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Host-parasitoid relationship of *Ceratitis capitata* (Diptera: Tephritidae) and *Coptera occidentalis* (Hymenoptera: Proctotrupoidea: Diapriidae) under host heavy metal stress

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Insects, *Ceratitis capitata*, *Coptera occidentalis*, pupal parasitoid, development, fecundity, heavy metals, copper, cadmium, lead

Abstract. The development and fecundity of *Ceratitis capitata* Wiedemann (Diptera: Tephritidae) and the host-parasitoid relationship of *C. capitata* and its pupal endoparasitoid, *Coptera occidentalis* (Muesebeck) (Hymenoptera: Proctotrupoidea: Diapriidae) were investigated under conditions in which the host was stressed by heavy metal ingestion. *C. capitata* larvae (from first instar to pupation) were fed diets that were separately contaminated with three metals; each contaminant was applied at four concentrations that differed by a factor of 2. The lowest concentrations were as follows: copper 100 μg/g, cadmium 25 μg/g and lead 100 μg/g diet dry weight (dw). Larval development, pupation rate and pupal weight of the fruit fly were negatively affected by increasing metal concentrations. Metal concentrations of 400 μg Cu, 50 μg Cd and 400 μg Pb/g diet dw were selected for studying reproductive performance of *C. capitata* and parasitisation rate, development and reproduction of *C. occidentalis*. Oviposition, actual fecundity and hatching rates of *C. capitata* were not significantly influenced by metal contamination. The parasitoid did not discriminate between metal-contaminated and control fruit fly pupae. Parasitisation rates were similar in all treatments (64.6–65%). Heavy metal induced stress of the host altered neither the parasitoid developmental rate nor the proportion of females in parasitoids that emerged from contaminated pupae. Life span and reproductive performance of *C. occidentalis* females that emerged from metal-stressed hosts were not significantly different from control females. However, a significantly lower percentage of females emerged from copper- and cadmium-contaminated hosts. In groups contaminated by 400 μg Cu, 50 μg Cd and 400 μg Pb/g diet dw, whole body concentrations of the respective metals were determined in pupae and imagines of *C. capitata* and imagines of *C. occidentalis*.

INTRODUCTION

Trace elements occur naturally in terrestrial as well as aquatic ecosystems. However, their concentration in the environment is increasing due to current rapid industrialisation. Heavy metal pollution in air and water has been associated with various effects on insects – from cellular level to populations and communities (Alstad et al., 1982; Hare, 1992). Both field and laboratory investigations that assessed the influence of heavy metal stress upon various insect species have documented detrimental effects and include the following examples: developmental retardation (Sivapalan & Gnanapragasam, 1980; Heliövaara & Väisänen, 1990; Cohn et al., 1992; Gintenreiter et al., 1993); growth reduction (Heliövaara & Väisänen, 1989; Gintenreiter et al., 1993); depression of reproduction

(Bengtsson et al., 1985; Andrzejewska et al., 1990; Weismann & Reháková, 1993; Gintenreiter et al., 1993); etc.

Some phytophagous insects, however, may benefit from increasing air pollution levels that are associated with physiological alteration of host plants (Braun & Flückiger, 1984; Heliövaara & Väisänen, 1986) and reduction of the efficiency of natural enemies (Heliövaara et al., 1991; San & Spitzer, 1993). Führer (1985) suggested that parasitic Hymenoptera are less tolerant to pollutants than are their herbivorous hosts; thus, pollution could lead to outbreaks of phytophagous insect populations in some areas. Nuorteva (1990) also stressed the importance of deleterious effects caused by heavy metal accumulation in the biocoenotic system, which controls forest pests. However, until recently only a few laboratory studies have dealt with the influence of heavy metals on hymenopteran parasitoids and host-parasitoid relationships (Ortel & Vogel, 1989; Ortel, 1991, 1995a; Ortel et al., 1993; Bishof, 1995a,b). Ortel et al. (1993), during investigations of the host-parasitoid relationship of *Lymantria dispar* (Lepidoptera: Lymantriidae) – *Glyptapanteles liparidis* (Hymenoptera: Braconidae), concluded that metal stress probably does not affect parasitoid development directly, rather, the stress induces alterations in the host haemolymph composition, thus modifying the trophic situation within the host larvae.

