HILGARDIA

A Journal of Agricultural Science Published by the California Agricultural Experiment Station

VOLUME 19 NOVEMBER, 1949 NUMBER 9

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THE TOXICITY AND REPELLENCE OF ORGANIC CHEMICALS TOWARD TERMITES, AND THEIR USE IN TERMITE-PROOFING FOOD PACKAGES[1]

W. F. CHAMBERLAIN[2] and W. M. HOSKINS[3]

INTRODUCTION

INTEREST IN THE prevention of damage by insects to packaged foods has increased markedly in the last few years. The scarcity of metal containers during the war intensified the search for substitutes which would exclude insects. Work already has been reported on the use of chemicals incorporated into or applied to packaging material to prevent the entrance of pests. Essig *et al.* (1934),[4] found that, among several species tested, the cadelle larva, *Tenebrioides mauritanicus*, was the most effective penetrator of food packages. Their results indicated that penetration by the cadelle larva can be prevented for a period of more than 50 days by 3,5-dinitro-*o*-cresol and for somewhat shorter periods by other chemicals.

Termites are among the most destructive of insects. In addition to their damage to wood, paper, and other wood substitutes, they also penetrate wooden or paper packages and contaminate the food contained therein. The odor, taste, or color of the ordinary termite-proofing chemicals, such as creosote, usually prohibit their use.

The present work involved the standardization of a method for comparing the resistance to termite penetration of various package materials and the effect of treating them with toxic or repellent chemicals. These chemicals represent several classes of compounds. The results add to the scanty information hitherto available regarding the chemosensory behavior of the Isoptera.

[1] Report on a portion of an investigation on protection of food packages undertaken at the suggestion of the Quartermaster Corps, U. S. Army. It is the third paper in a series on the insecticidal effects of organic compounds. Previous papers appeared in: Jour. Econ. Ent. 33:875–81, 1940; Jour. Econ. Ent. 39:589–97, 1946.

Received for publication, September 29, 1948.

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[4] See "Literature Cited" at the end of this paper for complete data on citations, referred to in the text by author and date of publication.

Termites are usually thought of as wood-eating insects, and previous laboratory methods for testing possible insecticides or repellents were limited to the use of pieces of treated wood. Natural resistance of various woods can be tested in the same way. Wolcott's (1943) laboratory method was to place eight $1\frac{1}{4} \times 1\frac{1}{2}$-inch wooden blocks $\frac{1}{16}$- to $\frac{1}{4}$-inch thick in a petri dish 10 cm. in diameter. The blocks were weighed before introduction of 100 to 200 termites and again after a period of 2 weeks or longer.

Kofoid *et al.* (1934), used two laboratory tests. In the method to determine wood preference (p. 496) the investigators used a block measuring $1 \times 1 \times 4\frac{1}{2}$ inches. The termites—usually 15—were introduced into a $\frac{3}{8}$-inch hole which had been drilled into the block. The hole was then covered with a microscope cover glass and black paper. The amount of wood eaten was measured by filling the hole with mercury before and after the test period. For their studies of wood impregnated with chemicals (p. 344) Kofoid *et al.*, faced together two 3-inch pieces of $\frac{1}{2}$-inch half-round stock. In the dowel thus formed, a $\frac{3}{16}$-inch diameter hole was drilled about half way down the center of the tapered end. This end of the dowel was inserted into a vial containing 10 termites. Observations were made at specified periods on the number of dead termites. None of these methods was suitable for the present purpose of determining if termites were able to penetrate a package made of the test material.

INSECTS USED AND METHODS OF TESTING

The insects used in the present study were removed from logs infested by dampwood termites, collected on the Monterey peninsula. The termites were cultured on damp towel paper in moisture chambers, from which they could be easily removed for the tests. The cultures were maintained at a temperature of 29° C. Drywood termites were obtained from southern California in sections of telephone poles, and were used as removed. The other insects used were available in the stock cultures of grain insects in the Division laboratory.

The relative humidity of the cabinet used for the principal tests was kept between 70 and 90 per cent by means of an evaporation pan with immersion heater, and the temperature was kept constant at 29° C. A fan set at a cabinet opening near the evaporation pan maintained a continual slow input and circulation of clean air within. The tests with the stored-products insects were run in a similar cabinet at the same temperature, but with the relative humidity varying between 20 and 40 per cent.

In preliminary trials the cadelle larva, *Tenebrioides mauritanicus,* the mealworm, *Tenebrio molitor,* the granary weevil adult, *Sitophilus granarius,* the dampwood termites, *Zootermopsis angusticollis* and *Z. nevadensis,* and the drywood termite, *Kalotermes minor,* were compared in their relative abilities to penetrate kraft paper and other materials. To prepare for this trial, the bottom was removed from a pound-sized coffee can and the lid was spread slightly. A paper to be tested was then placed between the lid and the top rim of the can. When the lid was pressed on, the paper was held tightly in place. This provided a circular arena of about 75 sq. cm. The can was then inverted, and 10 to 20 insects were inserted through the open bottom (fig. 1). This method was satisfactory for ordinary papers, but for other materials mechanical difficulties were encountered. Cardboard or thick paper could not be held between the can and the lid and waxed papers sometimes slipped loose during the course of a test. Either accident allowed the insects to escape.

The average periods required for penetration of several materials by the insects mentioned above are shown in table 1. These tests indicate that the ability of dampwood termites to penetrate paper and cellophane is at least equal to that of the cadelle larva. Since the two species of dampwood termites showed such a marked uniformity in rate of penetration, they were used interchangeably in future experiments, although usually *Zootermopsis angusticollis* was used more often than *Z. nevadensis*.

Table 1

TIME REQUIRED BY CERTAIN INSECTS TO PENETRATE VARIOUS PAPERS AND OTHER BAG MATERIALS

Material	Common dampwood termites	Nevada dampwood termites	Cadelle larvae	Mealworms	Granary weevil adults
Toweling	3½ hrs.	3 hrs.	1 day	19 days	29 days
Asphalt bagging	7 days	8 days	4 days	>40 days	>40 days
Cellophane No. 300*	4 days	5 days	8 days	40 days	>40 days
50-pound kraft paper	1 day	1 day	3 days	......	......
50-pound kraft paper plus 50 per cent sodium silicate solution	5 days	6 days	5 days	>40 days	>40 days
3/0 flint sandpaper	>35 days	>35 days	......	......	......
3/0 flint sandpaper—smooth side up	14 days	14 days	......	......	......
Cellophane No. 300 on 0.0006 in. lead foil	>35 days	>35 days	......	......	......
No. 30 sulfite paper on 0.00035 in. lead foil	10 days	10 days	......	......	......
0.00035 in. lead foil on No. 30 sulfite paper	>35 days	>35 days	......	......	......

* Thickness, 0.00088 in.

The arena method of testing just described proved so satisfactory that, with slight modifications, it was used in all the principal experiments. In these tests, the variously treated papers were fastened to the bottom rim of a wide two-piece mason-jar lid by a ring of wax around the outside. Since the top seal was not used, the arena had free access to air. This arena measured 8.5 cm. in diameter with the walls 2 cm. high. A 10-cm. petri dish was fastened on the under side of the paper directly below the lid. The dish prevented possible contamination of the paper from below, and served to trap the termites after they had penetrated the paper. The whole area could therefore consist of one kind of treated material, such as paper, or of treated and untreated semicircles of the same material; or a portion of the arena could be covered with an impenetrable floor, such as a sheet of metal. Figure 2 shows the mason-jar-top arena. The lids and paper were held together by a strong rubber band or by a clamp, but the addition of wax required very little time to apply and eliminated the possibility of insects escaping if the lids did not remain in close alignment.

