Effects of Cypermethrin Exposed to Host on the Developmental Biology of *Pimpla turionellae* (Hymenoptera: Ichneumonidae)

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ABSTRACT We investigated egg-to-adult developmental time, adult longevity, adult body size, and wing and antenna length of *Pimpla turionellae* (L.) (Hymenoptera: Ichneumonidae) reared on *Galleria mellonella* L. (Lepidoptera: Pyralidae) last instars that were fed various doses of cypermethrin in diet. The impacts of cypermethrin on larval behavior, pupal weight, and last instar-to-adult developmental time of host species also were examined. Percentage of pupation at doses >20 ppm and pupal weight of *G. mellonella* decreased, whereas last instar-to-adult developmental time prolonged gradually with increasing doses of cypermethrin. Cypermethrin treatment increased the intensity of abnormal behavior and the number of host larvae on diet at 1, 2, 4, 6, and 24 h posttreatments at doses >50 ppm. The differences in egg to adult developmental time, adult body size, wing, and antenna length of *P. turionellae* were not significant. However, cypermethrin exposure significantly affected the adult longevity of female wasps. Mean longevity of cypermethrin-treated females increased significantly at all doses of insecticide tested with respect to controls except for 100 ppm. This work suggests that parasitoid species as well as its host are susceptible to cypermethrin in terms of remarkable adverse effects on biological characteristics possibly due to metabolic, hormonal, and nutritional deficiencies.

KEY WORDS immature development, host behavior, morphology, weight, longevity.

To an increasing extent, our environment is exposed to many different kinds of toxicants and pollutants. Continuous or pulse exposure to pesticides may cause serious problems for nontarget organisms such as parasitoids. Predators and parasitoids are often more sensitive to toxicants than their prey (Croft 1990, Kazmírowá and Ortel 2000, Xu et al. 2001, Büyükgüzel 2006, Sak et al. 2006, Ergin et al. 2007, Uçkan et al. 2007). Several studies have shown that insecticides applied to insect pests cause various sublethal effects on parasitoids, such as changes in development and emergence rates, and sex ratio (Krespi et al. 1991, Willrich and Boethel 2001, Saber et al. 2005) either by direct chemical contact or by ingestion of treated prey (Wells et al. 2001). As such, it is essential to understand the impact that toxicants have on biological control agents so that these species can be protected and used successfully in integrated pest management (IPM) programs. Assessment of the potential effects that pesticides have on the natural enemies in a host–parasitoid system is therefore an important part of IPM programs. Both by direct interaction with parasitoids (Özkan Yanıkoğlu 1999, Schneider et al. 2003) and indirectly through host physiology (Sak et al. 2006, Ergin et al. 2007, Medina et al. 2007, Uçkan et al. 2008), pesticides cause numerous sublethal effects on biological and physiological parameters. Pyrethroids are the most widespread used insecticides against pests (Kamrin 1997, Usmani and Knowles 2001). Cypermethrin (CYP) [(±)-α-cyano-3-phenoxybenzyl (±) cis, *trans*-3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropanecarboxylate] is a pyrethroid insecticide killing insects by disrupting normal functioning of the nervous system (Vijverberg and Van Den Bercken 1990, Cox 1996).

The solitary wasp, *Pimpla turionellae* (L.) (Hymenoptera: Ichneumonidae), is a potential biological control agent of various lepidopterous species, including the greater wax moth, *Galleria mellonella* L. (Lepidoptera: Pyralidae) (Kansu and Uğur 1984, Fisher 1987). Caterpillars of *G. mellonella* are pests in beehives because they feed on pollen and generally destroy the combs. *P. turionellae* is an idiobiont endoparasitoid that depends upon its host pupae for food and shelter. Because some host species of this parasitoid also feed on plants during larval stages, the accumulation of environmental pollutants and transmission of these compounds to their parasitoids is likely to occur (Sak et al. 2006, Ergin et al. 2007). Adult wasps also feed on plant nectar and host pupae in nature. Therefore, the major route of toxic substance intake in endoparasitic wasps is through their host (Longley and Stark 1996), and it is likely that *P. turionellae* to be exposed to insecticides used against *G. mellonella*. We have previously detected the toxic effects of cyper-

