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Movement of *Rhyzopertha dominica* in response to temperature gradients in stored wheat☆

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ABSTRACT

The movement and temperature preference of *Rhyzopertha dominica* was determined in a 56 cm diameter cylinder with 9 cm high sides containing 19.9 kg of hard red winter wheat. Two temperature gradients were tested over a 24 h period: 42 to 20 °C and 24 to 20 °C with the cooler temperature being on the periphery of the cylinder. No preference existed when there was no temperature gradient. Beetles preferred the moderate temperature region of the cylinder in the 42 to 20 °C gradient, but avoided the highest temperature region. In the 24 to 20 °C gradient, insects did not move very much during the 24 h period. When a longer duration was used (96 h) for the 24 to 20 °C gradient, there were significantly more insects in the warmest center region of the gradient compared to the middle or outer regions. Compared to other stored grain Coleoptera, such as *Cryptolestes ferrugineus*, *R. dominica* appears to move more slowly through the grain into preferred temperature regions.

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1. Introduction

The lesser grain borer, *Rhyzopertha dominica* (F.) is one of the most common and damaging insect pests of stored wheat in the USA. (Flinn et al., 2010). The adults and larvae tunnel into the kernels while feeding, and this results in insect fragments in flour following milling. The population growth rate of *R. dominica* in stored grain is primarily determined by grain temperature (Hagstrum and Subramanyam, 2006). In the autumn, the periphery of the grain bulk cools faster than the center and this allows insects to continue to reproduce in the center during the cold winter months in grain that is not cooled by aeration. Beetle populations may be higher in the center of the grain bulk because they are able to move from the cool periphery of the grain into the warm center (Hagstrum, 1987). The steepness of the temperature gradient may affect the ability of the insect to detect the gradient and to move toward a preferred temperature region. Amos and Waterhouse (1969) showed that the distribution of *Tribolium castaneum* (Herbst) was different on steeper or shallower temperature gradients. Hagstrum et al. (1977) demonstrated that when *T. castaneum* were placed in a 36 to 22 °C gradient in wheat, they remained longer in the 30 °C region than in the cooler regions. Flinn and Hagstrum (1998) showed that *Cryptolestes ferrugineus* moved into warmer areas in gradients of 42 to 20 °C, 24 to 20 °C and even at a very shallow gradient of 21 to 20 °C. Jian et al. (2004a) showed that *C. ferrugineus* could detect temperature gradients in less than 1 h, preferred warmer temperatures, and responded faster to steeper temperature gradients than to shallower ones. The movement of male and female adult *C. ferrugineus* was not significantly different in temperature gradients (Jian et al., 2004b). At grain temperatures of 5 °C, adult *C. ferrugineus* moved less than 5 cm in 24 h (Jian et al., 2003). Jian and Jayas (2009) and Jian et al. (2009) have reviewed the effects of temperature gradients on *C. ferrugineus* movement in grain. There has been very little research on the effects of temperature gradients on *R. dominica* in stored grain. Yinon and Shulov (1970) investigated the effects of temperature gradients on several stored grain beetles, including *R. dominica*. They found that adult *R. dominica* preferred temperatures from 25 to 30 °C. However, their experiments were conducted in glass tubes without grain, which represents a very artificial environment for stored grain beetles. In this paper, we determine the effects of temperature gradients in stored wheat on movement and temperature preference of adult *R. dominica*.

2. Materials and methods

The arena consisted of a 56 cm diam. cylinder with 9 cm tall metal sides. The top and bottom of the arena were insulated with

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1.9 cm thick plywood and 2.5 cm thick plastic foam (Flinn and Hagstrum, 1998). The arena was filled with 19.9 kg of hard red winter wheat with a moisture content of 14% (dry weight basis). A temperature gradient was established in the grain by heating the center of the arena with a 50 W aquarium heater (Petcrest, Harrison, NJ, USA) immersed in a 2 cm diameter metal cylinder filled with water. The perimeter of the arena was cooled to 20 °C by placing the arena in an environmental chamber maintained at 20 ± 1 °C. Two different temperature gradients were used: 42 to 20 °C and 24 to 20 °C. For the no temperature gradient control, the aquarium heater was not used and the arena was placed in a 30 ± 1 °C environmental chamber. Temperatures in the grain were measured using a Digi Sense thermistor reader (±0.2 °C) (Cole Parmer, Chicago, IL, USA), using YSI series 400 thermistor probes (YSI, Yellow Springs, OH, USA). The probes were inserted through small holes drilled through the top of the arena. The seven probes were arranged at distances of 3.1, 6.2, 9.3, 12.4, 15.5, 18.6, 24.8, and 27.7 cm from the edge of the water-filled center cylinder. Temperatures were measured 24 h after the grain was added to the arena–this allowed sufficient time for the temperature gradient to stabilize in the grain.

