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Relationship between density of adult rusty grain beetle, *Cryptolestes ferrugineus* (Coleoptera: Laemophloeidae) and insector counts in stored wheat at uniform moisture content and small temperature fluctuations

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Abstract

Being able to frequently estimate the population density of pest insects inside stored grain bins with a reliable accuracy is a critical procedure for sound grain storage management. To find the relationship between insect densities and trap counts, an experiment was conducted in a plastic tank with 1.73 m diameter and 0.84 m wall height. The tank was filled with 14.0 ± 0.1 % hard red spring wheat and the grain was controlled at 30 ± 0.5 to 33.3 ± 0.5 ºC. Five Insectors (an electronic pit-hole trap) were installed inside the tank with two near the edge, two at half radius, and one at the center position. All Insectors were placed 2 cm below the grain surface. Adult rusty grain beetles, *Cryptolestes ferrugineus* (Stephens), were introduced into the grain to produce overall insect density of 0.1, 1.0, and 10.0 adults/kg wheat. After a desired time period (from 6 to 19 days) of the adult introductions, insect density immediately adjacent to the Insectors in a 25.4 cm diameter was determined by separating the adults from the grain. Insect densities at each position and vertical layer were different and not equal to the overall insect density. Insect density and distribution were mainly influenced by the grain temperature fluctuation (< 4 ºC). Daily count of the Insectors strongly related to the insect density around the Insector body in a range of 25.4 cm. The coefficient of the correlation was 0.97. The correlation coefficient decreased when insect density was determined away from the trap.

Key words: Population density, Rusty grain beetle, Insector, Insect movement, Stored grain.

Introduction

After harvest, stored grain products remain vulnerable to insect infestation. Being able to detect insects in real time and estimate their density with a reliable accuracy is a critical procedure for sound grain storage management. To detect insects, grain probe or trier is conventionally used (Campbell et al., 2002). This method has a low accuracy and sometimes misleading information (Johnston, 1981; White and Loschiavo, 1986) because its accuracy is dependant on the statistical representative of the sampling (such as size, location, and number of the sampling), grain physical condition, insect species, and their distribution patterns.

Traps to detect insects in stored grain are effective and sensitive tools for grain management (White and Loschiavo, 1986). The rusty grain beetle, *Cryptolestes ferrugineus* (Stephens), is a cosmopolitan insect pest of stored grain. Sampling rusty grain beetles using traps is well documented (Toews and Phillips, 2002). The

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advantage of the trap over the probe is that the traps can be left in the grain for hours or days, thus increasing the probability of detecting low infested or low active insects such at low temperatures (Loschiavo et al., 1986). However, trap checking is time consuming and sometimes it is impossible to check daily and continually (Toews et al., 2005). Recently, a commercial version of an electronic pit-hole trap, produced and known as the Insector (OPIsystems, Calgary, Canada), has been available. The electronic trap is inserted in desired locations inside grain mass and number of insects captured is recorded within seconds of their occurrence.

There are published researches that attempt to quantity the relationship between insect densities and trap catch numbers. However, these insect densities used in the researches were overall insect densities (White and Loschiavo, 1986), estimated insect densities through probe samples (Toews et al., 2005; Lippert and Hagstrum, 1987), or insect densities in small containers (Toews and Philips, 2002). These insect densities used to quantify the relationship might be inaccurate because insects are not uniformly distributed in a grain bin and their movement behavior might be atypical in a small grain container.

The aim of this study was to find the relationship between trap count and insect density by using Insector and directly determined insect density in a medium scaled experimental container at small fluctuated temperatures (< 4 ºC) and uniform moisture content.

Materials and methods

Test tank

The experiments were conducted in a plastic tank with 0.84 m high (cylinder part) and 1.73 m diameter. There were five openings on the top of the tank (Figure 1). During the experiment, container openings were sealed with lids. There was one 12 cm diameter screen on the edge lid to allow air ingress and egress (Figure 1).