This study investigated the effects of heavy metal contamination on development and fecundity of *Ceratitis capitata* (Diptera: Tephritidae) and the host-parasitoid relationship *C. capitata-Coptera occidentalis* (Hymenoptera: Proctotrupoidea; Diapriidae). One essential metal (copper) and two toxic metals (cadmium and lead) were selected for use in the study. The hypothesis that host metal stress could affect parasitisation rate, development and reproduction of the endoparasitoid of fruit fly pupae was tested.

MATERIAL AND METHODS

The Mediterranean fruit fly, *Ceratitis capitata* Wiedemann and the solitary pupal parasitoid *Coptera occidentalis* (Muesebeck) were derived from laboratory cultures that were maintained at 23 ± 1°C, 60 ± 5% RH and a 16 h photoperiod.

Rearing of the host

C. capitata larvae were reared throughout their development in plastic containers (6 cm diameter, 5 cm deep, with plastic lids) at an initial density of 300 eggs/50 g diet by Nadel (1970). Larval food was separately contaminated with 5% $CuCl_2 \cdot 2H_2O$, 5% $Pb(NO_3)_2$, 5% $CdCl_2 \cdot 2.5H_2O$ at each of the following concentrations: copper – 100, 200, 400, 800 µg/g; cadmium – 25, 50, 100, 200 µg/g; lead – 100, 200, 400, 800 µg/g dry weight (dw). Control groups were reared on uncontaminated diet. Each treatment group consisted of three replicates with 300 eggs. Egg hatch, pupation and adult eclosion rates, duration of larval development and pupal weight were recorded.

Concentrations of Cu 400 µg/g, Cd 50 µg/g and Pb 400 µg/g dw, referred to as Cu 400, Cd 50 and Pb 400, respectively, were determined to be levels at which the negative effects of heavy metals became apparent (growth retardation, pupal weight reduction), though not detrimental to *C. capitata*. Thus, these levels were selected for further experiments.

Adult *C. capitata* (10 females, 10 males, < 1 day old), from control and treatment groups subjected to Cu 400, Cd 50 and Pb 400, were confined in cages constructed of plastic containers (9 × 9 × 14 cm) with two 3 × 7 cm openings that were covered with gauze. These adult flies were provided water, sugar (cubes) and a mixture consisting of granulated sugar : enzymatic yeast hydrolysate : water (4 : 1 : 2) as described by Vallo (1979). Each cage contained a yellow, plastic, needle-pierced cupel (4 cm diameter) for egg-laying (Feron et al., 1958). Every 1–2 days, we counted the number of eggs and dead flies until female mortality reached 90%. The duration of preoviposition and oviposition, and the number of eggs per female were calculated for each cage. Eggs were placed on wet filter paper strips contained in a petri dish; after the larvae hatched, we recorded the number of eggs from which no larvae hatched.

Rearing of the parasitoid

Rearing of *C. occidentalis* and parasitisation of *C. capitata* pupae were carried out as described by Kazimírová & Vallo (1992).

C. capitata pupae from control and heavy metal treatment groups (Cu 400, Cd 50, Pb 400) (three samples with 300 pupae each) were exposed – together in one cage – to adult *C. occidentalis* for 8 h. Emergence of adult wasps from host pupae, the percentage of pupae containing dead parasitoids, the percentage female parasitoids that emerged and the parasitoid development time (from parasitisation to adult eclosion) in hosts were recorded. This experiment was repeated three times (further referred to as Experiment 1, 2 and 3).

Wasps (< 1 day old) eclosed from the control group and metal contaminated hosts were placed into cages (12 × 12 × 12 cm) and maintained on honey and water. 5 female and 5 male wasps were placed in each cage. The longevity, oviposition and fecundity of females and the percentage of female offspring were investigated as described by Kazimírová (1996).

Statistics

Results were evaluated using t-test and two-way ANOVA. Percentages were transformed to arcsine $\sqrt{p}$.

