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Effect of Wood Preservative Treatment of Beehives on Honey Bees and Hive Products

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Effects of wood preservatives on the microenvironment in treated beehives were assessed by measuring performance of honey bee (*Apis mellifera* L.) colonies and levels of preservative residues in bees, honey, and beeswax. Five hives were used for each preservative treatment: copper naphthenate, copper 8-quinolinolate, pentachlorophenol (PCP), chromated copper arsenate (CCA), acid copper chromate (ACC), tributyltin oxide (TBTO), Forest Products Laboratory water repellent, and no treatment (control). Honey, beeswax, and honey bees were sampled periodically during two successive summers. Elevated levels of PCP and tin were found in bees and beeswax from hives treated with those preservatives. A detectable rise in copper content of honey was found in samples from hives treated with copper naphthenate. CCA treatment resulted in an increased arsenic content of bees from those hives. CCA, TBTO, and PCP treatments of beehives were associated with winter losses of colonies.

Each year in the United States, about 4.1 million colonies of honey bees (*Apis mellifera* L.) produce approximately 225 million pounds of honey and 3.4 million pounds of beeswax. This represents an annual income of about $140 million; the agricultural economy receives an additional $20 billion benefit through pollination of vital food crops by bees (Levin, 1983). Investment for hive equipment alone is estimated at about $590 million. Although the useful life of wooden beehive parts may average 10 years, in some areas it is much less due to decay and insect attack. Wood preservatives can extend the useful life to 20 years or longer; the economic benefit of wider and more effective use of preserved wood in the beekeeping industry should be readily apparent.

Pentachlorophenol (PCP)-, creosote-, and copper naphthenate based preservatives have been used in treating beehives. Regrettably, the effect of preservatives on bees and hive products is largely unknown, so that little technical basis exists for selecting preservative treatments.

The objectives of this study were to determine which of several treatments for beehives are harmless to bees and if any of the preservative chemicals accumulate in the bees, honey, or wax. From a biological perspective, beehives may be viewed as a miniature model of a community where sensitive organisms live and work in the presence of wood treated with preservatives. For these reasons, results of this study may have significance beyond the immediate practical applications to the beekeeping industry.

The preservation of beehive parts and the effect of preservatives on bees was studied by Harrison et al. (1959) in New Zealand. Trials with arsenic-containing waterborne preservatives (fluorchrome-arsenate with dinitrophenol, copper-chrome arsenate, and zinc-copper-chrome-arsenate) showed that arsenic compounds were poisonous to bees. The latter preservative caused high bee mortality in the fast year, and the others had a weakening effect on the colonies resulting in robbing by other bees. Elevated levels of arsenic were found in dead and live bees, and traces (fractions of parts per million) were detected in honey. Harmful effect of arsenic compounds on bees was linked to orchard sprays and emissions from smelters in a Utah study by Knowlton et al. (1947). An average of approximately 0.1 μg of arsenic trioxide/dead bee was reported.

Use of PCP, creosote, copper and zinc naphthenate, and chromated zinc chloride preservatives on beehives was described by Dyce (1951) with only a passing reference to adverse effects but with a recommendation that the PCP-treated hive parts be ventilated outdoors for a week or two to evaporate the volatile solvents. Dyce (1955) suggested thorough airing of parts treated with PCP or creosote and mentioned toxicity of the latter to bees. Vorwohl (1968) reported acute toxicity of creosote to bees and warned against its use on interior surfaces. In addition, wood treated with creosote has been reported to taint honey (Harrison et al., 1959).

Recently, Morse (1980) stated that copper naphthenates or zinc naphthenates and PCP are not toxic to honeybees but that kerosene or fuel oil in the PCP mixture will kill bees unless the treated hive parts are aired for 3-8 months or unless a mixture of linseed oil and mineral spirits is substituted for the fuel oil or kerosene. PCP vaporizes measurably from treated wood (Ingram et al., 1981a,b), but even after years of exposure it will not be completely removed (Scheffer and Eslyn, 1978). We believe that the concentration and distribution of PCP within the hive and its tolerance by bees may be more significant than the choice of solvent, unless a solvent or carrier oil of low volatility is used. Wood impregnated with fuel oil emits odor for a long time.

Cross (1983) recently reviewed treatments of beehives with water repellents (waxes) and preservatives; of the newer compounds, he predicted a role for alkyl ammonium compounds in protecting hives.

