Knockdown, Mortality, and Progeny Production of Lesser Grain Borers (Coleoptera: Bostrichidae) and Rice Weevils (Coleoptera: Curculionidae) Exposed for Short Intervals on Wheat Treated with Cyfluthrin

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ABSTRACT Adult lesser grain borers, *Rhyzopertha dominica* (F.), and adult rice weevils, *Sitophilus oryzae* (L.), were exposed at bimonthly intervals for 2, 4, 8, and 24 h on wheat treated with 0, 1, 2, and 4 ppm cyfluthrin EC, then removed and held for 2 wk on untreated wheat. The percentage of lesser grain borers that were knocked down after they were exposed increased as exposure interval and concentration increased, and was usually >90% at intervals >4 h for 8 mo after the wheat was treated. Mortality after 2 wk on untreated wheat generally decreased as residues aged, with no difference in mortality among exposure intervals. F_1 production of lesser grain borers was low in untreated controls, so effect of exposure could not be determined. The percentage of rice weevils that were knocked down after exposure also increased as exposure interval and concentration increased; however, except for month 0, mortality after 2 wk on untreated wheat was usually <25% for all bioassays on wheat treated with 1 and 2 ppm cyfluthrin. Although the number of F_1 rice weevils was dependent on initial exposure interval and concentration, the exposure intervals were not sufficient to prevent oviposition. Progeny production also increased as the residues aged. Results of this study indicate that lesser grain borers and rice weevils will survive if exposed for 24 h or less on wheat treated with cyfluthrin EC.

KEY WORDS *Rhyzopertha dominica, Sitophilus oryzae*, wheat, borer, weevil, cyfluthrin

THE LESSER GRAIN borer, *Rhyzopertha dominica* (F.), and the rice weevil, *Sitophilus oryzae* (L.), are major cosmopolitan pests of stored wheat. The female lesser grain borer lays eggs on the surface of the wheat kernels, and the 1st instars bore into the kernels after hatching. The female rice weevil oviposits directly into the kernel. The larvae of both species complete development inside the kernel and emerge as adults. Once an infestation is detected, fumigation with phosphine is often necessary to eliminate the infestation. However, in situations where it may be difficult to effectively fumigate a particular storage environment, wheat may be treated with a protectant insecticide to prevent lesser grain borers and rice weevils from becoming established.

Currently there are few insecticides labeled in the United States for use on stored wheat. The organophosphate insecticide chlorpyrifos-methyl is labeled for direct application to stored wheat at the rate of 6 ppm. Malthion was extensively used in the past and although formulations are still available it is not being supported for reregistration. Other labeled products include new formulations of inert dusts (diatomaceous earths) but these chemicals are used primarily as surface treatments on stored grains.

Stored-product beetles usually infest wheat after it is stored, and these infestations are often concentrated in the top surface of the grain mass (Keever 1983; White and Loschiavo 1986; Hagstrum 1987, 1989). Therefore, treating the upper layers of the grain mass has been proposed to reduce the amount of insecticide applied and the costs involved with treating the entire grain mass. Field research data for this concept is limited. However, results from 1 study (Reed et al. 1993) with chlorpyrifos-methyl showed that a delayed application to the grain surface reduced insect densities, but did not lower economic costs compared with treating the entire grain mass at binning.

If malathion is removed from the postharvest market, chlorpyrifos-methyl will be the only conventional grain protectant labeled in the United States for stored wheat. The product label does not specify control of the lesser grain borer because of problems that have developed through reduced susceptibility and insecticide resistance (Zettler and Cuperus 1990, Guedes et al. 1996). Pyrethroids are used as grain protectants in other parts of the world, and although none are currently registered in the United States, cyfluthrin is an effective protectant for stored wheat (Arthur 1994) and is being considered for registration by Gustafson,

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Incorporated, Plano, TX. Cyfluthrin is currently labeled as an empty bin treatment.

In situations where grain is partially treated with insecticide, pest insects such as the lesser grain borer and the rice weevil may have the opportunity to survive if the exposure interval is not long enough to cause mortality. The objectives of this study were to determine for both species survival after exposure at 24-h intervals or less on wheat treated with several application rates of cyfluthrin, recovery after exposure, efficacy of aged residues, and suppression of F_1 progeny.

