Impact of *Rhyzopertha dominica* (F.) on quality parameters of milled rice

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The impact of *Rhyzopertha dominica*, the lesser grain borer, on milling quality of Francis and Wells cultivars of rough rice was assessed for the 2007 and 2008 crop years by infesting 200-g rough rice samples harvested at moderate and low moisture contents with 0, 10, 25, 50, and 100 parental adult insects, which were removed after one week. The samples were incubated for seven weeks at either 27 or 32 °C and 60% relative humidity to determine progeny production and feeding damage (insect frass), and subsequently the milled rice yield (MRY) and head rice yield (HRY). Progeny production from each parental density level varied with variety and temperature. The number of progeny produced by the parental adults was positively correlated with feeding damage, and the feeding damage caused by the progeny was in turn negatively correlated with MRY and HRY. For both years, more progeny production and feeding damage occurred in Francis versus Wells for each of the harvest moisture contents. Results show differential susceptibility of Francis and Wells cultivars to *R. dominica*, and also provide new methodologies for evaluating effects of infestation on rice milling quality.

1. Introduction

In most countries, cereal grains such as wheat, corn, and rice form the principle sources of dietary energy. These grains are highly susceptible to infestation by stored product insects such as the lesser grain borer, *Rhyzopertha dominica* (F.) (Coleoptera: Bostrichidae) (Jood et al., 1996). This and other stored product insects can cause significant economic losses in terms of grain mass (Subramanyam and Hagstrum, 1996) and nutrient depletion (Jood et al., 1996; Gitish et al., 1975), and pose a public health risk from contamination by allergens, such as uric acid (Jood and Kapoor, 1993; Swaminathan, 1977). Insect infestations in stored grains during warm weather can also lead to undesirable taste and off-odors that can render the product inedible (Vassancharoen et al., 2008).

*Rhyzopertha dominica* is a cosmopolitan insect pest of stored raw grains. This species is well adapted to dry conditions (Emekci et al., 2004) and is generally regarded as a strong flier, hence it can easily disperse from one storage facility to another and create new infestations (Stejskal et al., 2003; Khan and Marwat, 2004). Females lay eggs on the surface of grain kernels, and upon hatching, the larva enters the kernel (Neethirajan et al., 2007; Ozkaya et al., 2009) and remains inside until maturity (Chanbang et al., 2007). The developing larva feeds inside the kernel, causing weight loss and damage to the germ and endosperm (Gundu and Wilbur, 1957; Campbell and Sinha, 1976). The mature adult emerges from the kernel by boring a large exit hole, producing what is commonly referred to as an insect-damaged kernel (IDK) in wheat. Therefore, significant physical damage and weight loss result from internal and external feeding by larvae and mature adults, respectively (Evans, 1981).

Rice is usually stored as rough rice, and thus hulls may offer some protection from *R. dominica* (Chanbang et al., 2008). Hull thickness may discourage boring but a break in the hull, which can be caused by growing conditions, handling, and other cultural practices, provide an access point for the neonate larvae. Hulls with splits or cracks were more susceptible to *R. dominica* larvae than those with intact hulls (Chanbang et al., 2008). In this particular test, Wells cultivar had fewer cracked hulls and supported less progeny development compared to Francis cultivar.

In addition to cracked hulls, kernel fissuring raises concerns with regards to internal feeders such as *R. dominica*. Fissures create weak areas that could offer *R. dominica* larvae easy access to germ and endosperm. Numerous studies have determined pre-drying causes of rice kernel fissuring; environmental conditions such as rain can cause kernel fissuring, especially on late harvest dates when the moisture content (MC) of rice is low (Juliano, 1981; Cogburn et al., 1983; Chen, 1983; Siebenmorgen and Jindal, 1986; Siebenmorgen et al., 1992; Lan and Kunze, 1996). Fissuring can thus lead to increased feeding damage that can impact milling yield and grain quality.
In a recent test, Park et al. (2008) showed that R. dominica had a negative impact on characteristics used to assess quality of milled sorghum. Currently, there is little information published concerning the impact of R. dominica on rice milling yields. The purpose of this study was to examine progeny production and development of R. dominica on Francis and Wells with “moderate” and “low” harvest MC. The specific objectives were to determine: 1) if parental population levels of R. dominica on the two cultivars could be used to assess effects on milling quality, 2) if progeny production could be correlated with whole rice yield and percentage head rice yield (HRY), and 3) assess differences between cultivars and harvest moisture contents.