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methrin in total metabolite content in different developmental stages (Sak et al. 2006) and on larval hemocytes (unpublished data) of *P. turionellae.* Here, we aimed to determine whether feeding by a host on a sublethal cypermethrin-treated diet adversely affected the pupal weight, last instar-to-adult developmental time, and larval behavior of the host *G. mellonella* and egg-to-adult developmental time, adult longevity, adult body size, and wing and antenna length of *P. turionellae.*

Materials and Methods

Insect Rearing. *G. mellonella* original stock came from colonies kept in our laboratory at the Balıkesir University, Balıkesir, Turkey, and renewed periodically with individuals from the honeycombs maintained from beekeepers around Balıkesir, Turkey. A laboratory colony of *P. turionellae* was established from parasitized pupae of *G. mellonella* maintained from stock cultures at Çukurova University, Adana, Turkey. *P. turionellae* were mass reared on the pupae of the host, *G. mellonella* at 25 ± 1°C, 60 ± 5% RH, and a photoperiod of 12:12 (L:D) h. Adult parasitoids were fed 30% (wt:vol) honey solution and provided with host pupae (four pupae for 10 wasps) (Sak et al. 2006). Host colony was maintained by feeding the insects with a diet described by Bronskill (1961) and modified by Sak et al. (2006). A piece of honeycomb was added for egg deposition and feeding of the newly hatched larvae.

Bioassays. Cypermethrin (Imperator, 250 g/liter EC, Zeneca Ltd., İzmir, Turkey) was used in all bioassay as water source and prepared in distilled water as parts per million (micrograms per milliliter) of active ingredient. We have previously determined the PD_{50} (the median pupation dose) value of *G. mellonella* exposed to cypermethrin as 207.3 (181.7–235.1) ppm (Sak et al. 2006). Therefore, we applied doses around PD_{50} value to host instars to evaluate the dose-dependent effect of cypermethrin on *G. mellonella.* Various doses (5, 20, 50, 100, 150, 200, 300, 400, and 500 ppm) of cypermethrin and a distilled water control were added in 10 g of the diet in each 210-ml jar. Last instars of *G. mellonella* (n = 10 at 25°C; average weight = 0.16 ± 0.01 g) were exposed to selected doses of cypermethrin for 7 d. The intensity of abnormal behavior (impaired walking, twitching of body, turning on dorsally or dorsolaterally) was observed and the number of host larvae on diet (n = 10 at 25°C) was recorded at 1, 2, 4, 6, and 24 h posttreatments. Dead larvae were removed every 24 h, and living larvae were kept on the contaminated diet for 7 d before transferring them to other jars containing folded papers to facilitate pupation. Host larvae were controlled daily until adult emergence. Pupal weight and the time required for completion of host development from last instars to adult emergence was recorded. Experiments related to pupal weight were repeated four times, and experiments related to developmental time from last instars to adult emergence and larval behavior were repeated three times.

G. mellonella larvae were exposed to four different doses (20, 50, 100, and 150 ppm) below PD_{50} value to evaluate the effects of the insecticide on egg-to-adult developmental time, adult longevity, adult body size, and wing and antenna length of *P. turionellae.* Batches of 30 host larvae (0.16 ± 0.01 g) were exposed to 30 g of the diet including the selected doses of the cypermethrin for 7 d. Larvae were removed from the diet and those pupated were parasitized by *P. turionellae* females. All parasitized pupae in jars were observed daily until the emergence of adult parasitoids for each dose. The time required for completion of parasitoid development from egg deposition to adult emergence was recorded as egg-to-adult developmental time. Longevity of newly emerged adult female and male wasps (0–24-h-old) was assessed by placing individual mating pairs (n = 5 pairs at 25°C) in 80-ml jars each containing a piece of cotton ball soaked with a 30% (wt:vol) honey solution. Jars were covered with a cloth tied around the neck to maintain aeration and prevent adults from escaping and held under the environmental conditions mentioned above for the stock cultures. Food supplement was replenished at 2-d intervals until all parasitoids died. Parasitoids were observed daily and longevity of each individual was recorded. Adult body sizes (length), wing and antenna length of cypermethrin-treated wasps and controls were determined by selecting random samples (five pairs) of wasps for each treatment and control group. Adults were measured from the head to the tip of the abdomen using an Olympus S2X 12 stereodissecting microscope with a calibrated eyepiece micrometer. Antenna was measured from the point attached to the head to the tip of the antenna and wing length was measured from the point attached to the body to the tip of the wing. Experiments related to egg to adult developmental time were repeated four times and others were repeated three times with specimen taken from different populations at different times. Control groups also were prepared with the same methodology, but untreated diet including only distilled water instead of cypermethrin solution was used.

