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Note on the effect of low temperatures on the survival of immature stages of the rusty grain beetle, *Cryptolestes ferrugineus*

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Wheat infested with the rusty grain beetle (*Cryptolestes ferrugineus*) was held for varying numbers of weeks at temperatures of -5° , 0° , 5° , 10° , and 15°C in separate tests. Survival of the immature stages (eggs, larvae and pupae) of the beetle declined each week at each temperature. The LT_{50} and LT_{99} were determined for each of the temperatures except for -5°C where 100% mortality was observed in a 1- to 2-week period of exposure.

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Du blé infesté de cucujide roux (*Cryptolestes ferrugineus*) a été exposé pendant quelques semaines à -5° , 0° , 5° , 10° ou 15°C . On a observé une réduction de la survie des stades immatures (oeufs, larves et pupes) à toutes les températures. Les valeurs de TL_{50} et de TL_{99} ont été calculées pour chaque température, à l'exception du traitement à -5°C pour lequel la mortalité était de 100% en moins de 2 semaines.

The cooling of bulk grain and oilseeds has been recommended to prevent spoilage by insects and molds by eliminating hot-spots and halting the increase of insect populations. This cooling can be achieved by forcing cold winter air through bulk stored crops (Loschiavo *et al.* 1983). Watters (1963) showed that the transfer and turning of bulks of grain at intervals during 2 days of cold weather (-6.7 to $+4.4^{\circ}\text{C}$) reduced the average temperature of a bulk of wheat (*Triticum aestivum* L.) from 12.2° to 6.6°C . Smith (1970) found that the center of a 27.2 metric tonne bulk of wheat would cool naturally to temperatures below 0°C during 20 weeks of Manitoba's winter. The rusty grain beetle (*Cryptolestes ferrugineus* [Stephens]) cannot complete its development at temperatures of 17.5°C or less (Smith 1965), but can become cold-acclimated and survive prolonged exposure to freezing temperatures if subjected to slowly declining temperatures. Smith (1970) found that non-acclimated larvae are very susceptible to temperatures of 2° , -6° , and -12°C , but did not describe the effects of low temperatures between 2°C and the adult acclimation temperature of 15°C on the larvae. The aim of this work

was to ascertain the effect of low temperatures of -5 to 15°C on the survival of the immature stages of the rusty grain beetle.

Two hundred flakes of wheat germ, each containing a single egg of *C. ferrugineus* were placed individually in glass cells made from hanging drop slides and cover slips. Cover slips were fastened to the slides with cut down hairpins. These slides were placed in a desiccator and incubated at $30 \pm 1^{\circ}\text{C}$ and $75 \pm 5\%$ RH. After 5 weeks, each slide was examined under a dissection microscope to determine if live beetles had emerged.

Thriving six-week-old cultures of rusty grain beetles in hard red spring wheat (16% moisture content) were kept at $30 \pm 1^{\circ}\text{C}$ and $75 \pm 5\%$ RH. Cultures were mixed before use. One hundred and fifty mL of culture were placed in each of 32 jars (0.5 L) for each test. There were four replicates of seven exposure periods plus the untreated controls (kept at 31°C) for each low temperature. The exposure periods were 1, 2, 3, 4, 9, 10, and 12 weeks at each temperature. The temperatures for the tests were -5 , 0° , 5° , 10° , and 15°C . Three days after the start of each test, adults were removed from the treatments and controls by sieving the grain. The grain with the immature insects inside the kernels was returned to the respective jars at the original

experimental temperature. At the end of each exposure period, four treatment jars were moved from the test temperature and placed at $30 \pm 1^\circ\text{C}$ and $75 \pm 5\%$ RH. After four weeks the grain from each jar was sieved and the number of beetles found were recorded. Control jars were not incubated at low temperatures but placed at $30 \pm 1^\circ\text{C}$ and $75 \pm 5\%$ RH for 4 weeks after which the number of adult beetles were recorded. Mortality during low temperature incubation was calculated as the difference between the numbers of adults emerging in the treated jars and the number emerging in the controls. One hundred kernels were taken from the original cultures before the grain was placed in the jars and dissected under a low power microscope. All stages of development of the rusty grain beetle were present in the grain.