Materials and Methods

Cyfluthrin EC (emulsifiable concentrate, Tempo, 23% [AI]) was obtained from Gustafson and refrigerated at 4°C for ≈4 mo until used for the test. On 26 August 1996, solutions of 1 ppm cyfluthrin were formulated in 4 replicate 5-ml volumetric flasks with tap water, and each solution was used to spray a 1-kg replicate of Karl variety hard red winter wheat at the rate of 0.7 ml of formulated solution per 1-kg replicate. This rate is equivalent to 18.9 liter of formulated chlorpyrifos-methyl per 27,273 kg (5 gallons per 1,000 bushels), which is the spray volume specified on the insecticide label. The wheat was clean and contained very little dockage. Individual replicates were treated by spreading the wheat on the bottom surface of a plywood box (0.62 by 0.31 by 0.31 m) that was open in the front, and using a Badger 100 artists' airbrush (Franklin Park, IL) to mist the solution directly onto the wheat. An untreated control replicate was sprayed with tap water. Solutions of 2 and 4 ppm cyfluthrin were formulated and applied in the same manner on 27 and 28 August, and each concentration included an untreated control. After the wheat was treated, each 1-kg replicate was placed in a 0.95-liter plastic food container with holes punched in the lids. Humidity chambers were created by using pieces of waffle-grid type insulation cut to fit the bottom of a plastic box (26 by 36.5 by 15 cm) that contained 500 ml saturated NaCl to maintain the wheat at ≈14.5% moisture content. A separate box was used for each of the 3 concentrations and the untreated control, and all of the boxes were placed in an incubator set at 27°C.

The day after the wheat was treated (month 0), each of 10 vials (20 ml each) were filled with 18 g of wheat from each of the 4 treated replicates and the untreated control. Twenty unsexed adult lesser grain borers (1–2 wk old) were put into each of 4 treated and 1 untreated vials, and 20 adult unsexed rice weevils (1–2 wk old) were put in each of the remaining 4 treated and 1 untreated treated vials. Both sets of vials were capped with a screened lid, and held in the laboratory at 27°C and 60% RH. After exposure intervals of 2, 4, 8, and 24 h, the wheat was removed from each vial, and the beetles were collected and classified as knocked down (on their backs) or active (upright and moving). All beetles were then transferred to new vials with 18 g of untreated wheat, returned to the humidity chambers and the incubator. The process of counting and transferring the beetles took ≈5–10 min. After 2 wk, the wheat was sifted again and the beetles classified as active or dead (not visibly moving). All treated and untreated wheat was put back in the vials, which were again returned to the humidity chambers and held for an additional 8 wk to determine F_1 progeny production.

Bioassays were conducted at bimonthly intervals as described above for 8 mo. Vials were filled using wheat from each replicate and each species was exposed using the procedures described for the test at 0 mo. For each species, the number that were knocked down after the initial exposures and mortality after 2 wk on untreated wheat were converted to percentage values. Data for knockdown and mortality were analyzed using the general linear models procedure (GLM, SAS Institute 1987), with species and concentration as main effects, and exposure interval and residual bioassays as a repeated measures. Data for F_1 progeny were analyzed separately by species, with concentration as a main effect and exposure interval and residual bioassays as a repeated measure. Significant differences for knockdown, mortality, and F_1 adults among exposure intervals within each concentration were determined using the Waller–Duncan k-ratio *t*-test.

Results

The main effects species ($F = 298.8$; df = 1, 18; $P < 0.01$), concentration ($F = 41.8$; df = 2, 18; $P < 0.01$), and the repeated measures exposure interval ($F = 209.4$; df = 4, 54; $P < 0.01$) and residual bioassays ($F = 98.6$; df = 4, 72; $P < 0.01$) were significant for knockdown. At each bimonthly bioassay the percentage of lesser grain borers that were knocked down upon completion of the exposure intervals generally increased as the exposure interval increased, with little difference between concentration until month 6 (Fig. 1). With 2 exceptions, at least 90% were knocked down after they were exposed for 2, 4, 8, and 24 h on treated wheat at 0–6 mo. The percentage of lesser grain borers knocked down in the untreated controls after exposure was not significant with respect to month ($F = 1.40$; df = 4, 72; $P = 0.24$), and averaged 0.3 ± 0.2%.