In all tests, 10 large nymphs were added one day after the units were assembled. New insects were introduced each week until penetration occurred, unless preliminary trials showed no possibility of penetration before several weeks. Except as otherwise noted, the units were examined once a week. All termites were removed, the dead counted, and scratching, penetration, or other phenomena of interest were recorded. The time for penetration of each paper was determined to the end of the week in which it occurred. Since the three or more separate tests of a given material nearly always agreed within a week, the average time given later in the tables probably is accurate in most cases to about half a week.

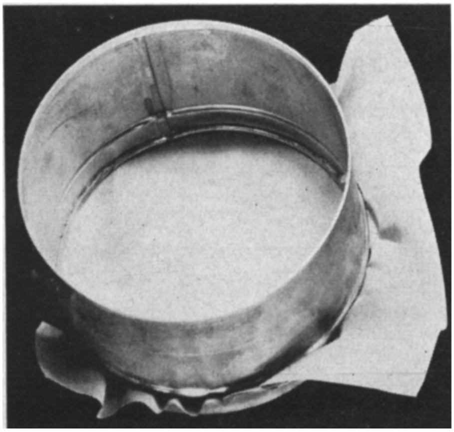

Figure 1

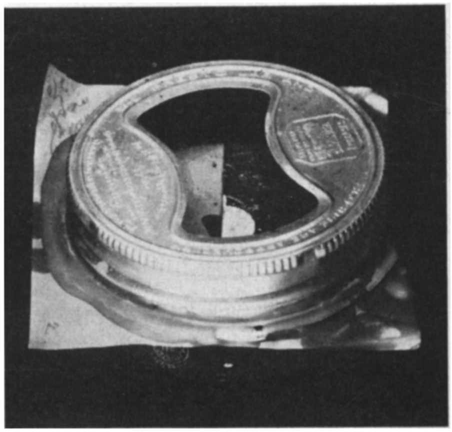

Figure 2

Fig. 1. The can-arena method was so satisfactory that, with slight modifications, it was used in all the principal experiments.

Fig. 2. The mason-jar-top arena is a modification of the can-arena method shown in accompanying figure 1.

Some of the test methods were devised as the work progressed, but for convenience they may be summarized at this point. From the viewpoint of simple usage, a toxicant or repellent incorporated in the paper or in the glue between layers would be desirable. Since the latter could be studied in the laboratory, it was tried first.

In this first procedure, which is called Test A, the glue was prepared, according to a commercial formula, by warming together the following constituents in the given proportions by weight: starch 16 per cent, sodium carbonate 1.4 per cent, borax 2.6 per cent, water 80 per cent. Two per cent of the desired chemical was then added, and the mixture was uniformly applied, while warm, with a roller. The following laminated sheets were prepared: a) Two layers of 50-pound kraft paper; and b) three layers of cardboard. The outside cardboards were 0.49 mm. thick and contained an asphalt glue laminating layer, while the inside cardboard was solid reprocessed paper 0.53 mm. thick. After the glue was applied, the sheets were pressed together and allowed to dry under pressure. Both dampwood and drywood termites were used as test insects.

In Test B (split arena method) 2 pieces of 50-pound kraft paper were used. One paper was dipped in a solution of the toxicant in acetone, removed, and allowed to dry. The other paper was untreated. Both papers were folded and stapled together securely so that no insect could slip through the joint. The joined papers were then mounted so that of the arena exposed to the termites half was treated and half was untreated. This type of test gives an indication of toxicity, but is more useful to measure repellency, both by the ratio of numbers of insects observed on the two halves of the arena and by the half preferentially penetrated. Observations were made two or more times a week, and insects were added at weekly intervals.

In Test C, 50-pound kraft papers were treated with the toxicant dissolved in a volatile solvent. No fold was made, but half the arena was covered with a metal sheet. The solvents used were acetone, ether, benzene, or water. Their selection depended on the solubility of the tested material. The paper was kept in the solution for 10 seconds and allowed to dry for 24 hours before it was mounted. The metal sheet over half the area was fitted closely to prevent termites from crawling under it. If the chemical was repellent, the insects could remain on the metal but not be able to escape through an untreated area. Thus the method would show repellency and give the total period of the repellent and the toxic effects. The observations to determine repellency were made two or more times a week. Dampwood termites were used.

In Test D the kraft papers were treated with the toxicant dissolved in wax, and half the arena was covered with a metal sheet. In these experiments, chemicals, which had proved to have possibilities when dissolved in more volatile solvents, were applied in wax. This was done by melting 25 gms. of wax and stirring in the desired amount of the test chemical. The wax used was a synthetic resin wax, supplied by the Dewey and Almy Company, called Thermoplastic Coating P 16 C., solidification point, 144–134° F. After the test chemical had completely dissolved, 50-pound kraft paper was dipped in the hot solution, and the excess wax was removed by drawing the paper between two smooth glass surfaces under uniform pressure. The reproducibility of the method is shown by the following data: The thickness of the waxed paper varied from 0.15 to 0.19 mm. as measured by a micrometer and the weight from 98.5 to 109.2 mg./sq. in. The kraft paper was 0.12 to 0.13 mm. thick before it was waxed, and had an average weight of 54.4 mg./sq. in. Twenty-four hours later the papers were mounted with half the area covered with metal. They were then exposed to 10 dampwood termites, or, if the chemical had previously shown a strong toxic or repellent effect, the papers were left to weather in the laboratory for a period approximating one half the time to the previous penetration. Usually only one test chemical was used at a time in the papers, but a few tests were conducted with a combination of two chemicals having high toxic or repellent properties separately. Dampwood termites were used.

In Test E the kraft papers were treated with the toxicant dissolved in wax. In some instances the paper was then folded and mounted so that the fold was across the middle of the arena. This was done to determine if a fold increased the potentialities for penetration by the termites as it does with certain grain insects (Essig, *et al.*, 1943). Dampwood termites were used.

Test F was a more or less practical use of a few chemicals which had given most promise in the previous tests. It consisted of exposing treated cardboard boxes designed for dried eggs. These were 2″ × 2¾″ × 4″, and made of 0.018″ to 0.020″ natural kraft-faced chipboard in accordance with specifications of the Food Distribution Administration. The ends were folded over to give three thicknesses and were glued in place. The boxes were dipped in molten wax or in molten wax containing the chosen chemical. Exposure was made by placing the boxes (empty) on damp earth in separate gallon glass jars containing 10 or 20 dampwood termites.

RESULTS

Test A (chemical in glue between kraft paper or cardboard). The materials tested by this procedure were sodium pentachlorophenate, DDT, sodium-3,5-dinitro-*o*-cresylate, morpholine-3,5-dinitro-*o*-cresylate, 2-methyl-

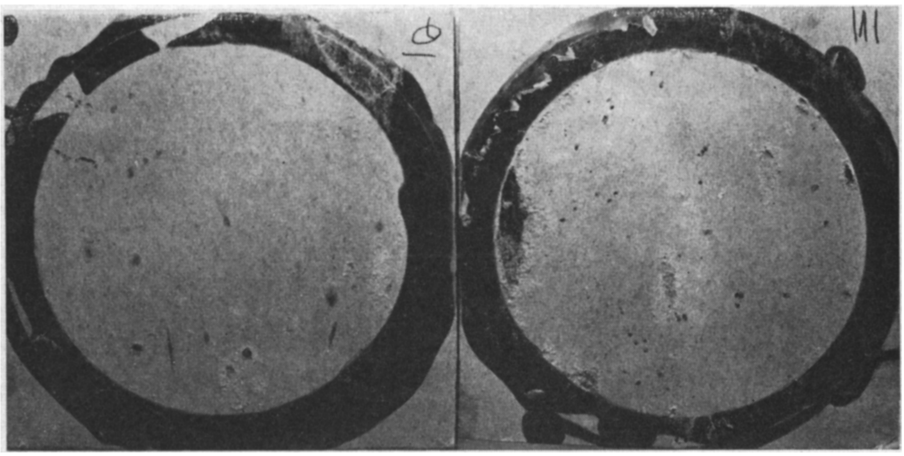

Fig. 3. Dampwood termites scrape out large areas, whereas the drywood species make small round holes perpendicular to the surface.

