Use of a Web-Based Model for Aeration Management in Stored Rough Rice

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ABSTRACT A web-based model was used to simulate the impact of aeration on population growth of the lesser grain borer, *Rhyzopertha dominica* (F.), and the rice weevil, *Sitophilus oryzae* (L.), in stored rough rice, *Oryza sativa* L., at Beaumont, TX. Simulations were run for each of 10 yr with 1 August as the start date; 31 December as the end date; beginning populations of 2.5 adults per metric ton (1,000 kg); starting grain temperatures of 29.4, 32.2, and 35.0°C; and aeration airflow rates of 0.27, 0.79, and 1.40 m^3/min/metric ton of rice. In the absence of aeration, populations of both species increased exponentially, with maximum production of *R. dominica* and *S. oryzae* at starting grain temperatures of 35.0 and 32.2°C, respectively. Final predicted populations of *R. dominica* on 31 December from grain starting temperatures of 29.4, 32.2, and 35.0°C were 5,465, 6,848, and 11,855 per ton, respectively; final predicted populations of *S. oryzae* were 13,288, 21,252 and 4,355, respectively. Aeration led to a reduction in grain temperature and a decrease in pest populations, regardless of starting grain temperature or aeration airflow rates. Predicted populations of *R. dominica* on 31 December ranged from 12 to 63 adults per ton at all grain starting temperatures and airflow rates; populations of *S. oryzae* on 31 December ranged from 108 to 193 adults per ton at all grain starting temperatures and airflow rates. The predicted population levels in aerated rice represented at least a 98% reduction compared with unaerated rice. Results show the utility of the web-based model and how the various model inputs can help define broader patterns of insect control in rice stored in the south central United States.

KEY WORDS rice, storage, aeration, modeling, insects

The lesser grain borer, *Rhyzopertha dominica* (F), and the rice weevil, *Sitophilus oryzae* (L.), are cosmopolitan insect pests of stored grains. Both species feed internally on the grain kernel and as such are considered primary pests because they damage whole grains. A variety of strategies can be used as part of management programs for these and other stored grain insects (Hagstrum et al. 1999), including aeration that uses ambient air at low airflow rates to cool stored grain and limit insect population development. Typical airflow rates used for aeration of stored wheat, *Triticum aestivum* L., in the southern plains of the United States range from 0.07 to 0.42 m^3/min/metric ton (1,000 kg) (Arthur and Casada 2010). These rates are far lower than those used for grain drying, with a range from 1.4 to 14 m^3/min/metric ton (Harner and Hagstrum 1990).

The optimum temperature for the development of most stored grain insects is between 24.0 and 32.0°C, whereas the lower developmental threshold is ≈15.0°C (Howe 1965, Fields 1992). Aeration can be accomplished manually through continuous airflow or by the use of automatic controllers. Simple controllers activate the aeration fan(s) when outside temperatures drop below set levels, whereas more complex controllers measure internal temperature at specified locations in the grain mass and ambient temperature outside the bins and are activated by comparing ambient and internal grain mass temperature. There are several modeling simulation studies that predict the impact of aeration on insect populations in corn, *Zea mays* L., stored in the United States (Maier et al. 1996; Arthur et al. 1998, 2001; Throne and Arbogast 2010) and in wheat stored in the United States (Flinn et al. 1997, Arthur and Flinn 2000). Field studies also have been conducted with aeration on corn (Arthur and Throne 1994) and wheat (Reed and Harner 1998a,b; Casada et al. 2002; Flinn et al. 2004; Arthur and Casada 2005, 2010). However, only a limited amount of research has been conducted using aeration to manage rice stored in the United States, with the exception of a study by Arthur and Siebenmorgen (2005) that described how historical weather data could be used to determine when rice stored in Arkansas could be

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cooled through the use of aeration, and two field trials comparing manual versus automatic aeration (Ranali et al. 2002, Arthur et al. 2008).

