Pergamon

J. stored Prod. Res. Vol. 34, No. 2/3, pp. 107–112, 1998
Published by Elsevier Science Ltd
Printed in Great Britain
0022-474X/98 $19.00 + 0.00

PII: S0022-474X(98)00002-2

Distribution of *Cryptolestes ferrugineus* (Coleoptera: Cucujidae) in Response to Temperature Gradients in Stored Wheat

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(Accepted 12 December 1997)

Abstract—Temperature gradients were established in a 56 cm diameter cylinder with 9 cm high sides filled with 19.9 kg of hard red winter wheat to determine if adult rusty grain beetle, *Cryptolestes ferrugineus* (Stephens), would disperse to warmer areas. *C. ferrugineus* moved into and remained in warmer areas of the grain mass after 24 h. Beetle preference for the warmest area of the grain mass occurred at 21–20°C, 24–20°C, and 42–20°C temperature gradients. No preference was shown for any area of the grain mass when no gradient was established. The beetles were able to locate the warmest area even at the 21–20°C gradient. In autumn, grain stored in bins cools fastest on the outside of the bulk and remains warmer longer in the center. This study suggests that *C. ferrugineus* should move toward the warmer center region of a grain mass as the periphery of the grain cools in the fall. This would allow *C. ferrugineus* populations to continue to increase in the center of the grain mass during the winter months in large, unaerated, grain bins. Published by Elsevier Science Ltd

Key words—Cryptolestes ferrugineus, stored grain, movement, temperature gradient, spatial dynamics

INTRODUCTION

The rusty grain beetle, *Cryptolestes ferrugineus*, is one of the most common insect pests of stored wheat in the United States and Canada. Adults and larvae feed mostly on the wheat germ and cause damage to the grain (Rilett, 1949). Population growth rate of *C. ferrugineus* is primarily affected by grain temperature and moisture (Hagstrum and Milliken, 1988). Some work has been done on the effects of moisture on dispersal of *C. ferrugineus* in grain. Loschiavo (1983) showed that adult *C. ferrugineus* move towards and remain in areas of higher grain moisture. However, not much is known about the effects of temperature gradients on dispersal of *C. ferrugineus* in stored grain. In autumn, the periphery of the grain bulk cools faster than the center. This allows insect populations to continue to increase in the center of the grain mass during the winter in large, unaerated, grain bins, when the temperature in the center does not fall below the limit for reproduction and development. Beetle populations also may be higher in the center of the grain mass if they move from the cool periphery towards the warm center of a grain mass. However, temperature gradients in a grain bin are often only 7–10°C/m (Hagstrum, 1987), so it may be difficult for insects to locate warmer regions of a grain mass. The steepness of a temperature gradient also may affect insect distribution. Amos and Waterhouse (1969)

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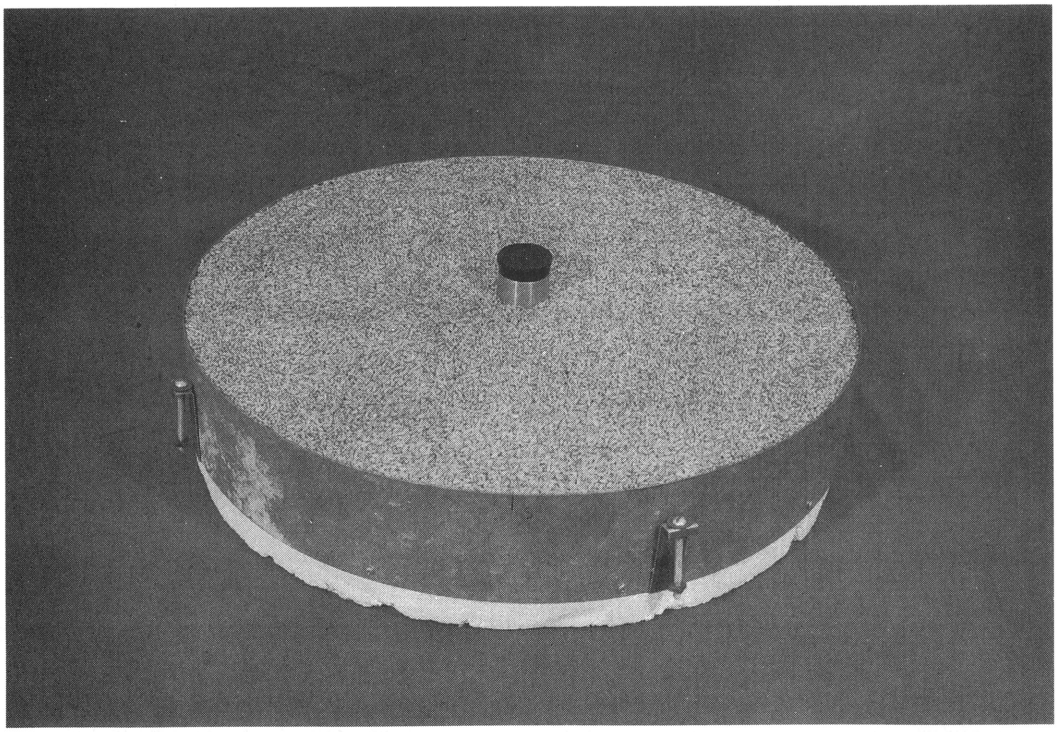