2. Materials and methods

2.1. 2007 crop year

Francis and Wells, which were combine-harvested from Stuttgart, Arkansas, in the fall of 2007, were used for this study. Francis was harvested at 15.7 and 13.8% MC (moderate and low) respectively and Wells was harvested at 16.8 and 13.8% MC (moderate and low). Harvest MC was varied to produce differences in kernel fissuring and milling quality. All four lots were cleaned (MC2 Kicker Grain Tester, Mid-Continent Industries, Inc., Newton, KS, USA) immediately after harvest to remove immature kernels and foreign material and then dried to approximately 12.3% MC on screens held in an environment where temperature and relative humidity (r.h.) were maintained by an air control unit (Model AA-558, Parameter Generation & Control, Inc., Black Mountain, NC, USA) at 25 °C and 56% r.h., respectively. The rice was transported to the USDA Center for Grain and Animal Health Research (CGARH), Manhattan, Kansas, where it was held in cold storage at −10 °C until used for testing.

Either 0, 10, 25, 50, or 100 1–2-week-old adult R. dominica were placed in 200-g rough rice samples from each harvest MC lot, and held in 0.475-L glass jars. For each cultivar, samples were held in incubators (I-30 NL, Percival Scientific Inc., Perry, IA, USA) and maintained at either 27 or 32 °C and 60% r.h., giving a total of 40 jars per experiment (5 parental density levels × 2 temperatures × 2 moisture contents × 2 cultivars). These differing levels of parental adults were used to ensure sufficient progeny production to cause feeding damage to the rough rice. The temperatures were chosen because previous studies showed potentially greater progeny production at 32 °C compared to 27 °C (Park et al., 2008). The parental generation of adults was allowed to remain on the rice for one week, and then the adults were removed. The amount of feeding damage (insect frass) from the parental adults was weighed and put back into the jars, which were returned to the incubators. The rice was then held for an additional seven weeks, at which time it was removed, the adult progeny were sieved and counted, and the insect frass was weighed and returned to the jars. The rice was then frozen for one week at about −10 °C to kill any internal infestation. Five separate replicate experiments, each prepared as described above, were set up on 7 July, 23 July, 30 July, 6 August, and 8 August of 2008. Hence, these replicates were analyzed as blocks.

All samples of both cultivars for each experimental unit were removed from the jars, put into individual plastic bags, and shipped to the Food Science Department at the University of Arkansas where milling quality was assessed using 150 g rough rice samples from the original lot of 200 g. The 150 g samples were dehulled (THU 35A, Satake Engineering Co., Ltd., Tokyo, Japan), milled (McGill #2, Rapsco, Brookshire, TX, USA) for 30 s, and aspirated (South Dakota Seed Blower, Seedboro, IL, USA). The mass of milled rice was divided by the original mass of rough rice (150 g) to calculate milled rice yield (MRY). Head rice was separated from broken kernels using a double-tray sizing machine (Grainman, Crian Machinery MFG, Miami, FL, USA) and HRY calculated as the mass percentage of rough rice remaining as head rice. Head rice is defined as milled kernels having length at least three-fourths of the original kernel length.

Data were analyzed using the Statistical Analysis System (SAS, 2007) with parental density and cultivar as treatment effects and HRY as the dependent variable. Analyses were conducted using the General Linear Models Procedure (GLM) which accounted for all main effects and all interactions, in this case contributing 39 degrees of freedom from the total of 199. Each sample was also used to determine the relationship between progeny production, feeding damage, and milling yield parameters, as affected by cultivar differences. Progeny production, frass weight, and milling quality parameters were analyzed by correlating these variables in a series of comparisons using the Correlation Procedure of SAS (Proc CORR) and Table Curve 2-D 5.1 software (Golden Software, Golden CO, USA), which estimates the R^2 of a curve-fit line and the maximum R^2 of any model that could be fitted to the dataset. The correlations include the data for the replicates where no parental R. dominica were added to the 200-g rice samples.

