult *R. dominica* were fed on the rice varieties for 2 weeks, removed, and assessed for progeny production after an additional 6 weeks. *Sitotroga cerealella* susceptibility was evaluated by exposing two mating pairs of moths on a particular variety until the adults died. *Rhyzopertha dominica* parental survival, progeny production, and feeding damage by parental and progeny adults were variable, with survival ranging from 19.4 to 95 %. *Rhyzopertha dominica* parental feeding damage, progeny production, and progeny feeding damage were all correlated ( $r = 0.35\text{--}0.97$ ,  $P < 0.001$ ). Parental feeding of *R. dominica* provided access for neonate larvae to infest the rice hull. All rice varieties supported development of *S. cerealella*, and the variety Vista, which did not support growth of *R. dominica*, was one of the most susceptible varieties to *S. cerealella*. Progeny production of both

species was generally correlated, but we observed only two instances of specific correlation for any rice variety. Results show that differences in variety susceptibility to stored product insects and differential susceptibility among species are important factors to consider when developing insect pest management programs for stored rice.

**Keywords** Rice · Insects · Susceptibility · Development

## Introduction

The lesser grain borer, *Rhyzopertha dominica* (Fab.), and the Angoumois grain moth, *Sitotroga cerealella* (Olivier), are important pests of stored rough rice in the south-central United States (Brees 1960; Cogburn and Bollich 1990). Females of both pest species lay eggs on rice husks, and the neonate larvae must penetrate the husk to feed on the kernel. Historical studies show that cracks or splits in the husk, husk surface area and texture, and weak spots in the vascular bundle can affect larval entry, and, therefore, provide varieties with strong husks some level of tolerance to infestation (Cogburn 1974, 1977; Cogburn et al. 1983). Studies by Chanbang et al. (2008) correlated *R. dominica* survival from egg to adult on different rice varieties with the increased presence of cracked husks; however, Cogburn and Bollich (1990) noted that larvae of *S. cerealella* penetrated sound rice husks and suggested that environmental or biochemical factors may also influence susceptibility or tolerance.

Various techniques have been used to assess the susceptibility of rice varieties to *R. dominica* and *S. cerealella*, including direct exposure of either eggs or parental adults to grain to assess progeny development. Although adults of *R. dominica* feed on rough rice and adults of *S. cerealella*

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do not, adult exposure might be a more accurate mimic of actual conditions in which females would lay eggs directly on rice grain. Feeding damage by adult *R. dominica* might also alter assessments of susceptibility from those developed through exposure of eggs on rough rice (Kavallieratos et al. 2012).

Other than a study by Chanbang et al. (2008), which assessed rice varietal susceptibility to *R. dominica* through egg exposures, the last published study in the U.S. was by Cogburn and Bollich (1990), who evaluated resistance in hybrid rice varieties by examining progeny production of different stored product pest species. In this study, eggs of *S. cerealella* and mixed-sex adults of *R. dominica* were exposed on rice grain, and Cogburn concluded that resistance to *S. cerealella* predicted resistance to *R. dominica*; however, experiments included only a limited number of varieties, and many of the varietal assessment studies conducted in the U.S. during the 1970s and 1980s did not assess the relationship between *R. dominica* parental feeding and resulting progeny production. In addition, there are no recent studies in which adults of *S. cerealella* have been directly exposed on rough rice to assess progeny production. Therefore, the objectives of our experiments were to: (1) assess different rice varieties for susceptibility of *R. dominica* and *S. cerealella* through exposure of parental adults to grain, (2) correlate *R. dominica* progeny production and parental feeding damage, (3) correlate progeny feeding damage and progeny production for both *R. dominica* and *S. cerealella*, (4) determine if susceptibility of different rice varieties is related to feeding damage by each species, and (5) determine if rice varietal susceptibility is consistent between *R. dominica* and *S. cerealella*.