At each bioassay the percentage of rice weevils that were knocked down after exposure usually increased as exposure interval and concentration increased, but was much less than the percentage knockdown for lesser grain borers, especially at the 2- and 4-h exposure intervals (Fig. 2). After month 0, knockdown on wheat treated with 1 and 2 ppm cyfluthrin did not exceed 90%, except for month 4 (24-h exposure) and generally declined with each successive bioassay, whereas knockdown on wheat treated with 4 ppm was >90% at all bioassays except for month 8 (2–4 h exposure). The number of rice weevils knocked down in the untreated controls after exposure was not significant with respect to month ($F = 1.0$; df = 4, 72; $P = 0.41$), and averaged 0.1 ± 0.1%.

Mortality of beetles 2 wk after being removed from the treated wheat and placed on untreated wheat was significant for species ($F = 83.1$; df = 1, 18; $P < 0.01$),

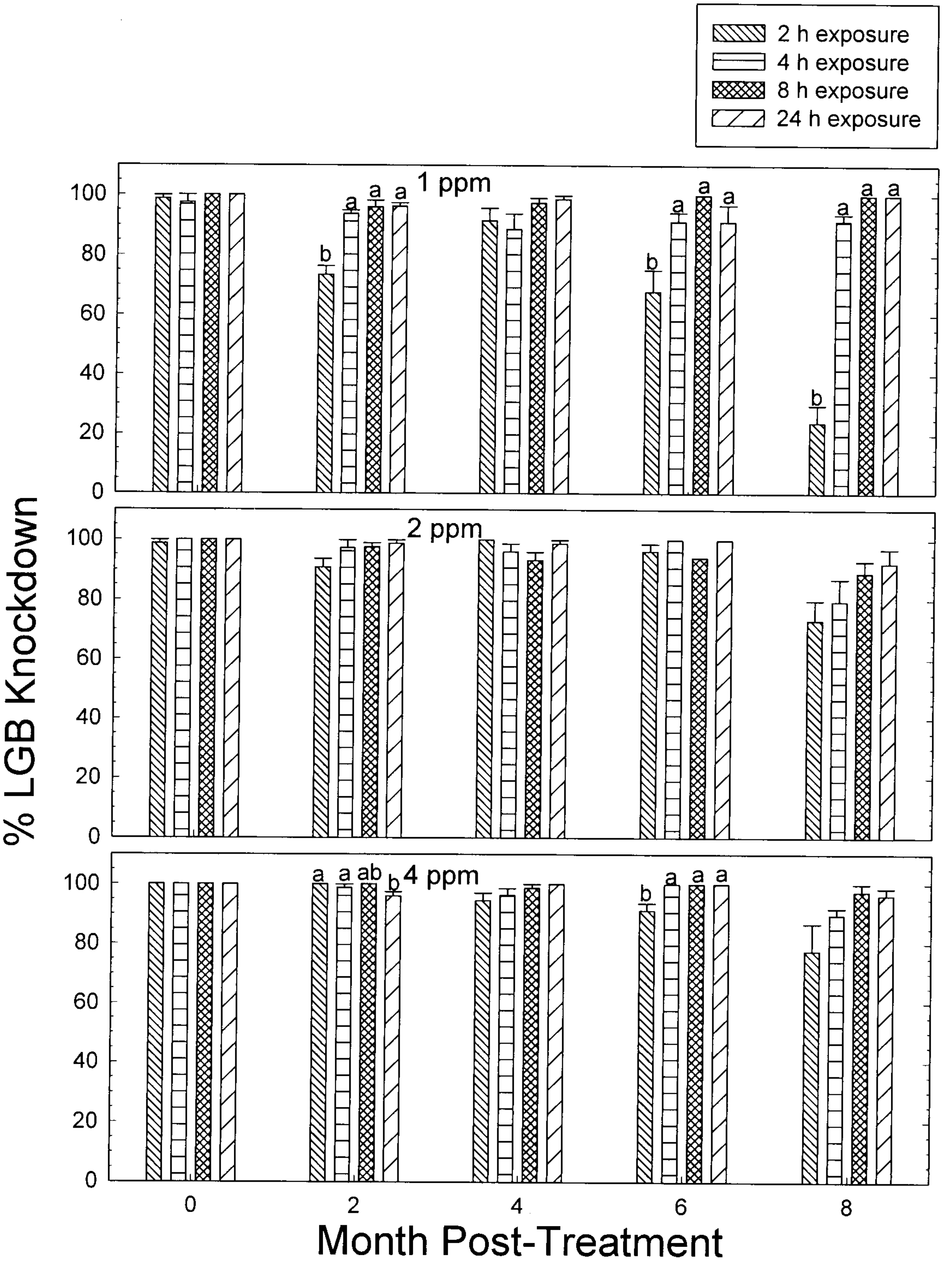

Fig. 1. Percentage of lesser grain borers (LGB, means ± SEM) knocked down after exposure for 2, 4, 8, and 24 h at bimonthly intervals on wheat treated with 1, 2, or 4 ppm cyfluthrin EC. Means between exposure intervals followed by different letters are significantly different ($P < 0.05$), Waller–Duncan k-ratio t-test.

