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TESTS OF VARIOUS ALIPHATIC COMPOUNDS AS FUMIGANTS
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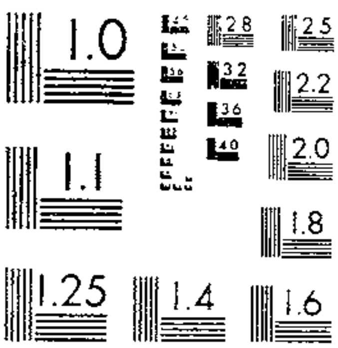

MICROCOPY RESOLUTION TEST CHART
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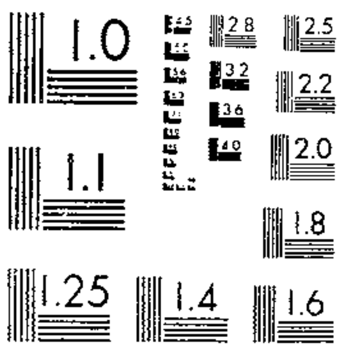

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NATIONAL BUREAU OF STANDARDS-1963-A

TECHNICAL BULLETIN No. 162 — MARCH, 1929

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WASHINGTON, D. C.

TESTS OF VARIOUS ALIPHATIC COMPOUNDS AS FUMIGANTS

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INTRODUCTION

The action of several organic compounds in the vapor phase upon rice weevils, flour beetles, granary weevils, and the Indian-meal moth was tested in a previous investigation,[1] and the results were reported in Department Bulletin 1313. The object of that investigation was to find a material free from the fire hazard of carbon disulphide that would be suitable for killing insects in grain. When the tests were made in glass flasks about 30 of the 100 compounds tested were more toxic to the rice weevil than was carbon disulphide. In tests made when grain was present, especially in box cars loaded with wheat, only ethyl acetate and ethyl formate gave uniformly good results, and because of its lower cost and greater availability the acetate was considered preferable to the formate. A mixture of 40 volumes of ethyl acetate and 60 volumes of carbon tetrachloride was recommended as a fumigant safe from fire hazard at fumigating temperatures, that is, up to 90° F.

In order to make ethyl acetate nonflammable at temperatures up to 122° F. (50° C.), however, the temperature at which the underwriters' laboratories conduct tests to determine whether a vapor will propagate a flame, it is necessary to add carbon tetrachloride to the

[1] NEIFERT, I. E., COOK, F. C., ROARK, R. C., TONKIN, W. H., BACK, E. A., and COTTON, R. T., FUMIGATION AGAINST GRAIN WEEVILS WITH VARIOUS VOLATILE ORGANIC COMPOUNDS. U. S. Dept. Agr. Bul. 1313, 40 p., illus. 1925.

extent of 70 per cent by volume of the mixture. Ethyl acetate has only a moderate toxicity to insects exposed to its vapor, and the addition of carbon tetrachloride, which has a low toxicity to insects, produces a mixture having an insecticidal value lower than that of ethyl acetate alone.

Furthermore, wheat that has been fumigated with the ethyl acetate mixture may have a sour odor, resulting from acetic acid formed by hydrolysis of the ethyl acetate. This odor is similar to that of fermenting grain, and sometimes causes the wheat to be classed as Sample grade.

The experiments herewith reported were conducted in order to develop effective fumigants more suitable for treating infested grain, and for use in fumigating against insects infesting foodstuffs, clothing, carpets, and furniture. Some of the compounds previously investigated and many additional organic compounds were thoroughly tested.

TESTS IN ONE-HALF LITER FLASKS

METHOD

In order to select the more promising fumigants from the large number of compounds to be tested, an initial series of tests was made in ½-liter Erlenmeyer flasks. By fumigating on a small scale it was possible to make 30 or 40 fumigations in a day and thus test possible fumigants more quickly than if trials were made on a large scale. On account of its resistance to fumigants the rice weevil (*Sitophilus oryza* L.) was used exclusively in these small-scale tests. The weevils were confined in cotton-stoppered glass vials containing cracked corn, 10 weevils to each vial. One, or in some cases two, of the vials were placed on the bottom of a ½-liter Erlenmeyer flask, 200 grams (approximately 250 c. c.) of wheat was put in, and the calculated quantity of fumigant was added. The flasks were made airtight with rubber stoppers and allowed to stand 24 hours at room temperature, which averaged about 25° C. At the end of the 24-hour fumigation period the percentage of dead weevils was determined. To avoid reporting as dead any that were only stupefied, all specimens were reexamined after 24 hours and also after 48 hours. Many specimens were kept for 30 days after fumigation, but none revived after the 48-hour period. The percentage of dead weevils reported in Table 1 is that determined at the end of the 48-hour period.

