

16 February 1995

JOURNAL OF THE KANSAS ENTOMOLOGICAL SOCIETY
67(4), 1994, pp. 331-339

**Suppression of Maize Weevil, *Sitophilus zeamais*
(Coleoptera: Curculionidae), Populations in Drums of Corn by
Single and Multiple Releases of the Parasitoid
Anisopteromalus calandrae (Hymenoptera: Pteromalidae)**

BIRAN WEN AND JOHN H. BROWER

Stored-Product Insects Research and Development Laboratory,
USDA-ARS, 3401 Edwin Street, Savannah, Georgia 31405

ABSTRACT: Drums containing 45.36 kg (100 lbs) of shelled corn were used to test the ability of *Anisopteromalus calandrae* (Howard) to suppress populations of the maize weevil, *Sitophilus zeamais* Motschulsky. On July 15, 1992, 10 pairs of maize weevils were released into each drum. Three weeks later, *A. calandrae* were released in half the treatment drums (4 replicates) at rates of 5, 10, 20 or 40 pairs. No further *A. calandrae* were released in these drums. At the same time, releases of *A. calandrae* were begun in the other treatment drums at rates of 2, 5, 10 or 20 pairs and continued at these rates for 29 weeks. Insect populations were sampled four times during the experimental period: at 8, 14, 23 and 33 weeks. In control (untreated) drums and drums from single and multiple release treatments, maize weevil populations increased from 8 weeks to 33 weeks; however, populations in the controls increased much more rapidly than in either treatment. Both single release and multiple release treatments greatly suppressed maize weevil population growth. Final population counts showed that percentage suppression was over 90% in all release rates of both treatments. At high maize weevil population levels there was no significant difference between single and multiple release treatments in suppressing maize weevil populations in drums of corn.

Because of the increasing resistance of stored product insect pests to synthetic insecticides in recent decades, many scientists have been looking for alternative control measures. The maize weevil, *Sitophilus zeamais* Motschulsky, is the most damaging insect pest species of stored corn (Storey et al., 1983; Okelana and Osuji, 1984). One possible alternative for the control of this pest is the use of entomophagous insects such as the parasitoid *Anisopteromalus calandrae* (Howard) (Brower et al., 1991).

Anisopteromalus calandrae, a small pteromalid parasitoid, is distributed worldwide and is a common ectoparasitoid of the larvae and pupae of many beetles found within stored grain kernels (e.g., Chatterji, 1955; Ghani and Sweetman, 1955; Okamoto, 1971; van den Assem et al., 1984). Smith (1992) reported that the estimate of finite rate of increase for this parasitoid is larger than those of its major hosts, *Sitophilus oryzae* (L.) and *S. zeamais*. This suggests that *A. calandrae* may be able to suppress populations of these weevils. *Anisopteromalus calandrae* was a more effective and dominant parasitoid in corn when competing with *Choetospila elegans* Westwood, another pteromalid parasitoid of the maize weevil (Wen et al., 1994). Laboratory tests have demonstrated that *A. calandrae* has the potential to control the maize weevil in corn (Williams and Floyd, 1971) and the rice weevil in wheat (Press et al., 1984; Cline et al., 1985; Press, 1992). Arbogast and Mullen (1988) studied the population dynamics of a natural population of

A. calandreae and its host, the maize weevil, in a large quantity of shelled corn. This research indicated that in a natural infestation the rate of parasitism responded to changes in host density but lagged behind the host population. They suggested releasing sufficient numbers of this parasitoid early in the storage period to suppress the initial buildup of weevil populations, and that for long storage, additional introductions would be required to prevent weevil populations from rebounding once the parasitoid population declined. However, there are no reports on the effects of multiple releases of *A. calandreae* over a period of time on control of host populations. The purpose of the present research was to compare single releases of *A. calandreae* with multiple releases into shelled corn in drums. Comparisons between single versus multiple releases and to untreated controls were made to determine whether this parasitoid can suppress maize weevil populations in this storage condition and whether or not multiple releases are needed.