Metal analysis

The heavy metals (Cu, Cd, Pb) were analysed in pooled samples of *C. capitata* pupae (1 day after pupation, 150–200 individuals) and imagines (1 day old, 100–150 individuals, both mixed both sexes), and in *C. occidentalis* imagines (1 day old, 100–150 individuals, mixed both sexes). Samples were dried at 70°C to constant weight and mineralised in concentrated HNO_3 for 10 min using microwave dissolution (Paar Physica). Cd and Pb contents were analysed using atomic absorption with electrothermal atomisation (Pye Unicam/SP9 system with furnace programmer) or (Cd) on an atomic absorption spectrometer (AAS3, Carl Zeiss, Jena) by flame. Cu contents were determined by an inductively-coupled, argon plasma-atomic emission spectrometer (ICP AES/ARL). These results were not evaluated statistically.

RESULTS

Larval development, pupation and adult eclosion of *C. capitata*

Different dietary metal concentrations did not effect hatching rates of *C. capitata* eggs (Table 1). Increased metal concentrations resulted in prolonged larval development, decreased pupation rate and reduced pupal weight. 100% larval mortality was recorded at 200 µg/g cadmium.

Oviposition, fecundity and egg hatch rate of *C. capitata*

In general, no negative effects on oviposition period, life span, number of eggs per female or egg hatch rates of *C. capitata* were observed in relation to the investigated metal concentrations (Fig. 1, Table 2). In the Pb 400 group, the mean number of eggs per female was lower, however, it was not significantly different from the control group. In this treatment, a shorter oviposition period was also registered.

Parasitisation of *C. capitata* and development rate of *C. occidentalis*

Results obtained in experiments with parasitisation of *C. capitata* pupae showed that *C. occidentalis* females did not discriminate between uncontaminated and heavy metal contaminated hosts (Fig. 2). No significant differences between control and treatment groups were recorded in the percentage of host pupae with emerging wasps. The control group contained a significantly higher proportion of host pupae that contained dead parasitoids ($P < 0.05$; Fig. 2B). The percentage of emergent female wasps did not differ among treatment groups, however, a significantly higher percentage of females was recorded in all groups in Experiment 2 ($P < 0.05$; Fig. 2D). The development time of female parasitoids

(from parasitisation to adult eclosion) was significantly longer in copper-contaminated hosts ($P < 0.05$; Fig. 3). Development of both females and males was significantly faster in all groups in Experiment 3 ($P < 0.01$; Fig. 3).

TABLE 1. Hatching, pupation and adult eclosion rates, larval development and pupal weight in *Ceratitis capitata* after heavy metal contamination of larval diet. Dietary metal concentrations: Copper – Cu 100, 200, 400, 800 = 100, 200, 400 800 µg Cu/g diet dw; cadmium – Cd 25, 50, 100, 200 = 25, 50, 100, 200 µg Cd/g diet dw; lead – Pb 100, 200, 400, 800 = 100, 200, 400 800 µg Pb/g diet dw.

Treatment group*	Hatching rate (%)	Pupation rate (%)	Adult eclosion rate (%)	Larval development (days)	Pupal weight (mg)
Control	82.00	90.36	99.14	11.07	11.52
Cu 100	85.67	76.85	98.23	11.07	10.68
Cu 200	83.84	71.06	99.51	11.25	10.70
Cu 400**	83.84	65.13	98.62	12.19	10.27
Cu 800	78.67	23.60	90.18	16.76	7.90
Cd 25	88.16	95.11	99.60	11.01	10.70
Cd 50**	72.00	76.42	97.42	11.54	9.82
Cd 100	84.50	64.10	94.53	15.89	8.43
Cd 200	82.00	0.00	–	–	–
Pb 100	85.00	86.56	98.66	11.10	10.67
Pb 200	85.67	93.75	98.88	11.70	10.35
Pb 400**	80.34	71.38	97.94	13.07	9.30
Pb 800	91.84	76.33	95.66	15.34	8.76

* Treatment groups contained three replicates with an initial density of 300 eggs/50 g diet each. Pupation rate and adult eclosion rate was calculated from the number of hatched larvae and the number of pupae, respectively.