1,4-naphthoquinone, 2,6-dimethyl-8-sodium naphthalenesulfonate, thiocoumarin, phenothiazine, and chromated zinc chloride. All were used at 2 per cent, although some were only partially dissolved.

The characteristic difference in attack upon the surfaces is shown in figure 3. The dampwood termites scrape out large areas and expose much of the glue and toxicant contained therein, whereas the drywood species make small round holes perpendicular to the surface and, hence, encounter a minimum amount of the toxicant. These behaviors are in agreement with the insects' normal methods of boring, and are responsible for the decided superiority of the drywood species in penetrating the cardboard. Complete results are given in table 2. In this, and in the remaining tables, the compounds are arranged in the order: halogen, nitrogen, oxygen, sulfur compounds, natural products, and miscellaneous. Some of the glue and the chemicals included were seen to soak through the paper and expose the insects from the moment they were put into the arena. This was not true of the thicker cardboard. Some decomposition of DDT probably occurred

[5] Acknowledgment is made of the assistance of Mr. Henry Hurtig in this part of the work.

in the glue, since it was somewhat alkaline and was made by warming all constituents together. This may have affected the toxicity. Sodium pentachlorophenate at 2 per cent had no noticeable effect. In the alkaline glue, it could not be converted to the more toxic free phenol form.

Table 2

TIME REQUIRED BY TERMITES TO PENETRATE LAMINATED PAPER AND CARDBOARD WITH CHEMICALS AT 2 PER CENT CONCENTRATION IN THE GLUE

Chemical	Average time in weeks to first penetration		Per cent mortality first week		Per cent mortality last week		Time in weeks to scratching	
	Dampwood termites	Drywood termites	Dampwood termites	Drywood termites	Dampwood termites	Drywood termites	Dampwood termites	Drywood termites
A. TWO LAYERS 50-POUND KRAFT PAPER								
None	1½	1	15	25	..	..	..	..
Sodium pentachlorophenate. C_6Cl_5ONa	2	..	10	..	0	..	..	..
1,1,1-trichloro-2,2-*bis*-(*p*-chlorophenyl), ethane* (DDT). $Cl_3CCH(C_6H_5Cl)_2$	2	8+	0	100	20	100	..	..
Sodium-3,5-dinitro-*o*-cresylate. $C_6H_2CH_3(NO_2)_2ONa$	24+	1	90	0	70	..	..	..
2-methyl-1,4-naphthoquinone. $C_{10}H_5(CH_3)O_2$	4	4+	100	60	40	30	..	..
2,6-dimethyl-8-sodium naphthalene sulfonate. $C_{10}H_5(CH_3)_2SO_3Na$	2	1	80	30	10	..	..	..
Thiocoumarin.* $C_6H_4SC(O)CH{=}CH$	12	1	40	30	20	..	4	..
Phenothiazine.* $C_6H_4SC_6H_4NH$	9	4+	80	40	40	40	4	..
Chromated zinc chloride. $Na_2CrO_4+ZnCl_2$	1	2	0	50	..	40	..	..
B. THREE LAYERS OF CARDBOARD								
None	8	3	20	20	0	20	1	1
Sodium pentachlorophenate	10	..	10	..	20	..	4	..
1,1,1-trichloro-2,2-*bis*-(*p*-chlorophenyl), ethane.* (DDT)	16	8	10	30	20	40	1	4
Sodium-3,5-dinitrocresylate	17	4	20	70	30	10	1	..
2-methyl-1,4-naphthoquinone	17	4	50	40	20	20	1	2
2,6-dimethyl-8-sodium naphthalene sulfonate	18	3	100	20	50	20	4	2
Thiocoumarin*	6+	3	10	20	20	10	1	2
Phenothiazine*	17	3	30	20	20	10	4	2
Chromated zinc chloride	17	3	50	40	30	10	10	2

* Not all dissolved.

The obvious difference in the effect of DDT upon the two kinds of termites probably is due to a difference in the amount of external wax on their bodies. The small amount of wax on the dampwood species accounts for their susceptibility to desiccation. Since they live in a humid atmosphere, their integument is moist. The drywood species, on the other hand, is very resistant to desiccation, doubtless because of a heavy waxy layer on the integument (Wigglesworth, 1946). This kind of body surface might be expected to facilitate the entry of DDT and account for its higher toxicity to this species. Dampwood termites are more likely to enter food packages than drywood termites. These packages often rest on basement or storehouse floors, or temporarily may be left on the ground—for instance, on beaches during war—where these species of termites live. Hence, the dampwood termites were used exclusively in the remaining experiments.

Table 3

SELECTIVE PENETRATION OF 50-POUND KRAFT PAPER BY DAMPWOOD TERMITES. ONE HALF THE ARENA WAS UNTREATED; THE OTHER HALF HAD BEEN DIPPED IN A SOLUTION OF THE CHEMICAL IN ACETONE. TEN LARGE NYMPHS WERE ADDED EACH WEEK

Chemical	Concentration in weight/volume, per cent	Total number of penetrations in four tests		Average time in weeks to penetration	Per cent mortality first week	Per cent mortality last week
		Treated area	Untreated area			
2,4,5-trichlorophenol $CCl{=}CH\text{-}CCl{=}CClCH{=}COH$	2	0	8	1	20	..
1,1,1-trichloro-2,2-*bis*-(*p*-chlorophenyl), ethane (DDT). $Cl_3\text{-}CCH\text{-}(C_6H_5Cl)_2$	0.05	4	2	1	50	..
	0.5	2	2	6	100	65
	1	0*	6	1	70	..
Chloroacetamide. $Cl\text{-}CH_2\text{-}C(O)\text{-}NH_2$	2	2	2	2	70	20
o-chlorohydroquinone $HOC{=}CClCH{=}C(OH)CH{=}CH$	2	0*	16	1	5	..
p-nitrobromobenzene $NO_2C{=}CHCH{=}CBrCH{=}CH$	2	4	4	1	20	..
o-nitroiodobenzene $NO_2C{=}CHCH{=}CHCHCI$	1	0*	6	1	30	..
p-bromoaniline $NH_2C{=}CHCH{=}CBrCH{=}CH$	2	2	8	1	15	..
Quinoline. $C_6H_4N{=}CHCH{=}CH$	2	0‡	4	1	20	..
o-nitro-nitroso-*m*-cresol $HOC\text{-}CHC(CH_3)\text{-}CHCH\text{-}C(NO)$	1†	2	6	1	5	..
Benzil. $C_6H_5C(O)C(O)C_6H_5$	2	0	6	1	30	..
Terpineol $(CH_3)_2\text{-}C(OH)_2CH\text{-}CH_2\text{-}CH_2\text{-}C(CH_3)\text{-}CH\text{-}CH_2$	2	0*	6	1	5	..
Borax.* $Na_4B_2O_7 \cdot 10\,H_2O$	3	0	1	1 day	0	..

* Dissolved in water.
† Not all dissolved.
‡ Indicates this area was scratched.

Representatives of the paper and cardboard industry, when consulted regarding the incorporation of chemicals in the glue used for lamination, were reluctant to undertake such a program. They contended that the greater part of their products is used for purposes in which insect attack is of no importance. Papers and cardboards usually are not made for a particular use. It would, therefore, be a considerable nuisance and expense to store and keep accurate account of treated and untreated materials of otherwise identical composition. And cost would prohibit treating everything made, as it would the incorporation of a protective chemical in the paper pulp during manufacture. Hence, such experiments as Test A were considered impractical, and attention was turned toward the application of chemicals to the outside of paper products.