Materials and Methods

The maize weevils were originally collected from stored corn in South Carolina and reared in the laboratory for about 12 generations in corn. Maize weevil adults four to five weeks old were used to start the experiment. Stock cultures of *A. calandreae* were maintained at $28 \pm 0.5^\circ\text{C}$ and $60 \pm 5\%$ RH in the laboratory on the rice weevil, *S. oryzae*, reared in wheat for more than four years. Newly emerged to 3-day-old *A. calandreae* adults were obtained for release by aspirating from stock cultures.

The test was conducted in an unheated, insulated, metal shed. Cylindrical fiberboard drums (72 cm high \times 38.5 cm inside diameter) with metal covers were used as storage containers for this test. Each drum was filled with 45.36 kg (100 lbs) of corn which had been cleaned and disinfested by phosphine fumigation and then held in cold storage at -4°C , >2 month. After the corn was equilibrated to ambient shed temperature (about 30°C) for two days, ten pairs of four to five week-old sexed maize weevil adults were added to the middle of each grain mass in each drum by using a long glass tube, and the drums were then covered with metal tops. Ten pairs of weevils were used to ensure a high level of infestation and to accentuate differences between treatments. The moisture content of the corn after equilibration was $14.2 \pm 0.1\%$. Twenty-one days after maize weevil infestation, *A. calandreae* adults were first introduced into the drums. There were two categories of release: a single release and multiple releases. For the single release, *A. calandreae* were released on August 4, 1992 (at 3 weeks) at rates of 5, 10, 20 or 40 pairs. For the multiple releases, *A. calandreae* were released weekly from August 4, 1992 (3 wk) to February 16, 1993 (32 wk), at the weekly release rates of 2, 5, 10 or 20 pairs. Each release rate of each type was replicated four times. Four drums without released parasitoids were to serve as untreated controls. However, one of the control drums was contaminated by *A. calandreae* during the course of the experiment, so only three drums were used as controls in the analyses.

During the test period, insect populations were sampled on September 8 (8 wk), October 20 (14 wk), December 15, 1992 (23 wk), and February 23, 1993 (33 wk) by using a sampling probe constructed from PVC plastic pipe that was 60 cm long with an inside diameter of 5 cm. Corn was retained in the probe by plastic whiskers inserted into the pipe near the bottom. Each time, about 0.75 liters of corn were obtained from each of two locations in the drum and these samples

were combined. The combined samples were sifted immediately over a sieve with an opening of 4.75 mm in diameter and dust and insects were removed. Live and dead maize weevil adults and live parasitoid adults were counted. The samples were then incubated at 30°C and 65% RH for four weeks. During incubation, the samples were sifted weekly to remove and count emerged maize weevils and parasitoids. When the test was finished, the drums of corn were fumigated with phosphine and the entire contents of each drum were passed through a "Cargo Type Divider" to obtain a representative sample of 6 liters of corn from each drum. The samples were sifted and the dead maize weevils were counted. Then a one liter volumetric sub-sample was taken from each divider sample after thorough mixing, and the weight of each sub-sample was recorded to assess direct damage to the corn from feeding of the maize weevil. For comparison, the weight of uninfested corn from the same source as the experimental corn was recorded using the same method as above.

Data were analyzed using the General Linear Model (GLM) Procedure (SAS Institute, 1988). Orthogonal contrasts (also GLM) were used to determine differences in maize weevil numbers and corn weight per liter between controls vs. treatments, and single release treatments vs. multiple release treatments. The numbers of maize weevils in the single 5, 10, 20 pairs parasitoid releases and the multiple 5, 10, 20 pairs parasitoid releases were compared using an analysis of variance (ANOVA) (SAS Institute, 1988). Lack of fit was used to test model fitness (Draper and Smith, 1981).

Results

Temperature: During the test period, temperature in the experimental shed changed seasonally, and all drums were exposed to nearly identical conditions. In July and August, the high daily temperatures averaged 35.2 and 32.4°C, the low daily temperatures averaged 26.6 and 25.3°C. In January and February, temperature dropped to highs of 15.2 and 18.4, and lows of 8.0 and 10.7°C.

