Using trap and kill to successfully manage phosphine-resistant populations of rusty grain beetle, *Cryptolestes ferrugineus* (Stephens), in bulk grain

Wang, D.*#[1], Cao, Y.[2], Su, J.[3], Huang, Z.[4], Lu, Q.[5]
[1]School of Food Science and Technology, Engineering Research Center of Grain Storage and Security, Ministry of Education, Henan University of Technology, Zhengzhou 450001, China
[2]Academy of State Administration of China, Beijing 100037, China
[3]State Grain Reserves Linli Depot, Linli 415216, China
[4]TaiZhou Luqiao Central Grain Depot, Tainzhou 318050, China
[5]State Grain Reserves Zhengzhou Depot, Zhengzhou 450066, China

*Corresponding author, Email: wangdianxuan62@126.com
#Presenting author, Email: wangdianxuan62@126.com

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Abstract

Very high resistance to phosphine has made control of rusty grain beetle, *Cryptolestes ferrugineus* (Stephens), with this fumigant very difficult in many bulk grain storages in China. A new, integrated management approach is needed. We tested the potential of using trap and kill methods to reduce populations so that the need for fumigation would be reduced. In field trials, we compared efficacy of two trap types, high pressure mercury lamp linked to an electric net, and traps baited with pheromone and food. In addition, we undertook phosphine fumigations to establish dosages required for complete control of insects in bulk grain. One light trap was placed in a storage head space 1.5 m above the grain bulk at the beginning of the storage period. The highest number of insects caught with the light trap was >275,900 adults in a period of 7 days at about 33ºC. For the attractant trap, 26-30 adult insects were caught in one week at 22-24ºC. There was no significant difference between traps in the numbers of insects caught at 19-22ºC and both traps did not catch insects below 19ºC. At the same time, there were no insects found in the grain using sample and sieve methods. Trap catches increased with increasing temperature. Phosphine concentrations were 580 ppm at the peak, >300 ppm for 21 days, >200 ppm for 24 days and >150 ppm for 29 days. *Tribolium castaneum* and *Sitophilus oryzae* in cages were killed completely in 7 days, while *Rhyzopertha dominica* required 19 days, *Liposcelis bostrychophila* 21 days, and 29 days was required for complete control of *C. ferrugineus*. The use of trap and kill greatly reduced population size in storages resulting in relatively slow population increase. This meant that fumigation with phosphine could be significantly delayed or was unnecessary over the 12 month storage period.

Keywords: *Cryptolestes ferrugineus*, attractant trap, light trap, phosphine fumigation, resistance management

1. Introduction

The rusty grain beetle, *Cryptolestes ferrugineus*, is a common insect pest of stored grain in many countries (Nayak, et al., 2010; Mann et al., 1999). Very high resistance had made control of this beetle with phosphine very difficult in many bulk grain storages in China (Wang, et al., 2004). Resistance is likely to have developed in situations where insects were exposed to under-dosing of phosphine, either lower phosphine concentrations or reduced fumigation periods, caused by inadequate gas-tightness of warehouses. Unfortunately, in these situations, control failures are often followed by repeated inadequate fumigations that result in accelerated resistance development.

There are essentially two choices for preventing or managing resistance to phosphine. The first is to not use the fumigant. The second is to apply phosphine at a high enough concentration and for a fumigation period long enough that all life stages are controlled.

The no phosphine option requires introducing an integrated management approach into bulk grain storages in China. Theoretically, there are several ways that integrated pest management may be implemented. However, for large scale of bulk grain storage the most practical option is a combination of infestation prevention and insect population control. Traps are sometimes used to monitor insect populations during storage. In this research, we evaluated the potential of trapping as an approach for insect population control to both prevent new infestations and to reduce insect numbers in grain bulk, especially early in the development of infestations.

In this paper, we report on the potential of using light and attractant traps to reduce populations so that the need for fumigation is reduced. In field trials, we compared efficacy of two types of trap, high pressure mercury lamp linked to an electric net, and traps baited with pheromone and food ("XLure MST"). In addition, because in an integrated management system effective fumigations are essential, we undertook phosphine fumigations to establish dosages required for complete control of insects in bulk grain.