Test B (chemical in volatile solvent over half arena, other half untreated). The results shown in table 3 indicate that 2,4,5-trichlorophenol, *o*-chlorohydroquinone, *o*-nitroiodobenzene, benzil, quinoline, and terpineol are repellent to the termites. The degree of repellency cannot be estimated quantitatively since an effect, no matter how small, would be enough to cause the insects to penetrate the untreated rather than the treated side. DDT at the low concentration of 0.05 per cent showed no appreciable repellency, but at 1 per cent the effect was marked. At 0.5 per cent no repellency was apparent; the high initial kill and the long period before either side was penetrated indicate that the insects spent enough time on the treated side to ensure quick mortality.

Test C (chemical in volatile solvent over half arena, metal plate over other half). The results of these tests are given in table 4. Because of the many compounds tested, the results with only the more effective ones will be mentioned. The choice of materials was based on several considerations. Inorganic poisons, such as arsenicals or fluorides, and such materials as creosote were omitted as objectionable around foods. Since protection for at least several months was desired, highly volatile chemicals were not considered. Numerous essential oils are known to have repellent (and/or toxic) effect upon termites (Wolcott, 1946). Accordingly, several firms which deal in such materials were asked to supply samples of their more persistent products. Eight materials were collected. Most of them were solids and probably should be called gums rather than oils. Many of the common termite remedies were tested and, in addition, a considerable number of chemicals which had been used in the tests against cadelle larvae in continuing the work reported by Essig *et al.* (1943).

The compounds preventing penetration for more than 3 months include DDT at 0.5 to 2 per cent; morpholine-3,5-dinitro-*o*-cresylate, 2 per cent; phenothiazine-3,5-dinitro-*o*-cresylate, 2 per cent; 3,5-dinitro-*o*-cresyltrichloroacetate, 2 per cent; and β,β'-dithiocyanodiethyl ether (used as Lethane A70, 10 per cent), 9 per cent. It was found by observation that all the dinitro compounds showed a slight repellency to the termites, causing the termites to stay on the metal more than on the paper. The Lethanes similarly were somewhat repellent, but the DDT tests showed no appreciable difference in the amount of time spent on the paper and spent on the metal. By comparison with the results in table 2, this indicates that repellency is much more obvious when the termites have a choice between treated and untreated paper.

The compounds which prevented penetration for 8 weeks, then were either no longer tested or failed in less than 3 months, were: 1,1-dichloro-2,2-*bis*-(*p*-chlorophenyl), ethylene, 2 per cent; 2,4-dinitro-6-*sec*-butylphenol, 2 per cent; diphenylamine-3,5-dinitro-*o*-cresylate, 2 per cent; phenothioxine-3,5-dinitro-

Table 4

TIME REQUIRED BY DAMPWOOD TERMITES TO PENETRATE 50-POUND KRAFT PAPER TREATED WITH CHEMICALS IN ACETONE (EXCEPT AS NOTED). ONE HALF ARENA COVERED WITH METAL SHEET. TEN LARGE NYMPHS ADDED EACH WEEK

Chemical	Concentration in weight/volume, per cent	Average time in weeks to first penetration	Per cent mortality first week	Per cent mortality last week	Time in weeks to first scratching
None	..	1 day	0	..	..
2,4,5-trichlorophenol CCl=CHCCl=ClCH=COH	2	2	100	20	1
Tetrachlorophenol C_6HCl_4OH	2	3½	75	45	..
o-chlorohydroquinone HOC=CClCH=C(OH)CH=CH	2	1	50	..	..
Chloranil* O=CCCl=CClC(O)CCl=CCl	1.5	1	45	..	..
Chloroacetamide $ClCH_2C(O)NH_2$	2	5½	100	20	1
Trichloroacetamide $Cl_3CC(O)NH_2$	2	2	30	30	..
m-nitrobenzoylchloride O=CClC=CHC(NO_2)=CHCH=CH	2	1	10	..	..
p-nitrobenzoylchloride O=CClC=CHCH=C(NO_2)CH=CH	2	1	10	..	..
1,1,1-trichloro-2,2-*bis*-(*p*-chlorophenyl), ethane (DDT) $Cl_3CCH(C_6H_5Cl)_2$	0.05	1	15	..	..
	0.5	13½	95	55	13
	1	13+	100	95	..
	2	22+	100	90	..
1,1,1-trichloro-2,2-phenylethane $Cl_3CCH(C_6H_5)_2$	2	1½	50	30	1
1,1,1-trichloro-2,2-*bis*-*p*-tolylethane $Cl_3CCH(C_6H_5CH_3)_2$	2	1	30	..	..
1,1-dichloro-2,2-*bis*-(*p*-chlorophenyl), ethylene $Cl_2C=C(C_6H_5Cl)_2$	2	8+	100	60	..
1,1,1-trichloro-2,2-*bis*-(acrylonitrile), ethane $Cl_3CCH(CH=CHCN)_2$	2	2	20	10	..
p-nitrobrombenzene NO_2C=CHCH=CBrCH=CH	2	1	40	..	..
p-bromoaniline NH_2C=CHCH=CBrCH=CH	2	1	15	..	..
2,4,6-tribromoaniline NH_2C=CBrCH-CBrCH=CBr	2	2	90	20	..
Tribromonaphthol† $C_{10}H_4Br_3OH$	2	1	10	..	..
Iodoform† CHI_3	2	2	40	30	..
o-nitroiodobenzene NO_2C=CHCH=CHCHCI	1	1	10	..	..

* Benzene as solvent.
† Ether as solvent.
‡ Very little dissolved.
§ Active ingredient, 50 per cent in light spray oil.
¶ Water as solvent.
|| Active ingredient, 90 per cent in light spray oil.

Table 4—*Continued*

Chemical	Concentration in weight/volume, per cent	Average time in weeks to first penetration	Per cent mortality first week	Per cent mortality last week	Time in weeks to first scratching
beta-iodonaphthalene $C_6H_4CH{=}CICH{=}CH$	2	2	100	20	..
beta-nitrotoluene† $NO_2C{=}CHCH{=}CHC(CH_3){=}CH$	2	1	15	..	..
o-nitrodiphenyl $C_6H_5C_6H_4(NO_2)$	2	4½	55	30	..
o-nitroso-*m*-cresol $HOC{=}CHC(CH_3){=}CHCH{=}C(NO)$	1	1	5	..	..
3,5-dinitro-*o*-cresol $CH_3C{=}C(OH)C(NO_2){=}CHC(NO_2){=}CH$	2	13+	100	100	..
Barium-3,5-dinitro-*o*-cresylate $[C_6H_2CH_3(NO_2)_2O]_2Ba$	2	2	..	10	..
Copper-3,5-dinitro-*o*-cresylate† $[C_6H_2CH_3(NO_2)_2O]_2Cu$	2‡	13+	100	100	..
Diphenylamine-3,5-dinitro-*o*-cresylate $(C_6H_5)_2NH\cdot HOC_6H_2CH_3(NO_2)_2$	2	9	100	50	4
Morpholine-3,5-dinitro-*o*-cresylate $CH_2CH_2OCH_2CH_2NH\cdot HOC_6H_2CH_3(NO_2)_2$	2	13+	100	100	..
Phenothioxine-3,5-dinitro-*o*-cresylate $C_6H_4SC_6H{=}O\cdot HOC_6H_2CH_3(NO_2)_2$	2	3	100	15	4
Phenothiazine-3,5-dinitro-*o*-cresylate $C_6H_4SC_6H_4NH\cdot HOC_6H_2CH_3(NO_2)_2$	2	22+	100	70	..
3,5-dinitro-*o*-cresylacetate $C_6H_2CH_3(NO_2)_2OC(O)CH_3$	2	17+	100	65	17
3,5-dinitro-*o*-cresyltrichloroacetate $C_6H_2CH_3(NO_2)_2OC(O)CCl_3$	2	15	100	40	14
2,4-dinitro-6-*sec*-butylphenol $(CH_3)_2CHCH_2C_6H_2(NO_2)_2OH$	2	9	100	60	..
2,4-dinitroanisole $CH_3OC{=}C(NO_2)CH{=}C(NO_2)CH{=}CH$	1.5	1½	60	25	1
2,4-dinitroaniline $NH_2C{=}C(NO_2)CH{=}C(NO_2)CH{=}CH$	1	1½	30	25	1
Quinoline $C_6H_4N{=}CHCH{=}CH$	2	1	10	..	..
Diphenylguanidine† $HN{=}C(NHC_6H_5)_2$	2	1	5	..	..
Triphenylguanidine† $C_6H_5N{=}C(NHC_6H_5)_2$	2	1	15	..	..
Dicyandiamide¶ $NH_2C({=}NH)CHCN$	2	2	20	30	1
Nicotine pectate $C_{10}H_{14}N_2\cdot C_{17}H_{24}O_6$	2	1	10	..	..
Xanthone $C_6H_5OC_6H_5C{:}O$	0.5	4	100	40	..
Coumarin $C_6H_4CH{:}CHC(O)O$	2	3	80	30	..
Benzophenone $C_6H_5C(O)C_6H_5$	2	1	50	..	..
Benzil $C_6H_5C(O)C(O)C_6H_5$	2	1	15	..	..