Probit analyses and tests for parallelism and potency ratios were performed on the mortality data obtained (Bliss 1935; Finney 1971).

Mortality during development of the insects on wheat germ in hanging drop glass cells averaged 12.2%. This mortality rate of 12% was similar to that reported by Smith (1965) and was used to correct for mortality in the untreated grain controls before use of Abbott's (1925) formula in the probit analyses (Bliss 1935; Finney 1971). The total numbers of insects recovered from the controls after incubation of the grain were 166, 460, 992, and 862 beetles at 0° , 5° , 10° , and 15°C , respectively.

The times required to obtain 50 and 99% mortality (LT_{50} and LT_{99}) of the immature stages of laboratory-reared rusty grain beetles when subjected to temperatures of 0° , 5° , 10° , and 15°C were determined (Table 1). At -5°C only 4.9% of the immature stages survived for 1 week and none survived after 2 weeks at this temperature, confirming the results obtained by Smith (1970) at -6°C for non-acclimated beetles.

Mortality of the immature stages increased with time at all temperatures (Table 1), including 15°C (slopes of probit lines were positive). There was also a progressive increase in the median lethal time (LT_{50}) as temperatures rose from 0° to 15°C . Mortality of immature stages at 15°C was unexpected because Smith (1970) acclimated rusty grain beetles at 15°C to get them to survive long exposures at -6° and -12°C . The immature stages do not become acclimated, but die at temperatures of 15°C or less, thus offering an opportunity for a practical, non-toxic, method of control of this species. Control should include two steps: one which cools the grain to temperatures below 10°C to kill the immature stages, and the second in which adult beetles are removed from the grain, possibly by sieving methods.

The LT_{50} was lower at 0°C than at 5° , 10° , or 15°C (Table 1). Table 2 shows the ratios between the LT_{50} obtained at the different temperatures and the potency ratios that were calculated assuming parallelism of the probit lines. There was no conflict with the hypothesis of parallelism only

Table 1. The effect of time of exposure at four temperatures on the mortality of the immature stages of the rusty grain beetle §

Temperature ($^\circ\text{C}$)	LT_{50} (weeks)	LT_{99} (weeks)	Heterogeneity factor	Slope	Intercept
0	1.4 (0.9 - 2.2)†	4.3 (1.6 - 11.8)	0.1	4.9	4.1
5	1.7 (1.5 - 1.8)	6.1 (5.1 - 7.3)	1.2	4.2	3.9
10	1.7 (1.5 - 1.9)	47.8 (35.6 - 64.3)	8.3	1.6	4.6
15	2.6 (2.4 - 2.8)	35.0 (27.9 - 43.8)	5.6	2.1	4.1

§ Outputs from probit analysis.

† Confidence interval at 95%.

Table 2. Potency ratios from comparisons of the LT_{50} obtained from exposure of immature *Cryptolestes ferrugineus* to different temperatures

Comparison between temperatures (°C)		Actual ratio of LT_{50}	Potency ration \pm variance at the LT_{50} assuming parallelism
low	high		
0	5 [§]	1.17	1.202 \pm 0.001
0	10	1.18	1.516 \pm 0.007
0	15	1.75	3.533 \pm 0.001
5	10	1.00	1.399 \pm 0.001
5	15	1.49	1.813 \pm 0.001
10	15	1.48	1.342 \pm 0.001

§ No conflict with the hypothesis of parallelism ($P > 0.1$)

for comparison of the probit lines obtained from the data of 0° and 5°C.

The times required to obtain 99% mortality (LT_{99}) at 0°C and 5°C were similar (4 to 6 weeks), as were the LT_{99} obtained at 10° and 15°C (35 to 48 weeks). The slopes of the probit lines for 0° and 5°C were steeper than those for 10° and 15°C. The high values of the LT_{99} for both 10° and 15°C suggest that these temperatures may not be low enough, even for a very long period of exposure, to provide practical control of the immature stages of the rusty grain beetle. However, the lower temperatures of 0° and 5°C might be adequate for beetle control, provided that the adults, which become acclimated, are removed from the grain, in some manner.

This work has shown that the immature stages of the rusty grain beetle will slowly succumb to temperatures of 15°C or less, and that in grain in experimental jars an effective kill of 99% can be obtained within 6 weeks at temperatures of 0° and 5°C.

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