2. Materials and Methods

2.1. Trial 1: trapping with a pressure mercury lamp

The light trap trial was carried out in a horizontal, rectangular, concrete warehouse (60 x 24 x 6 m, l x w x h for the grain bulk) with a storage capacity of 4,946 t paddy that height of the head space was near four meters, located at the Sino-grain Linli Grain Depot, Linli, China. The grain bulk was 6.7 m high and the moisture content of the stored paddy was 11.8%. The light trap was hung 1.5 m above the bulk surface at one end of the warehouse. The light trap was a pressure mercury lamp linked to an electric net with 38 watts of power. An insect collecting bag was under the electric net.

The number of adult insects caught in the light trap was counted one day per week at 08:00-09:00 am. Rusty grain beetle adults were initially counted individually, however, because catch numbers became so great they were estimated by weight at a rate of 5,700 adults per g. A measure of infestation in the grain bulk was also made each time the trap catch was counted. A 2 kg sample of grain was taken from the top 300 mm depth of grain and sieved for insects at 12 sampling points distributed across the surface of the bulk (Fig. 1).

2.2. Trial 2: trapping with 'XLure MST' traps baited with pheromone and food

This trial was undertaken in a horizontal, rectangular, concrete warehouse (27 x 18 x 5 m, l x w x h for the grain bulk) with a storage capacity of 1,275 t paddy that height of the head space was about three meters, belonging to the Grain Buying and Storage Limited Cooperative, Taizhou Luqiao, China. The moisture content of the paddy was 12.3%. Inspection of the grain by sampling and sieving in early May, 2013 showed that there was no detectable insect infestation in the bulk.

On 10 May, 2013, 18, 'XLure MST' traps (Fig.2) baited with three kind of pheromone and two kind of food according to the product instruction were placed across the surface of the paddy bulk as shown in Figure 3. For three days, 15-17 May, the number of adult insects in each trap was counted at 08:00, 11:00, 15:00 and 20:00. From 20 May to 15 July, insect numbers were recorded at 17:00 for each of the five days. Each time insect numbers in the traps were counted, a 2 kg sample of grain was taken from the top 300 mm depth of grain close to each trap. The grain sieved for insects and the number of insects recorded.

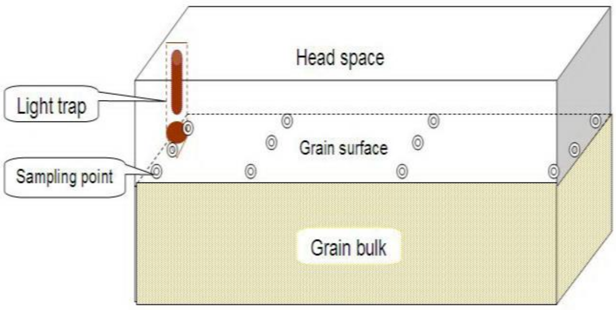

Figure 1 The position of light trap and sample checking.

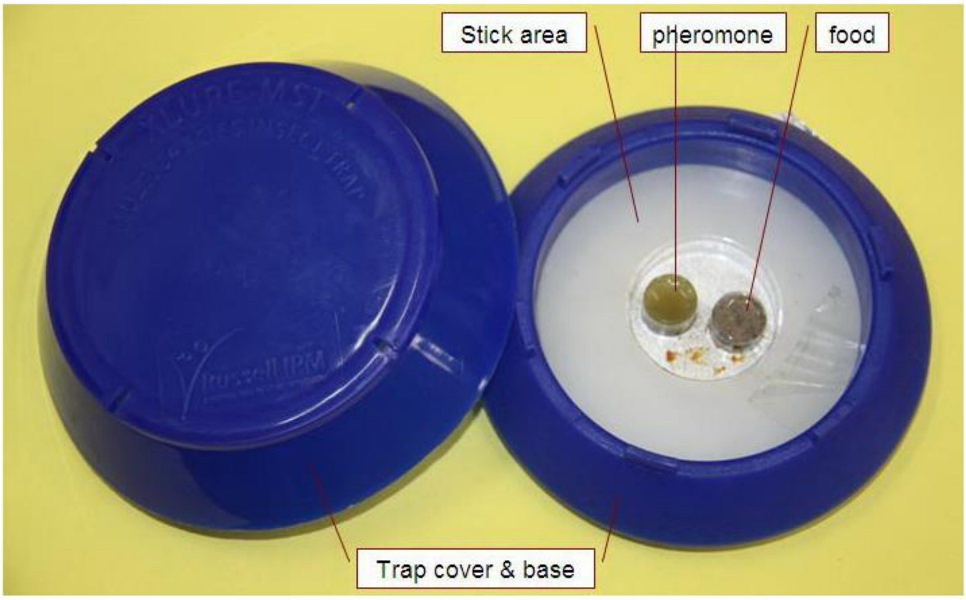

Figure 2 The picture of 'XLure MST' traps.