Expert systems have been developed to manage insect pest populations in wheat stored on-farm and in commercial elevators (Flinn and Hagstrum 1990, Flinn et al. 2007). Recently, a web-based expert system was developed for management of stored rice, which integrates a bin cooling model with population models for *R. dominica* and *S. oryzae* (Yang et al. 2004). This model allows for direct incorporation of weather data and configuration of several input variables, including initial grain temperature and insect population density, storage time and duration, aeration airflow rate or fan type, and bin dimensions. This model was used to 1) predict population development of *R. dominica* and *S. oryzae* on unaerated rough rice at different initial storage temperatures, 2) evaluate the effects of ambient aeration at several airflow rates on population development of both species, 3) determine whether the patterns shown by the model were consistent with available data for insect pest management in stored rough rice, and 4) define model inputs that could be used to develop predictions regarding impacts of aeration on rough rice stored in the south central United States. The site chosen for the simulations was Beaumont, TX, a warm humid region of the United States that represents a high-risk area for rice storage.

Materials and Methods

The web-based storage rice management program is accessible to any user at http://beaumont.tamu.edu/RiceSSWeb. For the purposes of this study, the bin dimensions were fixed at 7.7 m in height and 5.5 m in diameter, or a volume of 10 metric tons (10,000 kg). The model inputs were starting grain temperatures of 29.4, 32.2, and 35.0°C; with either no aeration or aeration airflow rates of 0.27, 0.79, and 1.40 m^3/min/metric ton (0.2, 0.5, and 1.0 CFM/bushel of rice, 45 lb), and a starting date for rice storage of 1 August and an ending date of 31 December. Grain moisture content was held constant at 13%. Simulations were run separately for each species, assuming an infestation of 2.5 adults per metric ton that occurred 1 d after the rice was stored. The output variables reported herein were average temperature of the stored rice and the average number of adult insects per metric ton. Aeration is automatically triggered when ambient temperature is below the average grain temperature and stopped when it reaches the target temperature.

For the scenario with unaerated rough rice, simulations were run for each of the years 1998–2007 by using daily high and low temperature for Beaumont, TX, obtained from NNDC Climate Data Online (http://www7.ncdc.noaa.gov/CDO/cdo). The weather data were dynamically linked and incorporated into the program. Predicted grain temperature and adult density of each species for each year were then averaged, using the Means Procedure of the Statistical Analysis system (SAS Institute 2007). The same methods were followed for the simulations with aerated rice, except at each temperature separate simulations were run for each of the three specified airflow rates. Results were graphed using SigmaPlot, version 11 (SPSS Inc., Chicago, IL).

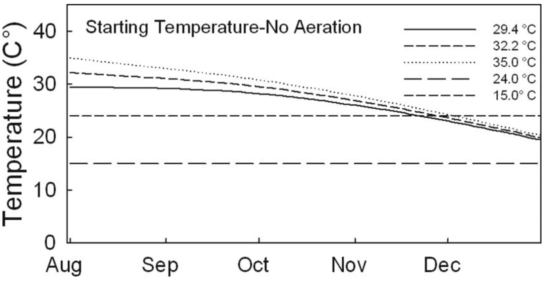

Fig. 1. Predicted temperature of rough rice stored in Beaumont, TX from 1 August to 31 December, with starting grain temperatures of 29.4, 32.2, and 35.0°C. The dimensions of the storage bin were set at 7.7 m in height and 5.5 m in diameter, which can hold ≈10 metric tons of rough rice. The dashed line at 24.0°C represents the approximate lower limit for maximum population growth of stored grain insects; the dashed line at 15°C represents the approximate lower developmental limit.

Results

In the absence of aeration, predicted grain temperatures for rice stored in Beaumont, TX, were within the optimum range for insect development during the entire storage period, at each of the three starting temperatures (Fig. 1). Furthermore, predicted grain temperature never reached 15°C, the lower developmental threshold for most stored grain insects. Predicted populations of *R. dominica* increased with increasing starting grain temperature, and at each temperature populations increased exponentially during midautumn and were still increasing at the end of the storage period (Fig. 2A). Predicted populations of *S. oryzae* increased as temperature increased from 29.4 to 32.2°C but declined as starting grain temperature increased from 32.2 to 35.0°C (Fig. 2B). The predicted populations of *S. oryzae* were greater than those for *R. dominica* at 29.4 and 32.2°C but not at 35.0°C, which is consistent with the biology and ecology of these species.