Insects in probe samples: Counts of live maize weevil adults from the first siftings are shown in Table 1. At 8 weeks, no live maize weevil adults were found either in samples from treatment drums or control drums. Maize weevil populations were for the most part present as immatures and therefore undetectable in the 1.5 liter samples. Even by the second sampling date (14 wk), the density of adult maize weevils was low, and only a few live adults were found in either treatment or control drum samples. Subsequently, maize weevil populations increased rapidly in the three useable control drums, with an increase of 280 times from 14 weeks to 33 weeks, to produce very heavy infestation levels. Treatment populations increased much more slowly.

Orthogonal contrasts were performed only on the data of 23 and 33 weeks because there were few live maize weevil adults in either treatments or controls at 14 weeks. The average number of live maize weevil adults was significantly different in controls vs. treatments at 23 weeks ($F = 21.42$; d.f. = 1, 26; $P = 0.0001$) and again at 33 weeks ($F 90.96$; d.f. = 1, 26; $P = 0.0001$). However, there were no significant differences between single release treatments and multiple release treatments at either 23 weeks ($F = 0.89$; d.f. = 1, 26; $P = 0.3531$) or 33 weeks ($F = 0.18$; d.f. = 1, 26; $P = 0.6736$). Comparing single release 5, 10 and 20 with multiple release 5, 10 and 20, respectively, also there were no significant

Table 1. Live maize weevil numbers (\pm SE)* from the initial sift of 1.5 liter probe samples from drums of corn with single or multiple releases of *Anisopteromalus calandrae*.

Treatment	Sampling date		
	(14 weeks) Oct. 20, 1992	(23 weeks) Dec. 15, 1992	(33 weeks) Feb. 23, 1993
Control	1.3 \pm 0.8	31.7 \pm 6.0	367.0 \pm 122.0
Single release			
5 Pairs	2.0 \pm 1.7	16.3 \pm 12.7	34.5 \pm 20.9
10 Pairs	0.8 \pm 0.3	4.8 \pm 4.1	25.5 \pm 15.7
20 Pairs	0.0 \pm 0.0	1.5 \pm 0.7	6.0 \pm 3.1
40 Pairs	0.3 \pm 0.3	2.0 \pm 1.7	5.8 \pm 1.9
Multiple release			
2 Pairs	0.3 \pm 0.3	3.5 \pm 1.3	11.8 \pm 3.9
5 Pairs	0.3 \pm 0.3	2.8 \pm 0.6	7.8 \pm 1.3
10 Pairs	0.5 \pm 0.5	4.0 \pm 1.7	11.0 \pm 3.7
20 Pairs	0.0 \pm 0.0	1.3 \pm 0.8	4.3 \pm 2.0

* Live maize weevil numbers sampled on Sep. 8 (at 8 weeks) were zero in all treatments and in controls.

differences (ANOVA: d.f. = 1, 6; $P > 0.25$). The effect of increasing parasitoid numbers released on live maize weevil numbers was analyzed by regression against parasitoid number for single release and multiple release treatments on each sampling date. The regressions were both non-significant ($P > 0.18$).

The numbers of live *A. calandrae* in the initial sifting of the 1.5 liter corn-probe samples from the single release treatments are shown in Table 2. Even 33 weeks after the parasitoids' release, there were still live parasitoids present in the drums. The numbers of live *A. calandrae* recovered did not depend on the number of released parasitoids on any sampling date ($P > 0.12$). However, from the first to the third sampling dates there was an increasing trend in live parasitoid numbers, but at 33 weeks the parasitoid numbers had decreased in all treatments. For example, at 23 weeks, in the five pairs release rate, an average of 5 live parasitoids were found in each drum, while at 33 weeks, there were just 0.8 parasitoids. The decrease in live parasitoid numbers between 23 and 33 weeks was significant ($F = 18.73$; d.f. = 1, 60; $P = 0.0001$).