** Treatment group selected for further investigations.

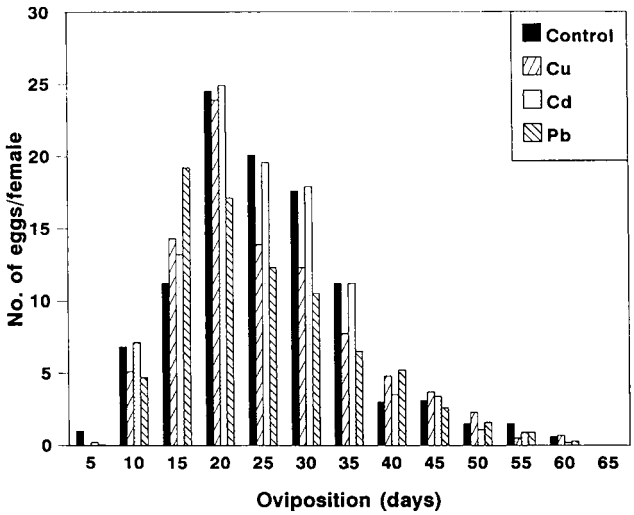

Fig. 1. Age-related fecundity (number of eggs laid per female and day) in *Ceratitis capitata* after heavy metal contamination of larval diet. Dietary metal concentrations: Cu = copper (400 µg/g), Cd = cadmium (50 µg/g), Pb = lead (400 µg/g diet dw).

TABLE 2. Fecundity, hatching rate, preoviposition, oviposition period and life span in *Ceratitis capitata* females after rearing larvae on heavy metal contaminated diet. Dietary metal concentrations: Cu 400 = 400 μg Cu/g diet dw, Cd 50 = 50 μg Cd/g diet dw, Pb 400 = 400 μg Pb/g diet dw.

		Control	Cu 400	Cd 50	Pb 400
No. of cages with 10 females : 10 males		10	11	12	11
Eggs/female:	mean ± SE	92.32 ± 11.88	85.29 ± 7.26 (t = 0.515) ns	98.35 ± 9.87 (t = 0.394) ns	76.89 ± 9.07 (t = 1.043) ns
	min–max	45–141	55–125	25–136	33–143
Hatching rate (%):	mean ± SE	87.29 ± 2.08	86.99 ± 2.06 (t = 0.092) ns	88.29 ± 1.53 (t = 0.331) ns	87.58 ± 2.16 (t = 0.124) ns
	min–max	73.77–94.48	71.38–95.92	74.63–94.70	69.50–95.73
Preoviposition (days):	mean ± SE	9.90 ± 1.38	11.54 ± 1.21 (t = 0.889) ns	9.25 ± 0.70 (t = 0.441) ns	10.09 ± 1.26 (t = 0.102) ns
	min–max	5–17	5–18	5–14	5–21
Oviposition (percentage of cages where oviposition lasted longer than 25 days)		100	90.91	91.67	81.82
Life span (percentage of cages where 50% of females lived longer than 40 days)		60	63.64	83.33	63.64

Means, minima and maxima represent values calculated per cage. For analysis, percentages were transformed to arcsine $\sqrt{p}$. Actual percentages are presented. ns – not significantly different from the control group (t – test).