Model predictions show that aeration at all three airflow rates gradually cooled the rice at starting grain temperature of 29.4°C, with little difference among the three rates (Fig. 3A). The predicted temperature was below the optimum developmental threshold of 24.0°C by late September and below the minimum developmental threshold of 15.0°C by late October. When starting grain temperature was increased to 32.2°C, aeration immediately cooled the grain, but there was little difference in the time required to reach the threshold temperature for optimum development and the minimum developmental threshold temperature (Fig. 3B). At the final starting grain temperature of 35.0°C (Fig. 3C), the rice was again immediately cooled with the same predicted patterns.

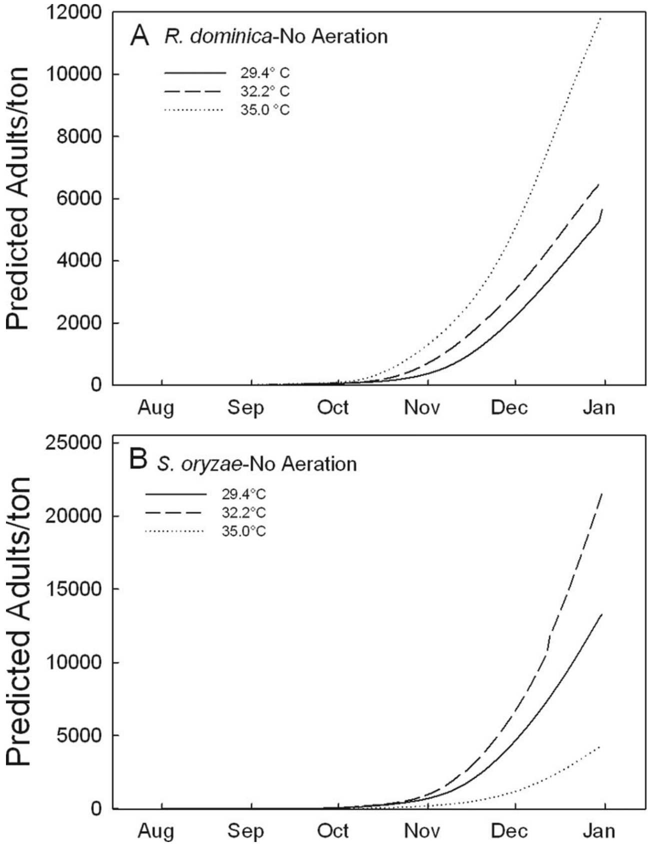

Fig. 2. Predicted populations of adult *R. dominica* (A) and adult *S. oryzae* (B) in unaerated rough rice stored in Beaumont, TX, with starting grain temperatures of 29.4, 32.2, and 35.0°C. Storage time, bin dimensions, and capacity were as described for Fig. 1, and the starting insect populations were 2.5 adults per metric ton for both species.

At the starting grain temperature of 29.4°C, predicted populations of *R. dominica* decreased by two-fold as aeration increased from 0.79 to and 1.4 m^3/min/ton (Fig. 4A). However, as the starting grain temperatures increased to 32.2°C (Fig. 4B) and 35.0°C (Fig. 4C) the same predicted level of population decrease did not occur with increasing aeration airflow rate. Regardless of starting grain temperature or aeration airflow rate, the predicted levels of *R. dominca* in aerated rice did not exceed 75 adults per ton on 31 December, far less than the range of 5,465–11,855 adults per metric ton in unaerated rice.

Aeration had similar predicted impacts on populations of *S. oryzae* in rough rice, although the patterns were slightly different. At the starting grain temperature of 29.4°C, increasing the aeration rate from 0.27 to 0.79 m^3/min/ton resulted in a two-fold population decrease, but in contrast to *R. dominica,* there was only a slight decrease as aeration increased from 0.79 to 1.4 m^3/min/ton (Fig. 5A). As the starting grain temperature increased first to 32.2°C (Fig. 5B) and then to 35.0°C (Fig. 5C), the optimal aeration rate was 0.79 m^3/min/ton. These results contrasted with those for *R. dominica,* where the optimum airflow rate was 1.4 m^3/min/ton. Predicted populations of *S. oryzae* in aerated rice on 31 December did not exceed 200 adults per metric ton in aerated rice, compared with 4,355–13,288 adults per ton in unaerated rice.