Statistics. One-way analysis of variance (ANOVA) was used to test the effect of cypermethrin applied to host larvae on pupal weight, last instars to adult developmental time, and the number of host larvae on diet and egg to adult developmental time, longevity, adult body size (length), and wing and antenna length of *P. turionellae.* Subsequently, means were separated by Tukey's honestly significant difference (HSD) tests (SPSS Inc. 1999). Data for the number of host larvae on diet also were subjected to two-way ANOVA (SPSS Inc. 1999) to determine the main effects of cypermethrin dose, time, and their interaction on the number of host larvae on diet. Data for egg-to-adult developmental time and adult longevity were also subjected to two-way ANOVA to determine the main effects of cypermethrin dose, sex, and their interaction on egg to adult developmental time and adult longevity. Results were considered statistically significant when $P < 0.05$.

Table 1. Cypermethrin-related changes in the pupation rate (percentage), pupal weight (grams), and last instar-to-adult developmental time (days) of *G. mellonella*

CYP (ppm)	Pupation (%)	Pupal wt (g)		Last instar-to-adult developmental time (d)	
		Range	(Mean ± SE)[a]	Range	(Mean ± SE)[a]
Control	100	0.09–0.16	0.125 ± 0.003a	18–19	18.67 ± 0.33a
5	100	0.10–0.16	0.121 ± 0.003ab	18–20	19.00 ± 0.58a
20	100	0.08–0.13	0.100 ± 0.003bc	19–21	20.00 ± 0.58a
50	92.5	0.03–0.11	0.089 ± 0.003cd	21–21	21.00 ± 0.00ab
100	80	0.04–0.11	0.082 ± 0.003cd	21–23	22.00 ± 0.58ab
150	72.5	0.05–0.13	0.085 ± 0.004cd	23–28	25.67 ± 1.46bc
200	57.5	0.04–0.11	0.077 ± 0.003cd	25–29	27.00 ± 1.16cd
300	35	0.04–0.11	0.079 ± 0.006cd	30–35	31.67 ± 1.67d
400	20	0.04–0.010	0.074 ± 0.007d		
500	5	0.06–0.07	0.065 ± 0.005d		

[a] Numbers in the same column followed by the same letter are not significantly different from each other ($P > 0.05$; Tukey's HSD test).

Results

The percentage of pupation did not differ from that of the control when *G. mellonella* larvae were exposed to 5 and 20 ppm cypermethrin and the rate was 100% in all cases. Pupation rate decreased in a dose-dependent manner when the host larvae were exposed to higher doses of cypermethrin above 20 ppm (Table 1). The pupation data were taken from Sak et al. (2006) except for at 20 ppm. Pupal weight of *G. mellonella* larvae exposed to different doses of cypermethrin in diet was significantly lower than those larvae developed on untreated diet except for 5 ppm ($F = 29.697$; df = 9, 255; $P < 0.001$). Cypermethrin treatment induced a considerable decrease in pupal weights at all doses >5 ppm and finally decreased >40% at doses of 400 and 500 ppm. Development from last instars to adult at 25°C normally required 18–19 d. However, larvae exposed to various doses of cypermethrin tested required significantly longer days to complete development ($F = 22.890$; df = 7, 16; $P < 0.001$ (Table 1). The increase in last instar-to-adult developmental time was considerably higher at doses >100 ppm, and no adults emerged at 400 and 500 ppm (Table 1).

Dietary exposure of cypermethrin also caused significant effects on the behavior of *G. mellonella* larvae. At each inspection, larvae on diet were classified as moribund, intoxicated, or normal (exhibiting normal walking and feeding behaviors), and larvae in diet were classified as normal. Moribund and intoxicated larvae exhibited abnormal behaviors. That is, moribund larvae were not moving or had only minute nerve twitches, and turning on dorsally or dorsolaterally. The larvae started to die after 24 h. Intoxicated larvae exhibited partial paralysis, locomotory difficulty (i.e., impaired walking) and excessive twitching of their body. Normal larvae walked normally, achieved to get into diet, showed feeding behavior either on or in diet and did not exhibit abnormal behaviors those mentioned above. The effect of cypermethrin on the number of host larvae on diet was dose ($P = 0.000$) and time ($P = 0.000$) dependent, and the relationship between doses and the number of host larvae was significantly influenced by the time ($P = 0.000$) (Table 2).