## Materials and methods

Twenty different varieties of long-grain rough rice from the 2010 crop year were obtained from university Experiment Stations in Louisiana (LA), Mississippi (MS), and Texas (TX). Several varieties were obtained from more than one state, or from two sites within a state, and are labeled accordingly (Table 1). Most of these varieties were grown commercially, but others were maintained for seed stock in limited quantities. About 1 kg of each variety was received during a 3-month period in autumn of 2010. When a particular variety arrived at the USDA-ARS Center for Grain and Animal Health Research (CGAHR) in Manhattan, KS, it was placed in cold storage at about 4 °C. Before being used in tests, a lot of about 150 g of each variety was removed from cold storage, cleaned using a #12 sieve, and tempered to 12 % moisture content (MC). Individual rice lots were tempered according to the equation:  $\{(100 - MC_{\text{Initial}})/100\} \times \text{Weight of Rice}_{\text{Initial}} = \{(100 - MC_{\text{Final}})/$

$100\} \times \text{Weight of Rice}_{\text{Final}}$ . The initial MC, initial weight, and final MC could then be used to determine final weight of rice as follows:  $\text{Weight of Rice}_{\text{Final}} = \{[(100 - MC_{\text{Initial}})/100] \times \text{Weight of Rice}_{\text{Initial}}\} / \{(100 - MC_{\text{Final}})/100\}$ . The  $\text{Weight of Rice}_{\text{Initial}}$  was subtracted from  $\text{Weight of Rice}_{\text{Final}}$  to determine amount of water to add to rice. In nearly all cases, the rice received from the various experiment stations had MC lower than 12.5 %, so adding water to the various sample lots was necessary to bring them to 12.5 % MC. This value was chosen because it is within the normal range of 12.0–12.5 % for rough rice stored in the south-central U.S. (Cogburn and Bollich 1990).

Individual replicate bioassay units for evaluations of susceptibility to *R. dominica* consisted of about 12 g of rough rice of each variety placed inside a 7-dram plastic vial. Ten mixed-sex 1- to 2-week-old adults were placed in a vial containing each of the varieties listed in Table 1. All parental adults were obtained from laboratory stock colonies that had been cultured on rough rice for about 2 years. These cultures were maintained in continual darkness in an incubator at 27 °C and 60 % RH. The vials containing the different rice varieties with parental adults were set inside a second incubator at 27 °C and 60 % RH. Parental adults were removed from the vials after 2 weeks and classified as alive or dead. The rice was sieved and the feeding damage (ground wheat plus excretions from the beetles, in µg) in each vial was weighed, then the contents were put back into the vials. The vials were returned to the incubator and held for an additional 8 weeks. Progeny adults were then counted, the rice was sieved, feeding damage weighed a second time (in mg), and the weight of adult feeding

**Table 1** Rice varieties evaluated for response to *Rhyzopertha dominica* and *Sitotroga cerealella* in the study and their U.S. state of origin

Variety	State of origin	Variety	State of origin
Carolina Select Gold	Texas (TX)	Neptune	LA
Catahoula	Louisiana (LA)	Presidio 1	TX
Charleston Gold	TX	Presidio 2	TX
Chenier	LA	Rex	MS
CI 261	LA	Rondo 1	TX
Cocodrie	TX	Rondo 2	TX
Cocodrie	LA	Sabine 1	TX
Dawn	TX	Sabine 2	TX
Dixiebelle	TX	Sierra 1	TX
Jasmine 85	TX	Sierra 2	TX
Jazzman	LA	Trenussee	LA
Mutica	TX	Vista	TX
		Wells	TX

Varieties from TX designated 1 were from rice stored in bins at the Texas A&M Experiment Station in Beaumont, TX; varieties designated 2 were from seed stocks maintained at the station

damage was subtracted from the total to obtain feeding damage produced by the progeny. Four separate replicates were done for each variety, on different dates, as described above.

Individual replicate bioassay units for evaluations of susceptibility to *S. cerealella* consisted of about 18 g of rough rice of each variety placed inside 7-dram plastic vials. The amount was increased over that used for *R. dominica* to help ensure progeny had enough rice to survive to the adult stage but leave room for parental adults to fly. These parental adults were obtained from laboratory cultures maintained on rough rice for about 1 year; all cultures were maintained inside the same incubator described for stock cultures of *R. dominica*. Two mating pairs of adults were collected from the stock cultures, placed into each vial, and allowed to remain on the rice until death. Only two mating pairs were used to avoid excessive progeny production on the rice. All vials were held for approximately 6 weeks inside the second incubator used for the study with *R. dominica*, and the vials were then frozen at  $\sim -4\text{ }^{\circ}\text{C}$  for 1 week to kill all adults. The number of adults was counted, and the original four parental adults were subtracted from the total. The rice was sieved and the feeding damage in

each vial was weighed and recorded. Five separate replicates were done for each variety, on different dates, using the procedures described above.