†, ‡, ¶ (See first page of table 4 for footnotes.)

Table 4—*Concluded*

Chemical	Concentration in weight/volume, per cent	Average time in weeks to first penetration	Per cent mortality first week	Per cent mortality last week	Time in weeks to first scratching
Lethane 384§ $C_4H_9OCH_2CH_2OCH_2CH_2SCN$	2	5	100	20	3
	5	8+	100	70	5
	10	8+	100	100	..
Lethane A-70‖ $NCSCH_2CH_2OCH_2CH_2SCN$	1	8	100	30	..
	5	8+	100	60	6
	10	16+	100	100	..
Dixanthogen $C_2H_5OC(S)SSC(S)OC_2H_5$	2	5	100	45	..
Thiocoumarin $C_6H_4SC(O)CH{=}CH$	2	2	20	20	..
Phenothioxine $C_6H_4SC_6H_4O$	2	2	100	55	..
Balsum (Peru)	2	1½	30	10	..
Balsum (Tolu)	2	1	0	..	..
Camphor $C_{11}H_{16}O$	2	1	0	..	..
Oil of cedarwood	2	2	20	5	..
Oil of guaiac wood	2	1½	30	10	..
Oil of opopanax	2	1½	10	0	..
Oil of patchouli	2	1	5	..	..
Oil of sandalwood	2	1	5	..	..
Styrax (American)	2	3	20	20	..
Terpineol $(CH_3)_2C(OH)CHCH_2CH_2C(CH_3){=}CHCH_2$	2	1	20	..	..
Terpin hydrate $(CH_3)_2C(OH)CHCH_2CH_2C(CH_3)(OH)CH_2CH_2$	2	1	30	..	..
Phenylsalicylate $C_6H_4(OH)C(O)OC_6H_5$	2	1	100	..	..
2,6-dimethylnaphthalene $C_{10}H_6(CH_3)_2$	2	1	0	..	..
Phenanthrene $C_{14}H_{10}$	2	8	90	25	..
Copper sulfate¶ $CuSO_4 \cdot 5H_2O$	2	3	0	20	..
Borax¶ $Na_4B_2O_7 \cdot 10H_2O$	3	1	0	..	..
Sodium silicate¶ Na_2SiO_3	50	1	0	..	..

§, ‖, ¶ (See first page of table 4 for footnotes.)

o-cresylate, 2 per cent; *β,β′*-dithiocyanodiethyl ether (used as Lethane A70, 5 and 1 per cent), 4.5 and 0.9 per cent; *β*-butoxy-*β′*-thiocyanodiethyl ether (used as Lethane 384, 10 and 5 per cent), 5 and 2.5 per cent; and phenanthrene, 2 per cent. All the other compounds tested failed to last 8 weeks, and most allowed penetration in the first week. The low solubility of barium 3,5-dinitro-*o*-cresylate decreased its value to such an extent that it offered no protection of food packages. Papers treated with this compound were penetrated in 2 weeks. None of the other nitrogen compounds showed any promise.

Thiocoumarin when first tested showed a higher repellency than any other compound tested. During the first week, 90 per cent of the termites remained on the metal area during numerous observations. The high volatility of this material caused it to dissipate so rapidly that the termites readily penetrated during the second week. Coumarin showed a marked repellency during the first week, also.

The natural oils as a group showed no value in preventing penetration. All allowed entry in less than 2 weeks, with the exception of styrax, which was effective for only 3 weeks. None of the natural oils showed any marked repellency to the termites, which remained on the treated paper as much as on the metal. The more delicate test of repellency (table 1) had shown terpineol, a constituent of many essential oils, to be somewhat repellent. Phenanthrene, which is a hydrocarbon occurring in coal tar, prevented penetration for 8 weeks but showed no marked repellency. Penetration seemed to be delayed by toxic properties rather than by repellency.

Test D (chemical in wax over half arena, metal plate over other half). The following chemicals in wax-dipped paper prevented penetration for longer than 6 months: hexachlorocyclohexane, $3\frac{1}{3}$ per cent (30 per cent gamma isomer); DDT, 5 per cent and 2 per cent; 3,5-dinitro-*o*-cresol, 2 per cent; phenothiazine-3,5-dinitro-*o*-cresylate, 2 per cent; 3,5-dinitro-*o*-cresyltrichloroacetate, 1 and 2 per cent; 3,5-dinitro-*o*-cresylacetate, 1 and 2 per cent; diphenylamine-3,5-dinitro-*o*-cresylate, 2 per cent; and phenothiazine, 2 per cent. Special mention should be made of hexachlorocyclohexane. For 18 months after the papers were prepared, all exposed termites became semiparalyzed within 12 hours.

When the concentration of some of the above compounds was reduced, there was a corresponding reduction in time to penetration. Diphenylamine-3,5-dinitro-*o*-cresylate at 1 per cent was still of considerable value, and in these tests prevented penetration over 5 months but less than 6 months. At 2 per cent 2,4-dinitro-6-*sec*-butylphenol prevented penetration of the test papers for not less than 4 months. Compounds of minor effectiveness include 1,1-dichloro-2,2-*bis*-(*p*-chlorophenyl), ethylene at 1 per cent and 2 per cent; *o*-nitrodiphenyl at 2 per cent and 2-methyl-1,4-naphthoquinone at 2 per cent, all of which were effective up to 3 months. Compounds effective for only 2 months were tetrachlorophenol; thiocoumarin; phenothioxine; *β*-butoxy-*β′*-thiocyanodiethyl ether at 5 and 2.5 per cent; and *β,β′*-dithiocyanodiethyl ether at 4.5 per cent. The Lethanes are not necessarily justifiably placed here, since the tests were incomplete. It is possible the Lethanes could be effective for a longer period. Only a slight reduction in their toxicity at

Table 5

TIME REQUIRED BY DAMPWOOD TERMITES TO PENETRATE 50-POUND KRAFT PAPER TREATED WITH CHEMICALS IN WAX. ONE HALF ARENA COVERED WITH METAL SHEET EXCEPT AS NOTED. TEN LARGE NYMPHS ADDED EACH WEEK

