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THE EFFECT OF LINDANE VAPOUR ON STORED PRODUCT INSECTS.

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Recent tests at Onderstepoort on the control of granary weevils [*Sitophilus* (*Calandra*) *granaria* L.] in stored cereals by means of Lindane dust have shown that the insects were killed mainly by the vapour originating from small quantities of Lindane admixed with the grain rather than by contact with the insecticidal deposit. As stored grain encloses well-defined air spaces consisting of numerous narrow air channels between the seeds, the insecticidal vapour, constantly emitted from the finely distributed Lindane, can accumulate and finally reach a concentration that is highly toxic to weevils.

That the gamma isomer of BHC possesses marked fumigating properties when volatilized by heat or given off from spray deposits into the air of a confined space, has been demonstrated by several authors (Fulton *et al.* 1950; Petty and Lochner, 1950; Moore and Sweetman, 1952). The amount of Lindane that is needed for a given volume of air to cause complete kill can be assessed easily when the insecticide is rapidly vaporized by heat. The minimum deposit of Lindane for a given air space that is capable of producing an atmosphere entirely lethal to insect life is still unknown.

In order to assess the insecticidal effect of vapour originating from small quantities of Lindane at room temperatures, as normally encountered in South Africa during the greater part of the year, twelve series of experiments were conducted in which several types of stored product insects in an enclosed space were subjected to the vapour from decreasing dosages of Lindane deposits.

METHOD.

Rectangular glass containers ($11\frac{1}{2} \times 7\frac{1}{2} \times 7\frac{1}{2}$ in.) each having a capacity of 647 cubic inches (0·377 cubic feet) were used as fumigation chambers. These could be tightly closed by means of a flat glass lid. The test insects were exposed in glass cylinders, 3 in. in diameter and $1\frac{1}{2}$ in. in length, covered with organdie at one end to serve as a bottom, or in small wire cages of about the same size. Small wire frames held the exposure cages in the middle of the chamber about 3 in. above the insecticidal deposit placed on the floor.

To ensure the application of a correctly measured quantity of insecticide evenly distributed on surfaces of equal size, sheets of a coarse type of printing paper (10×8 in.) were impregnated with the correct amount of Lindane by immersion into a solution of desired strength. Each sheet was capable of taking up 4·8 ml. of acetone, and a solution containing 2·085% Lindane was required to obtain a deposit of 100 mg. on the individual sheet. By appropriately diluting this solution, sheets containing 100, 50, 25 and 10 mg. Lindane were prepared and dried at room temperature.

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As the fumigation chambers possessed a volume less than one cubic foot (0·377 cub. ft.), only an equivalent amount of the insecticide (37·7 mg.) had to be applied to give a dose of 100 mg. per cub. ft. This was achieved by cutting off a 3·77 in. wide strip from the length of the sheet. The smaller dosages were prepared accordingly from the corresponding sheets.

The following insect species were included in the tests:—

(1) *Triboleum confusum* Duval—Confused Flour Beetle.
(2) *Sitophilus* (*Calandra*) *granaria* L.—Granary Weevil.
(3) *Rhizopertha dominica* F.—Lesser Grain Weevil.
(4) *Acheta bimaculata* de G.—House Cricket.
(5) *Dermestes vulpinus* F. (larvae)—Larder Beetle.
(6) *Tineola bisselliella* Hummel (larvae)—Clothes Moth.

The insects were exposed together with food and inspected at intervals of one or several days. Controls were included in each test. The climatic conditions of the different trials are given in table I.

RESULTS.

A detailed account of the findings with decreasing dosages of Lindane per cubic foot is shown in tables I to VI. To make possible an accurate count of the insects the fumigation chambers had to be opened on certain days and the cages taken out, as counts were impossible with the lids in position. Such inspections are marked in the tables with an asterisk. In cases where numerical counts were not taken, the presence of dead as well as unaffected specimens in the test cages is indicated by a cross. The results of each count are given as percentages and expressed in the columns of the table as two figures separated by a stroke. The figure in front of the stroke represents the percentage kill of the total number of insects under test, whereas the mortality in the control is denoted by the second figure. The horizontal line in each column indicates the end of the exposure period.

Triboleum confusum Duval. Table II.