This series of experiments differs from that reported in Department Bulletin No. 1313, in that all the fumigants were tested in the presence of wheat. Inasmuch as under practical fumigating conditions absorptive materials are always present, it was believed that tests in the presence of wheat, which has a great absorptive capacity for some vapors, would determine fumigants of low toxicity more quickly than if the tests were made in flasks containing no absorptive material.

The compounds selected for testing were obtained for the most part from the Eastman Kodak Co. A few materials were synthesized in the laboratory. In all cases, compounds of the highest possible purity procurable were used for these tests.

The liquid fumigants were applied by means of a pipette graduated to 0.01 c. c. The dosages are therefore known within 0.02 cubic centimeter per liter, which is equivalent to about 13 mg. per liter.

(0.8 pound per 1,000 cubic feet) for a material of low specific gravity, such as *n*–pentane; or to about 66 mg. per liter (4 pounds per 1,000 cubic feet) for a material of high specific gravity, such as methylene iodide. The solid fumigants were weighed to the nearest milligram and added to the flasks. In general, in this series of tests, where the minimum lethal dosage of the fumigant was determined to within 0.01 c. c. per ½-liter flask, the results are accurate to within about 2 pounds per 1,000 cubic feet. For a more exact determination of the minimum lethal dosage of a fumigant, tests on a larger scale are necessary.

Each fumigant was tested from 5 to 30 times over a range of different concentrations. No fumigant was tested at a concentration of more than 0.5 c. c. per liter. Some fumigants killed 100 per cent of the weevils at the minimum dosage it was possible to employ, 0.02 c. c. per liter. In other cases many dosages were tried, and the minimum that killed 100 per cent of the weevils during an exposure of 24 hours was taken as the minimum lethal dosage.

As some fumigants were tested in quantities varying by 0.05 c. c. per ½-liter flask, the lethal dosage of these compounds is not known closer than 0.10 c. c. per liter. Only compounds of low toxicity, however, were tested in this way, as the object of this first series of tests was to select the fumigants worthy of trial on a large scale, rather than to determine the exact minimum lethal dosage of the compounds.

EXPERIMENTAL RESULTS

The results of the tests are given in Table 1, which presents in addition the following information regarding each fumigant: Empirical and structural formulas, synonyms, molecular weight, boiling point,[2] specific gravity,[2] concentration of fumigant, expressed in milligrams per liter, and percentage mortality of weevils after 24 hours' exposure.

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[2] Data taken from NATIONAL RESEARCH COUNCIL. INTERNATIONAL CRITICAL TABLES OF NUMERICAL DATA, PHYSICS, CHEMISTRY AND TECHNOLOGY . . . v. 1, 415 p., illus., New York and London, 1926.

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigants, and percentage mortality of weevils after exposure for 24 hours*

Empirical formula	Compound with synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity 20°/4°	Minimum lethal dosage of fumigant	Weevils killed after exposure for 24 hours
				° C.		*Mg. per liter*	*Per cent*
C_5H_{12}	Pentane	$CH_3CH_2CH_2CH_2CH_3$	72.096	36.2	0.631	[1] 316	40
	(Mixture; largely *n*-pentane)						
	Amyl hydride						
	Pentan						
	Normales pentan						
	n-Pentan						
C_6H_{14}	*n*-Hexane	$CH_3CH_2CH_2CH_2CH_2CH_3$	86.108	69.0	.660	[1] 330	60
	Dipropyl						
	Hexan						
	Normales hexan						
	n-Hexan						
C_7H_{16}	*n*-Heptane	$CH_3(CH_2)_5CH_3$	100.12	98.4	.684	260	100
	Heptyl hydride						
	Methyl hexane						
	Dipropylmethane						
	Heptan						
	Normales heptan						
	n-Heptan						
C_8H_{18}	*n*-Octane	$CH_3(CH_2)_6CH_3$	114.144	124.6	.707	[1] 354	60
	Octan						
	Normales octan						
	n-Octan						
$C_{10}H_{22}$	Decane	$(CH_3)_2CH(CH_2)_4CH(CH_3)_2$	142.176	160.0	.722	[1] 361	0
	2, 7-Dimethyloctane						
	Di*iso*amyl						
	2,7-Dimethyl-octan						
C_5H_{10}	Amylene		70.077		.7	[1] 350	0
	Mixture of:						
	*Iso*propylethylene	$(CH_3)_2CHCH=CH_2$	20.2				
	Trimethylethylene	$(CH_3)_2C=CHCH_3$	38.4				
	as-Methylethylethylene	$CH_2=C(CH_3)C_2H_5$	31-33				
	2-Pentene	$CH_3CH_2CH=CHCH_3$	36				
	*Iso*pentane	$(CH_3)_2CHCH_2CH_3$	28				
	Käufliches Amylen						
	Gewöhnliches Fuselölamylen						
C_5H_{10}	Trimethylethylene	$(CH_3)_2C=CHCH_3$	70.077	38.4	.668	[1] 334	40
	2-Methyl-2-butene						
	Pental						