The effect of cypermethrin on the number of *G. mellonella* larvae on diet significantly differed among cypermethrin-treated and untreated groups at each time point of observation at the end of 1 h ($F = 29.672$; df = 8, 18; $P < 0.05$), 2 h ($F = 173.875$; df = 8, 18; $P < 0.05$), 4 h ($F = 204.219$; df = 8, 18; $P < 0.05$), 6 h ($F = 138.977$; df = 8, 18; $P < 0.05$), and 24 h ($F = 177.528$; df = 8, 18; $P < 0.05$) (Table 3). Larvae showed no signs of difficulty in mobility as those in control group at 20 and 50 ppm except for one to two larvae seen still on diet but mobile at 4, 6, and 24 h posttreatment. Exposure to higher doses of cypermethrin >50 ppm resulted in a dose-dependent immobility and abnormal behavior in larvae. The intensity of abnormal behaviors and immobility increased at doses 400 and 500 ppm. There were almost no larvae achieved to get into diet and showing feeding behaviors at doses >200 ppm from 2 h onward whereas all larvae were on diet only at 500 ppm at the end of 1 h (Table 3).

Two-way ANOVA indicated that the effects of cypermethrin doses on egg-to-adult developmental time of *P. turionellae* were not significant ($P > 0.05$), but the effects of sexes were significant ($P < 0.01$). Cypermethrin dose–sex interactions were not significant ($P > 0.05$) for egg-to-adult developmental time, indicating that variation as a result of dose was consistent among sexes (Table 4). Egg-to-adult developmental time of parasitoid adults varied 17–20 d when hosts were fed on a cypermethrin-free diet. Cypermethrin treatment did not considerably affect the developmental time of both sexes, regardless of the dose tested ($F = 0.240$; df = 4, 15; $P > 0.05$ for females and $F = 2.352$; df = 4, 15; $P > 0.05$ for males) (Table 5).

Table 2. ANOVAs of the effects of cypermethrin dose, time, and their interactions on the number of *G. mellonella* larvae on diet ($r^2 = 0.977$)

Source	df	MS	*F*	*P*
Cypermethrin dose	8	285.450	448.090	0.000
Time	4	12.193	19.140	0.000
Cypermethrin × time	32	2.001	3.141	0.000
Error	90	0.637		

Table 3. Cypermethrin-related changes on the number of last instars of *G. mellonella* on diet

CYP	Time posttreatment (h)[a]									
	1		2		4		6		24	
	Range	Mean ± SE	Range	Mean ± SE	Range	Mean ± SE	Range	Mean ± SE	Range	Mean ± SE
Control	0–0	0.00 ± 0.00a	0–0	0.00 ± 0.00a	0–0	0.00 ± 0.00a	0–0	0.00 ± 0.00a	0–0	0.00 ± 0.00a
20	0–0	0.00 ± 0.00a	0–0	0.00 ± 0.00a	0–0	0.00 ± 0.00a	0–2	1.00 ± 0.58a	0–0	0.00 ± 0.00a
50	0–0	0.00 ± 0.00a	0–0	0.00 ± 0.00a	0–2	01.00 ± 0.58a	0–2	1.00 ± 0.58a	0–1	0.67 ± 0.33a
100	0–4	2.00 ± 1.15ab	6–9	7.67 ± 0.88b	6–7	6.67 ± 0.33b	7–8	7.67 ± 0.33b	5–6	5.67 ± 0.33b
150	4–9	6.67 ± 1.45cd	8–8	8.00 ± 0.00b	8–9	8.67 ± 0.33c	9–9	9.00 ± 0.00bc	8–8	8.00 ± 0.00c
200	4–7	5.67 ± 0.88bc	8–10	9.00 ± 0.58bc	8–10	9.00 ± 0.58c	8–10	9.00 ± 0.58bc	7–10	8.33 ± 0.88c
300	7–10	8.67 ± 0.88cd	10–10	10.00 ± 0.00c	10–10	10.00 ± 0.00c	9–10	9.67 ± 0.33c	10–10	10.00 ± 0.00d
400	8–10	9.00 ± 0.58cd	10–10	10.00 ± 0.00c	10–10	10.00 ± 0.00c	10–10	10.00 ± 0.00c	10–10	10.00 ± 0.00d
500	10–10	10.00 ± 0.00d	10–10	10.00 ± 0.00c	10–10	10.00 ± 0.00c	10–10	10.00 ± 0.00c	10–10	10.00 ± 0.00d