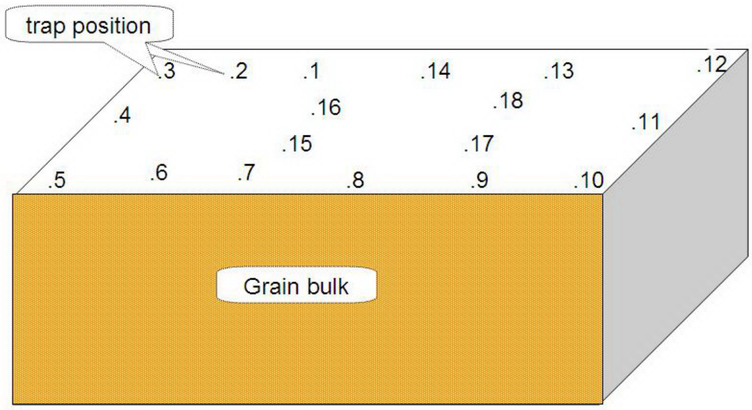

Figure 3 ‘XLure MST’ traps baited with pheromone and food position on the grain top.

2.3. Trial 3: phosphine fumigation

The phosphine fumigation trial was carried out in horizontal, rectangular, concrete warehouse (54 x 30 x 6m, l x w x h for the grain bulk) with a storage capacity of 7,766 t wheat (11% moisture content) that height of the head space was about four meters, located at the Sino-grain Zhengzhou Depot, Zhengzhou, China. Sampling and sieving the wheat revealed an existing insect population of 15 adults of *C. ferrugineus* per kg. The temperature of the wheat was 25.5 ºC at the top layer (at 0.5 m deep), 15.3 ºC for middle layer (2 m deep) and 15.9 ºC for bottom layer (5.5 m deep).

Aluminium phosphide tablets were applied on trays at a rate of 3 g/m^3 of total storage space (grain volume plus head-space). Phosphine released from the tablets was re-circulated by a closed loop fumigation system and monitored by phosphine monitor (Wang et al., 2002). The phosphine was sampled through three gas pipes which were inserted at three positions 500 mm into the bulk.

Adults of phosphine-resistant strains of *C. ferrugineus*, *Liposcelis bostrychophila* Badonnel, *Rhyzopertha dominica* (Fabricius), *Tribolium castaneum* (Herbst) and *Sitophilus oryzae* (Linnaeus) in separate cages were placed on the surface of the wheat bulk. Each cage was linked by a cotton string to facilitate removal during fumigation. Resistance factors were: 825 times for *C. ferrugineus*, 458 times for *L. bostrychophila*, 248 times for *T. castaneum*, 128 times for *R. dominica* and 69 times for *S. oryzae*, measured using the FAO recommended method (Anonymous, 1975). Each cage contained 50 adult insects with some feed. Every second day, two replicate cages of each species were removed from the fumigation and insect mortality was counted. The location of insect cages and phosphine concentration monitoring positions are shown in Figure 4.

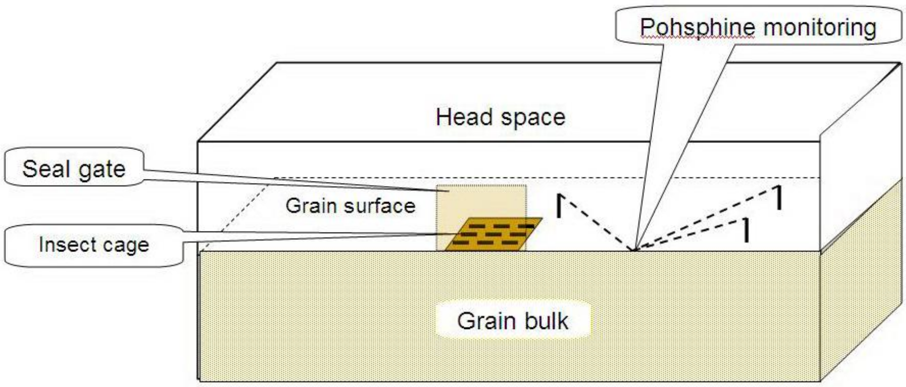

Figure 4 The position of insect cages and phosphine monitoring.