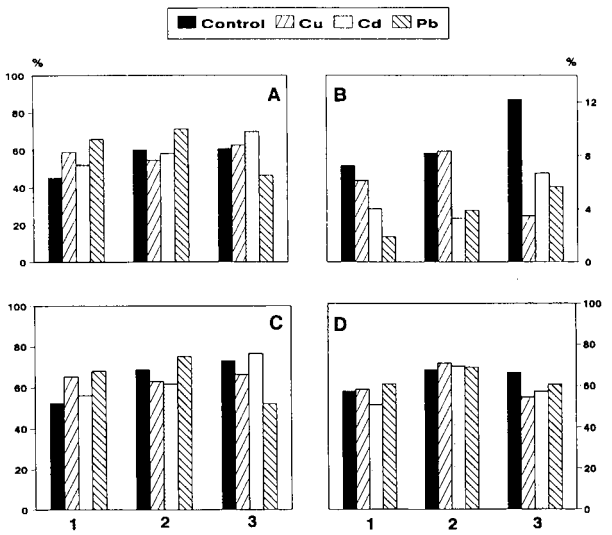

Fig. 2. Parasitisation of heavy metal contaminated *Ceratitis capitata* pupae by *Coptera occidentalis*. A – percentage of pupae with emerging wasps (F_m = 0.165, F_e = 0.360, F_{mxe} = 1.096); B – percentage of pupae with parasitoids dying in host (F_m = 5.736*, F_e = 2.123, F_{mxe} = 1.713); C – percentage of pupae with emerging and dying parasitoids (F_m = 0.003, F_e = 0.655, F_{mxe}= 0.988); D – percentage of emergent female wasps (F_m = 0.556, F_e = 7.46*, F_{mxe} = 0.724). F_m, F_e, F_{mxe} – F-ratio for the influence of metal treatment, experiment and for the interaction of both factors, respectively. * P < 0.05 (two-way ANOVA). During analysis, percentages were transformed to arcsine $\sqrt{p}$. Actual percentages are presented. 1, 2, 3 – experiments (see Material and methods). For Cu, Cd and Pb see Fig. 1.

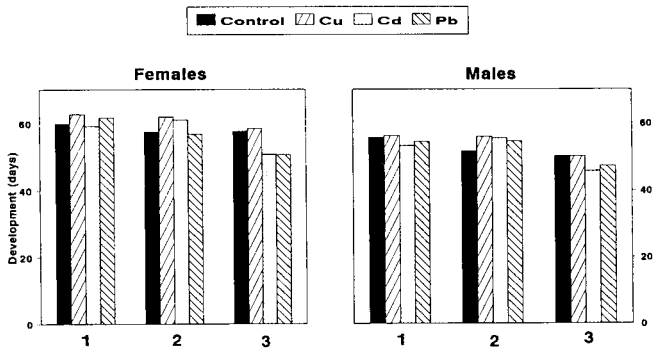

Fig. 3. Development time (from parasitisation to adult eclosion) of *Coptera occidentalis* females and males in heavy metal contaminated *Ceratitis capitata* pupae. Females: $F_m = 5.843^*$, $F_e = 21.142^{***}$, $F_{mxe} = 3.321$; males: $F_m = 2.087$, $F_e = 28.349^{***}$, $F_{mxe} = 1.825$. * $P < 0.05$, *** $P < 0.001$. For others see Figs 1 and 2.

TABLE 3. Female *Coptera occidentalis* life span, oviposition period, and fecundity and percentage of female offspring after rearing on heavy metal contaminated *Ceratitis capitata* pupae. For Cu 400, Cd 50 and Pb 400 see Table 2.

		Control	Cu 400	Cd 50	Pb 400
No. of cages with 5 females : 5 males		20	20	20	20
Female life span (days):	mean ± SE	41.12 ± 1.70	44.03 ± 1.62 (t = 1.237) ns	46.70 ± 1.49 (t = 2.463)*	45.42 ± 1.27 (t = 2.022)*
	min–max	7–75	5–76	8–76	10–72
Oviposition (days):	mean ± SE	20.35 ± 0.92	20.85 ± 0.77 (t = 0.419) ns	21.25 ± 0.47 (t = 0.875) ns	21.20 ± 0.86 (t = 0.677) ns
	min–max	13–33	16–29	17–26	14–30
No. of progeny emerging from host pupae/female:	mean ± SE	13.11 ± 0.87	14.87 ± 0.89 (t = 0.418) ns	14.00 ± 0.96 (t = 0.691) ns	12.35 ± 1.02 (t = 0.564) ns
	min–max	6.8–21.4	4.4–21.4	6.6–23.0	3.4–20.6
No. of progeny dying in host pupae/female:	mean ± SE	3.46 ± 0.53	2.83 ± 0.33 (t = 1.011) ns	3.54 ± 0.32 (t = 0.125) ns	4.60 ± 0.66 (t = 1.346) ns
	min–max	0.8–8.6	1.0–7.2	0.8–6.4	0.8–12.8
No. of progeny emerging from and dying in host pupae/female:	mean ± SE	16.57 ± 0.81	17.70 ± 0.75 (t = 1.024) ns	17.54 ± 0.88 (t = 0.772) ns	16.95 ± 1.02 (t = 0.293) ns
	min–max	11.8–24.8	9.8–24.2	11.0–26.0	8.0–25.2
Percentage of female offspring:	mean ± SE	56.81 ± 2.78	41.49 ± 3.46 (t = 3.425)**	44.62 ± 2.67 (t = 3.168)**	51.54 ± 2.75 (t = 1.381) ns
	min–max	29.54–79.59	13.64–72.31	25.00–63.38	22.81–64.94

Minima and maxima represent values calculated per cage, except life span, which was documented for individual females. During analysis, percentages were transformed to arcsine $\sqrt{p}$. Actual percentages are presented. ns – not significantly different from the control group, * $P < 0.05$, ** $P < 0.01$ (t-test).