Chemical	Concentration in per cent by weight	Average time in weeks to first penetration	Per cent mortality first week	Per cent mortality last week	Time in weeks to first scratching
None	..	2 (2)¶	0	0	..
Tetrachlorophenol C_6HCl_4OH	2	9	80	30	8
1,1,1-trichloro-2,2-*bis*-(*p*-chlorophenyl), ethane (DDT)	2	28+	100	80	..
$Cl_3CCH(C_6H_5Cl)_2$	5	25+	100	100	..
1,1-dichloro-2,2-*bis*-(*p*-chlorophenyl), ethylene	1	12	40	40	..
$Cl_2C=C(C_6H_5Cl)_2$	2	16+	80	40	3
Hexachlorocyclohexane (isomer) $C_6H_6Cl_6$ (BHC)	1§	87+	100	100	..
Chlordan $C_{10}H_6Cl_8$	1	29	100	100	..
Iodine I_2	2	1	30	..	..
o-nitrodiphenyl $C_6H_5C_6H_4NO_2$	2	13 (10)	70 (50)	40 (40)	8
3,5-dinitro-*o*-cresol	0.5	21** (8)	100 (100)	15 (60)	..
	1	21** (16)	100 (100)	50 (50)	..
	2	28 (29+)	100 (100)	45 (100)	9
Barium-3,5-dinitro-*o*-cresylate $\{C_6H_2CH_3(NO_2)_2O\}_2Ba$	2	2	40	45	..
Diphenylamine-3,5-dinitro-*o*-cresylate	1	22 (22)	100 (100)	35 (60)	(21)
$(C_6H_5)_2NH\cdot HOC_6H_2CH_3(NO_2)_2$	2	26 (28)	100 (100)	50 (45)	(26)
Phenothiazine-3,5-dinitro-*o*-cresylate	1	26 (10)	100 (60)	90 (50)	(1)
$C_6H_4SC_6H_4NH\cdot HOC_6H_2CH_3(NO_2)_2$	2	30 (28)	100 (100)	50 (30)	8
3,5-dinitro-*o*-cresylacetate	1	26 (27)	100 (100)	30 (60)	..
$C_6H_2CH_3(NO_2)_2OC(O)CH_3$	2	29+(29+)	100	100 (100)	..
3,5-dinitro-*o*-cresyltrichloroacetate	1	30½ (28)	100 (100)	30 (30)	(10)
$C_6H_2CH_3(NO_2)_2OC(O)Cl_3$	2	28 (28)	100 (100)	35 (25)	(8)
2,4-dinitro-6-*sec*-butylphenol $(CH_3)_2CHCH_2C_6H_2(NO_2)_2OH$	2	20 (29)	100 (80)	30 (20)	8
o-aminodiphenyl $C_6H_5C_6H_4NH_2$	2	2	50	0	..
2-methyl-1,4-naphthoquinone $C_{10}H_5(CH_3)O_2$	2	13	90	50	7
Sulfur S	2	8+	20	0	..

* Active ingredient, 50 per cent in light mineral oil.
† Active ingredient, 90 per cent in light mineral oil.
‡ Essentially same results with corresponding lead and zinc salts.
§ 30 per cent γ material used at 3⅓ per cent concentration in wax.
¶ All data in ( ) refer to arena without metal.
‖ Poor dispersion.
** No test between tenth and twenty-first week.

Table 5—*Concluded*

Chemical	Concentration in per cent by weight	Average time in weeks to first penetration	Per cent mortality first week	Per cent mortality last week	Time in weeks to first scratching
Lethane 384* $C_4H_9OCH_2CH_2OCH_2CH_2SCN$	2	5½	100	40	3
	5	8+	100	69	..
	10	8+	100	95	..
Lethane A 70† $NCSCH_2CH_2OCH_2CH_2SCN$	2	6½	100	50	5
	5	8+	100	90	..
Thiocoumarin $C_6H_4SC(O)CH{=}CH$	2	9	0	10	8
Phenothioxine $C_6H_4SC_6H_4O$	2	9 (11)	30 (20)	30 (25)	8 (10)
Phenothiazine $C_6H_4SC_6H_4NH$	2	27	60	30	8
α-naphthylthiourea $C_{10}H_6NHC(S)NH_2$	1	1	20	..	..
Sodiumdiethyldithiocarbamate‡ $(C_2H_5)_2NC(S)SNa$	1	1	10	..	..
Sodiumdibutyldithiocarbamate‡ $(C_4H_9)_2NC(S)SNa$	1	1	0	..	..
Oil of guaiac	2	1	0	..	..
Oil of sandalwood	2	1	0	..	..
Styrax (American)	2	1	40	...	..
Copper sulfate $CuSO_4 \cdot 5H_2O$	2‖	1	0	..	..

the higher concentrations was noted during the last week of the test. The rest of the compounds tested would be of no value in protecting packages from termites. In table 5 the complete results are shown.

In general, the use of 2 toxic compounds did not materially increase the effectiveness of a treated paper as the increased time to penetration averaged only 3 weeks. However, a few exceptions may be noted. Two sets of papers, one with DDT and phenothiazine-3,5-dinitro-*o*-cresylate, and the other with DDT and 3,5-dinitro-*o*-cresylacetate, were still unpenetrated at the end of 32 weeks when it was necessary to conclude the studies. The 2 per cent mixture of DDT and phenothiazine-3,5-dinitro-*o*-cresylate was more than twice as effective as the 1 per cent mixture as was also the 2 per cent mixture of DDT and 3,5-dinitro-*o*-cresyltrichloroacetate. The addition of 2-methyl-1,4-naphthoquinone to either DDT or thiocoumarin increased its own effectiveness from 13 to 29 weeks, that of thiocoumarin from 9 to 29 weeks, but did not influence the effect of DDT appreciably. Table 6 lists all the combinations along with concentration of each chemical, time to penetration, and the per cent kill at the beginning and end of each experiment.

Test E (chemical in wax; fold across center of arena in some cases). In contrast to the situation with certain grain insects (Essig *et al.*, 1943), a fold does not facilitate penetration by the dampwood termites. Hence, this test only served to show any possible difference in behavior between a

Table 6

TIME REQUIRED BY DAMPWOOD TERMITES TO PENETRATE 50-POUND KRAFT PAPER TREATED WITH TWO CHEMICALS IN WAX. ONE HALF ARENA COVERED WITH METAL SHEET. TEN LARGE NYMPHS ADDED EACH WEEK

Chemica	Concentration in per cent by weight of each	Average time in weeks to penetration	Per cent kill first week	Per cent kill last week	Time in weeks to first scratching
DDT plus phenothiazine-3,5-dinitro-*o*-cresylate	1 1	14	100	60	..
DDT plus phenothiazine-3,5-dinitro-*o*-cresylate	2 2	32+	100	100	..
DDT plus 3,5-dinitro-*o*-cresylacetate	1 1	31½	100	25	..
DDT plus 3,5-dinitro-*o*-cresylacetate	2 2	32+	100	100	..
DDT plus 3,5-dinitro-*o*-cresyltrichloroacetate	1 1	14	100	95	..
DDT plus 3,5-dinitro-*o*-cresyltrichloroacetate	2 2	31	100	50	30
DDT plus 2-methyl-1,4-naphthoquinone	1 1	21½	100	65	13
DDT plus 2-methyl-1,4-naphthoquinone	2 2	30	100	35	..
Thiocoumarin plus 2-methyl-1,4-naphthoquinone	1 1	22	100	40	..
Thiocoumarin plus 2-methyl-1,4-naphthoquinone	2 2	29	100	40	..