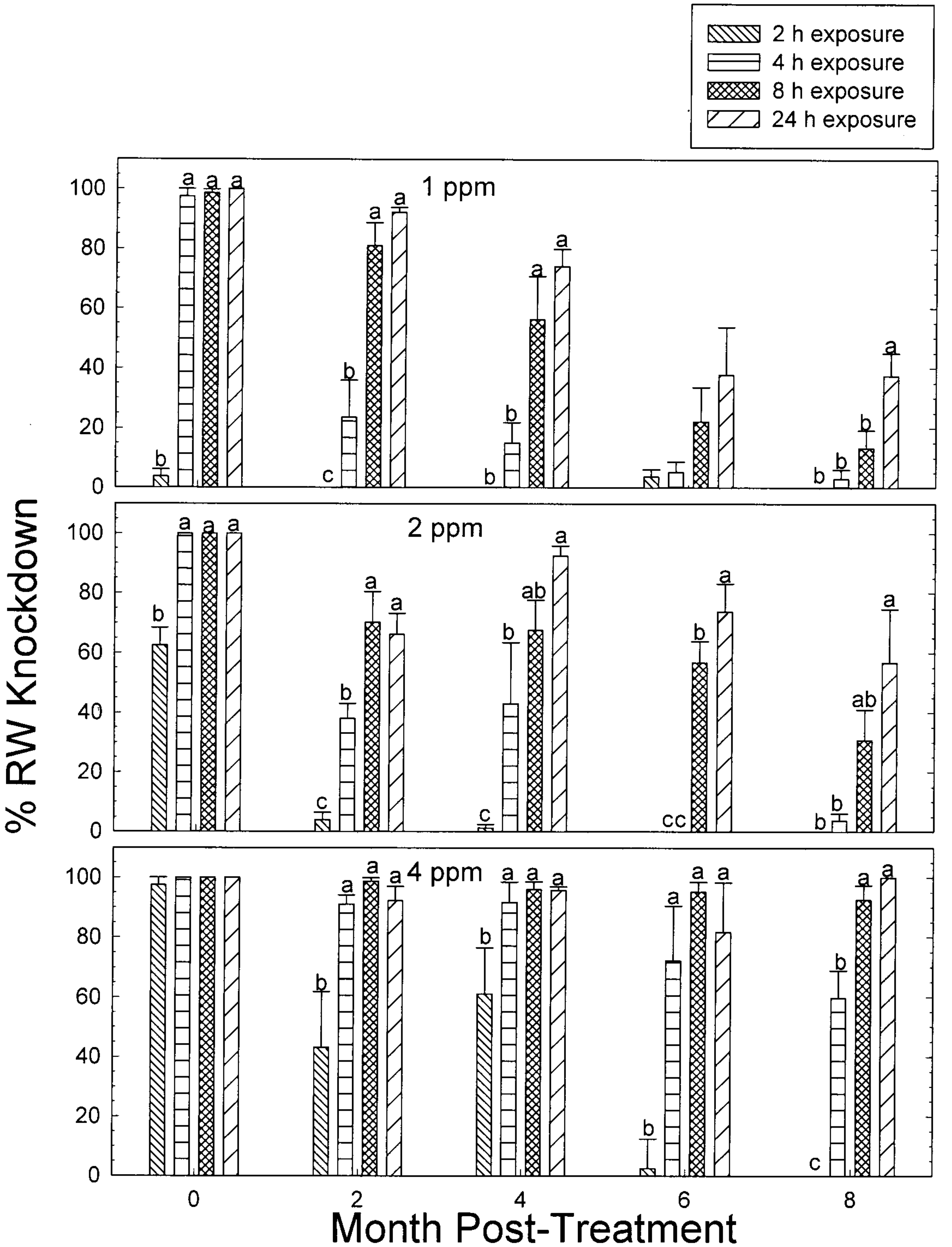

Fig. 2. Percentage of rice weevils (RW, means ± SEM) knocked down after exposure for 2, 4, 8, and 24 h at bimonthly intervals on wheat treated with 1, 2, or 4 ppm cyfluthrin EC. Means between exposure intervals followed by different letters are significantly different ($P < 0.05$).

Table 1. Percentage mortality of lesser grain borers (means ± SEM) after 2 wk on untreated wheat

ppm	Bioassay month				
	0	2	4	6	8
1	82.2 ± 2.2b	48.6 ± 5.4b	65.0 ± 4.4c	35.6 ± 3.8b	13.9 ± 2.7c
2	80.8 ± 2.9b	66.9 ± 4.4a	76.6 ± 3.8d	36.0 ± 4.7b	26.0 ± 4.7b
4	92.6 ± 2.6a	78.9 ± 5.2a	87.7 ± 3.0a	64.5 ± 5.9a	46.2 ± 4.7a

Lesser grain borers were originally exposed for 2, 4, 8, and 24 h at bimonthly intervals on wheat treated with 1, 2, or 4 ppm cyfluthrin EC. Means between exposure intervals followed by different letters are significantly different ($P < 0.05$, Waller–Duncan k-ratio *t*-test).

concentration ($F = 32.8$; df = 2, 18; $P < 0.01$), and the repeated measures exposure interval ($F = 33.3$; df = 3, 54; $P < 0.01$) and residual bioassays ($F = 287.7$; df = 4, 72; $P < 0.01$). Although the overall F value for exposure was significant for the lesser grain borer, the only combination where significance occurred ($P < 0.05$) was 4 ppm, month 8. Data were combined for exposure and analyzed for significance with respect to concentration. Mortality generally increased as concentration increased and decreased as residues aged but was usually <90% (Table 1). The percentage of dead lesser grain borers in the untreated controls after 2 wk was not significant with respect to month ($F = 0.86$; df = 4, 55; $P = 0.49$), and averaged 4.6 ± 0.6%.