Longevity, oviposition and fecundity of *C. occidentalis*

Longevity, oviposition period, fecundity (number of offspring emerging from and dying in host pupae), and the percentage of females in parasitoid progeny are presented in Table

3. Females that emerged from cadmium- and lead-treated hosts lived significantly longer ($P < 0.05$) than females that emerged from control hosts. Oviposition and fecundity of wasps were not related to host metal contamination. As compared with control, a significantly lower percentage of female offspring ($P < 0.01$) was recorded in wasps which developed in copper- and cadmium-contaminated *C. capitata* pupae.

Heavy metal concentrations

The results of metal analyses in *C. capitata* pupae and imagines and in *C. occidentalis* imagines are presented in Table 4. Both heavy metal treated hosts and parasitoids contained high metal concentrations in their bodies. In *C. capitata*, whole body metal concentrations were higher in imagines than in pupae (except for the amount of cadmium in the control group). Concentration factors (CFs) (*C. capitata* imago/pupa) for the copper- and lead-treated groups were lower than in respective controls. In all metal contaminated groups, CFs (parasitoid/host pupa) were lower ($CF < 1$) than in the control.

TABLE 4. Heavy metal concentrations (μg/g dry weight) in pupae and imagines of *Ceratitis capitata* and imagines of *Coptera occidentalis* after application of copper, cadmium and lead (400, 50 and 400 μg/g diet dw, respectively; see Table 2) into larval *C. capitata* diet.

		Copper **		Cadmium*		Lead*	
		Control	Cu 400	Control	Cd 50	Control	Pb 400
Ceratitis capitata	Pupae	10.41	164.78	1.45	205.43***	0.54	218.32
	Imagines	54.99	168.71	0.36	262.17***	0.95	222.7
	(CF 1)	(5.28)	(1.02)	(0.25)	(1.28)	(1.76)	(1.02)
Coptera occidentalis	Imagines	19.77	28.39	0.10	5.37	0.64	13.60
	(CF 2)	(1.90)	(0.17)	(0.07)	(0.03)	(1.19)	(0.06)

Metals analysed by: * electrothermal atomisation, ** ICP, *** flame AAS (see Material and methods). CF 1 and CF 2 – concentration factors of metals for *C. capitata* imagines/pupae and for *C. occidentalis* imagines/*C. capitata* pupae, respectively.

DISCUSSION

A number of laboratory and field studies have dealt with impacts of heavy metal contamination on various insect species. The mode of action and the extent of the damage caused by different toxicants depends on the specific metal, its bioavailability and concentration in the environment, and the receptor insect species and the developmental stage at which the metal is encountered (Andrzejewska et al., 1990; Hare, 1992; Gintenreiter et al., 1993). Gintenreiter et al. (1993), while considering developmental rate, growth, mortality and reproduction of *Lymantria dispar* (Lepidoptera: Lymantriidae), determined that dietary no-observed-effect-concentrations are 10 μg/g copper, 2 μg/g cadmium and 4 μg/g lead. While cadmium and lead seemed to have strong impact on growth, copper primarily affected reproduction of this species. In *Homona coffearia* (Lepidoptera: Tortricidae), copper-contaminated diet (12.5–150 ppm) was found to prolong larval development, reduce pupal weight and decrease adult emergence (Sivapalan & Gnanapragasam, 1980). With chronic exposure to cadmium (50 μg/g) and copper (3 μg/g) via larval food, histological changes in ovaries and decrease in fecundity of *Scotia segetum* (Lepidoptera: Noctuidae) were reported by Zelenayová & Weismann (1983) and Zelenayová (1986),