This is the least susceptible species of all the insects tested, but it was possible, nevertheless, to achieve a complete kill at the lowest dosage (5 mg.). The variation in individual susceptibility towards Lindane vapour, however, was considerably higher amongst this species and especially was this the case at the lower concentrations of 10 and 5 mg. per cubic foot. A number of specimens were encountered, which did not succumb after an exposure of ten days. It was noticeable with this species that the mortality rate depended on the length of exposure. A period of 24 hours (test No. 3, 100 and 200 mg./cub. ft.) was not sufficient to produce a decisive effect, and a number of beetles that had been knocked down by that time recovered when removed from the fumigation chamber.

Sitophilus granaria L. Table III.

This species is much more susceptible to Lindane vapour than the flour beetle. Complete kill was achieved at all concentrations after a comparatively short exposure.

Rhizopertha dominica F. Table IV.

This beetle was only included in the tests at a later date. It responded well to the vapour treatment and showed a susceptibility similar to that of the granary weevil.

Acheta bimaculata de G. Table V.

The house cricket was the most susceptible species of all. Complete kill was constantly achieved within two days at a dosage as low as 25 mg./cub. ft.; at 10 and 5 mg./cub. ft. death occurred after three and five days, respectively.

Dermestes vulpinus F. Table VI.

The larvae of the larder beetle are readily affected by Lindane vapour, the later stages being slightly more resistant than the earlier instars. Generally speaking, their susceptibility is very similar to that of the granary weevil, except that the larger larvae take a longer time to succumb. An exposure of 24 hours at 100 and 200 mg./cub. ft. is ultimately fatal, but many days elapse before death occurs. Individuals showing knock-down do not recover, in contradistinction to the flour beetle, but will finally die after a long period of paralysis. For this reason all specimens in the paralytic stage were included with those killed.

Tineola bisselliella Hummel. Table VII.

Clothes moth larvae of all sizes were exposed to the vapour in their natural environment (woollen blanket), lest they should be affected by handling. The effect of the insecticidal vapour was apparent after a short exposure. The larvae ceased feeding and began to abandon their webs. The younger larvae always showed this reaction first. Complete mortality was achieved after twelve to 14 days at all dosages, except in one test (No. 9) with 10 mg./cub. ft., where an exposure of 20 days was apparently not enough for the larger larvae. Fully grown larvae included in the trials were still able to pupate in some cases, but the pupae were killed by the higher dosages (200 down to 25 mg./cub. ft.); only at 10 and 5 mg./cub. ft. were living pupae found at the end of the tests. Pupae that were formed prior to the commencement of the experiments were able to hatch during the first few days of exposure, but the moths always died within a few hours of hatching.

The results of the twelve test series are summarized in Table VIII, in order to make a comparison between the different species possible.

As a whole the tests have confirmed the potency of the gamma isomer of BHC as a fumigant. At a temperature of 25° C. (77° F.), which is commonly encountered under South African conditions, the vapour originating from 5 mg. Lindane in one cubic foot of air is sufficiently toxic to produce a complete kill or high mortality. The susceptibility of the different insect species varies considerably, and even within one species, e.g. *Triboleum confusum*, certain individuals show a greater resistance than others of the same age. All insects tend to succumb sooner in an insecticidal atmosphere originating from a larger amount of Lindane (200–100 mg.) than from a smaller dose (10–5 mg.), yet the period that has to elapse until death occurs does not correspond with the dosage applied. The mortality rate is dependent rather on the length of exposure. This indicates that minute traces of Lindane vapour are capable of rendering the atmosphere fatal to insects that are compelled to remain in it for long periods.

Furthermore, it was found that the final results were not influenced by the loss of vapour which occurred when the fumigation chambers had to be opened for inspection on several occasions during the course of a test. Due to the comparatively high vapour pressure of the gamma isomer minute quantities of Lindane can create an insecticidal atmosphere in an enclosed space at normal temperatures and maintain it for long periods as only very little of the deposit is vaporized.

These findings confirm the results of Moore and Sweetman (1952), which they achieved with Lindane vapour generated by means of an electric vaporizer. These authors found that the length of exposure had a decisive effect on mortality. The longer the period of exposure, the higher the kills, and no apparent difference in the rate of mortality between the different dosages was evident.