This decrease was probably due to the effects of low temperatures on parasitoid reproduction. In January and February, the average temperature was below 15°C. Smith (1992) reported that the finite rate of increase for *A. calandrae* at 20°C was 1.028, which is near the lower limit of positive population growth. In this study, we did not report the number of live parasitoids from the first sift of multiple release treatments because we could not distinguish between parasitoids that were released and their progeny. According to Smith (1992), at 30 and 35°C, female *A. calandrae* only survive an average of 6 days; however, at lower temperatures, they would live longer. In single release treatments at 33 weeks, more than half a year after parasitoid introduction, there were still live parasitoid adults. This suggests that *A. calandrae* became established with single releases in the treatment drums and populations persisted throughout the test period.

Maize weevil populations from incubation: After 4 weeks of incubating the probe samples obtained at 8 weeks there were no live maize weevil adults in

Table 2. Numbers (\pm SE) of live *A. calandreae* from the initial sift of 1.5 liter corn samples from drums with a single parasitoid release.

Treatment	Sampling date			
	(8 weeks) Sep. 8, 1992	(14 weeks) Oct. 20, 1992	(23 weeks) Dec. 15, 1992	(33 weeks) Feb. 23, 1993
5 Pairs	0.5 \pm 0.5	1.8 \pm 0.6	5.0 \pm 1.4	0.8 \pm 0.5
10 Pairs	0.3 \pm 0.3	1.3 \pm 1.3	4.5 \pm 1.5	1.3 \pm 0.6
20 Pairs	0.8 \pm 0.5	0.5 \pm 0.3	1.8 \pm 0.5	0.3 \pm 0.3
40 Pairs	0.8 \pm 0.3	0.8 \pm 0.5	2.3 \pm 1.3	0.8 \pm 0.5

samples from either treatment or control drums. At 14 weeks, there were only a few live maize weevil adults except in the control and the single release of five pairs (Table 3). However, the live maize weevil population increased greatly between 14 and 23 weeks and again between 23 and 33 weeks (Table 3). After four weeks of incubation, adult emergence from 23 week and 33 week samples averaged 566.3 and 1900.0, respectively (Table 3). Maize weevil numbers in controls vs. treatments were significantly greater at 14 weeks ($F = 6.24$; d.f. = 1, 26; $P = 0.02$), at 23 weeks ($F = 290.14$; d.f. = 1, 26; $P = 0.0001$) and again at 33 weeks ($F = 149.31$; d.f. = 1, 26; $P = 0.0001$). However, differences between single release treatments and multiple release treatments were not significant at 14 weeks ($F = 1.56$; d.f. = 1, 26; $P = 0.22$), at 23 weeks ($F = 0.19$; d.f. = 1, 26; $P = 0.66$) or at 33 weeks ($F = 0.09$; d.f. = 1, 26; $P = 0.77$). At the same release rate, also no significant difference existed between single release and multiple release (ANOVA: d.f. = 1, 6; $P > 0.10$). For both the single release treatments and the multiple release treatments on any given sampling date, regressions for increasing parasitoid release rate did not show a significant decrease ($P > 0.16$) in the numbers of live maize weevils emerging.

From probe samples, after four weeks of incubation, the number of maize weevils that emerged during the incubation period was much higher than the

Table 3. Live maize weevil numbers (\pm SE) from incubation of the 1.5 liter probe samples of corn.*

Treatment	Sampling date		
	(14 weeks) Oct. 20, 1992	(23 weeks) Dec. 15, 1992	(33 weeks) Feb. 23, 1993
Control	23.3 \pm 4.3	566.3 \pm 63.8	1900.0 \pm 463.6
Single release			
5 Pairs	22.3 \pm 18.4	56.0 \pm 28.6	182.3 \pm 99.8
10 Pairs	4.3 \pm 1.4	63.5 \pm 48.6	154.8 \pm 98.7
20 Pairs	0.3 \pm 0.3	10.3 \pm 4.9	33.5 \pm 14.0
40 Pairs	1.0 \pm 0.4	11.8 \pm 4.7	29.0 \pm 12.0
Multiple release			
2 Pairs	2.5 \pm 1.5	35.8 \pm 11.8	86.5 \pm 28.7
5 Pairs	1.5 \pm 0.9	41.5 \pm 18.6	83.5 \pm 31.8
10 Pairs	1.3 \pm 0.3	13.0 \pm 6.2	61.5 \pm 18.1
20 Pairs	0.0 \pm 0.0	19.0 \pm 9.0	63.0 \pm 34.6

* Live maize weevil numbers from incubation sampled on Sep. 8, 1992 (at 8 weeks) were zero in all treatments and in controls.