Data for percentage adult survival, weight of adult feeding damage (mg), number of progeny produced, and weight of progeny feeding damage (mg) were analyzed using analysis of variance (ANOVA) in version 9.1 of the Statistical Analysis System (SAS Institute 2002). Data were transformed by square root analysis, but this transformation did not affect statistical significance, hence further analysis was done on the raw data. The General Linear Models (PROC GLM) procedure was used to determine significance with varietal source as the main effect. Means, when significant, were separated using Bonferroni analysis at  $P = 0.05$  to control experiment-wise error rate. The SAS Correlation Procedure was used to determine correlation between the four *R. dominica* variables of interest.

**Results**

Survival of *R. dominica* parents on different varieties ranged from 19.4 to 95 % (Table 2), and was significantly

**Table 2** Mean  $\pm$  SE % survival of *R. dominica* adults and mean  $\pm$  SE feeding damage ( $\mu\text{g}$ ) 2 weeks post-infestation on 24 rice varieties at 27  $^{\circ}\text{C}$ , 60 % RH<sup>a</sup>

Variety	Mean $\pm$ SE % adult survival	Variety	Mean $\pm$ SE feeding damage (mg)
Jasmine	95.0 $\pm$ 5.0a	Sabine 2	48.5 $\pm$ 30.2
Charleston Gold	95.0 $\pm$ 5.0a	Rex	40.6 $\pm$ 18.6
Rex	95.0 $\pm$ 2.9a	Wells	35.9 $\pm$ 21.2
Dawn	93.3 $\pm$ 4.1ab	Dawn	27.9 $\pm$ 8.2
Wells	91.9 $\pm$ 5.3ab	Sabine 1	25.8 $\pm$ 6.9
Neptune	90.0 $\pm$ 5.8abc	Mutica	22.8 $\pm$ 13.5
Sabine 1	90.0 $\pm$ 7.1abc	Dixiebelle	22.6 $\pm$ 16.4
CI 261	88.3 $\pm$ 4.4abcd	Charleston Gold	18.0 $\pm$ 7.3
Sierra 1	87.2 $\pm$ 9.4abcd	Jasmine	16.7 $\pm$ 6.7
Mutica	85.0 $\pm$ 6.5abcd	Rondo 1	16.6 $\pm$ 5.3
Sabine 2	82.5 $\pm$ 11.1abcd	Carolina Select Gold	15.6 $\pm$ 4.8
Jazzman	75.0 $\pm$ 13.3abcd	Presidio 2	14.8 $\pm$ 2.8
Carolina Select Gold	72.5 $\pm$ 14.9abcd	Sierra 1	14.3 $\pm$ 4.3
Dixiebelle	68.1 $\pm$ 5.1abcd	CI 261	13.2 $\pm$ 1.6
Sierra 2	71.3 $\pm$ 14.4abcd	Neptune	11.3 $\pm$ 2.5
Presidio 2	67.5 $\pm$ 23.4abcd	Jazzman	10.4 $\pm$ 2.3
Trenussee	66.4 $\pm$ 14.6abcd	Presidio 1	10.3 $\pm$ 2.5
Rondo 1	61.9 $\pm$ 7.1abcd	Sierra 2	10.1 $\pm$ 2.1
Presidio 1	45.0 $\pm$ 15.0abcd	Trenussee	10.0 $\pm$ 2.1
Chenier	43.3 $\pm$ 4.1abcd	Rondo 2	8.5 $\pm$ 3.1
Cocodrie (LA)	42.3 $\pm$ 19.9abcd	Cocodrie (LA)	7.0 $\pm$ 3.2
Rondo 2	35.5 $\pm$ 19.1abcd	Chenier	5.4 $\pm$ 2.8
Cocodrie (TX)	25.0 $\pm$ 14.4bcd	Catahoula	4.9 $\pm$ 2.2
Catahoula	21.9 $\pm$ 18.7 cd	Cocodrie (TX)	3.7 $\pm$ 1.1
Vista	19.4 $\pm$ 19.4c	Vista	1.2 $\pm$ 0.3

<sup>a</sup> The model was significant for survival ( $F = 4.1$ ,  $df = 24$ , 99;  $P < 0.01$ ) but non-significant for feeding damage ( $F = 1.4$ ,  $df = 24$ , 99,  $P = 0.150$ ); means for survival followed by the same letter are not significantly different ( $P > 0.05$ , Bonferroni analysis)

greater on kernels of Jasmine (LA), Charleston Gold (TX), and Rex (MS) (all 95 %), than on Cocodrie (TX), Catahoula (LA), and Vista (TX) (25.0, 21.9, and 19.4 %, respectively). Feeding damage produced by parental adults ranged from 1.2 to 48.5 mg, but these differences were non-significant even with this wide range, possibly due to variation among replicates (Table 2). Mean *R. dominica* parent survival and feeding damage were correlated ( $r = 0.35$ ,  $P < 0.001$ ), and the variables at the lower end of the range of each variety exhibited more consistency.