[a] Numbers in the same column followed by the same letter are not significantly different from each other ($P > 0.05$; Tukey's HSD test).

The effect of cypermethrin on adult longevity was dose- ($P < 0.001$) and sex-dependent ($P < 0.001$), and the relationship between insecticide dose and adult longevity was significantly influenced by gender ($P < 0.001$) (Table 4). Adult longevity of females fluctuated among treatments and increased considerably at all doses except for 100 ppm with respect to control (Table 6; $F = 7.012$; df = 4, 70; $P < 0.001$). However, there were no significant differences in adult longevity of males produced by wasps reared on cypermethrin-treated hosts with respect to the control ($F = 0.797$; df = 4, 70; $P > 0.05$) (Table 6).

Cypermethrin treatment did not affect the wing (Table 7; males: $F = 1.395$; df = 4, 70; $P > 0.05$ and females: $F = 0.831$; df = 4, 70; $P > 0.05$) and antennal length (Table 7; males: $F = 1.266$; df = 4, 70; $P > 0.05$ and females: $F = 0.985$; df = 4, 70; $P > 0.05$) of male and female wasps. However, adult body size was considerably influenced by gender for males (Table 7; $F = 2.735$; df = 4, 70; $P < 0.05$), whereas there were not significant differences for females (Table 7; $F = 0.639$; df = 4, 70; $P > 0.05$). Cypermethrin induced a considerable increase in adult body size at 50 ppm for males. Wing and antenna length of female wasps seemed to be slightly longer than that of the control group, whereas they were slightly shorter in males (Table 7).

Discussion

Insecticides may not always be lethal but can effect biological parameters such as developmental time, survival, pupation rate, and weight (Biddinger and Hull 1999, Takada et al. 2001, Tomberlin et al. 2002, Sak et al. 2006, Ergin et al. 2007) and physiological parameters such as metabolite or hormone content in the body or hemolymph (Dedos et al. 2002, Sak et al. 2006). Seven-day exposure of *G. mellonella* larvae to a diet containing cypermethrin resulted in a dose-wise decline in the pupation rate, so did prolongation of pupation time, with a loss in weight and retardation in the developmental time from last instars to adult especially at the higher doses. These results are in good agreement with others reporting the effect of some insecticides on the larval and pupal developmental time and mortality rates of some lepidopterous species (Biddinger and Hull 1999, Hill and Foster 2000). In another study, the treatment of *G. mellonella* larvae with cadmium contaminated synthetic diet caused a remarkable prolongation of the larval stage and an increase in larval mortality (Mathova 1990). Mathova (1990) also indicated that both the retardation of development and larval mortality were dose-dependent. It has been suggested that the neurotoxic effects of cypermethrin may suppress juvenile hormone levels in the host (Oppenoorth 1985). Therefore, hormonal milieu changes of host may cause such developmental changes. The decrease in the pupal weight in cypermethrin-treated groups >5 ppm with respect to control has also been observed in *Hermetia illucens* (L.) (Diptera: Stratiomyidae) larvae exposed to cyromazine and pyriproxifen (Tomberlin et al. 2002) and in *Platynota sultana* (Walshingham) (Lepidoptera: Tortricidae) exposed to two benzoylphenylureas (Hejazi and Granett 1986). In contrast, most of the insecticides exposed to the larval stages of *Platynota idaeusalis* (Walker) (Lepidoptera: Tortricidae) did not significantly affect the pupal weight of insects, whereas

Table 4. ANOVAs of the effects of cypermethrin dose, sex, and their interactions on egg-to-adult developmental time and adult longevity of *P. turionellae*