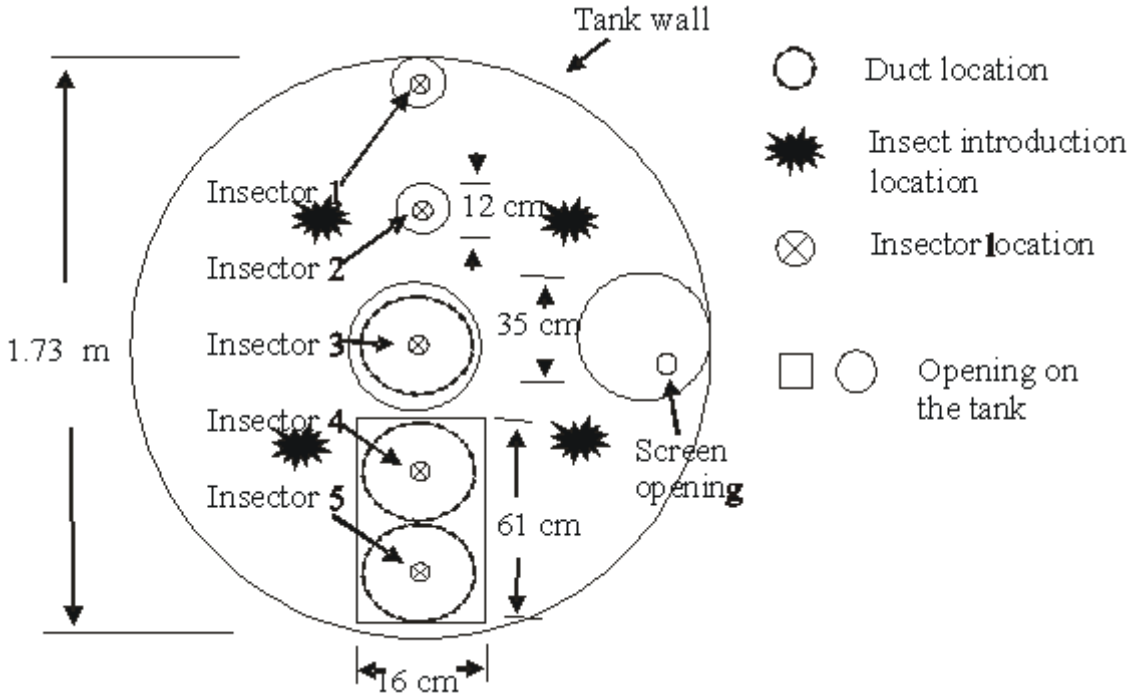

Figure 1. Top view of the tank showing the location of the openings, Insectors, insect introduction, and the metal ducts (not scaled).

Grain

Grain used in this experiment was hard red spring wheat with 0.65 ± 0.17 % dockage, and shrunken and broken kernels 14.6 ± 2.1 % (n = 3 in all of the testing). The dockage included 0.012 ± 0.004 % small materials (smaller than 2 mm diameter, consisting of small stones, weed seeds, and small foreign materials) and 0.63 ± 0.19 % large material (larger than 4.75 mm, consisting of wheat chaff and straw). Grain moisture content (14.0 ± 0.1 %, n=3) was tested before insects were introduced.

Control of the grain temperature and moisture

Grain was heated by using heat mats before being loaded into the tank. Warmer and cooler grains were mixed during grain loading. Grain temperature was measured by the Insectors which were inserted into the grain at 5 positions of the tank (Figure 1). The temperature sensors (± 0.5 ºC) were 40 cm from surface of the grain mass. It was found the grain temperature was not uniform at the start of the experiment and it was 33.3 ºC at the center position and 31 (east side of the tank) or 30 ºC (west side of the tank) near the edge of the tank.