Production of *R. dominica* progeny and progeny feeding damage differed significantly among varieties (Table 3); however, most varieties were similar in response, with the exception of Sabine 2 and Wells, which were more susceptible. Adult survival and adult feeding damage were weakly correlated with progeny production ( $r = 0.39$  and  $r = 0.41$ , respectively,  $P < 0.001$ ), but the correlation was much stronger between progeny produced and progeny feeding damage ( $r = 0.97$ ,  $P < 0.001$ ).

In contrast to results for *R. dominica*, progeny of *S. cerealella* were produced on all varieties (Table 4). More than 100 *S. cerealella* progeny were produced on

kernels of Vista rice even though adult *R. dominica* did not survive on that variety and produced no progeny. However, progeny production of *S. cerealella* exceeded 100 on Sierra 1 and Wells varieties as well, but both of these varieties also supported progeny of *R. dominica*. The fewest number of progeny and the lowest amount of feeding damage occurred on Cocodrie variety from LA. Overall, far more *S. cerealella* progeny were produced from fewer parental adults compared with *R. dominica*, yet mean rice damage from *S. cerealella* feeding was far less than from *R. dominica* feeding. Although mean progeny feeding damage of *R. dominica* and *S. cerealella* was correlated ( $r = 0.77$ ,  $P < 0.001$ ), *S. cerealella* results suggest that larval *S. cerealella* are far better adapted to feed on rough rice than adult *R. dominica*.

Although the overall correlation between progeny production of *R. dominica* and *S. cerealella* was small, we found two instances of significant correlation ( $P < 0.05$ ) for a particular variety. The first was a negative correlation in Cocodrie from TX ( $r = 0.95$ ), which sustained reduced production of *R. dominica* progeny but increased production of *S. cerealella* progeny. The second instance was a

**Table 3** Mean  $\pm$  SE number of *R. dominica* progeny produced and mean  $\pm$  SE progeny feeding damage (mg) 8 weeks post-infestation on 24 rice varieties at 27 °C, 60 % RH<sup>a</sup>

Variety	Mean $\pm$ SE number progeny	Variety	Mean $\pm$ SE progeny feeding damage (mg)
Sabine 2	84.5 $\pm$ 9.2a	Sabine 2	706.7 $\pm$ 125.8a
Wells	56.0 $\pm$ 9.1ab	Wells	579.7 $\pm$ 98.2ab
Rex	31.5 $\pm$ 9.9bc	Dawn	273.0 $\pm$ 135.6bc
Dawn	27.8 $\pm$ 14.7bc	Sierra 1	260.8 $\pm$ 174.9bc
Sierra 1	26.2 $\pm$ 13.9bc	Rex	251.6 $\pm$ 78.9bc
Sabine 1	20.5 $\pm$ 5.5bc	Sabine 1	170.6 $\pm$ 48.0bc
Mutica	20.5 $\pm$ 11.3bc	Carolina Select Gold	155.5 $\pm$ 54.8c
Presidio 2	19.5 $\pm$ 11.6bc	Charleston Gold	141.6 $\pm$ 59.1c
Neptune	17.2 $\pm$ 12.0bc	Presidio 2	130.6 $\pm$ 92.2c
Charleston Gold	16.5 $\pm$ 5.6bc	Neptune	129.6 $\pm$ 94.1c
Dixiebelle	16.2 $\pm$ 9.9bc	Jasmine	128.7 $\pm$ 67.0c
Carolina Select Gold	13.5 $\pm$ 4.5bc	Mutica	127.2 $\pm$ 76.1c
Jasmine	13.2 $\pm$ 5.4bc	Sierra 2	123.8 $\pm$ 92.7c
CI 261	13.0 $\pm$ 6.1bc	Dixiebelle	105.5 $\pm$ 70.6c
Sierra 2	12.2 $\pm$ 8.8c	CI 261	96.6 $\pm$ 48.0c
Rondo 2	9.7 $\pm$ 7.7c	Rondo 2	71.4 $\pm$ 62.6c
Cocodrie (LA)	4.7 $\pm$ 2.2c	Chenier	37.1 $\pm$ 24.1c
Chenier	4.7 $\pm$ 2.9c	Cocodrie (LA)	32.0 $\pm$ 16.2c
Presidio 1	4.0 $\pm$ 2.0c	Presidio 1	29.0 $\pm$ 16.0c
Rondo 1	3.2 $\pm$ 1.5c	Rondo 1	22.8 $\pm$ 12.6c
Jazzman	3.2 $\pm$ 1.4c	Trenussee	20.3 $\pm$ 14.8c
Trenussee	3.2 $\pm$ 1.7c	Jazzman	18.7 $\pm$ 9.7c
Cocodrie (TX)	0.5 $\pm$ 0.0c	Catahoula	6.1 $\pm$ 1.3c
Vista	0.0 $\pm$ 0.0c	Cocodrie (TX)	5.3 $\pm$ 3.5c
Catahoula	0.0 $\pm$ 0.0c	Vista	2.5 $\pm$ 1.8c