respectively. Increasing concentrations of copper (16.4–24.1 ppm) and lead (6.7–35.2 ppm) in leaves of *Taraxacum officinale* grown within sites subjected to air pollution negatively affected fecundity of *Spodoptera littoralis* (Lepidoptera: Noctuidae) (Andrzejewska et al., 1990). Rising levels of copper and lead (both between 15–150 µg/g diet dw) increased mortality and depressed reproduction of *Onychiurus armatus* (Collembola) (Bengtsson et al., 1985). Vogel (1988) observed development retardation in *Tenebrio molitor* (Coleoptera: Tenebrionidae) after exposure to cadmium. Both development time and mortality of *Chironomus riparius* (Diptera: Chironomidae) larvae were negatively affected by increasing levels of cadmium (2–6 µg/l), however, no changes due to toxicant exposure were recorded in the life span and fecundity of adults (Postma et al., 1994). In *Drosophila melanogaster* (Diptera: Drosophilidae), cadmium and lead were reported to have growth-retarding effects on preimaginal stages but had no apparent influence on weight, fecundity or adult behaviour (Akins et al., 1992; Cohn et al. 1992).

In *C. capitata*, chronic metal exposure has been associated with growth retardation and pupal weight reduction. Cadmium proved to be the most toxic metal (100% larval mortality at 200 µg/g) among the toxicants investigated in this study. In contrast to the insect species discussed above, *C. capitata* larvae seem to be less susceptible to relatively high doses of copper and lead.

Despite reported developmental consequences of metal stress in preimaginal stages of *C. capitata* and high metal concentrations in their imagines, adult reproductive performance was not affected by cadmium- and lead-stress in these short-term laboratory experiments. This observation is consistent with other studies, e.g., *C. riparius* and *D. melanogaster* (Postma et al., 1994; Cohn et al., 1992). On the other hand, our results regarding *C. capitata* reproductive performance under copper-stress suggest that this species is probably less susceptible to high copper doses than other insects, e.g., several lepidopteran species. Investigations of next generation life characteristics of *C. capitata* that are reared under metal stress might elucidate whether the fruit fly loses its fitness, e.g., as documented in Collembola by Bengtsson et al. (1985) or, if *C. capitata* achieves metal adaptation, e.g., as reported in *D. melanogaster* and other species by Posthuma & Van Straalen (1993).

As far as metal transfer during metamorphosis of holometabolous insects is concerned, concentration of copper in imagines has been documented to be either higher (Lindqvist, 1992: Lepidoptera and phytophagous Hymenoptera) or lower (Gintenreiter et al., 1993: *L. dispar*) than in preimaginal stages. Cadmium concentrations analysed in *Sarcophaga peregrina* (Diptera) imagines (Aoki & Suzuki, 1984), Lepidoptera and phytophagous Hymenoptera (Lindqvist, 1992), and *T. molitor* (Lindqvist & Block, 1995) were lower than in corresponding larvae or pupae. On the other hand, increases in cadmium and lead concentrations during metamorphosis (due to weight loss) was observed in *L. dispar* (Gintenreiter et al., 1993). In *C. capitata* imagines, concentrations of all heavy metals analysed in this experiment were higher than in corresponding pupae. These results allow only preliminary conclusions concerning metal transfer during metamorphosis of *C. capitata*, because analyses of heavy metals in larvae, pupal exuviae, meconium, etc., of these insects have not been performed.

In contrast to the relatively large body of knowledge about the impact of anthropogenic toxicants on phytophagous insects, data regarding toxicant effects on secondary consumers