Table 7

TIME REQUIRED BY DAMPWOOD TERMITES TO PENETRATE DRIED-EGG BOXES TREATED WITH CHEMICALS AT 1 PER CENT IN WAX. BOXES PLACED ON DAMP EARTH IN GALLON JARS CONTAINING 10 TO 20 TERMITES

Chemical	Immediate exposure				Later exposure*			
	Duration	Per cent mortality	Penetration	Scratching	Duration	Per cent mortality	Penetration	Scratching
None	20 days	10	–	+	8	0	+	–
1,1,1-trichloro-2,2-*bis*-(*p*-chlorophenyl), ethane (DDT)	5	90	–	+	8	5	+	–
Chlordan	5	80	–	–	8	0	+	–
Hexachlorocyclohexane (isomer)†	2	100	–	–	8	15‡	–	–

* Eighteen months later. Boxes left in laboratory meanwhile.
† 30 per cent γ isomer material used at 3⅓ per cent concentration in wax.
‡ Termites avoided package.

completely treated arena and one half covered by metal (Test D). The results by these two methods differed so little that they are all included in table 5.

The experiments with dried-egg boxes (Test F) showed that after 18 months neither DDT nor Chlordan at 1 per cent in wax prevented speedy penetration (table 7). However, hexachlorocyclohexane was still effective. This substance was rapidly toxic at the first exposure and slightly toxic 18 months later. The most marked effect at that time was the avoidance of the treated boxes by the termites, which normally tend to crowd under any object placed in the jar. Thus, a repellent effect persisted after the high toxicity had disappeared.

DISCUSSION

The present work has shown that termites readily bore through various kinds of paper, cardboard, and thin cellophane. The inability of the different weekly populations to penetrate sandpaper from the sandy side was accompanied by mortality varying from 100 per cent during the first week to 35 per cent during the fifth. Probably this was due to abrasion of the integument and consequent excessive loss of body moisture (Wigglesworth, 1944). When the smooth side of the paper was upward, the termites penetrated it fairly readily and with much lower mortality. A few experiments with lead foil did not disclose direct attack, but if the foil was covered with a thin layer of paper both were penetrated readily. This is an illustration of a phenomenon noticed many times—that the chief delay is in the initial attack. Once a surface is scratched, it will be penetrated soon thereafter unless exceptionally thick—as 3-layered cardboard (table 2, part B). The increase in time required for penetration when sodium silicate solution was applied to kraft paper (table 4) also illustrates the effect of a hard, smooth surface.

The addition of toxic or repellent chemicals to the paper pulp or to the glue used in lamination is commercially impractical and, therefore, the possibility of protecting foodstuffs in paper or cardboard containers largely depends upon finding a method of treating the finished package. One method would be to use a treated overwrap made of strong but inexpensive paper which would prevent direct contact of chemical and food. Fifty-pound kraft paper was chosen as representative of such material. Tests of paper dipped in volatile solvents containing a wide variety of chemicals, in most cases at 2 per cent concentration, showed greatest promise for DDT, 3,5-dinitro-*o*-cresol, and certain salts of the latter compound, especially those with phenothiazine and with acetic acid. Some compounds, such as thiocoumarin, which were highly repellent at first, volatilized so rapidly that their effect was soon lost. The use of a relatively expensive volatile solvent to impregnate paper products with chemicals involves the difficulty of recovering the solvent and concomitant hazards of fire and toxic effects upon operators. Hence, a nonvolatile solvent was preferable.

Considerable protection from termites had been found previously by application of paraffin wax to wood (Snyder, 1924) and to canvas or boxes (Gravely, 1945). Under the conditions of continuous exposure in an arena, the wax has little practical effect in delaying penetration (1 to 2 weeks as contrasted to 1 to 2 days for untreated kraft paper). However, it seemed probable that the addition of wax to a chemical which, by itself, had considerable ability to prevent penetration might greatly prolong its action. Accordingly, the test was made with a number of chemicals, usually at 1 and 2 per cent concentration in the wax.

Comparison of the periods required for penetration of papers treated with chemicals in wax (table 5) and without wax (table 4) shows that, on the average, a period three and a half times as long was needed when wax was used. Part, at least, of this effect is due to better retention of the chemical. Exceptions to this rule are certain oily, nonvolatile substances, such as Lethanes and heavy essential oils. Further advantages in the use of wax are protection of packaged materials from moisture—and consequent damage from mold—and reduction in loss of the toxic or repellent chemicals by leaching. This last point is of great importance with water-soluble chemicals exposed to damp conditions, and is the chief reason for failure of such materials when treated wood is exposed to the earth.

Unfortunately it was not possible to continue all tests to penetration, but complete mortality for at least 6 months was obtained with 3⅓ per cent hexachlorocyclohexane (30 per cent gamma isomer) 5 per cent DDT, 2 per cent 3,5-dinitro-*o*-cresylacetate, a mixture of the latter two compounds each at 2 per cent and with one containing the phenothiazine salt of 3,5-dinitro-*o*-cresylate and DDT, each at 2 per cent (table 6). The dinitro compounds all stain the surroundings a strong, persistent yellow which is very difficult to remove. Efforts to find a derivative sufficiently nonvolatile and nondiffusible to avoid this serious difficulty were not successful. The barium compound does not stain, but it appears to be so insoluble that it cannot prevent prompt penetration. Unless a more suitable derivative can be found, use of these substances near foodstuffs appears to be inadvisable.

DDT does not stain, and its initial toxicity persists for a long time. The box tests indicate that 1 per cent concentration in wax is insufficient, but probably 5 per cent would have a very persistent effect. However, DDT is somewhat volatile and the possibility of diffusion into the contents of a treated package should be investigated. Unfortunately DDT is slowly decomposed at the temperature of melted wax—for instance, a reduction in toxicity is noticeable after 6 hours and marked after 12 hours. For commercial use the DDT-wax solution would need to be melted in small batches which could be used within a few hours.

Chlordan was obtained too late in the work to permit more than a preliminary examination, but the results with both waxed paper (table 5) and waxed boxes (table 7) were promising. The possibility of serious contamination of food within a treated container is not known. It may be noted in table 5 that penetration occurred in the twenty-ninth week of exposure, but all termites subsequently died during the same week. This latter circumstance is of little consequence, for it has been found repeatedly that once a hole is made, other insects enter also and, of course, moisture and mold organisms have easy access to the contents. The latter point is very important, for experience has shown that most cases of food damage observed in the tropics during the war were due primarily to mold.

Hexachlorocyclohexane was by far the most effective chemical studied. Its toxicity to termites is very great, and it volatilizes and contaminates all surrounding surfaces. Thus, a large number of papers treated with other materials were made unfit for further study after being used in the test chamber at the same time as the hexachlorocyclohexane papers. This is why the results are incomplete with several chemicals listed in the tables. The volatility of hexachlorocyclohexane, combined with its repulsive odor, makes its use around food impossible. On the other hand, there is reason to expect that hexachlorocyclohexane will give lasting protection from termites when impregnated in piles, posts, and foundation lumber. Best penetration probably can be secured in a light organic solvent. The loss by volatilization from heavy timbers would be low, for even a thin film of wax is able to retain the chemical for many months. Papers and boxes treated with this substance were only slightly infested with mold during long exposure to moisture, but no study was made of this result. The high gamma product now called "lindane" was not available.

An examination of the data in tables 3, 4, and 5 permits the repellent chemicals to be divided into two groups. The first includes those showing little toxicity, such as chlorohydroquinone, nitroiodobenzene, quinoline, thiocoumarin, benzil, and terpineol. Marked toxicity characterizes those of the second group, such as hexachlorocyclohexane, DDT at higher concentrations, dinitrophenol compounds and their salts, the Lethanes, and coumarin. Doubtless the avoiding reactions with these materials is the irritation phase of the toxic process and, hence, according to the definition of Campbell (1932), should be called "deterrency."