<sup>a</sup> The model was significant ( $P < 0.001$ ) for progeny ( $F = 6.0$ ,  $df = 24$ , 99) and progeny feeding damage ( $F = 5.3$ ,  $df = 24$ , 99); means for each variable followed by the same letter are not significantly different ( $P > 0.05$ , Bonferroni analysis). Correlation between progeny produced and progeny feeding damage ( $r = 0.97$ ,  $P < 0.001$ )

**Table 4** Mean ± SE number adult *S. cerealella* progeny and mean ± SE progeny feeding damage (mg) after approximately 6 weeks at 27 °C, 60 % RH on 24 rice varieties<sup>a</sup>

Variety	Mean ± SE number progeny	Variety	Mean ± SE progeny feeding damage (mg)
Sierra 1	109.8 ± 14.7a	Sabine 2	25.7 ± 2.5a
Wells	106.4 ± 21.8a	Sierra 2	25.2 ± 2.2ab
Vista	103.2 ± 26.4ab	Vista	23.6 ± 8.4abc
Sabine 2	94.2 ± 32.3ab	Sabine 1	17.4 ± 6.8abcd
Sierra 2	89.0 ± 11.1ab	Wells	16.2 ± 4.4abcd
Rondo 2	76.2 ± 5.0ab	Sierra 1	13.1 ± 5.5abcd
Mutica	70.8 ± 24.1ab	Presidio 1	12.7 ± 3.2abcd
Cocodrie (TX)	70.2 ± 12.7ab	Mutica	12.4 ± 4.8abcd
Jasmine	66.8 ± 2.6ab	CI 261	10.9 ± 3.0abcd
CI 261	65.8 ± 12.3ab	Rex	9.8 ± 2.6abcd
Presidio 2	54.8 ± 19.4ab	Rondo 2	9.5 ± 1.8abcd
Presidio 1	54.6 ± 19.6ab	Carolina Select Gold	9.5 ± 3.1abcd
Dawn	54.2 ± 18.1ab	Jasmine	9.4 ± 0.8abcd
Chenier	49.2 ± 2.9ab	Charleston Gold	8.7 ± 2.4abcd
Charleston Gold	48.0 ± 17.4ab	Cocodrie (TX)	8.2 ± 1.7abcd
Dixiebelle	42.8 ± 16.1ab	Dawn	8.2 ± 3.1abcd
Carolina Select Gold	42.8 ± 17.2ab	Catahoula	7.8 ± 2.6abcd
Rex	40.8 ± 17.0ab	Dixiebelle	7.2 ± 2.1abcd
Catahoula	40.0 ± 11.9ab	Chenier	6.7 ± 0.4bcd
Trenussee	38.0 ± 7.3ab	Presidio 2	6.2 ± 1.2cd
Jazzman	32.2 ± 10.0ab	Neptune	6.1 ± 1.1cd
Neptune	29.0 ± 11.5ab	Jazzman	5.5 ± 1.8 cd
Rondo 1	28.6 ± 9.4ab	Trenussee	5.5 ± 1.8 cd
Sabine 1	17.4 ± 6.8ab	Rondo 1	5.2 ± 1.5cd
Cocodrie (LA)	15.0 ± 5.2b	Cocodrie (LA)	4.2 ± 1.3d

<sup>a</sup> The model was significant ( $P < 0.001$ ) for progeny ( $F = 2.6$ ,  $df = 24$ , 100) and progeny feeding damage ( $F = 3.5$ ,  $df = 24$ , 99); means for each variable followed by the same letter are not significantly different ( $P > 0.05$ , Bonferroni analysis). Correlation between progeny and feeding damage:  $r = 0.77$ ,  $P < 0.001$

positive correlation in Jasmine ( $r = 0.96$ ). In the overall analysis, progeny feeding damage for each species was correlated when varietal sources were combined, but correlations were not significant ( $P \geq 0.05$ ) for any individual varietal source.