Fig. 1. Arena (filled with wheat) used to test *C. ferrugineus* movement under different temperature gradients.

showed that the distribution of *Tribolium castaneum* (Herbst) was different on temperature gradients of 0.8°C/m and 2.3°C/m. Hagstrum *et al.* (1997) showed that when *T. castaneum* were placed in a 22–36°C temperature gradient, they remained longer in the 30°C temperature region than at cooler temperatures.

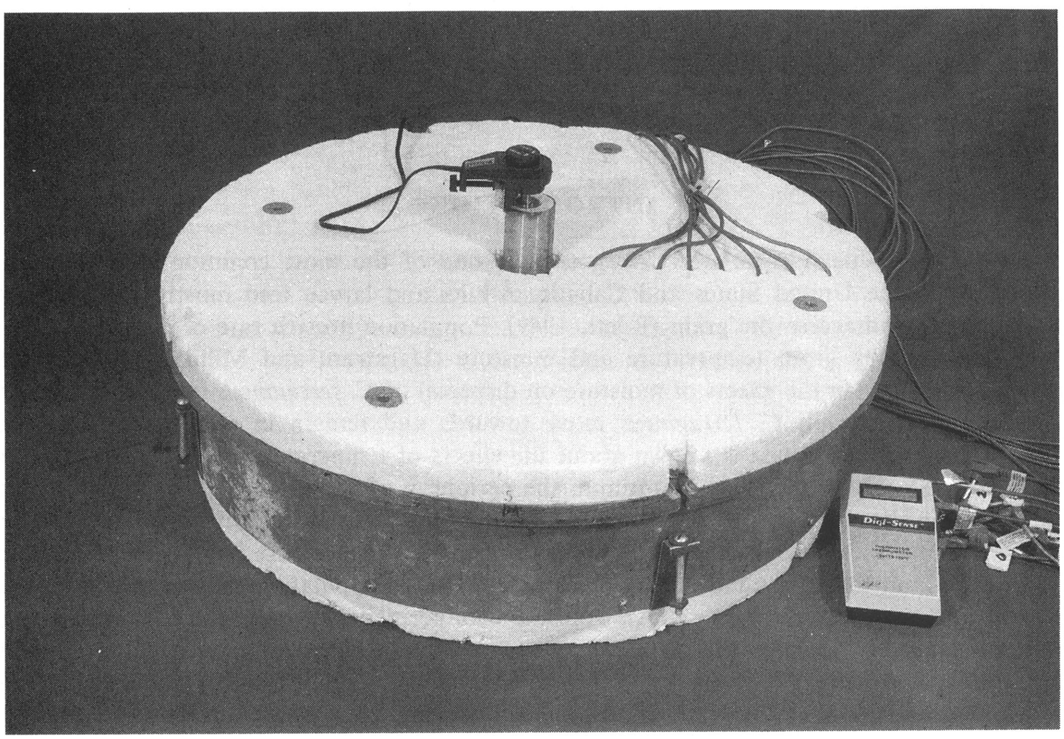

Fig. 2. Arena with insulated top and bottom attached and with aquarium heater inserted into the center water bath.