Fig. 1. Box plots showing progeny production (y-axis) at each parental density level (x-axis) for Francis and Wells cultivar rice at 16.8% harvest moisture content (moderate MC, A and B), and Francis and Wells at 13.8% moisture content (low MC, C and D) for the crop year 2007. The solid line in each box is the mean, the dashed line is the median, and the upper and lower bars are the extreme values above the 90% percentile and below the 10% percentile, respectively.
2.2. 2008 crop year

Francis and Wells cultivars were obtained for a second year from the Department of Food Science at the University of Arkansas, Fayetteville, AR. Francis cultivar had been harvested at 15.0 and 13.8% MC, while Wells was harvested at 16.8 and 13.8% MC. Grain were dried to a 12.3% MC, transported to USDA-ARS-CGAHR, and held in cold storage at –10 °C until used for the test. Procedures for infesting the rice with *R. dominica*, removal of parental adults, and measurement of variables were as described above. The rice was sampled and prepared as described above for the 2007 crop year and again a total of five separate replicate experiments were set up, on 18 February, 13 April, 26 August, 23 September, and 30 September 2009. Upon completion of the insect bioassays, the rice was sent to the University of Arkansas for milling quality analysis and statistical analysis was conducted as described for the 2007 crop year.

3. Results

3.1. 2007 crop year

Progeny production increased with increasing parental density (*F* = 24.6, df = 4, 160, *P* < 0.01), with a significantly greater number when rice was held at 27 °C (*F* = 9.8, df = 1, 160, *P* < 0.01). However, a contrast of individual means showed that the temperature effect was only significant for the parental density level of 100 for each of the two cultivars (*P* < 0.05). The lack of significance was due to progeny production being highly variable and not closely associated with parental density levels (Fig. 1A–D).

As the parental *R. dominica* were only present on the rice for one week, the feeding damage (insect frass, ground rice, etc.) collected 7 weeks after the parental adults were removed was almost entirely caused by the developing progeny. The number of progeny adults, feeding damage, the amount of whole rice obtained from the experimental units, and the % HRY were all significantly correlated with each other (*P* < 0.01, Proc CORR in SAS). As the number of progeny increased, feeding damage increased, with more feeding damage in Francis than in Wells at the moderate harvest MC (Fig. 2A and B) and at the low harvest MC (Fig. 2C and D).

As feeding damage increased, milled rice decreased (Fig. 3). Because there was more progeny and feeding damage in Francis than in Wells, there was less milled rice in Francis than in Wells at the moderate MC (Fig. 3A and B, respectively) and at the low harvest MC (Fig. 3C and D, respectively). Correspondingly, the % HRY decreased as feeding damage increased (Fig. 4), with a greater range of loss for Francis than for Wells at both the moderate harvest MC (A and B,

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**Fig. 2.** Correlations between *R. dominica* progeny (x-axis) and feeding damage (insect frass, ground kernel and hull material; y-axis) for Francis and Wells cultivar rice at the moderate MC (A and B) and at the low MC (C and D) for the crop year 2007. The *R*² is given for the calculated equation for each graph, and the max *R*² is the maximum *R*² of any equation that could be fitted to the dataset.

**Fig. 3.** Correlations between feeding damage (x-axis) and amount of whole rice obtained from a 150-g sample (y-axis) from the 200-g experimental units of Francis and Wells cultivar rice at the moderate MC (A and B) and at the low MC (C and D) for the crop year 2007. The *R*² is given for the calculated equation for each graph, and the max *R*² is the maximum *R*² of any equation that could be fitted to the dataset.
respectively) and the low harvest MC (C and D, respectively). However, the % HRY was low for Wells at the low harvest MC (Fig. 4D), which could have been caused by additional factors other than the feeding damage from *R. dominica*.

### 3.2. 2008 crop year

Progeny production increased with increasing parental density ($F = 71.3$, df = 4, 160, $P < 0.01$) and was greater at 32°C than at 27°C ($F = 10.2$, df = 1, 160, $P < 0.01$). There was no temperature effect for any parental density level or any difference between cultivars at any parental density level ($P > 0.05$). Progeny increased slightly with parental density for Francis at the moderate MC, but was inconsistent for Wells (Fig. 5B). There was a pattern of increase in progeny production for Francis at the low MC (Fig. 5C), but not for Wells (Fig. 5D). Furthermore, progeny production was very low on Wells at the low MC regardless of parental density. As with the 2007 experiment, parental density was not a useful predictor of *R. dominica* impact on rice milling quality.