MATERIALS AND METHODS

Beehives were constructed of clear Ponderosa pine sapwood. In addition to the controls (untreated wood), six preservative pressure treatments and a preservative-free, water-repellent dip treatment were used: CCA, ACC, PCP, TBTO, copper 8-quinolinolate, copper naphthenate, and the Forest Products Laboratory (FPL) paintable water repellent (paraffin wax and varnish in mineral spirits) (Feist and Mraz, 1978). Treatment was done after the hive parts had been sawn. The hive parts treated with waterborne preservatives were kiln-dried under restraint

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to minimize the incidence of drying defects. Wood was treated to retentions usually specified for above-ground use or to higher retentions:

preservative	target
CCA (chromated copper arsenate)	4 kg/m^3 (0.25 lb/ft^3)
ACC (acid copper chromate)	4 kg/m^3 (0.25 lb/ft^3)
PCP (pentachlorophenol)	6.4 kg/m^3 (0.40 lb/ft^3)
TBTO (tributyl tin oxide)	1.9 kg/m^3 (0.12 lb/ft^3)
copper 8-quinolinolate	1.9 kg/m^3 (0.12 lb/ft^3)
copper naphthenate	3% copper in wood
FPL water repellent	3-min dip

Five honey bee colonies were used for each treatment for a total of 40 colonies. Hive equipment for each colony consisted of a bottom board, eight Illinois-depth [168 mm ($6\frac{5}{8}$ in.)] hive bodies, and. a flat cover. The colonies were maintained at the same location near Madison and were managed by U.S. Department of Agriculture-Science and Education Administration and University of Wisconsin personnel.

Each colony was established on May 2, 1980, by installing a 2-lb package of bees with a queen on frames with wax foundation. Sugar syrup was provided to each colony for the initial food supply. The colonies were maintained by standard single-queen management practices. Colony behavior and temperament, queen supersedure, bee and brood mortality, brood production, winter survival, honey production, and similar parameters were recorded and will be reported later. Hive parts were examined annually for evidence of decay. Relative durability of hive parts with the various treatments will be reported later, when sufficient decay is present to allow comparison.

Measurements reported in this paper were taken periodically over a 2-year period. Production of honey and wax was measured by weighing the entire hive, and samples of dead bees were collected in dead bee traps. During the first year of this study, sampling was begun when the colonies had become established in their hives and accustomed to their location. Honey, beeswax, and bee samples were analyzed for the presence of wood preservative chemicals.

Analyses for copper, chromium, arsenic, tin, and PCP were performed by Hazleton-Raltech, Inc., Madison, WI. Metals were determined by atomic absorption spectroscopy, and PCP was analyzed with a gas chromatograph equipped with an electron capture detector; mass spectrometry was used to confirm the identity of PCP in representative samples, including controls. In addition, a validation study was performed with known quantities of PCP added to preweighed portions of bees, honey, and wax so as to bracket the concentrations found. The percent recovery at low and high levels was determined for each matrix.

RESULTS AND DISCUSSION

Bees. Bees were collected at weekly intervals from June to Sept 1980 in Todd-type dead bee traps. The largest number of dead bees came from hives treated with ACC; high counts were noted during the 1st and 11th weeks. The second highest number of dead bees came from the copper naphthenate treated hives (which showed some early bleeding of preservative) with high early counts. Neither the high numbers of dead bees per treatment nor high numbers of dead bees collected in a given period correlated with subsequent winter kill, high levels of preservative residues, or hive weight. Dead bee traps monitor the number of bees that die within the hive but not the' total mortality because many die in the field. Furthermore, the number of bees collected in the dead bee traps was low compared with the expected natural mortality. This indicates a low efficiency of the dead bee traps; therefore, there was no statistical significance to the numbers of dead bees that were collected.

PCP. The weekly bee samples were combined for trace analysis. Compared to levels of PCP in dead bee samples from control hives, the average in samples from hives treated with PCP was higher by 100× during the first year and 73× during the second. The level of PCP in bees from the control (untreated) hives averaged 126 parts per billion (ppb). In bees from hives treated with PCP preservative, an average of 12513 ppb was detected. The source of PCP in the bees from control hives is not known. Drifting of bees between adjacent hives can occur, but there was no indication of significant drifting. The presence of PCP in water, soil, and air samples has been repeatedly noted (U.S. Department of Agriculture, 1980). and could account for PCP translocation to bees via plant waxes, nectar, pollen, or water at any stage in the lifetime of a bee.