A spatial model that predicts population growth of *C. ferrugineus* in a grain bin has been developed (Flinn *et al.*, 1992, 1997). However, this model does not predict how temperature gradients affect *C. ferrugineus* movement. To predict *C. ferrugineus* population growth in bins, we need to know if beetles move towards and remain in warmer regions of a grain mass, and how small a gradient will cause this behavior. This information also would be valuable in determining optimum sampling programs for this insect. In this paper we examine the effects of different temperature gradients on distribution of *C. ferrugineus* within a wheat mass.

MATERIALS AND METHODS

The test arena consisted of a 56 cm diameter cylinder with 9 cm high metal sides (Fig. 1). The top and bottom of the cylinder were insulated with 1.9 cm plywood and 2.5 cm of plastic foam. The cylinder was filled with 19.9 kg of hard red winter wheat (14% m.c.). A temperature gradient was established by heating the center of the cylinder with a 50 watt aquarium heater (Petcrest, Harrison, NJ, USA), immersed in a 2 cm diameter metal water bath (Fig. 2). The perimeter of the cylinder was cooled to 20°C by keeping the arena in an environmental chamber maintained at 20 ± 1°C. Three different temperature gradients were used: 21–20°C, 24–20°C, and 42–20°C. For the no temperature-gradient experiment, the aquarium heater was not used and the chamber was kept at 30 ± 1°C. Temperatures in the grain were measured using a Digi-Sense thermistor reader ($\pm$0.2°C) (Cole Parmer, Chicago, IL, USA), using YSI series 400 thermistor probes (YSI, Yellow Springs, OH, USA).

Twenty-four hours after the temperature gradient was established, 98 adult rusty grain beetles were evenly distributed over the grain surface and the insulated top was secured to the cylinder. The beetles were approximately 10s day old and were obtained from a laboratory culture. The even distribution served to minimize the effect of release point on subsequent beetle movement. For example, if the beetles were released in one location, the adults would be less likely to move from the release point because *C. ferrugineus* produces an aggregation pheromone (Borden *et al.*, 1979). Twenty-four hours after the release, the top was removed and a metal divider was

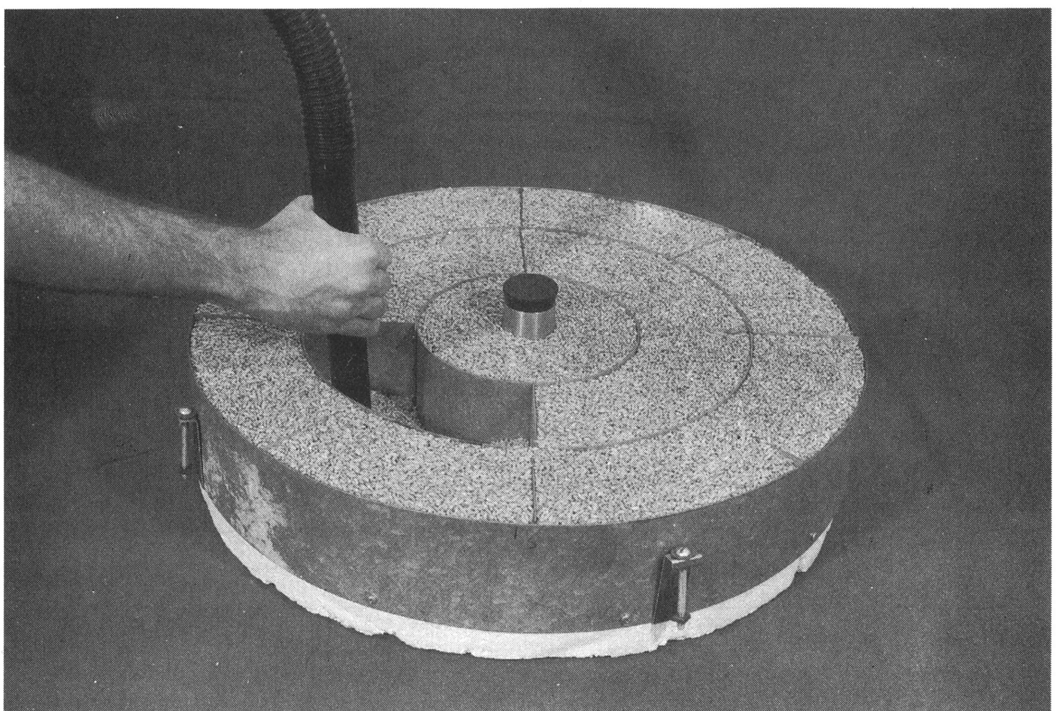

Fig. 3. Arena with metal grid inserted into the grain and vacuum device used to remove the grain from each compartment.