(parasitoids, predators) are scarce. Most information has been derived from field observations that suggest that, in polluted areas, parasitisation of herbivorous insects, e.g., *Operophtera brumata* (Lepidoptera: Geometridae) (San & Spitzer, 1993), *Neodiprion sertifer* (Hymenoptera: Diprionidae) (Heliövaara et al., 1991) and *Aphis pomi* (Homoptera: Aphididae) (Braun & Flückiger, 1984), is declining; this is probably due to higher sensitivity of parasitoids to pollutants as compared with their hosts. In laboratory studies of *Pimpla turionellae* (Hymenoptera: Ichneumonidae), a parasitoid of *Galleria mellonella* (Lepidoptera: Pyralidae) pupae, exposure of adults to cadmium or lead reduced their life span and respiration rate (Ortel & Vogel, 1989), decreased total lipid and protein content and increased water content in wasp bodies (Ortel, 1991). Ortel (1995a), while investigating the transfer of cadmium and lead from food to *G. mellonella* pupae and to *P. turionellae*, classified the host and parasitoid as "deconcentrator" and "macroconcentrator", respectively, i.e., relatively low contamination in the host yielded high metal concentrations in parasitoid bodies. The situation is different in parasitoids that feed on host haemolymph; elevated copper, cadmium and lead concentrations were recorded in *Glyptapanteles liparidis* (Hymenoptera: Braconidae) adults (Ortel et al., 1993), whereas larvae (Bishof, 1995b) that eclosed from contaminated *L. dispar* larvae did not contain a proportionate increase in whole body metal concentrations as compared with the host. The reduction of the concentration of copper, cadmium and lead in *C. occidentalis* imagines, as compared with high concentrations of these metals in host pupae, suggests that the mechanism of heavy metal transfer in this host/parasitoid system is quite different from that observed in *G. melonella/P. turionellae*, and *C. occidentalis* seems to be a "deconcentrator" of heavy metals.

Enhanced metal levels in *L. dispar* larvae (copper 10 and 50 µg/g; cadmium 2 and 10 µg/g; lead 4 and 20 µg/g) did not alter parasitisation success of *G. liparidis*. The developmental rate of this parasitoid was positively correlated with that of the host (Ortel et al., 1993). This result has led the authors to conclude that host metal stress did not affect *G. liparidis* directly, rather, the parasitoid is probably influenced by changes in the trophic situation within the host. This theory is also supported by observations of the changes in concentration of proteins and free amino acids (Ortel, 1995b), lipids (Ortel, 1995c) and carbohydrates (Bishof, 1995a) in *L. dispar* haemolymph due to metal stress.

In this study, no negative impacts of host metal stress on parasitisation rate, development, or reproduction of *C. occidentalis* were observed. This suggests that *C. occidentalis* females, like *G. liparidis*, probably do not discriminate between heavy metal contaminated and uncontaminated host pupae, even though metal analyses verified that relatively high concentrations of all investigated metals were absorbed by the host. The only apparent difference between the treatment groups and the control was the significantly lower proportion of female offspring in F1 generation wasps that eclosed from copper- and cadmium-contaminated hosts.

In general, parasitic wasps are able to evaluate the nutritional or physiological status of their host and allocate progeny accordingly. Insect parasites react to or benefit from alterations in the host physiology only within the limits of their own biological ability (Thompson, 1986; Rivers & Denlinger, 1995). The ability of parasitoids to assess host quality and the impact of host metal stress on these organisms may vary between parasitoids with differing reproductive strategies. For this reason, it is quite difficult and perhaps

inappropriate to compare the influence of host metal stress in *G. liparidis* feeding on haemolymph of *L. dispar* larvae with that in *C. occidentalis*, an endoparasitoid of fruit fly pupae. Until the present, little information has been available regarding the influence of host quality on diapriids. *C. occidentalis* probably does not derive host suitability information from host size (Kazimírová & Vallo, 1992). Furthermore, development and fecundity of *C. occidentalis* were not altered despite rearing on *C. capitata* pupae of differing sizes (Kazimírová, 1996), although fruit fly pupae, obtained by rearing larvae at different densities, might have differed in their nutritional status.

This study might lead us to the conclusion that parasitisation success and reproduction of *C. occidentalis* are not directly influenced by rearing in metal contaminated hosts or in hosts obtained from high population densities. The ability of *C. occidentalis* to excrete a high proportion of ingested heavy metals could explain the fact that harmful effects of the toxicants on the parasitoid were not observed in this study. However, the impact of heavy metals on the parasitoid might be apparent in next generations, thus leading to fitness decrease. Therefore, studies that focus on the effects of host metal stress on subsequent generations of *C. occidentalis* should be conducted. Also, more detailed studies of metal transfer from *C. capitata* to *C. occidentalis*, including metal analyses in parasitoid larvae and meconium, are necessary to explain uptake and excretion of toxicants by this pupal parasitoid.

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