The hundredfold increase of PCP content in bees from hives treated with PCP can be related to the measurable volatility of PCP (vapor pressure of 0.00011 mmHg at 20 °C) (U.S. Department of Agriculture, 1980). Measurements of PCP vapor coming from treated wood in enclosed spaces have recently been reported (Gebefugi et al., 1979; Ingram et al., 1981a,b; Saur et al., 1982). The presence of cosolvents is known to reduce efflorescence (blooming) and volatilization of PCP (Ingram et al., 1981b). Although we used methyl ethyl ketone as a cosolvent for PCP, undoubtedly PCP vapor was present within hives that were treated with PCP.

Bee samples collected during the second summer gave qualitatively similar results: bees from control and water repellent treated hives averaged 71 ppb of PCP (Table I). The level of the preservative in bees from hives treated with PCP was lower (average 5192 ppb) during the second summer and probably reflects a lowered concentration of PCP vapor in the hives.

Copper. Copper content was higher by only 1.5× and 1.7× (first and second summer, respectively) in dead bee samples from hives treated with copper naphthenate when compared with samples from control hives (Table I).

Copper in bee samples collected during the first summer from hives treated with copper naphthenate averaged 14 parts per million (ppm), compared with 9 ppm in bees from controls. During the second summer, the increase of the copper content of bees from copper naphthenate treated hives was modest and similar to the first: from an average of 9.23 ppm in bees from controls to 15.5 ppm in bees from hives treated with copper naphthenate.

Chromium and Arsenic. Chromium content was 1.7× and 4× higher (first and second summer, respectively) in dead bee samples from hives treated with CCA compared with samples from control hives (Table I). The corresponding increase of chromium content in bee samples from hives treated with ACC was 3.5× and was detectable in the first summer only. Elevated levels of arsenic were also detected in bee samples from CCA-treated hives (near 1 ppm, second summer).

Tin. A pronounced increase in the tin content was detected in bee samples from the TBTO-treated hives: from less than 0.5 ppm in controls to 3.24 ppm. Bee samples collected during the second summer from TBTO-treated hives still had elevated levels of tin (average 1.33 ppm).

Honey. PCP levels in samples from hives treated with PCP were about 8× higher during the first summer and 20× higher during the second compared with levels in the respective control samples. The level of PCP in honey

Table I. Pentachlorophenol (PCP) and Metal Content of Bee Sampler

type of treatment of beehive	PCP, ppb		Cu. ppm		Cr. ppm		As, ppm		Sn, ppm	
	let summer[a]	2nd summer	1st summer	2nd summer	1st summer	2nd summer	1st summer	2nd summer	1st summer	2nd summer
control (no treatment)	172[b]	75		8.68		0.09		<0.1		<0.5
	81	136		9.31		0.34		<0.1		<0.5
				9.70		<0.06		<0.1		<0.5
water repellent		74	9.22	8.43	0.19	0.0785	0.27	<0.1	<0.5	<0.5
		26		10.4		<0.005		<0.1		<0.5
		45								
PCP	15411	12997								
	9815	3773								
		2163								
		3470								
		3558								
CCA			9.17	9.86	0.33	0.8	0.17	0.770		
				10.0		0.72		1.11		
				10.5		0.58		0.790		
ACC			8.82	10.2	0.66	<0.005				
				9.78		<0.005				
				13.4		0.165				
copper naphthenate			14.1	13.8						
				21.5						
				11.2						
copper 8-quinolinolate			9.43	9.02						
				9.89						
				9.30					3.24	1.20
TBTO										1.50
										1.30

[a]Combined weekly bee samples [b]Identity of PCP confirmed by gas chromatography and mass spectrometry.

Table II. Pentachlorophenol (PCP) and Metal Content of Honey Samples

type of treatment of beehive	PCP, ppb		Cu. ppm		Cr, ppm		As, pmm		Sn, ppm	
	1st summer	2nd summer	1st summer	2nd summer	1st summer	2nd summer	1st summer	2nd summer	1st summer	2nd summer
control (no treatment)	2.8[c]	3; 5; 8[b,c]		0.190		<0.06		<0.1		<0.5
				0.240		<0.06		<0.1		<0.5
				0.200		<0.06		<0.1		<0.5
water repellent		7;6;7	0.18	0.156	<0.06	<0.005	<0.1	<0.1	<0.5	<0.5
				0.160		<0.005		<0.1		<0.5
				0.282		<0.005		<0.1		<0.5
PCP	22.3[a]	175; 241								
		117; 128								
		104; 94[c]								
CCA			0.13	0.160	0.19	0.100	<0.1	<0.1		
				0.210		0.460		<0.1		
				0.140		0.220		<0.1		
ACC			0.27	0.144	0.06	0.065				
				0.223		0.030				
				0.236		<0.005				
copper naphthenate			0.28	0.396						
				0.449						
				0.446						
copper 8-quinoliolate			0.1	0.213						
				0.249						
				0.200						
TBTO									<0.5	<0.5
										<0.5
										<0.5