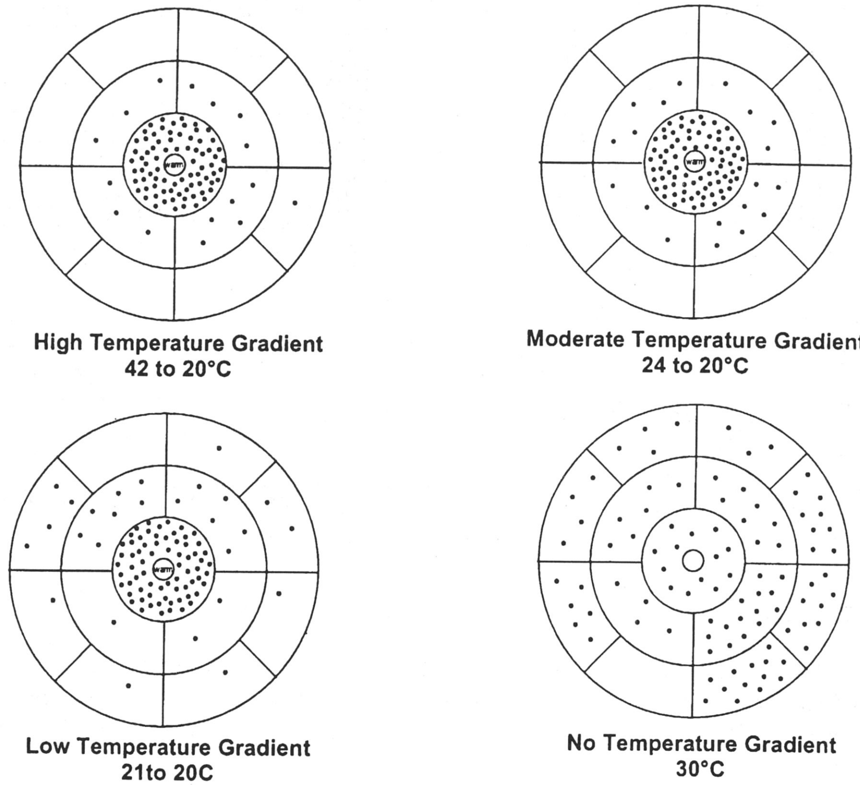

Fig. 4. *Cryptolestes ferrugineus* distributions (replicate ♯1) in the arena after 24 h in three different temperature gradients and the control (no temperature gradient). Each dot represents one insect.

inserted into the grain that partitioned the cylinder into 13 compartments (Fig. 3). The grain was removed from each compartment using a vacuum device and sieved for insects.

Each experiment was repeated two times, with new grain for each replication. The arena was exposed to a 30°C air stream for at least 1 week between experiments to degrade any aggregation pheromones that may have been absorbed by the plywood surface. Differences in mean beetle density between outer, middle, and center sections of the arena were analyzed using one-way analysis of variance (ANOVA) with SAS statistical software (SAS Institute, 1992).

RESULTS AND DISCUSSION

After 24 h, *C. ferrugineus* moved into and remained in the warmest portion of the grain mass in the 21–20°C, 24–20°C, and 42–20°C temperature gradients (Fig. 4). *Cryptolestes ferrugineus* tended to aggregate more in the warm center of the arena in the 42–20°C and 24–20°C than in 21–20°C temperature gradient. The optimum temperature for *C. ferrugineus* is about 35°C (Smith, 1965). In the 42–20°C gradient, grain temperatures in the center compartment ranged

Table 1. *Cryptolestes ferrugineus* per kilogram in the outer, middle and center sections of a cylindrical arena with temperature gradients after 24 h

	Section		
Temperature gradient	Center	Middle	Outer
42–20°C	35.96 ± 0.00a	2.13 ± 1.68b	0.32 ± 0.66c
24–20°C	35.74 ± 0.99a	2.35 ± 1.17b	0.37 ± 0.75c
21–20°C	31.07 ± 2.07a	2.65 ± 1.87b	0.98 ± 0.75c
None: 30°C	5.98 ± 0.21a	4.38 ± 1.98a	4.48 ± 2.67a

Means ± SEM followed by the same letter within rows are not significantly different at $P < 0.05$ (Tukey's Highest Significant Difference 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.