The tank was situated in a room where the temperature was controlled at 30 ± 1 ºC by using a base board heater which was near one side of the tank (50 cm away). To control the grain moisture content, the room was controlled at 65 ± 5 % RH by an automatic humidifier. The grain did not lose grain moisture over the duration of the test.

Insect

Rusty grain beetles, *Cryptolestes ferrugineus*, were reared in laboratory at 30 to 35 ºC and 75 ± 5 % RH for six months. The feed was whole wheat (same as testing wheat) mixed with approximately 25 % broken wheat. Adults were selected using a gentle vacuum and were kept inside four 4 L glass bottles with about 3 kg of wheat in each bottle. Before introduction of the insects, the bottles were kept inside the tank for at least 24 h to let the insects acclimate to the experimental conditions.

Experimental procedure

Grain was loaded to a depth of 0.84 m and the grain surface was leveled before the five Insectors were inserted into the tank (Figure 1). Insectors were equipped with a release cup having four 0.5 cm diameter holes near the bottom, allowing captured insects to escape. 140 adults were introduced, making an overall insect density of 0.1 adults/kg wheat. The introduced insects were evenly divided into four 4 L bottles and were introduced at four locations (Figure 1). Each location was at the half radius of the tank. Eight days later after the introduction, three metal ducts (25.4 cm inner diameter and about 1 m length) were inserted around the Insector at the center, edge, and half radius positions of the tank (Figure 1). Grain inside the ducts was removed using a gentle vacuum. During operation, grain at the top, middle, and bottom layers (each layer was about 28 cm) of the duct was extracted into separate buckets. Adults inside the wheat were removed using an oscillating screen and their number was counted (Jian et. al., 2006). After counting, grain and insects were return to their previous locations. One hour after the return of the grain, an additional 1,260 adults (to create an overall density of 1.0 adult/kg wheat) were introduced. After another 11 days, the previous procedure was repeated and an additional 12,600 adults (to create an overall density of 10 adults/kg wheat) were introduced. After further periods of 6 and 13 days, the grain was removed and the insects were counted again. The grain and insects were returned on the surface of the grain mass each time.

Data collection and analysis

Daily insect capture numbers were used to conduct the data analysis. To find relationship between insect density and Insector count for the

24 h before the grain was removed, graphs were draw and regressions were conducted using SigmaPlot. More than 30 equations were tried for each layer to find the goodness of fit. The position with highest coefficients of determination (R^2) and correlation (r) was assumed as the layer and specific location which had the best relationship between insect density and count.

Results and discussion

Insect density around the Insectors

Insect densities around an Insector in a 25.4 cm diameter varied by location and did not equate to the overall insect density (Table 1). This uneven distribution of the insects could be caused by the small temperature variation (Figure 2). This variation was caused by: 1) the sampled grain returning to its previous position or to the top surface of the grain mass; 2) the east side of the tank was closer to the room's heat source; and 3) the uneven temperature across the tank at the beginning of the experiment. Just before the grain was removed, the difference in grain temperatures between each Insector location was less than 1ºC (Figure 2) and there was a uniform moisture