	Source	df	MS	*F*	*P*	r^2
Egg-to-adult developmental time	Cypermethrin dose	4	3.037	1.418	0.252	0.39
	Sex	1	24.025	11.218	0.002	
	Cypermethrin × sex	4	1.088	0.508	0.730	
	Error	30	2.142			
Adult longevity	Cypermethrin dose	4	2317.707	6.791	0.000	0.58
	Sex	1	55719.207	163.258	0.000	
	Cypermethrin × sex	4	1967.607	5.765	0.000	
	Error	140	341.2950			

Table 5. Cypermethrin-related changes in egg-to-adult developmental time (days) of *P. turionellae*

CYP (ppm)	Egg-to-adult developmental time (d)			
	Female		Male	
	Range	Mean ± SE[a]	Range	Mean ± SE[a]
Control	18–20	18.75 ± 0.48a	17–20	18.25 ± 0.63a
20	18–20	19.00 ± 0.41a	16–20	17.25 ± 0.95a
50	17–20	18.00 ± 0.71a	16–18	16.75 ± 0.48a
100	17–21	18.25 ± 0.95a	16–17	16.50 ± 0.29a
150	16–22	18.25 ± 1.31a	15–17	15.75 ± 0.48a

[a] Numbers in the same column followed by the same letter are not significantly different from each other ($P > 0.05$; Tukey's HSD test).

fenoxycarb increased only female pupal weight (Biddinger and Hull 1999). The decrease in the pupal weight of *G. mellonella* also may be attributed to the nonspecific toxicity of diet as amounts of cypermethrin increase, resulting in a decline in diet quality and an interference of sufficient food supply from the diet by host larvae (Sak et al. 2006).

Animals require high energy under stress conditions and may consume more energy to repair mechanisms. Therefore, the decrease in energy storages of the *G. mellonella* resulting from cypermethrin-induced stress may prolong the growth and development of insect progeny especially at higher doses. The manifestation of cypermethrin inhibitory effect was reversible; time- and dose-dependent, reflecting the probable induction of some detoxication or adaptation mechanisms in the host larvae. After the elimination of the inhibitory effect of cypermethrin, larvae continued their development normally, pupated, and reached to adult stage as those in the control group. However, last instar-to-adult developmental time of *G. mellonella* was significantly longer at 150, 200, and 300 ppm than untreated larvae. Such an insecticide-related prolongation in the most deleterious larval stage of pests will give rise to more damage in nature and may increase the economical losses caused by pests. Furthermore, prolongation in the larval developmental time of host species on exposure to insecticides represents a potential threat to the survival and continuity of the generation of the pupal parasitoids and may disrupt the ecological balance between parasitoids and hosts.

Pesticides have been shown to cause some behavioral changes (e.g., feeding, mating, parasitization) in insects. Kunkel et al. (2001) demonstrated that exposure to imidacloprid of adult *Harpalus pennsylvanicus* DeGeer (Coleoptera: Carabidae) caused high incidence of sublethal, neurotoxic effects including paralysis, impaired walking, and excessive grooming. Wegerhoff et al. (2001) indicated that fenvalerate-treated *Manduca sexta* L. (Lepidoptera: Sphingidae) at the second or third stage of pupal development displayed tetanic muscle movements. Similarly, adults of the lepidopteran parasitoid *Hyposoter didymator* (Thunberg) (Hymenoptera: Ichneumonidae) treated with spinosad showed typical nerve poison symptoms: tremors and involuntary movements followed by paralysis (Schneider et al. 2003). It has been reported that pyrethroids change the mechanism of voltage-gated sodium channels by prolonging sodium currents and initiating repetitive after-discharges in motor and sensory neurons (Ruigt 1985, Vijverberg and Van Den Bercken 1990, Wegerhoff et al. 2001). Cypermethrin-related disruption in the normal functioning of nervous system would result more stimulation of neurons and organs and cause abnormal behaviors observed in *G. mellonella* larvae.

Table 6. Cypermethrin-related changes in adult longevity (days) of *P. turionellae*

CYP (ppm)	Adult longevity (d)			
	Female		Male	
	Range	Mean ± SE[a]	Range	Mean ± SE[a]
Control	29–93	52.27 ± 5.41a	24–50	37.40 ± 2.03a
20	30–110	82.13 ± 6.15bc	10–53	35.73 ± 2.98a
50	31–110	79.27 ± 6.34bc	27–56	36.60 ± 2.07a
100	33–113	70.93 ± 7.33ab	22–49	39.60 ± 1.92a
150	47–125	98.13 ± 6.31c	24–54	40.67 ± 2.44a

[a] Numbers in the same column followed by the same letter are not significantly different from each other ($P > 0.05$; Tukey's HSD test).