3. Results and Discussion

3.1. Trial 1: Number insects caught by lamp traps

Numbers of insects caught by high pressure mercury lamp linked to an electric net is compared in Table 1 to that by sieving method. There were few insects caught by light trap during 14 to 28 of May when we would expect the beginning of insect population development. The number of insects caught in the light trap increased markedly from 7 June to 7 July indicating that the insect population was developing to the next generation as temperature was increasing. However, numbers of adults detected by the sieving method were close to nil in this period indicating that the light trap was providing some control over initial colonizing adults. Numbers of insects caught in the trap continued to increase indicating that the population was increasing over time. The greatest number of insects caught by the light trap was >275,900 adults in a period of 7 days at about 33ºC. Despite this massive increase in trap catch, the total number of insects detected by sampling and sieving was still <100 adults over the same time period. It appears that most of the insects in the warehouse were trapped and killed by the light trap. This resulted in only a very slow increase in the population infesting the grain.

3.2. Trial 2: Number of insects caught by attractant traps

No insects were detected in the grain on 10 or 15, 16 and 17 May using he sample and sieve method, however, adult insects were caught in the light trap from 15 May onwards (Table 2). These numbers increased over the time of monitoring. There were 26-30 adult insects in caught one week at 22-24ºC. There was no significant difference between traps in the numbers of insects caught at 19-22ºC. However, no insects were caught in traps at temperatures less than 19ºC. These results indicate that adult *Cryptolestes ferrugineus* are attracted to the XLure MST traps at a higher rate when the temperature of the grain is >21ºC, however, they cannot be detected using the sample and sieve method. Thus, traps baited with pheromone and food can capture adults when the population is small. Also, time of day is not critical as there was little difference in numbers caught at various times on the same day.

From 20 May to 15 July (Table 3), numbers caught in the pheromone and food traps increased as temperature increased and were much higher than insects detected using the sample and sieve method. There were 398 adult *C. ferrugineus* caught during the trial. These insects were prevented from colonizing the grain and initiating an infestation. Although insect numbers detected using the sample and sieve method increased slowly with time as temperature increased, indicating establishment of an infestation, our results indicate that traps baited with pheromone and food can function to significantly suppress population growth.

Table 1 Number of rusty grain beetle adults caught in a light trap compared to numbers of adults counted using a sample and sieve method.

Date/ Month	Temperature of head space (°C)	Total insect number trapped by light trap (adult)	Total insect number by sieving method (adult)	Top insect number by sieving method (adult)
14/May	24	2	1	1
28/May	24	0	3	3
7/June	28	1314	0	0
13/June	26	212	0	0
19/June	30	5892	0	0
25/June	32	19405	0	0
1/July	34	63939	0	0
7/July	35	25444	0	0
13/July	27	18683	20	12
19/July	34	53414	34	21
25/July	31	85842	56	28
31/July	34	157833	47	24
6/August	33	239172	99	30
12/ August	34	275900	100	31
18/ August	31	-	85	32
24/ August	25	-	102	37
2/September	27	-	84	27
8/ September	22	-	71	24

Table2 The insert number (*Cryptolestes ferrugineus* adult) trapped and sieved on different time each day.