In conclusion it may be stated that surprisingly small dosages of Lindane are able to generate sufficient vapour at ordinary temperatures to produce a lethal effect on insect life in an enclosed space. This principle is suited to long term protection of stored products and to the control of insect pests in places like wardrobes, boxes, suitcases, closed rooms, etc., where the change of air is very slow and an insecticidal atmosphere can be built up and maintained.

SUMMARY.

To assess the insecticidal effect of vapour originating from small quantities of Lindane at a temperature of 25° C. (77° F.) twelve series of experiments were conducted in which stored product insects in closed fumigation chambers were subjected to the vapour from decreasing dosages of Lindane deposits (200–5 mg. per cub. ft.). The correctly measured quantity of the insecticide evenly distributed on surfaces of equal size was achieved by impregnating sheets of paper with a Lindane solution of desired strengths. The following insect species were included in the tests:— *Triboleum confusum* Duval, *Sitophilus* (*Calandra*) *granaria* L., *Rhizopertha dominica* F., *Acheta bimaculata* de G., *Dermestes vulpinus* F. larvae, and *Tineola bisselliella* Hummel larvae.

The susceptibility of the different insect species varied considerably, but vapour originating from 5 mg. Lindane in one cubic foot of air was sufficiently toxic to produce a complete kill or high mortality after several days of exposure. The period until death supervenes does not correspond with the dosage applied. The mortality rate is dependent rather on the length of exposure.

This principle is recommended for long term protection of stored products and for the control of insect pests in enclosed spaces.

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TABLE I.—*Conditions under which the tests were conducted.*

Test No.	1	2	3	4	5	6	7	8	9	10	11	12
Date	4.11.52	6.11.52	10.11.52	11.11.52	17.11.52	20.11.52	27.11.52	9.12.52	15.12.52	22.12.52	5.1.52	12.1.53
Average Temperature, Degrees C.	26·3	25·0	25·0	25·0	25·0	25·0	25·0	25·0	25·0	25·0	25·0	25·0
Average Relative Humidity	—	—	77	75	78	77	77·5	80	85	81	84	86

TABLE II.—*Percentage mortality of* Triboleum confusum *caused by the vapour of different Lindane deposits in an enclosed space.*

Mg.γ/cub. ft.	200				100						50			25			10					5		
Test No.	3	1	2	4	3	1	2	4	8	9	5	6	7	5	6	7	8	9	10	11	12	10	11	12
No. Insects	50	100	50	50	50	100	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Exposure (Days)	1	2	4	3	1	2	4	3	3	10	2	6	2	3	6	4	6	10	10	5	4	10	7	4
Days after commencement of Test—																								
1	14/0	†/0	†/0	†/0	20/0	†/0	†/0	†/0	†/0	—	†/0	†/0	†/0	†/0	†/0	†/0	†/0	—	0/0	0/0	—	0/0	0/0	0/0
2	16/0	93/2	96/0	98/0	20/0	96/2	†/0	98/0	*96/0	*†/0	100/0	*†/0	100/†	*96/0	*†/0	*96/2	*80/0	*†/0	*†/0	†/0	*80/0	*0/0	0/0	*74/0
3	16/0	—	—	100/0	20/0	—	—	100/0	100/0	—	—	—	—	100/0	—	—	*96/0	—	—	†/0	—	—	*0/0	—
4	16/0	—	98/4	—	20/0	—	94/4	—	—	*60/0	—	*92/0	—	—	*88/0	100/2	—	*6/0	—	—	*100/0	—	—	*98/0
5	16/0	—	98/4	—	20/0	—	94/4	—	—	—	—	—	—	—	—	—	—	—	*†/0	100/0	—	*0/0	*98/0	—
6	—	—	100/4	—	—	—	98/4	—	—	—	—	94/6	—	—	94/4	—	100/0	—	—	—	—	—	—	—
7	—	—	—	—	—	—	—	—	—	*96/0	—	—	—	—	—	—	—	*60/0	—	—	—	—	100/0	—
8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
10	—	—	—	—	—	—	—	—	—	100/0	—	—	—	—	—	—	—	92/0	82/0	—	—	20/2	—	—
11	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

* = Fumigation chamber opened for inspection.
† = No detailed count taken, but mortality apparent.
100/0 = Left figure indicates percentage mortality in the test; right figure shows mortality in the control.
—— = Horizontal line in each column marks the end of exposure.