Except for month 0, <20% of the rice weevils that had been exposed for 2, 4, and 8 h on wheat treated with 1 and 2 ppm were dead 2 wk after being transferred to the untreated wheat (Fig. 3). Mortality of weevils exposed on wheat treated with 4 ppm cyfluthrin ranged from 75.0 to 94.0% at month 0 and 26.7 to 73.5% at month 2, increased somewhat at month 4, then declined as residues aged, with no difference between exposure interval. Exposure interval was significantly different for some but not all of the bimonthly bioassays at each concentration. The percentage of dead rice weevils in the untreated controls after 2 wk was not significant with respect to month ($F = 0.72$; df = 4, 55; $P = 0.58$), and averaged 2.7 ± 0.6%.

The number of F_1 adults produced by lesser grain borers after they were exposed on the treated wheat was not significantly different with respect to concentration ($F = 0.61$; df = 2, 27; $P = 0.56$) and exposure interval ($F = 1.32$; df = 3, 27; $P = 0.29$) but was significantly different for residual month ($F = 17.0$; df = 4, 36; $P < 0.01$). The numbers of F_1 in the combined treatments were 0.7 ± 0.1, 1.0 ± 0.2, 0.4 ± 0.1, 3.1 ± 0.5, and 0.98 ± 0.1 at months 0, 2, 4, 6, and 8, respectively. Although F_1 production in the untreated controls was significant with respect to moth ($F = 14.4$; df = 4, 55; $P < 0.01$), the averages were only 1.5 ± 0.3, 2.5 ± 0.5, 5.1 ± 0.8, 62.5 ± 4.9, and 1.1 ± 0.3 for months 0, 2, 4, 6, and 8, respectively.