Discussion

The simulation model developed for *R. dominica* and *S. oryzae* postulates exponential populations and does not incorporate a limiting factor, similar to other models predicting insect pest populations in stored grains (Arthur et al. 1998, 2001; Flinn et al. 2007; Throne and Arbogast 2010). These models are often validated using data generated from laboratory studies, as does ours (Yang et al. 2004). The value of these models may lie more in their ability to depict overall patterns of population development at different conditions rather than the actual population densities. They describe the processes inherent in the system, and the patterns shown by the results of our simulations are consistent with other models that describe temperatures of aerated and unaerated stored grain and associated insect population development (Arthur et al. 1998, 2001, Arthur and Flinn 2000). The model also shows increased population growth and development of *R. dominica* as temperatures increase

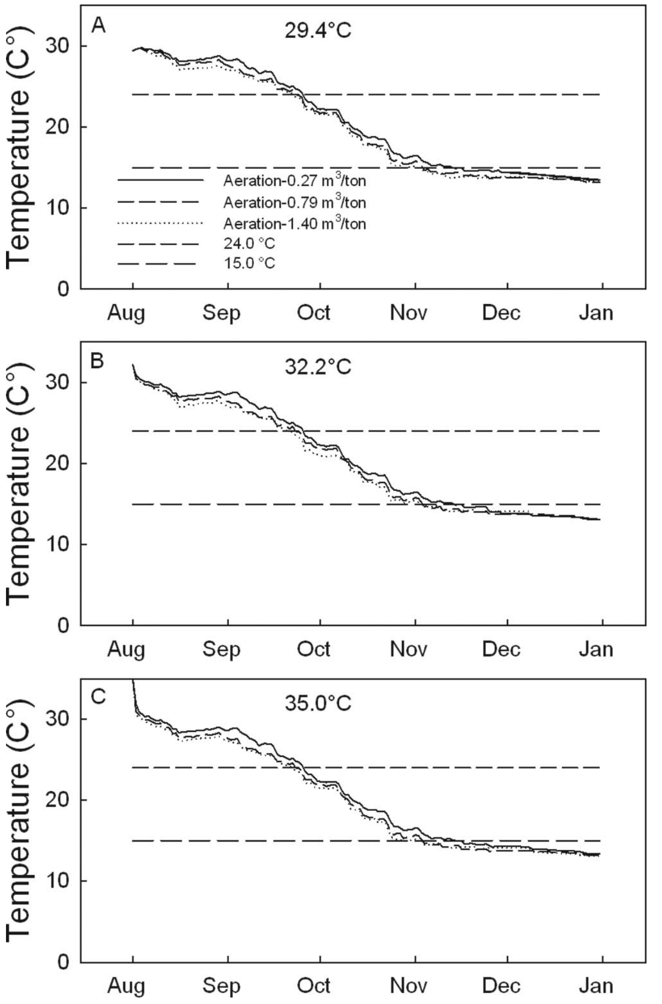

Fig. 3. Predicted temperature of aerated of rough rice stored in Beaumont, TX, from 1 August to 31 December, with starting grain temperatures of 29.4 (A), 32.2 (B), and 35.0°C (C). Storage time, bin dimensions, capacity, and starting insect populations were as described for Figs. 1 and 2; aeration airflow rates were 0.27, 0.79, and 1.4 m^3/min/metric ton.

but the reverse for *S. oryzae*, which is consistent with results from previous studies that show greater reproduction of *R. dominica* at 32 versus 27°C (Vardeman et al. 2006, Chanbang et al. 2007), and less reproduction of *S. oryzae* at 32 versus 27°C (Arthur 2004).