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TABLE III.—*Percentage mortality of* Sitophilus granaria.

Mg.γ/cub. ft.	200		100				50			25			10					5		
Test No.	1	3	1	3	8	9	5	6	7	5	6	7	8	9	10	11	12	10	11	12
No. Insects	100	50	100	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Exposure (Days)	1	1	2	1	3	2	1	2	3	1	3	4	3	4	5	3	4	5	3	4
Days after Commencement of Test—																				
1	100/0	100/16	†/0	100/16	†/0	—	100/0	†/0	†/0	100/0	†/0	†/0	†/0	—	0/0	0/0	—	0/0	0/0	—
2	—	—	100/20	—	*90/0	100/0	—	100/0	*98/0	—	*94/0	*94/0	*80/0	*80/0	*0/0	†/0	*94/16	*0/0	†/0	*88/16
3	—	—	—	—	100/0	—	—	—	100/6	—	100/0	—	100/0	—	—	100/28	—	—	100/28	—
4	—	—	—	—	—	—	—	—	—	—	—	100/16	—	100/16	—	—	100/42	—	—	100/42
5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	100/18	—	—	100/18	—	—
6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

TABLE IV.—*Percentage mortality of* Rhizopertha dominica.

Mg.γ/cub. ft.	100		10				5	
Test No.	8	9	8	9	10	11	10	11
No. Insects	50	50	50	50	50	50	50	50
Exposure (Days)	3	4	6	5	5	5	5	5
Days after Commencement of Test—								
1	†/0	—	†/0	—	—	0/0	—	0/0
2	*36/0	*†/0	*40/0	*†/0	†/0	†/0	*†/0	†/0
3	100/0	—	*92/0	—	—	*86/4	—	*78/4
4	—	100/0	—	88/0	—	—	—	—
5	—	—	—	100/0	100/20	100/8	100/20	100/8
6	—	—	100/0	—	—	—	—	—
7	—	—	—	—	—	—	—	—

TABLE V.—*Percentage mortality of* Acheta bimaculata.

Mg.γ/cub. ft.	200		100				50			25			10				5	
Test No.	1	4	1	4	8	9	5	6	7	5	6	7	8	9	10	11	10	11
No. Insects	5	3	5	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4
Exposure (Days)	1	2	1	2	2	2	2	2	2	2	2	2	2	2	3	3	5	5
Days after Commencement of Test—																		
1	100/0	†/0	100/0	†/0	†/0	—	0/0	†/0	0/0	0/0	†/0	†/0	0/0	—	0/0	50/0	0/0	0/0
2	—	100/0	—	100/0	100/0	100/0	100/0	100/0	100/0	100/0	100/0	100/0	100/0	100/0	*0/0	75/0	*0/0	0/0
3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	100/0	100/0	—	*75/0
4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	100/0	100/0
6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

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TABLE VI.—*Percentage mortality of* Dermestes vulpinus.

A.—Large Larvae.

Mg.γ/cub. ft.....	200				100						50			25			10					5		
Test No.....	3	1	2	4	3	1	2	4	8	9	5	6	7	5	6	7	8	9	10	11	12	10	11	12
No. Insects.....	6	13	6	12	6	13	6	12	8	12	12	12	12	12	12	12	8	12	12	12	12	12	12	12
Exposure (Days).	1	2	4	4	1	2	4	6	3	4	2	2	2	3	2	2	3	4	5	5	4	5	7	4
Days after Commencement of Test—																								
1.....	0/0	†/0	0/0	0/0	0/0	†/0	0/0	0/0	0/0	—	0/0	0/0	†/0	†/0	0/0	†/0	0/0	—	0/0	0/0	—	0/0	0/0	—
2.....	33/0	100/0	†/0	0/0	33/0	100/0	†/0	0/0	*75/0	*83/0	100/0	100/0	100/0	*83/0	100/0	100/0	*62/0	*59/0	*†/0	17/0	*83/0	*0/0	0/0	*75/0
3.....	33/0	—	—	†/0	33/0	—	—	†/10	100/0	—	—	—	—	100/0	—	—	100/0	—	—	*58/0	—	—	*0/0	—
4.....	33/0	—	100/0	100/16	50/0	—	100/0	75/16	—	100/0	—	—	—	—	—	—	—	100/0	—	—	100/0	—	—	100/0
5.....	83/0	—	—	—	66/0	—	—	—	—	—	—	—	—	—	—	—	—	—	100/0	100/0	—	100/0	*84/0	—
6.....	—	—	—	—	—	—	—	100/16	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
7.....	100/0	—	—	—	83/0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	100/0	—

TABLE VI.—*Percentage mortality of* Dermestes vulpinus.