[a]August samples; all first summer metal determinations on pooled three monthly samples. [b] All second year honey samples collected at the end of summer. [c] Identity of PCP confirmed by gas chromatography and mass spectrometry.

samples obtained from untreated hives during the first summer was 2.8 ppb (Table II). Honey from hives treated with PCP had 22.3 ppb of PCP. Samples from the second summer gave an average of 7.2 ppb in honey from controls (untreated and water repellent treated hives) and 143 ppb in honey from PCP-treated hives.

Copper. Increases in copper content of honey samples from hives treated with copper naphthenate were marginal (1.4×, less than 1 ppm) compared to the copper content of honey samples from controls. The content of copper in honey from untreated or water repellent treated hives was less than 0.3 ppm. In honey from hives treated with copper naphthenate the copper content averaged 0.43 ppm (Table II).

Chromium. Chromium content of honey from CCA-treated hives was higher than that in controls but still below 1 ppm. Somewhat higher chromium levels were noted in the samples collected during the second summer from hives treated with CCA (Table II), which averaged 0.26 ppm (controls <0.06 and <0.005 ppm).

Wax. The affinity of PCP for wax is evident in samples from control hives (untreated and water repellent-treated) (Table III). The average level of PCP in the sample from the first summer was 98.4 ppb and from the second sum-

Table III. Pentachlorophenol (PCP) and Metal Content of Wax Samples

type of treatment of beehive	PCP, ppb		Cu, ppm		Cr, ppm		As, ppm		Sn, ppm	
	1st summer	2nd summer	1st summer	2nd summer	1st summer	2nd summer	1st summer	2nd summer	1st summer	2nd summer
control (no treatment)	98.4[a]	1071		0.1		<0.06		<0.1		<0.5
		378		0.05		0.19		<0.1		<0.5
		1018		0.45		<0.06		<0.1		
		668[b]								
water repellent		481	0.04	0.114	<0.005	0.384	<0.1	<0.1	<0.5	<0.5
		679		0.125		0.114		<0.1		2.03
		815		0.096		<0.005		<0.1		<0.5
PCP	2994[a]	63 156								
		47 785								
		24 779								
		28 500								
		34 650								
		40 200[b]								
CCA			0.08	0.21	<0.06	0.53	<0.1	<0.1		
				0.11		0.14		<0.1		
				0.11		<0.06		<0.1		
ACC			0.31	0.247	0.12	<0.005				
				0.236		<0.005				
				0.095		<0.005				
copper naphthenate			0.33	0.349						
				0.095						
				0.329						
copper 8-quinolinolate			0.17	0.097						
				0.092						
				0.182						
TBTO									8.67	5.7
										3.1
										5.1

[a]Combined July and August samples; all other first-summer samples *were* combined with June samples as well. [b] Identity of PCP confirmed by gas chromatography and mass spectrometry.

mer 730 ppb. Samples of wax from hives treated with PCP averaged 2994 ppb in the first summer (30× control) and 39 845 ppb of PCP (55× control) in the second summer. The highest level of PCP detected was 63 156 ppb in a beeswax sample from a hive treated with PCP. It appears that the buildup of PCP in beeswax is time dependent.

Noteworthy are the relatively high levels of PCP that were found in various other beeswax samples, some of which had no known contact with PCP:

Pentachlorophenol (PCP) in Beeswax from Various Sources

description of sample	PCP, ppb
commercial rendered beeswax	3690
commercial cut-comb foundation	860
commercial cut-comb foundation	694[a]
commercial wired foundation	1474
fresh cappings, University of Wisconsin apiary	231

The commercial wax samples may well be pooled material from numerous sources. Conceivably, some of the beeswax could have come from hives treated with PCP. Furthermore, accidental contamination, or reuse of containers that formerly held PCP but were used to collect melted beeswax, cannot be ruled out. The fresh cappings from the University apiary had no known exposure to PCP. It should be mentioned that low background levels of PCP have been reported in the environment, namely, soil and surface water samples (U.S. Department of Agriculture, 1980). Water could be one source of PCP that was detected in beeswax from untreated hives. In addition, diffusion of PCP from a commercial foundation through walls of honeycomb to the cappings is suggested as another explanation for the presence of PCP in the cappings (Figure 1). The presence in cappings of a chemical added to foundations for the purpose of wax moth control has been observed (Atkins, 1984).