Table 4. Maize weevil numbers (\pm SE) from 6 liter samples obtained with a Cargo Divider and the percentage suppression (%) of maize weevil by *A. calandrae*.

Treatment	No. of maize weevils	Percentage suppression
Control	10,374.7 \pm 2020.6	—
Single release		
5 Pairs	1005.0 \pm 234.4	90.31 \pm 2.15
10 Pairs	953.0 \pm 373.4	90.81 \pm 3.60
20 Pairs	440.0 \pm 95.8	95.76 \pm 0.57
40 Pairs	397.5 \pm 40.6	96.17 \pm 0.39
Multiple release		
2 Pairs	769.8 \pm 72.5	92.58 \pm 0.70
5 Pairs	635.8 \pm 106.2	93.87 \pm 1.02
10 Pairs	445.0 \pm 61.5	95.71 \pm 0.59
20 Pairs	439.8 \pm 107.8	95.76 \pm 1.04

count of adults from initial sifting. Because all the maize weevil adults were removed before the samples were incubated, the high numbers that emerged during incubation indicated that a large proportion of the maize weevil population was in an immature stage.

Cargo Divider samples: Total maize weevil population numbers from 6-liter representative samples obtained with a Cargo Divider were determined after fumigation. This sample consolidated all living and dead adult weevils into the dead category. The numbers of maize weevils from divider samples were greater proportionately than the numbers from the smaller probe samples (Table 4). The number of maize weevils in the controls was significantly greater than those in the treatments (contrast: $F = 247.80$; d.f. = 1, 26; $P = 0.0001$), and the percentage suppression in every case was over 90% (Table 4). The contrast between single release treatments and multiple release treatments was again not significant ($F = 0.16$; d.f. = 1, 26; $P = 0.69$). Also, no significant difference was detected between single release 5, 10, 20 and multiple release 5, 10, 20, respectively (ANOVA: d.f. = 1, 6; $P > 0.11$). For maize weevil numbers sifted from divider samples, linear regressions against parasitoid density were significant ($P < 0.05$). For single releases, with the increase in parasitoid release rates, the total maize weevil numbers decreased significantly. This relationship can be expressed as $Y = 1042.5 - 18.3X$ (Y is the maize weevil numbers, and X is the number of parasitoid pairs; $F = 5.13$; d.f. = 1, 14; $P = 0.04$; lack of fit: $F = 0.77$; d.f. = 2, 12; $P = 0.48$). For multiple releases, total maize weevil numbers also decreased linearly, and this can be expressed as $Y = 732.13 - 17.3X$ (Y is the maize weevil numbers, and X is the number of parasitoid pairs; $F = 6.65$; d.f. = 1, 14; $P = 0.02$; lack of fit: $F = 1.33$; d.f. = 2, 12; $P = 0.30$).

In this experiment, we used two different sampling methods: a nondestructive sampling probe and a destructive sample by Cargo Divider. The last probe sampling was conducted two days before we fumigated the corn and sampled each drum with the Cargo Divider. Thus, the numbers of maize weevils per liter from the last probe sampling and the divider sampling might have been expected to be similar. However, they were quite different. A similar relationship occurred in both treatment groups and the check. This may have resulted because a large

Table 5. Weight in grams per liter of corn (\pm SE) from Cargo Divider samples.*

Release rate	Weight (g) per liter corn	
	Single release	Multiple release
0	580.2 \pm 34.4a	—
2	—	707.4 \pm 3.4b
5	705.5 \pm 9.0b	723.8 \pm 4.3b
10	712.7 \pm 11.2b	708.2 \pm 9.4b
20	725.9 \pm 7.3b	723.7 \pm 7.6b
40	725.8 \pm 2.4b	—

* Corn not infested with *Sitophilus zeamais* with no release of parasites weighed on average 749.6 \pm 3.7 g/liter.

percentage of the adult weevils in the drums were dead and these dead weevils tended to accumulate at the bottom of the drums. Although the probe reached the bottom of the drum, it could not retrieve corn or dead weevils from just above the bottom of drums where most maize weevils were concentrated, especially dead ones.