The number of F_1 adults produced by rice weevils after they were exposed on the treated wheat was significant for concentration ($F = 36.6$; df = 2, 27; $P < 0.01$), exposure interval ($F = 17.8$; df = 3, 27; $P < 0.01$), and residual month ($F = 59.9$; df = 3, 36; $P < 0.01$). The actual number of F_1s usually decreased with exposure interval and concentration, and increased as the residues aged (Fig. 4). After month 0, the number of F_1s produced by weevils exposed for 2, 4, and 8 h on wheat treated with 1 and 2 ppm cyfluthrin usually exceeded 200, but there were only 4 occasions where the number of F_1 was significant among exposure interval. F_1 production in the untreated controls was significant with respect to month ($F = 4.3$; df = 4, 55; $P < 0.01$), and averaged 143.3 ± 20.1, 257.0 ± 29.2, 245.0 ± 29.7, 211.3 ± 20.6, and 223.3 ± 12.8 for months 0, 2, 4, 6, and 8, respectively.

Discussion

Results of this study indicate that exposure intervals of 24 h or less will not control lesser grain borers or rice weevils exposed on wheat treated with cyfluthrin EC. Bengston et al. (1987) reported survival of 4% or less at various residual testing intervals for 2 field strains of rice weevils exposed for 3 d on wheat treated with 2 ppm cyfluthrin + 10 ppm piperonyl butoxide, but no F_1 progeny were produced. In the same test, some lesser grain borers were alive after 3 d of exposure but all were dead after 28 d of exposure, with no F_1 progeny. In another study using a 5-d exposure period (Arthur 1994), a maximum survival of 37.0 ± 5.0% was reported for lesser grain borers exposed at bimonthly intervals for 10 mo on wheat treated with 0.5–2.0 ppm unsynergized cyfluthrin, with no progeny production. However, some rice weevils survived exposure and produced F_1 progeny when exposed on wheat treated with 0.5 and 10 ppm, particularly during the latter months of the test.

The rice weevil is less susceptible than the lesser grain borer to pyrethroids compared with organophosphate protectants (Samson and Parker 1989, Arthur 1994), and results from this study showed that both higher application rates of cyfluthrin EC and longer exposure intervals will be required to give the same level of control for the rice weevil compared with the lesser grain borer. Pyrethroids are generally more toxic than organophosphates to the lesser grain borer, but are also more expensive to apply as protectants (White and Leesch 1996). Combination treatments of organophosphates mixed with lower rates of pyrethroids to control the lesser grain borer are used to manage stored wheat in Australia (Collins et al. 1993), but currently no combination treatments are registered in the United States.

The absence of F_1 adults in untreated controls prevent any conclusions from being made regarding the effects of exposure on the fecundity of lesser grain borers. All lesser grain borers that were transferred to untreated wheat after they were exposed on either treated or untreated wheat were held at ≈27°C and 60% RH for 8 wk. Predicted egg to adult developmental times for lesser grain borers at 27.5 and 30.0°C are 49.9 and 42.4 d, respectively (Hagstrum and Milliken 1988). Perhaps the act of removing and transferring the lesser grain borers after they were exposed delayed egg laying so that development was not completed during the 8 wk. Predicted egg to adult devel-