B.—Small larvae.

Mgγ/cub. ft.....	200		100		50	25
Test No.....	2	3	2	3	5	5
No. Insects.....	6	6	6	6	12	12
Exposure (Days).....	2	1	2	1	2	2
Days after Commencement of Test—						
1.....	0/0	100/0	0/0	100/0	0/0	0/0
2.....	100/0	—	100/0	—	100/0	100/0
3.....	—	—	—	—	—	—

TABLE VII.—*Percentage mortality of* Tineola bisselliella *larvae of all sizes.*

Mg.γ/cub. ft.	100		50		25		10				5	
Test No.	8	9	6	7	6	7	8	9	10	11	10	11
No. Insects	19	5	36	29	28	32	11	9	10	4	6	9
Exposure (Days)	13	7	12	12	12	12	13	20	14	14	14	14
Days after Commencement of Test—												
1	—	—	—	—	—	—	—	—	—	—	—	—
2	*16/†	*	*0/†	*14/0	*0/†	*28/†	*27/†	*	*	—	*	—
3	*	—	—	[2m]/	—	[1m]/	*	—	—	*	—	*
4	—	*60/†	*28/†	*45/†	*43/†	*47/†	—	*11/†	*	—	—	—
5	—	—	—	—	—	—	—	[3m]/	[2m]/	*	*	*
6	*53/†	—	*39/†	*72/†	*61/†	*78/†	*55/†	—	—	—	—	[2m]/
7	—	100/†	—	—	—	—	—	*22/†	—	*	—	*
8	*84/†	—	*86/†	*	*72/†	*	*91/†	—	—	—	—	—
9	—	—	—	—	—	—	—	—	—	—	—	—
10	—	—	*89/†	—	*75/†	—	—	—	*	—	*	—
11	—	—	—	—	—	—	—	—	—	—	—	—
12	—	—	100/9	100/5	100/9	100/5	—	*44/†	—	—	—	—
13	100/0	—	/(4m)	/(3m)	[1p]/(4m)	[1p]/(3m)	100/0	—	—	—	—	—
14	/(2p)	—	—	—	—	—	/(2p)	—	100/14	100/0	100/14	100/0
15	—	—	—	—	—	—	—	—	—	(1p)/	(1p)/	(2p)/
16	—	—	—	—	—	—	—	—	—	—	—	—
17	—	—	—	—	—	—	—	—	—	—	—	—
18	—	—	—	—	—	—	—	—	—	—	—	—
19	—	—	—	—	—	—	—	—	—	—	—	—
20	—	–/11	—	—	—	—	—	67/11	—	—	—	—
21	—	/(2m)	—	—	—	—	—	/(2m)	—	—	—	—

p = pupa formed. m = adult moth hatched. ( ) = specimen alive. [ ] = specimen dead.

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TABLE VIII.—*Figures indicate time of exposure in days to achieve complete kill of certain stored product insects in an enclosed space by means of the vapour produced by decreasing quantities of Lindane at 25° C.*

Insect Species.	Milligrams Lindane per Cubic Foot.					
	200	100	50	25	10	5
Triboleum confusum.....	3–6	3–10	2–over 6	3–over 6	4–over 10	7– over 10
Sitophilus granaria.....	1	1– 3	1– 3	1– 4	3– 5	3– 5
Rhizopertha dominica.....	—	3– 4	—	—	5– 6	5
Dermestes vulpinus large larvae.....	2–4	2– 4(6)	2	2– 3	3– 5	4– 7
Dermestes vulpinus small larvae.....	1–2	1– 2	2	2	—	—
Acheta bimaculata.....	1–2	1– 2	2	2	2– 3	5
Tineola bisselliella larvae of all sizes.....	—	7–13	12	12	13–14 (over 20)	14