Although the estimations of weevil population suppression from divider samples were very high (all were over 90%), the density of maize weevils in the treatments was also high (Table 4). However, most of the maize weevils were either already dead or from the bottom layer of the drums, as indicated by the difference in live maize weevil numbers from the last probe sample and total maize weevils from the divider sample. This suggests that in this test *A. calandreae* may have been less effective in controlling the maize weevil in the bottom of the drums perhaps because of the dust and debris in the bottom that limited the ability of *A. calandreae* to penetrate to the bottom of the drum. Thus, if we can remove dust and debris before releasing *A. calandreae*, the effectiveness of *A. calandreae* might be increased.

Effects on corn quality: In order to obtain a measure of the corn damage caused by the heavy infestation of maize weevils, we took one liter volumetric subsamples from each divider sample and determined the corn weight after insects and frass were removed (Table 5). In uninfested control samples the undamaged corn weighed 749.6 g/liter, and in controls, it was 580.2 g/liter. In contrast, even the lowest weight per liter from a treatment (five pairs—single release) was 705.5 g/liter. Corn from the single release treatments averaged 717.4 g/liter and corn from the multiple releases averaged 715.8 g per liter. Thus, the control samples lost 19% more by weight than did treatment samples and the difference between controls vs. treatments was significant ($F = 109.11$; d.f. = 1, 26; $P = 0.0001$). Again, there were no significant differences between single release treatments and multiple release treatments in the amount of weight lost (contrast: $F = 0.04$; d.f. = 1, 26; $P = 0.83$). No significant regressions of sample weight against release rates for either single or multiple release treatments were found ($P > 0.12$). However, corn weight from single and multiple release treatments was significantly lower than that from uninfested corn because of the high infestation levels used in this test.

Discussion

No regressions of increasing parasitoid release rates on maize weevil numbers from probe samples were significant. This indicates that there was only minimal

effect due to the increasing numbers of parasitoids; however, total maize weevil numbers obtained from the larger divider samples decreased linearly with an increase in number of parasitoids released in both single release and multiple release treatments. The reason for this difference between probe samples and divider samples is probably that the smaller probe samples had larger variations in maize weevil numbers within treatments that prevented detection of significant regressions.

The contrasts between single release vs. multiple release treatments at any sampling date and with both sampling methods were not significant. Comparing the same release rate between single release and multiple release, respectively, no significant difference existed either. This indicates that a single release and multiple release suppressed maize weevil populations equally in this situation. This happened because in single release treatments, *A. calandrae* established a sustained population in the drums, and several generations of progeny produced in the single release mimicked the effect of multiple releases. Also, multiple releases could cause more superparasitism, which could decrease the emergence of *A. calandrae*. In addition, intraspecific competition of *A. calandrae* is very strong (Wen et al., 1994), and multiple releases, especially at the higher release rates, probably caused greater interference that reduced the effectiveness of *A. calandrae*. So we conclude that in this situation, a single release of *A. calandrae* was enough to suppress but not eliminate a large maize weevil population. However, because the storage period in this research was not extremely long, additional releases might be required when the storage period is very long, but releasing once a week is probably too often.

Acknowledgments

The authors would like to thank T. Foard and J. Graham, biological technician and teacher intern, for technical assistance during this project, Dr. Victor Chew (USDA-ARS, University of Florida, Gainesville, FL) for statistical advice, and Drs. Lincoln Smith and E. Paul Wileyto (Stored-Product Insects Research and Development Laboratory, USDA-ARS, Savannah, GA), Dr. Dennis W. Keever (USDA-ARS Crops Research Laboratory, Oxford, NC) and Dr. J. Howard Frank (Department of Entomology & Nematology, University of Florida, Gainesville, FL) for reviewing an earlier version of the manuscript.