The number of progeny adults, feeding damage, the amount of whole rice obtained from the experimental units, and the % HRY were all significantly correlated with each other ($P < 0.01$, Proc CORR in SAS). As progeny increased, feeding damage increased, with more feeding damage in Francis than in Wells cultivars at the moderate harvest MC (Fig. 6A and B) and at the low harvest MC (Fig. 6C and D). Progeny production and feeding damage were very low on Wells with the low MC.

As feeding damage increased, milled rice yield decreased (Fig. 7), similar to results from the 2007 experiment. The decline in yield with increasing feeding damage followed the same general pattern for Francis and Wells at the moderate MC (A and B), but at the low MC the yield was generally below 105 g for Francis and occasionally was as low as 95 g (C), while in Wells yield was always above 105 g (D). The % HRY reflected this impact of feeding damage (Fig. 8).

### 4. Discussion

The results of our study indicate a greater susceptibility of Francis than Wells to *R. dominica*, which was consistent for both crop years. Francis had more cracked hulls than Wells, which provided access for neonate larvae to enter the husk (Chanbang et al., 2008; Kavallieratos et al., in press). It is possible that nutritional differences in the kernels...
for the two cultivars accounted for greater progeny production and hence greater feeding damage. Chanbang et al. (2008) used rice from the 2004 crop, while Kavallieratos et al. (in press) used rice from the 2008 crop of this study.

The inconsistent relationship between parental density and progeny production, and the high variability within and between each parental density level, precludes the use of the parental density as a determinant of milling quality effects. The variation in progeny production could partially be explained by the fact that the parental adults were only on the rice for one week. One-week-old mixed-sex adults were used for the parental exposures, and any variation in female fecundity or number of females in the mix could have affected progeny production. However, the number of cracked husks was perhaps the more limiting factor in progeny production, which may explain why progeny production did not appreciably increase with increasing parental density levels. Regardless, it is clear that *R. dominica* progeny developing inside the kernels caused the feeding damage, which in turn affected milled rice yield and head rice yield.

Linking *R. dominica* with losses in milling quality is difficult because of the multiplicity of other factors that affect the rice kernel. Variations in kernel moisture content may affect kernel fissuring, as rice at low MC can fissure when exposed to increasing r.h. (Chen, 1983; Siebenmorgen and Jindal, 1986; Lan and Kunze, 1996; Bautista and Siebenmorgen, 2005). Wells and Francis harvested at low MCs had lower milling quality than samples harvested at moderate MCs, which is related to kernel fissuring (Siebenmorgen et al., 2007). Hence, this increased tendency for fissuring could partially explain the greater progeny production of *R. dominica* on Francis at the lower MC than at the moderate MC because the fissuring might lead to more kernel feeding. However, this does not explain why a similar result did not occur for Wells. In fact, the opposite occurred, which indicates nutritional factors within the kernel may also affect susceptibility of fissured and non-fissured rice kernels to *R. dominica*. Also, it is important to distinguish between husk fissuring, which affects access of *R. dominica* to the kernel inside the husk, and kernel fissuring, which may affect insect feeding.

Correlations between feeding damage and milling quality parameters would seem to be a useful method for assessing impacts of *R. dominica* on rice quality. A direct relationship exists between milling quality and progeny production from a parental generation, and it is important to note that in our test, there was very little feeding damage from the parental adults because they were only left on the rice for a week. Perhaps an alternative method of determining impacts of *R. dominica* on rice milling quality would be to infest
samples with a single density, and then allowing those insects to remain on the rice until the F1 progeny have emerged.

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References


Fig. 8. Correlations between feeding damage (x-axis) and percentage head rice yield (% HRY) from a 150-g sample (y-axis) from the 200-g experimental units of Francis and Wells cultivar rice at the moderate MC (A and B) and at the low MC (C and D) for the crop year 2008. The R² is given for the calculated equation for each graph, and the max R² is the maximum R² of any equation that could be fitted to the dataset.