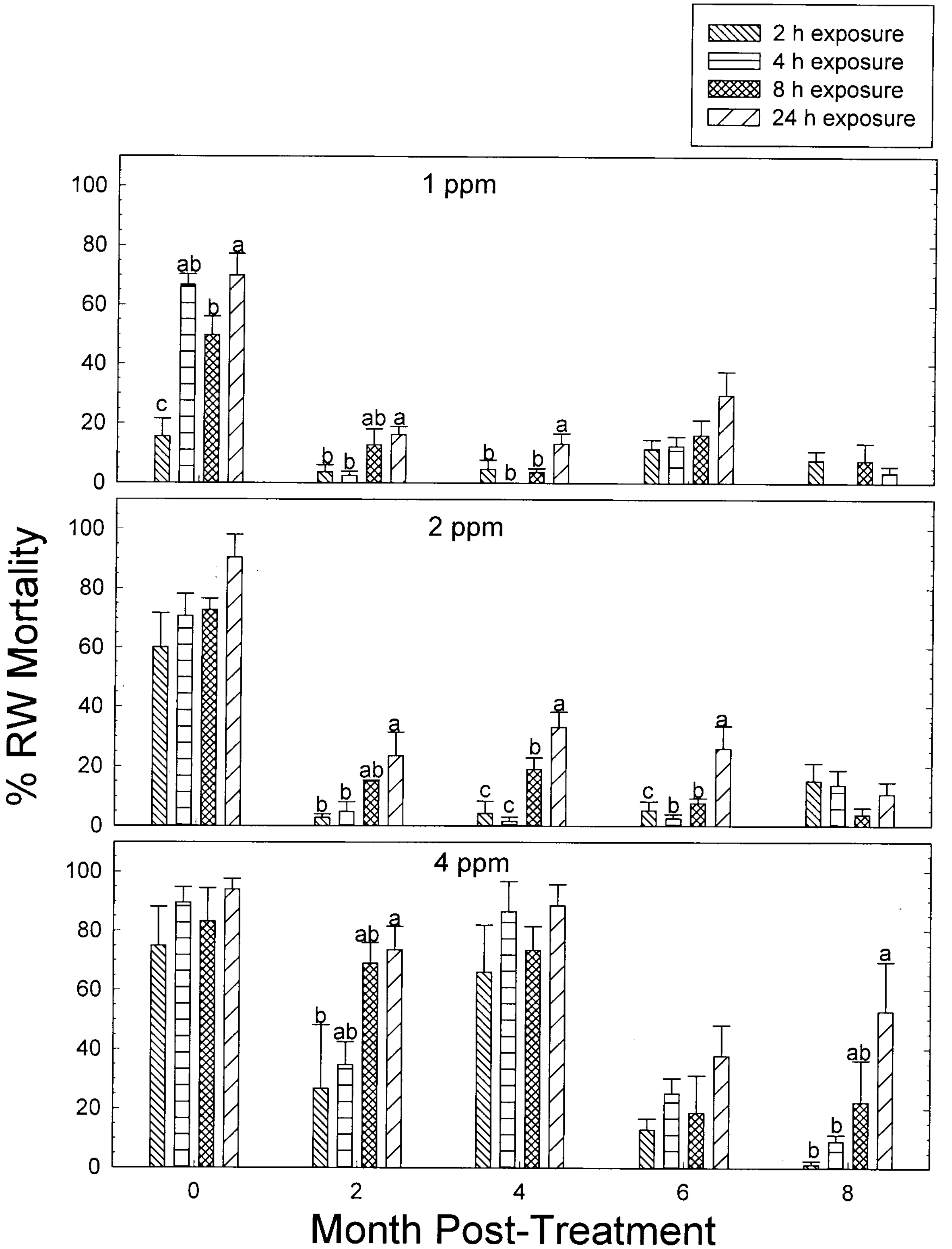

Fig. 3. Percentage mortality of rice weevils (RW, means ± SEM) after 2 wk on untreated wheat. Weevils were originally exposed for 2, 4, 8, and 24 h at bimonthly intervals on wheat treated with 1, 2, or 4 ppm cyfluthrin EC. Means between exposure intervals followed by different letters are significantly different ($P < 0.05$), Waller–Duncan k-ratio t-test.