Literature Cited

- Arbogast, R. T., and M. A. Mullen. 1990. Interaction of maize weevil (Coleoptera: Curculionidae) and parasitoid *Anisopteromalus calandrae* (Hymenoptera: Pteromalidae) in a small bulk of stored corn. *J. Econ. Entomol.* 83:2462-2468.
- Brower, J., R. Parker, and R. Cogburn. 1991. Biologicals: insect diseases, insect parasites, and predators. In G. Cuperus, V. Krischik, and H. Bahn (eds.), *Management of Grain, Bulk Commodities, and Bagged Products*, Chapter 29, pp. 195-200. Cooperative Extension Service Publication E912. 204 pp.
- Chatterji, S. 1955. Studies on the biology of *Aplastomorpha calandrae* Howard (Insecta: Hymenoptera: Chalcidae) parasitic on some storage pests. *Proc. Zool. Soc., Bengal* 8:11-23.
- Cline, L. D., J. W. Press, and B. R. Flaherty. 1985. Suppression of the rice weevil, *Sitophilus oryzae* (Coleoptera: Curculionidae), inside and outside of burlap, woven polypropylene, and cotton bags by the parasite wasp, *Anisopteromalus calandrae* (Hymenoptera: Pteromalidae). *J. Econ. Entomol.* 78:835-838.

- Draper, N. R., and H. Smith. 1981. Applied Regression Analysis, pp. 33-40. John Wiley & Sons, New York.
- Ghani, M. A., and H. L. Sweetman. 1955. Ecological studies on the granary weevil parasite, *Aplastomorpha calandrae* (Howard). *Biologia* 1:115-139.
- Okamoto, K. 1971. The synchronization of the life cycles between *Callosobruchus chinensis* (L.) and its parasite *Anisopteromalus calandrae* (Howard). *Jpn. J. Ecol.* 20:233-237.
- Okelana, F. A., and N. C. Osuji. 1984. Influence of relative humidity at 30°C on the oviposition, development and mortality of *Sitophilus zeamais* Motsch. (Coleoptera: Curculionidae) in maize kernels. *J. Stored Prod. Res.* 21:13-19.
- Press, J. W. 1992. Comparative penetration efficacy in wheat between the weevil parasitoids *Anisopteromalus calandrae* and *Choetospila elegans* (Hymenoptera: Pteromalidae). *J. Entomol. Sci.* 27:154-157.
- Press, J. W., L. D. Cline, and B. R. Flaherty. 1984. Suppression of residual populations of the rice weevil, *Sitophilus oryzae*, by the parasitic wasp, *Anisopteromalus calandrae*. *J. Georgia Entomol. Soc.* 19:110-113.
- SAS Institute. 1988. SAS/STAT User's Guide, release 6.04. SAS Institute, Cary, N.C.
- Smith, L. 1992. Effect of temperature on life history characteristics of *Anisopteromalus calandrae* (Hymenoptera: Pteromalidae) parasitizing maize weevil larvae in corn kernels. *Environ. Entomol.* 21:877-887.
- Storey, C. L., D. B. Sauer, and D. Walker. 1983. Insect populations in wheat, corn, and oats stored on the farm. *J. Econ. Entomol.* 76:1323-1330.
- van den Assem, J., F. A. Putters, and T. C. Prins. 1984. Host quality effects on sex ratio of the parasitic wasp *Anisopteromalus calandrae* (Chalcidoidea, Pteromalidae). *Neth. J. Zool.* 34:33-62.
- Wen, B., L. Smith, and J. H. Brower. 1994. Competition between *Anisopteromalus calandrae* and *Choetospila elegans* at different parasitoid densities on immature maize weevil in corn. *Environ. Entomol.* 23:367-373.
- Williams, R. N., and E. H. Floyd. 1971. Effect of two parasites, *Anisopteromalus calandrae* and *Choetospila elegans*, upon populations of the maize weevil under laboratory and natural conditions. *J. Econ. Entomol.* 64:1407-1408.