Contrary to that observed in *G. mellonella*, our results indicated that egg-to-adult developmental time of *P. turionellae* did not change when wasps were reared on the pupae of cypermethrin-treated host larvae. We could find no report on insecticide-dependent delay in adult parasitoid eclosion except for Ergin et al. (2007) reporting an increase in the overall time to adult eclosion by >50% when *Apanteles galleriae* Wilkinson (Hymenoptera: Braconidae) was reared on cypermethrin-treated host larvae. This difference is not unexpected considering that the larval endoparasitoid *A. galleriae* might have been exposed to cypermethrin longer than the pupal parasitoid, *P. turionellae* during egg-to-adult development. It is also important to note that the toxicity of insecticides seems to be highly dependent on the developmental stage being affected and the species itself (Suh et al. 2000, Tillman and Mulrooney 2000, Schneider et al. 2003). Examining the effect of cypermethrin on longevity of adults revealed that insecticide treatment significantly affected longevity of *P. turionellae* and the response was both dose- and sex-dependent. Surprisingly, the longevity of wasp females exposed to cypermethrin tended to increase more drastically with regard to males displaying no significant difference in longevity at all doses compared with controls. Our previous study examining the effect of cypermethrin on longevity of adults of *A. galleriae* reared on cypermethrin-treated host larvae revealed that insecticide treatment significantly reduced mean longevity of parasitoids (Ergin et al. 2007). Our results with longevity of parasitoid species are consistent with those of Ergin et al. (2007) that longevity of females exposed to cypermethrin tended to decrease more drastically relative to males. Sexual difference in susceptibility to pesticides has also been noted in some parasitoids with females being generally more susceptible than males (Spollen and Hoy 1992) or vice versa (Schoonees and Giliomee 1982, Rathman et al. 1992). The differences

Table 7. Cypermethrin-related changes in adult size and wing and antennal length of *P. turionellae*

CYP (ppm)	Size length (mm)		Wing length (mm)		Antenna length (mm)	
	Female (Mean ± SE)[a]	Male (Mean ± SE)[a]	Female (Mean ± SE)[a]	Male (Mean ± SE)[a]	Female (Mean ± SE)[a]	Male (Mean ± SE)[a]
Control	11.49 ± 0.44a	9.77 ± 0.23ab	7.76 ± 0.29a	7.33 ± 0.12a	7.79 ± 0.27a	7.49 ± 0.14a
20	11.93 ± 0.42a	9.55 ± 0.22ab	8.07 ± 0.17a	7.39 ± 0.15a	8.12 ± 0.23a	7.33 ± 0.17a
50	12.35 ± 0.42a	9.95 ± 0.17b	8.05 ± 0.17a	7.18 ± 0.15a	8.30 ± 0.24a	7.42 ± 0.14a
100	11.80 ± 0.40a	9.41 ± 0.17ab	8.15 ± 0.16a	7.04 ± 0.09a	7.95 ± 0.20a	7.29 ± 0.13a
150	11.62 ± 0.39a	9.15 ± 0.14a	7.80 ± 0.14a	7.09 ± 0.11a	7.78 ± 0.16a	7.06 ± 0.14a

[a] Numbers in the same column followed by the same letter are not significantly different from each other ($P > 0.05$; Tukey's HSD test).

may be partly related to variation in size and physiology between sexes (Croft 1990, Baker et al. 1995). It also should be noted that the increase in the longevity in favor of females when food quality is low may be an important adaptation for the parasitoid species to maintain its generation, because only a limited number of females are able to emerge (Uçkan and Ergin 2002). Our investigation did not document significant changes in adult body size, wing and antenna length of wasps except for the slight variation in size for in males. Ergin et al. (2007) also reported a slight but not considerable decline in adult size of *A. galleriae* exposed to cypermethrin via host. They interpreted that the slight decrease in size of wasps might have been caused by the cypermethrin-induced decline in diet quality.

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