The data, especially in tables 4 and 5, show a number of relations between insecticidal action and chemical composition. Among compounds containing chlorine on a ring, hexachlorocyclohexane is in a class by itself compared with tetrachlorophenol or trichlorophenol. Also in chloranil, 4 chlorine atoms on an aromatic ring conferred only moderate toxicity. The 2 benzoyl chlorides, which contain the -C(O)Cl group are nontoxic. A few scattered bromine and iodine compounds have little toxicity, but tribromoaniline exceeds the monobrom compound and may be an example of Wolcott's (1944) suggestion that polybromine compounds should be useful for control of termites. However, tribromonaphthol is entirely nontoxic (table 4).

In the DDT family, the original 1,1,1-trichloro-2,2-*bis*-(*p*-chlorophenyl), ethane is the most toxic of those tried, and the dichloroethylene derivative is next, ahead of the 2,2-phenyl and the 2,2-*p*-toluene compounds. The 2,2-*bis*-acrylonitrile compound, which also is a trichloroethane derivative, has no appreciable toxicity. In this group of compounds, it is obvious that the -CCl_3 group of itself does not confer toxicity to termites. This also is shown by the fact that the trichloroacetate of 3,5-dinitro-*o*-cresol is somewhat less toxic than the ordinary acetate salt (tables 4 and 5). Also, trichloroacetamide is decidedly less toxic than the monochloro compound. The structure in the latter is closely similar to that in the chloroacetate (of calcium), which Lennox (1940) found highly toxic to *Lucilia cuprina* larvae. It is also similar to that in the chloroacetate of butyl Cellosolve which is toxic to *L. sericata* larvae (Loeffler and Hoskins, 1946). Lastly, in iodoform the triiodo group $-CI_3$ seems to be associated with little toxicity.

Presence of one nitro group results in an appreciable increase in toxicity in some cases, for instance, *p*-nitrobrombenzene vs. *p*-bromoaniline (table 4) and *o*-nitrodiphenyl vs. *o*-aminodiphenyl (table 5). However, the table includes other mononitro compounds of no noticeable toxicity, in most cases this effect being decidedly less than when 2 nitro groups are present. No particular study was made of the effect of replacing the CH_3 group of 3,5-dinitro-*o*-cresol (DNOC) with other groups, but the *sec*-butyl derivative is somewhat less effective than DNOC. Removal of the OH group lowers the toxic effect in the case of dinitroanisole and dinitroaniline (table 4), but several salts, such as those with phenothiazine and morpholine and the ester with acetic acid, are fully as toxic as DNOC itself. Both the barium and copper salts lack the OH group, but whereas the first is very insoluble and stable and low in toxicity, the second readily hydrolyzes in water and is highly toxic. The effect on the termites is mostly due to the dinitro-*o*-cresol, for copper—for example, in the form of copper sulfate—is nontoxic (tables 4 and 5).

Oxygen in the carbonyl ($>C=O$) group, as in benzophenone and benzil (table 4), does not confer any marked toxicity, but coumarin and especially xanthone, which contain a second oxygen in a ring, are somewhat toxic. Wolcott (1947) found xanthone to be fairly effective in protecting wood from attack by *Cryptotermes brevis*. Methylnaphthoquinone (table 5), which of course has 2 $>C=O$ groups in the ring is moderately effective in preventing penetration, but reduction of the quinone structure as in a Cl hydroquinone (table 4) apparently decreases the effect.

None of the essential oils tried was promising. Probably this should have been expected from the results of Wolcott (1944), who had little success in preventing *C. brevis* from attacking wood treated with various extracts from naturally resistant trees—for example, "lignum-vitae" from which guaiac oil or gum is obtained. It will be noted in tables 4 and 5 that this is not effective either with or without wax. Generally speaking, the essential oils consisted chiefly of derivatives of cinnamic acid (balsum Peru, balsum Tolu, American styrax) or of terpenes (oil of cedarwood, patchouli, sandalwood, terpineol, terpin hydrate, camphor, guaiac, opopanax).

Free sulfur has no toxicity but apparently its repellent effect prevents penetration for a considerable period. Since a slight darkening occurs when sulfur is added to molten wax, possibly the repellent effect was due to some reaction product rather than to sulfur itself. The Lethanes, which contain the SCN group, have high and persistent toxicity if used at 5 per cent or more. Their oily nature is somewhat objectionable for use on paper products. Dixanthogen, which has been used in Europe for louse control (Reichmuth, 1943) is moderately toxic to termites.

Sulfur in the ring, as represented by thiocoumarin, does not confer toxicity, although phenothioxine has a short-lived toxic effect (table 4). Phenothiazine gave long protection, but was not highly toxic even at the start of exposure. It has both sulfur and nitrogen in the ring, and the effect seems to be due to the whole molecule, for other nitrogen compounds—for instance, quinoline (nitrogen in the ring, table 5) and the guanidine derivatives, which have ordinary amine groups (table 4), delay penetration inappreciably. It may be noted that phenothiazine (nitrogen and sulfur in the ring) is much more effective than phenothioxine (oxygen and sulfur in the ring), when they are used alone (table 5) and after reaction with 3,5-dinitro-*o*-cresol (table 4).

All preceding data on dampwood termites were obtained with specimens from the vicinity of Monterey and their immediate descendents. When the work was nearly finished, some colonies secured from the Berkeley hills were used in a few tests. The results showed that the Berkeley termites penetrated waxed 50-pound kraft paper in 1 week instead of the 2 weeks required by the Monterey group. A somewhat greater difference in the same direction was found when certain toxic chemicals were present. The effect does not seem to be related to rearing in the laboratory, for neither group changed appreciably in the first laboratory-reared generation. No further study has been made of this difference, but it indicates that care should be observed in using termites of a common origin for comparative studies.

SUMMARY

The toxic and repellent effects of chemicals toward termites may be studied by confining the insects in a circular arena over treated paper or cardboard. Several arrangements of treated and untreated areas were used, and results were expressed in terms of distribution of the termites on the areas and the length of time before they penetrated the floor of the arena. Chemicals as solutions in volatile solvents or in wax were applied to 50-pound kraft paper in an effort to develop an overwrap for packages of dry foodstuffs. The dampwood termites, *Zootermopsis angusticollis* and *Z. nevadensis,* were used. To a lesser extent, the drywood termite, *Kalotermes minor,* was used. A test was then made of the most promising chemicals which were applied in wax to small cardboard boxes.

The following substances were repellent to the *Zootermopsis* spp. when kraft paper was soaked in 1 or 2 per cent solutions and the solvent allowed to evaporate: copper sulfate; trichlorophenol; chlorohydroquinone; hexachlorocyclohexane; DDT; nitroiodobenzene; terpineol; benzil; quinoline; 3,5-dinitro-*o*-cresol and its reaction products with copper sulfate, morpholine, diphenylamine, phenothiazine, acetic acid or trichloroacetic acid; β,β'-dithiocyanodiethyl ether and β-butoxy-β'-thiocyanodiethyl ether; coumarin; and thiocoumarin. The latter was very strongly repellent at first but soon evaporated. A number of relatively nonvolatile essential oils were not noticeably repellent. Toxicity was associated with repellency in some instances but not in all.

Among the compounds which showed marked toxicity, hexachlorocyclohexane, DDT, 3,5-dinitro-*o*-cresol and its salts with phenothiazine or acetic acid were especially effective when used in wax. They all remained highly toxic and prevented the insects from boring through the treated papers for more than 6 months. The dinitro compounds stain everything nearby a strong yellow, so it is doubtful if they could be used on food packages. DDT is not colored, but it decomposes to some extent in the hot wax, so should be used at not less than 5 per cent. The phenyl-, *p*-tolyl-, and dichloroethylene members of the DDT family are much less effective. Hexachlorocyclohexane is both a powerful toxicant and a strong repellent for dampwood termites. Used at 1 per cent gamma isomer in wax it protected cardboard boxes for more than 18 months. Its objectionable odor makes its use around food scarcely possible, but this would not be a detriment in outdoor timbers.

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4m-11,'49(B5144) 141

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