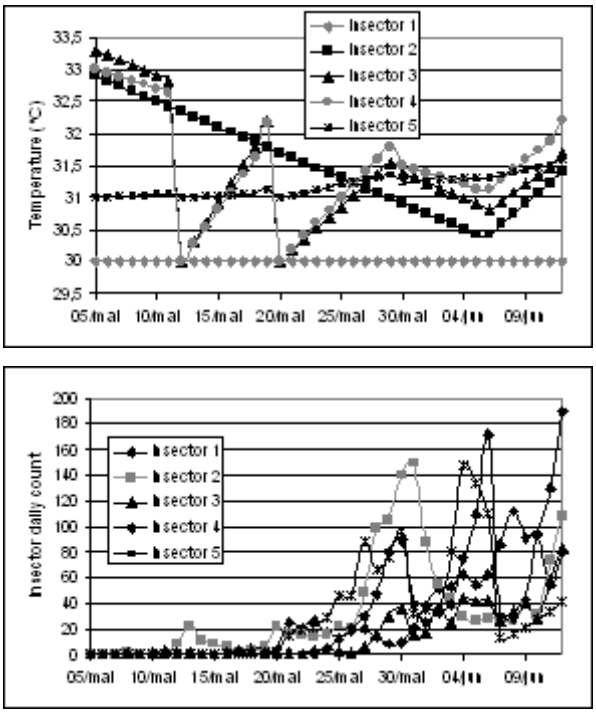

Figure 2. Grain temperature at each Insector location (top) and Insector daily count (bottom). Temperature sensor was located at the bottom of the Insector which was at 40 cm from the surface of the grain mass. Temperature fluctuation at Insector 3, 4, 5 was caused by the removing of the grain at the location. Overall insect density was 0.1 adults/kg wheat from May 5 to May 19, >1 adult/kg wheat from May 20 to May 30, and >10 adults/kg wheat from May 31 to June 12.

Table 1. Insect density (adults/kg grain) around the Insectors in a 25.4 cm diameter range on May 19 and June 12[1].

Layer	Center	Half radius	Wall
		Measured on May 19, 2006	
Top	2.6	0.27	1.03
Middle	2.0	0.33	2.3
Bottom	0.33	0	0.33
Mean ± SE	1.64±0.68	0.20±0.10	1.20±0.58
		Measured on June 12, 2006	
Top	11.5	20.1	10.6
Middle	31.4	61.6	12.5
Bottom	6.13	10.2	2.5
Mean ± SE	16.34±7.69	30.63±15.74	8.53±3.07

[1] Insect density was measured at May 11, 19, and 30, June 6 and 12 at the locations of the Insectors. Data presented in this table was only part of the results. The overall insect density was 0.1 and >10 adults/kg on May 19 and June 12, 2006.

content distribution inside the tank. This result indicated that insect gradually responded to the temperature fluctuation. Inside each metal duct, the insect density also varied between different layers (Table 1). The highest insect density was usually at the middle layer (100 % of the time at Insector 4 and 5, 75 % of the time at Insector 3) and the lowest density was at the bottom layer (100 % of the time at Insector 4 and 5, 75 % of the time at Insector 3). This could be caused by the temperature gradients because temperature was 29.5 ºC, 30.0 ºC, and > 31.4 ºC at the bottom and top surface of the grain, and at center of the grain mass at the time before the grain was removed. These results were consistence with the report of insect movement at temperature gradients in horizontal and vertical directions (Flinn and Hagstrum, 1998; Jian et al., 2006).

For each layer, a "goodness of fit" equation was found.

Top layer:

$$Y = \frac{aX^b}{c^b + X^b} \qquad R^2 = 0.94$$

(Sigmoidal: hill) (1)

Middle layer:

$$Y = a + bX \qquad R^2 = 0.84$$

(linear) (2)

Bottom layer:

$$Y = \frac{a}{1 + e^{-(X-b)/c}} \qquad R^2 = 0.72$$

(Sigmoidal: sigmoid) (3)

Where;

Y = insect density (adults/kg wheat) at the layer

X = Insector counts (Insector was at the same location of the duct as the insect density was determined)

a, b, c = parameters (Table 2)

Equation 1 had the highest coefficients of determination and correlation. Therefore, this equation was assumed as the best fit. This result showed that the insect density at the top layer had a strongest relationship with the Insector counts (Figure 3). This conclusion was explainable because the body of the Insector was at the top layer and insects move into the trap through this area. The correlation coefficient decreased with the lower layer. This result was also verified when insect density determined at the adjacent locations of the Insector was used (Figure 3). Therefore, Insector counts were strongly related to insect density measured around the Insector body.