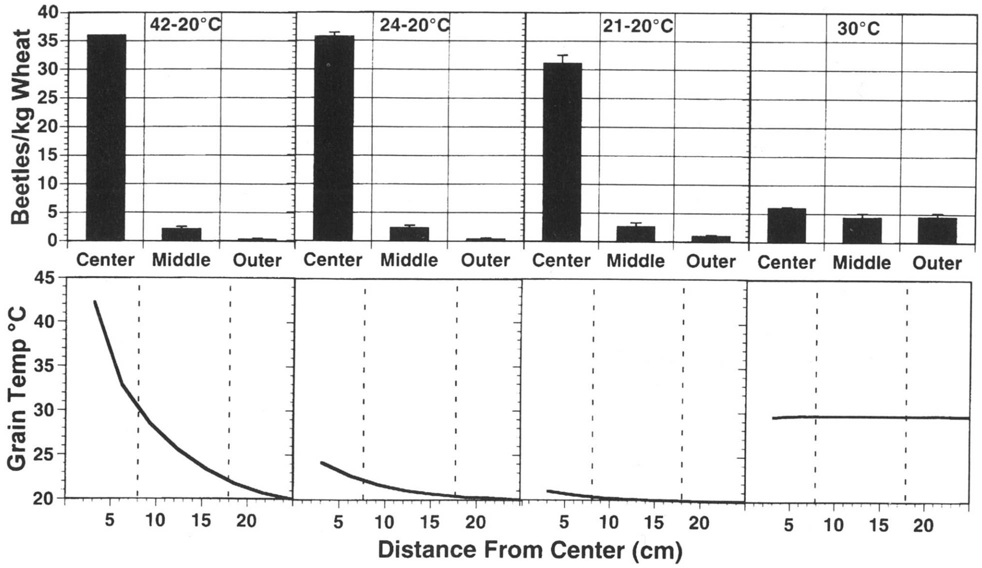

Fig. 5. Mean *C. ferrugineus* density in the center, middle and outer regions of the arena in three different temperature gradients and the control (no temperature gradient).

from about 42 to 30°C. Thus, it is reasonable that more beetles were attracted to this region. Beetles remained evenly distributed throughout the grain mass when there was no temperature gradient (Table 1). When a temperature gradient was established, insect densities were significantly different in the center, middle and outer compartments. Beetle densities were at least ten times higher in the center than in the middle section, 2.7 times higher in the middle than in the outer section, and 31 times higher in the center than in the outer section (Fig. 5).

Cryptolestes ferrugineus moved into and remained in the warmest portion of the grain mass even at the smallest temperature gradient of 21–20°C. This corresponds to a temperature gradient of 3.7°C/m (1°C/0.27 m). Temperature gradients in bins of farm-stored wheat often reach 7–10°C/m in the fall and winter months (Hagstrum, 1987). This experiment suggests that *C. ferrugineus* that are located in the periphery of the grain mass should move towards and remain in the warm center of the grain mass as the periphery cools in the fall. In an actual grain bin, beetles would need to move at least 1 m to move into areas of the grain mass that are warm enough to allow population growth in the winter. This distance is considerably more than the 27 cm radius of the arena we used in this experiment. However, because grain is a relatively good insulator, temperature gradients move inward slowly over a period of weeks, so *C. ferrugineus* should be able to stay ahead of the cold front. Adult movement toward warmer regions could accelerate the population growth rate of *C. ferrugineus* in large, unaerated, grain bins. Adult females could move into the center of the grain mass and lay eggs. The center of a large bin of unaerated grain will often remain warm during the winter months, which allows insect populations to continue to develop and reproduce. High beetle densities produce additional heat and moisture (Cotton *et al.*, 1960), making the grain environment even more suitable for insect development and reproduction. The movement of adult *C. ferrugineus* towards warmer areas of a grain mass will be incorporated into a spatial model of *C. ferrugineus* population dynamics (Flinn *et al.*, 1997) which should increase the accuracy of its predictions.

Acknowledgements—We thank G. Cuperus (Department of Entomology, Oklahoma State University), J. Throne (Grain Marketing and Production Research Center, USDA, ARS), and J. Nechols (Department of Entomology, Kansas State University) for reviewing an early version of the manuscript, and K. Friesen for excellent technical support.

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