Our simulations clearly show automatic aeration could be used to limit populations of *R. dominica* and *S. oryzae* in south central Texas, an area where rice is harvested and stored as early as August (Wilson et al. 2010). Harvest and storage of corn in this area of the United States also can occur in August, and Arthur et al. (1998) showed a dramatic reduction in predicted populations of *Sitophilus zeamais* Motschulsky, the maize weevil, by using similar aeration airflow rates for corn compared with unaerated corn. Their study used an aeration management strategy whereby the corn was cooled in discrete cycles first to 23.9°C and then to 15°C, and finally to 7.2°C. In our study, aeration occurred whenever ambient temperatures were below grain temperatures and stopped when it reached the target temperature, which provided a more gradual cooling, and hence lower predicted populations compared with using aeration in discreet cycles.

The simulations were run with different starting temperatures of the stored rice to show how the patterns of population development for *R. dominica* and *S. oryzae* change with temperature, and the necessity of quickly cooling stored rice even when initial storage occurs during the summer. Field studies and model simulations have shown that a summer cooling cycle for wheat at 29.9°C stored in the southern plains reduces insect pest populations compared with waiting until September to cool stored wheat to 15°C (Arthur and Casada 2005, 2010). This waiting time was recommended by some who thought the high temperatures at wheat harvest would limit insect populations when the wheat was placed in a bin, and as ambient temperatures approached 15°C, the wheat could be quickly cooled (Noyes et al. 1992). However, results from field trials and model simulation studies contra-

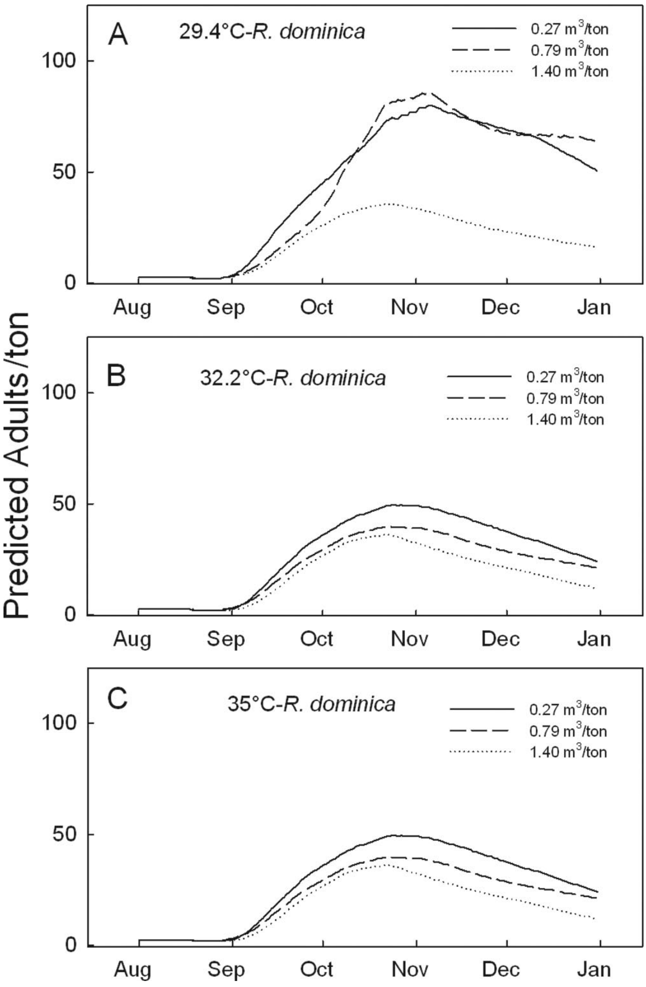

Fig. 4. Predicted populations of adult *R. dominica* in aerated rough rice stored in Beaumont, TX, from 1 August to 31 December, with starting grain temperatures of 29.4 (A), 32.2 (B), and 35.0°C (C). Storage time, bin dimensions, capacity, starting insect populations, and aeration airflow rates were as described for Figs. 1–3.

dict this approach, although it could have some merit for *S. oryzae* because this species is more limited by higher temperatures than *R. dominica* (Fields 1992).