Twenty-four hours after the arena was placed in the chamber, 98 *R. dominica* adults were evenly distributed over the grain surface and the insulated top was secured to the arena. The beetles were approximately two weeks old and were obtained from a laboratory culture from the USDA, ARS, Center for Grain and Animal Health Research. The culture was maintained on hard red winter wheat at 30 °C and 65% RH with no photoperiod. The culture has been maintained at the research center for about 20 years and new adult *R. dominica* were added to the culture approximately every two years to help maintain genetic diversity. Twenty-four hours or 96 h after the beetles were released, the top of the arena was removed and a metal divider was inserted into the grain that partitioned the cylinder into 13 compartments (Fig. 1). The grain was removed from each compartment using a vacuum sampler and sieved for insects. The average recovery rate was 95.7%.

Each treatment was repeated two times and new grain was used for each replication. The empty arena was exposed to air at 30 °C for at least a week between experiments to degrade any aggregation pheromones that may have been absorbed by the plywood surface. Differences in mean beetle density between the outer, middle and center sections of the arena were analyzed using one-way ANOVA (SAS version 9.2) (SAS Institute, 1988).

3. Results

After 24 h in the steepest temperature gradient, 42 to 20 °C, *R. dominica* adults moved out of the center region of the arena where the temperatures were the warmest, and into the middle region where temperatures ranged from 30 to 25 °C (Figs. 2 and 3). There did not appear to be any preference for the outer region, which was the coolest, over the warmer middle region of the gradient. Insect densities were significantly lower in the center region compared to the middle and outer regions (Fig. 3). In the control, after 24 h, the insect densities were not significantly different in the center, middle or outer regions. In the medium temperature gradient, 24 to 20 °C after 24 h, there were no significant differences in density in the center, middle or outer regions of the arena (Fig. 3).

Running the experiment for 96 h with the 24 to 20 °C gradient, there were significantly higher densities of *R. dominica* in the warmer center region compared to the cooler middle or outer regions (Fig. 3). There were no significant differences among regions in the control that was run for 96 h.

4. Discussion

Adult *R. dominica* appear to avoid warmer areas of the grain mass (42 to 35 °C) in favor of more moderate temperatures (32 to 25 °C). In a previous study on adult *C. ferrugineus* (Stephens) using the same methods as the current study, Flinn and Hagstrum (1998) showed that *C. ferrugineus* density was much higher in the center than in the middle or outer region in a 42 to 20 °C gradient after 24 h. They showed similar results for the 24 to 20 °C gradient after 24 h. The mechanisms that insects use to detect the direction of the temperature gradient probably involves insect movement (Jian and

Fig. 1. Arena with the insulating top removed and the metal divider inserted into the grain to partition the cylinder into 13 compartments. A small vacuum was used to remove the grain from each partition.

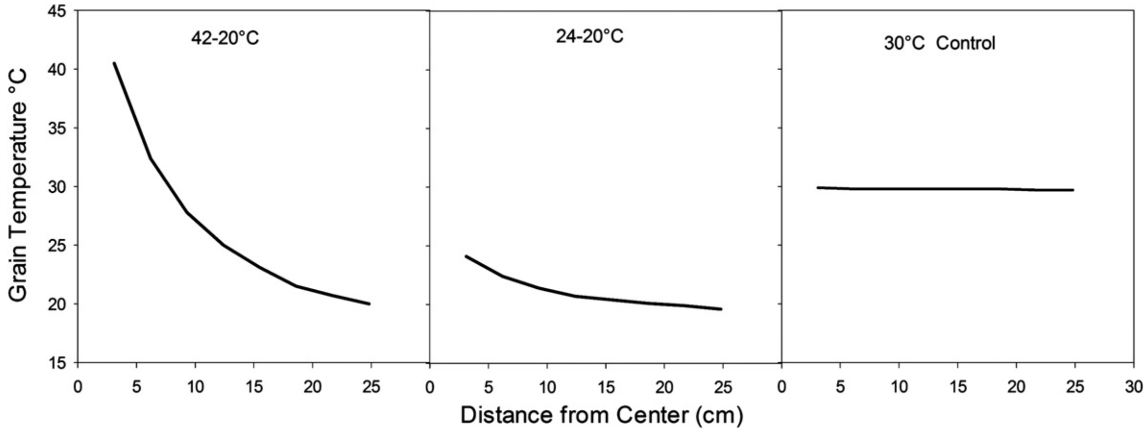

Fig. 2. Mean temperatures in the grain at different distances from the center of the arena.