	Pentene						
	Amylene						
	β-*Iso*amylene						
	2-Methyl-buten-(2)						
	Trimethyl-Äthylen						
	β-Methyl-β-butylene						
C_8H_{16}	Octylene		112.12	125	.7197	[1]360	70
	Caprylene						
	Mixture of:						
	α-Octylene (Octene-(1))	$CH_3(CH_2)_5CH{=}CH_2$					
	β-Octylene (Octene-(2))	$CH_3(CH_2)_4CH{=}CH\ CH_3$					
	Octylen						
	Caprylen						
	Mixture of:						
	Octen-(1) α-Octylen						
	Octen-(2) β-Octylen						
C_8H_{16}	Di*iso*butylene	$(CH_3)_3CCH{=}C(CH_3)_2$	112.12	102.6	.715	215	100
	Di*iso*butylen						
CH_2Br_2	Methylene bromide	CH_2Br_2	173.85	97.8	2.46	738	100
	Dibromomethane						
	Dibrommethan						
	Methylenbromid						
$CHBr_3$	Bromoform	$CHBr_3$	252.76	150.4	2.89	231	100
	Tribromomethane						
	Methenylbromide						
	Formyl tribromide						
	Methenyl tribromide						
	Tribrommethan						
	Methenylbromid						
CBr_4	Carbon tetrabromide	CBr_4	331.66	189.5	3.42	60	100
	Tetrabromomethane						
	Tetrabrommethan						
	Kohlenstofftetrabromid						
	Tetrabromkohlenstoff						
C_2H_5Br	Ethyl bromide	CH_3CH_2Br	108.955	38.0	1.43	172	100
	Bromoethane						
	Monobromoethane						
	Hydrobromic ether						
	Bromic ether						
	Brom-äthan						
	Äthylbromid						
$C_2H_4Br_2$	Ethylidene bromide	CH_3CHBr_2	187.86	110	2.056	617	100
	1, 1-Dibromoethane						
	1, 1-Dibrom-äthan						
	Äthylidenbromid						
$C_2H_4Br_2$	Ethylene dibromide	CH_2BrCH_2Br	187.86	131.7	2.182	87	100
	1, 2-Dibromoethane						
	Ethylene bromide						
	Dibromoethane						
	1, 2-Dibrom-äthan						

[1] The maximum dosage tested.

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigants, and percentage mortality of weevils after exposure for 24 hours*—Continued

Empirical formula	Compound with synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity 20°/4°	Minimum lethal dosage of fumigant	Weevils killed after exposure for 24 hours
$C_2H_4Br_2$	Ethylene dibromide—Continued						
	Äthylendibromid						
	Äthylenbromid			*° C.*		*Mg. per liter*	*Per cent*
$C_2H_2Br_4$	*sym.*-Tetrabromoethane	$CHBr_2CHBr_2$	345.68	151 (54 mm.)	2.964	[1] 1,482	0
	1, 1, 2, 2-Tetrabromoethane						
	Acetylene tetrabromide						
	Muthmann's liquid						
	1. 1. 2. 2-Tetrabrom-äthan						
	Acetylentetrabromid						
C_3H_7Br	*n*-Propyl bromide	$CH_3CH_2CH_2Br$	122.97	70.9	1.353	81	100
	1-Bromopropane						
	1-Brom-propan						
	α-Brom-propan						
	n-Propylbromid						
	prim.-Propylbromid						
C_3H_7Br	*Iso*propyl bromide	$(CH_3)_2CHBr$	122.97	59.6	1.310	262	100
	2-Bromopropane						
	2-Brom-propan						
	β-Brom-propan						
	*Iso*propylbromid						
	sek.-Propylbromid						
$C_3H_6Br_2$	Propylene bromide	$CH_3CHBrCH_2Br$	201.88	140	1.933	116	100
	1, 2-Dibromopropane						
	Propylene dibromide						
	1. 2-Dibrom-propan						
	Propylendibromid						
	Propylenbromid						
C_4H_9Br	*n*-Butyl bromide	$CH_3CH_2CH_2CH_2Br$	136.99	101.6	1.275	102	100
	1-Bromobutane						
	1-Brom-butan						
	n-Butylbromid						
	prim.-Butylbromid						
C_4H_9Br	*Iso*butyl bromide	$(CH_3)_2CHCH_2Br$	136.99	91.5	1.264	126	100
	1-Bromo-2-methylpropane						
	α-Bromo-*iso*butane						
	1-Brom-2-methylpropan						
	α-Brom-*iso*butan						
	*Iso*butylbromid						