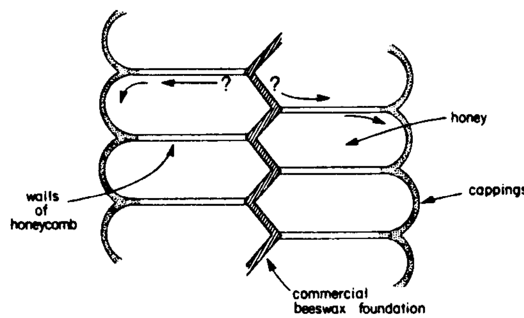

Figure 1. Cross section of honeycomb showing location of foundation, honey, and cappings. The PCP found in the cappings could have migrated from the commercial foundation or it could represent background levels of PCP in the environment.

Copper and Chromium. The levels of copper and chromium, at fractions of a ppm (Table III), showed some variability but did not demonstrate a consistent buildup in wax from hives treated with CCA, ACC, copper naphthenate, and copper 8-quinolinolate.

Tin. The content of tin in wax from hives treated with TBTO increased greatly. Less than 0.5 ppm tin was found in wax from controls. Samples from TBTO-treated hives averaged 8.67 ppm the first summer and 4.63 ppm (Table III) the second summer.

Winter Survival. Winter survival of colonies in hives treated with CCA, TBTO, and PCP was lower than in the other treatments and the control (0 of 5, 1 of 5, and 1 of 5, respectively). The respective survival of colonies in hives treated with copper naphthenate, copper 8-quinolinolate, ACC, water repellent, and controls was 5, 3, 3, 3, and 3 (of a total of 5 each).

Decay. In the fall of 1983, decay was observed starting in the bottom boards and top covers of the control hives. It also was present in the bottom boards of hives treated with water repellents.

CONCLUSIONS

Preservative treatment of hives with PCP, TBTO, and CCA has adverse effect on bees and leaves residues of preservative chemicals in bees, honey, or wax, depending on the individual treatment.

All of the above three treatments were associated with poor survival of colonies during the first winter.

PCP is translocated from treated hives to honey, bees, and wax (in an increasing order). Greatest concentration of PCP was in the beeswax (30-55× the controls, which had detectable levels themselves). This is particularly important, because beeswax has a number of uses for which a high degree of purity is required (cosmetics, for example).

CCA treatment of hives resulted in elevated arsenic and chromium levels in bees. Arsenic levels in the bees were in the reportedly lethal range. Chromium levels, though elevated, were still below 1 ppm in bees. Chromium levels in honey from CCA-treated hives were also below 1 ppm.

TBTO treatment resulted in tin levels of several ppm in bees and wax (higher levels in the latter).

Few, if any, adverse findings resulted from treatments of beehives with (1) a preservative-free water-repellent solution, (2) copper naphthenate, (3) copper 8-quinolinolate, and (4) ACC. Winter survival with these treatments was better than or comparable to that in controls. Of these four treatments, only copper naphthenate gave a slight increase in copper content of honey (less than 1 ppm).

We suggest that beekeepers not use PCP, TBTO, or CCA for treatment of beehives. The CCA treatment, being nonvolatile and largely insoluble (fixed in wood), could be used only on hive parts that rarely come in contact with bees.

Protection of wooden beehive parts without detrimental effects on bees, honey, and wax should result from treatment with copper naphthenate, ACC, and copper 8-quinolinolate.

Early indications are that the preservative-free, water-repellent treatments do not provide long-term protection against decay in all hive parts. Additional observations are needed to fully define the utility and limits of water-repellent treatments for beehives in this climate, but early results indicate that treatment of hive parts with an acceptable preservative is warranted.

Caution. Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife-if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

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Registry No. PCP, 87-86-5; TBOT, 56-35-9; CCA, 37337-13-6; ACC, 11104-65-7; copper 8-quinolinolate, 10380-28-6.

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