**Discussion**

Several varieties evaluated in this study, including the variety Dawn, were tolerant to *R. dominica* and *S. cerealella* in earlier studies (Cogburn 1974; McGaughey 1973, 1974). In the present study, however, *R. dominica* survived, fed well on Dawn kernels, and produced progeny populations that fed moderately well. Similarly, Chanbang et al. (2008) reported that Dawn was not resistant or tolerant to *R. dominica* neonate feeding and progeny development. Conversely, *S. cerealella* performed poorly on Dawn in the current study, which is consistent with results of Cogburn et al. (1980). Although previous studies (Russell and Cogburn 1977, Cogburn et al. 1983) found *R. dominica* resistance in Mutica and susceptibility in Vista, our results indicated moderate susceptibility of

Mutica and resistance in Vista, but *S. cerealella* progeny production was in the upper range for both varieties. One possible explanation for these discrepant results with earlier studies is possible variation from year to year in susceptibility of different rice varieties to stored product insects. Also, rice varieties grown in different locations show variation in susceptibility to *R. dominica* (Arthur et al. 2007), which is also seen in the current study where varieties from different sites did not necessarily show the same level of susceptibility.

In this study, parental *R. dominica* were allowed to feed on the rice husk, thereby presumably creating openings in the husk that would allow for neonate entry from any eggs laid on the husk. Feeding damage, however, was low on many varieties, and adult feeding damage for any particular variety was not usually correlated with progeny production. A number of studies have cited hull soundness and integrity to be important factors in conferring susceptibility to both *R. dominica* and *S. cerealella* (Cohen and Russell 1970; Cogburn et al. 1983; Chanbang et al. 2008; Kavallieratos et al. 2012), but other studies have suggested that characters such as chemical substances in the bran coat, percentage of bran, or nutritional characteristics of the endosperm affect

susceptibility (Cogburn 1977). Cultural practices and environmental conditions may also affect the external and internal characters of rice hulls and kernels that affect susceptibility to insect feeding, but results have not been consistent in studies investigating multiple varieties and multiple locations (Cogburn et al. 1983; Arthur et al. 2007). Several varieties used in our study were from multiple locations within and between states, and these sources varied in progeny production of both pest insect species. Although Wells rice grain was classified as tolerant to neonate larvae of *R. dominica* (Arthur et al. 2007; Chanbang et al. 2008), our results indicated Wells to be susceptible.

One aspect of insect infestation in rough rice that has received little attention is the impact of insect infestation on rice milling quality. Studies by McGaughey (1970, 1974) indicated that most stored product insects exhibit more rapid development on brown rice than on rough rice and reduced development on rice as it progresses through various levels of the milling process. The only recent study on effects of insect infestation on rice milling quality was by Arthur et al. (2012), who showed that *R. dominica* infestation can reduce milled rice yield and head rice yield. A similar study by Park et al. (2008) showed that *R. dominica* negatively affected quality parameters of milled sorghum.

Screening rice varieties for susceptibility to *R. dominica* by focusing on feeding damage and resulting progeny production is a valid technique that can be used for more extensive determinations of tolerance or susceptibility for a particular variety. Similarly, exposing adult *S. cerealella* directly on rough rice, allowing the females to oviposit, and larvae to enter the husk may offer better predictions regarding susceptibility than simply exposing eggs alone. Assessing actual feeding damage in addition to progeny production is also a valid indicator of susceptibility. Expanded studies could also include assessments of progeny production on brown rice and milled rice and how these two primary pest insect species affect rice milling quality. The results of our study also show that *S. cerealella* larvae may be able to penetrate rice husks and survive to the adult stage on a wider range of rice varieties than *R. dominica*. Infestations of *S. cerealella* have been reported in field sites away from storage areas, and a study has shown evidence that this species can infest rice in the field (Cogburn and Vick 1981). Given the reproductive potential of *S. cerealella* and the economic importance of rice in the United States, further investigations regarding the infestation potential and the economic impact of *S. cerealella* are warranted.

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