Jayas, 2009). Adult *C. ferrugineus* are smaller and move faster than adult *R. dominica* (Jian et al., 2004a; Navarro et al., 1981). Because adult *C. ferrugineus* are smaller than *R. dominica*, they are probably able to move through the grain interstitial spaces more easily, and can therefore sense and move into preferred temperature regions more rapidly. This may explain why adult *C. ferrugineus* showed a large difference in density between regions after 24 h and *R. dominica* showed no difference in the medium gradient (24 to 20 °C) after 24 h, but did show higher density in the center region after 96 h. Flinn and Hagstrum (1998) showed that adult *C. ferrugineus* preferred the highest temperature region in a 42 to 20 °C temperature gradient. Insect densities were 36.0, 2.1, and 0.3 insects per kg of wheat in the center, middle and outer regions after 24 h. After 24 h in the steepest temperature gradient (42 to 20 °C), *R. dominica* densities were lower in the center and higher in the middle and outer regions; whereas, *C. ferrugineus* densities were much higher in the center region than in middle or outer regions. Compared to *C. ferrugineus* adults, *R. dominica* prefers more moderate temperatures and takes longer to move into the warmer regions. It is possible that adult *R. dominica* may suffer higher winter mortality in grain bins compared to *C. ferrugineus* because *R. dominica* is not able to move quickly enough into the warmer regions of the grain mass as the periphery of the grain cools during the fall and winter months.

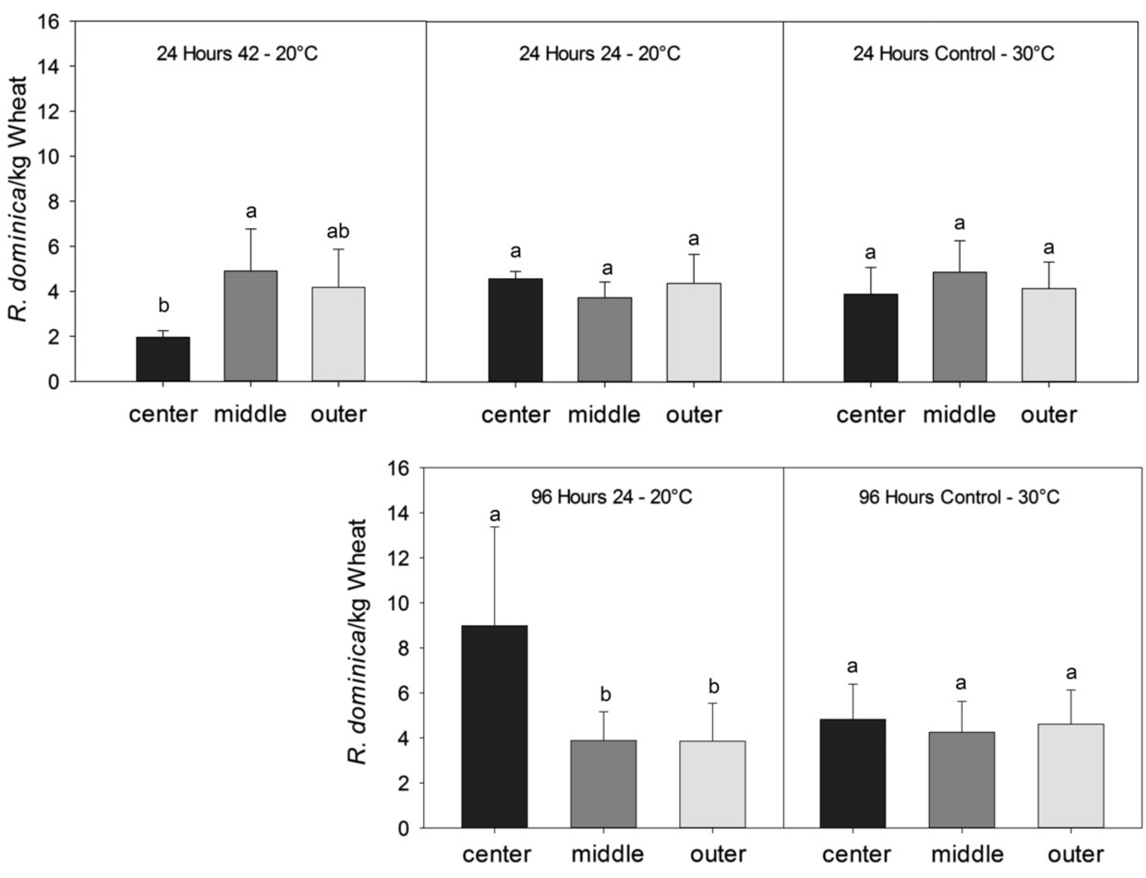

Fig. 3. Average Rhyzopertha dominica density in the center, middle, and outer sections of the arena after 24 and 96 h. Within a figure, bars marked with a different letter are significantly different ($P < 0.05$, Ryan-Einot-Gabriel-Welsch Multiple Range Test). The center, middle and outer compartments contained 2.1, 6.8, and 10.9 kg of wheat, respectively. $N = 2$, 8, and 16 for the center, middle and outer compartments, respectively.

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