Our results also show overall that all three aeration airflow rates were effective in lowering the temperature of stored rice, regardless of starting grain temperature, which led to the corresponding reduction in pest populations. Airflow rates ranging from 1.4 to 14 m^3/min/metric ton are usually used for drying grains with ambient air, including rice, which are much higher than rates required for aeration as a component of insect pest management (Ranali et al. 2002, Arthur et al. 2008). Hence, when fans on grain storage bins are sized for drying, it may not be possible to effectively use them for true aeration because the airflow rates may be excessively high and energy-consuming.

An objective of this study was to determine the optimal aeration measure to help develop an expanded system for management of *R. dominica* and *S. oryzae* in rice stored in the south central United States Given the current limitations in the rice storage system, it seems that 0.79 m^3/min/metric ton would provide optimal control. Although there are no fixed standards for insect infestations in stored rice, the accepted FGIS standard for U.S. export wheat is two live insects injurious to grain per kilogram, which is 2,200 per metric ton. For our simulations, predicted populations of either *R. dominica* or *S. oryzae* did not exceed 200 adults per ton when aeration was employed. The patterns generated by the web-based system would be similar regardless of the starting insect infestation, hence of the initial insect population size (2.5 adults per ton) and bin size and capacity (7.7 m in height by 5.5 m in diameter and ≈10 metrics tons). Starting grain temperatures can be adjusted by individual users to estimate insect populations in specific regions where rice is stored. The web-based system provides a convenient framework for analysis that covers wide geographic regions.

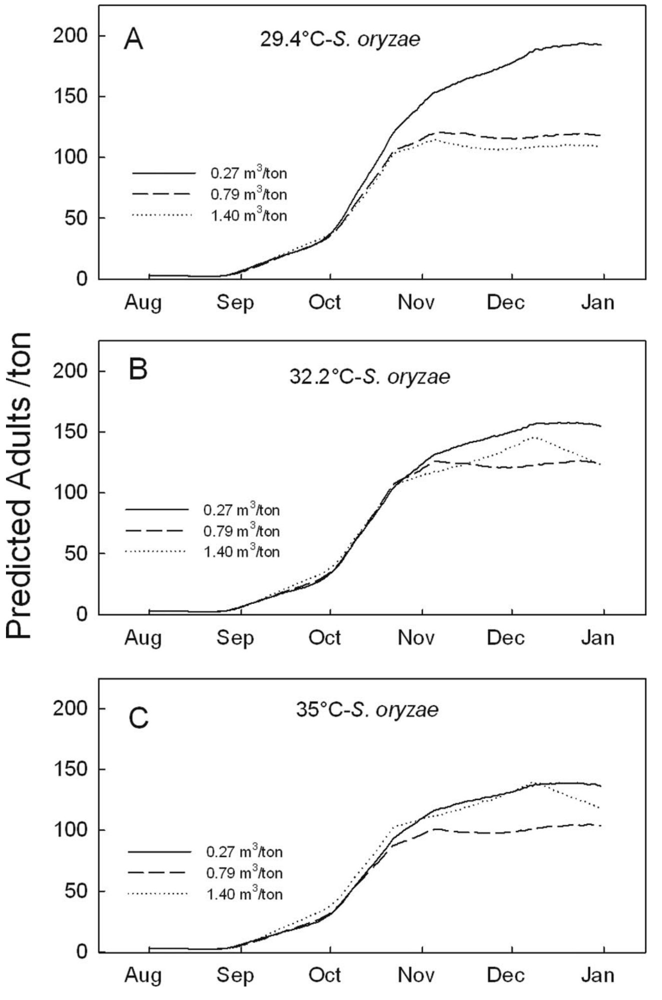

Fig. 5. Predicted populations of adult *S. oryzae* in aerated rough rice stored in Beaumont, TX, from 1 August to 31 December, with starting grain temperatures of 29.4 (A), 32.2 (B), and 35.0°C (C). Storage time, bin dimensions, capacity, starting insect populations, and aeration airflow rates were as described for Figs. 1–4.

Acknowledgments

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