Counting of the Insectors

The daily count varied between locations and with overall insect densities (Figure 2). However, the insect counts could be explained by the effects of temperature and insect density. For example, Insector 1 and 2 registered higher counts since the temperatures at these two positions were higher (because grain was not removed at these two locations). Insector 5 also registered higher counts because this position was nearest the heater. Therefore, the counts were related to insect movement. This conclusion was also verified by the fact of the gradually increasing of the counts at Insector 3 and 4 when the grain was gradually warmed up after it was returned. These

Table 2. Values of Parameters in Equation 1, 2, and 3.

Equation	a	b	c	r
1	399.5045±391.0444	0.5677±0.2842	28223.3621±564.2136	0.97
2	1.1962±2.7494	0.2513±0.0317		0.92
3	10.5110±1.6643	3.9469±5.3527	83.5815±4.3700	0.84

results indicated that Insector counts could be used to monitor the fluctuation of insect density.

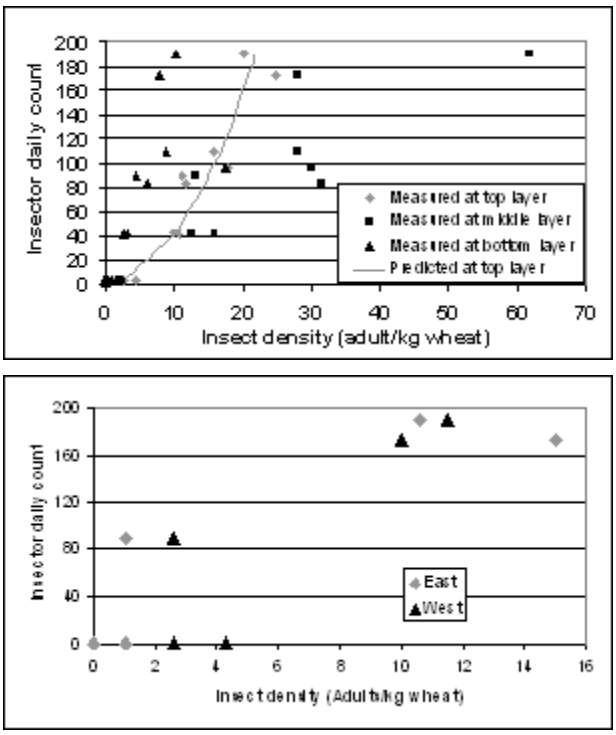

Figure 3. Predicted and measured insect densities. On the top graph, insect density was determined at the same location of the Insector and Insector counts were measured during the previous 24 hours. On the bottom graph, Insector was located at the half radius (location of Insector 4) and the insect density was measured at top layers of the two adjacent ducts which were at the east and west side of the Insector (location of Insector 3 and 5).

Insect movement is influenced by insect density, temperature, moisture, type of grain, and CO_2 concentration (Cox and Collins, 2002). The numbers of insects caught in traps are also related to trap type, duration of trapping period (Fargo, et al., 1989; White and Loschiavo, 1986), and trap location. Several authors question the reliability of using traps to quantify insect density (White and Loschiavo 1986, Lippert and Hagstrum 1987). Published researches show a low relationship between insect densities and trap counts (Lippert and Hagstrum, 1987; Toews and Phillips, 2002; Toews et al., 2005). This research showed a high coefficient of correlation. This disagreement might be caused by the determination difference of insect densities. The published research used overall insect densities or the experiment is conducted in a small scale container. Insect density around the trap was different than the overall insect density in this study. There could be an increased chance to capture insects in a small container because insect movement is limited in the container. Therefore, to estimate insect density with a higher accuracy, density determination around the trap at a large scale experimental condition might be required. This research found that Insector counts were strongly related to insect density around the Insector body and the correlation coefficient decreased when insect density was determined further away from the Insector. Therefore, insect density might be able to be estimated by using Insector (or trap) counts after the related factors were defined.

Conclusion

Insector daily counts were strongly related to insect density in the range of 25.4 cm around the Insector body. The coefficient of the correlation was 0.97.

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