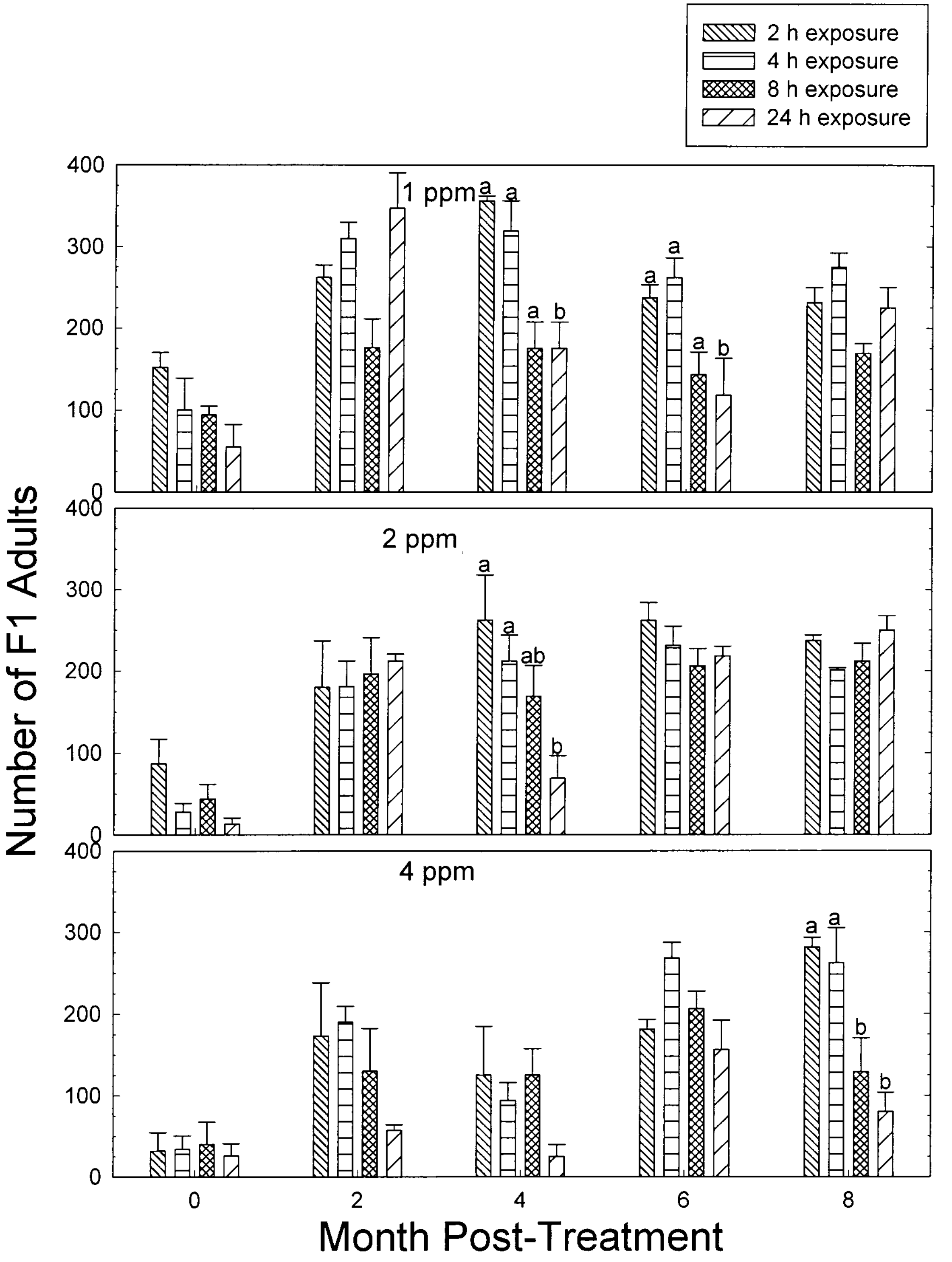

Fig. 4. Number of F_1 adults (mean ± SEM) produced by rice weevils exposed for 2, 4, 8, and 24 h at bimonthly intervals on wheat treated with 1, 2, or 4 ppm cyfluthrin EC. Means between exposure intervals followed by different letters are significantly different ($P < 0.05$), Waller–Duncan k-ratio t-test.

opmental times for rice weevils held at 27.5 and 30.0°C are 30.6 and 27.4 d (Hagstrum and Milliken 1988), and this shorter developmental period may have masked any negative effect caused by transferring the weevils after they were exposed. Weevils exposed on wheat treated with 1 and 2 ppm cyfluthrin recovered to the extent that subsequent F_1 populations were similar to those on untreated controls.

Lesser grain borers and rice weevils exposed for 24 h or less on wheat partially treated with cyfluthrin EC may survive if they are either moved from or can somehow escape the treated environment. This may not be a concern if the entire grain mass in an individual bin was treated for on-farm storage, because the beetles would be continuously exposed to the insecticidal residues. However, different sources of farm-stored wheat are usually combined when transferred to county and terminal elevators, and treated wheat can then be mixed with untreated wheat. If infestations of lesser grain borers or rice weevils occur in the elevator either from internal or external sources, the presence of untreated wheat could provide an opportunity for the insects to recover after they have been exposed to cyfluthrin.

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