Checking date	Checking time	Temperature of environment /ºC	Temperature in head space / ºC	Grain temperature / ºC	RH of environment /%	RH in head space /%	Total insect number in trap /adult	Maximum number adult insects in trap	Total insect number adults by sieving	Maximum number insects detected by sieving
10th,May		18	18	18.6	80	56	0	0	0	0
15th, May	08.00	18	18.2	18.6	80	56	0	0	0	0
	11.00	20	19	19	78	60	4	1	0	0
	17.00	20	19	19	79	58	6	2	0	0
	20.00	19	18.4	18.8	86	54	0	0	0	0
16th, May	08.00	20	18	20.2	72	54	0	0	0	0
	11.00	21	18.6	21.0	80	56	10	5	0	0
	17.00	21	19	21.0	84	57	10	5	0	0
	20.00	20	19	20.0	86	62	16	6	0	0
17th, May	08.00	22	21	21.2	86	58	16	6	0	0
	11.00	24	22	22.2	70	51	12	3	0	0
	17.00	23	22	22.0	78	62	15	5	0	0
	20.00	23	22.2	22.2	90	50	22	5	0	0

Table 3 The insect number (*Cryptolestes ferrugineus* adult) trapped and sieved on same time of each five days.

Checking date	Checking time	Temperature of environment /ºC	Temperature in head space /ºC	Grain temperature /ºC	RH of environment /%	Total insect number in trap /adult	Top insect number in trap /adult	Total insect number by sieving /adult	op insect number by sieving /adult
5.10	18	18	18.6	80	56	0	0	0	0
5.20	25	22.4	22.6	82	60	26	7	0	0
5.25	26	22.7	22.6	81	62	30	10	5	2
5.30	27	23.0	23.6	78	53	46	16	0	0
6.5	26	23.0	24.0	73	48	68	25	0	0
6.10	27	23.0	24.0	70	48	80	30	0	0
6.15	27	22.0	25.2	74	54	86	20	4	2
6.20	30	26.0	29.0	73	43	122	31	25	3
6.25	29	26.0	29.5	70	40	166	46	40	4
6.30	30	26.0	29.2	64	40	223	62	45	6
7.5	35	27.0	30.2	64	40	268	64	47	6
7.10	32	28.0	32.5	58	42	322	42	48	6
7.15	33	28.0	32.6	60	44	385	45	55	8

3.3. Trial 3: Phosphine concentration and insect mortality

In this trial, phosphine concentrations peaked at 580 ppm on day 6 and were >300 ppm for 21 days, >200 ppm for 24 days and >150 ppm for 29 days (Fig. 5). Complete mortality of resistant strains of *T. castaneum* and *S. oryzae* was achieved at 7 days, while *R. dominica* was completely controlled at 19 days, *L. bostrychophila* at 21 days, and 29 days was required for complete mortality of *C. ferrugineus*. This phosphine-resistant strain *C. ferrugineus* was the most tolerant of all species/strains tested making this species most difficult to control.

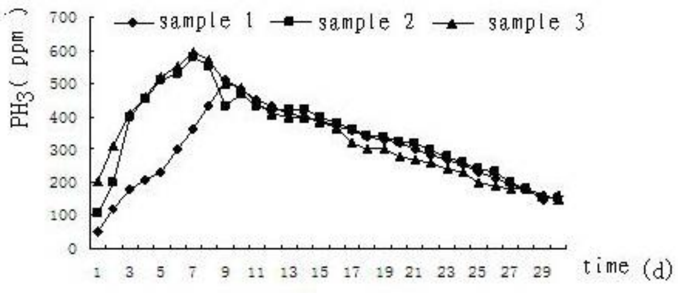

Figure 5 The phosphine concentration change during fumigation.

4. Conclusions

The rusty grain beetle can develop very high levels of resistance to phosphine making it the most difficult species to control. In many cases, grain warehouses are not suitable for fumigations aimed at controlling this species as concentrations of phosphine cannot be maintained for long enough to achieve complete control. In these trials, we have demonstrated that rusty grain beetle population growth can be significantly reduced, especially in the initial stage of an infestation, using trap and kill techniques. These methods greatly reduced colonizing population size resulting in a slowing down of population growth. This result means that fumigations with phosphine could be significantly delayed or even avoided over a 12 month storage period. It is essential though that when a fumigation is undertaken, phosphine concentrations much reach levels required for population extinction. In practice, as the tolerance of pupae and eggs to phosphine is often higher than that of adults of the same species (Hole et al., 1976; Price and Mills, 1988; Collins et al., 2005), a higher concentration of phosphine or longer exposure time may be necessary for the population extinction. We found that the use of insect cages can be a helpful to guide the effectiveness of a fumigation.

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