C_4H_9Br	*sec.*-Butyl bromide 2-Bromobutane 2-Brom-butan *sek.*-Butylbromid	$CH_3CHBrCH_2CH_3$	136.99	91.3	1.251	375	100
C_4H_9Br	*tert.*-Butyl bromide 2-Bromo-2-methylpropane β-Bromo-*iso*butane 2-Brom-2-methylpropan β-Brom-*iso*butan *tert.*-Butylbromid	$(CH_3)_3CBr$	136.99	73.3	1.222	[2] 24	100
$C_4H_8Br_2$	α-Butylene bromide 1, 2-Dibromobutane α-Butylene dibromide 1, 2-Dibrom-butan α-Butylendibromid	$CH_3CH_2CHBrCH_2Br$	215.89	166	1.820	[1] 910	80
$C_4H_8Br_2$	β-Butylene bromide 2, 3-Dibromobutane β-Butylene dibromide Pseudobutylene dibromide 2, 3-Dibrom-butan β-Butylendibromid Pseudobutylendibromid	$CH_3CHBrCHBrCH_3$	215.89	158	1.83	[1] 915	80
$C_4H_8Br_2$	*Iso*butylene bromide 1, 2-Dibromo-2-methylpropane α β-Dibromo-*iso*butane Butylene *iso*bromide Dibromo*iso*butane 1, 2-Dibrom-2-methylpropan α β-Dibrom-*iso*butan *Iso*butylendibromid	$CH_3CBr(CH_3)CH_2Br$	215.89	149	1.759	281	100
$C_4H_7Br_3$	1, 2, 3-Tribromobutane 1, 2, 3-Tribrom-butan	$CH_3CHBrCHBrCH_2Br$	294.80	113 (19 mm.)	2.190	[1] 1,095	0
$C_5H_{11}Br$	*Iso*amyl bromide 4-Bromo-2-methylbutane 4-Brom-2-methylbutan *Iso*amylbromid	$(CH_3)_2CHCH_2CH_2Br$	151	121	1.215	146	100
C_3H_5Br	Allyl bromide 3-Bromopropylene 3-Bromopropene 3-Brom-propen-(1) Allylbromid	$CH_2{=}CHCH_2Br$	120.955	71.3	1.398	[2] 28	100
CH_2Cl_2	Methylene chloride Dichloromethane Methylene bichloride Dichlormethan Methylenchlorid	CH_2Cl_2	84.931	40.1	1.336	428	100
$CHCl_3$	Chloroform Trichloromethane Methenyl chloride Trichlormethan Methenylchlorid	$CHCl_3$	119.38	61.2	1.489	298	100

[1] The maximum dosage tested.

[2] The minimum concentration tested.

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigants, and percentage mortality of weevils after exposure for 24 hours*—Continued

Empirical formula	Compound with synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity 20°/4°	Minimum lethal dosage of fumigant	Weevils killed after exposure for 24 hours
				° C.		Mg. per liter	Per cent
CCl_4	Carbon tetrachloride	CCl_4	153.83	76.8	1.595	638	100
	Tetrachloromethane						
	Perchloromethane						
	Tetrachlormethan						
	Kohlenstofftetrachlorid						
	Tetrachlorkohlenstoff						
$C_2H_4Cl_2$	Ethylidene chloride	CH_3CHCl_2	98.947	57.3	1.174	564	100
	1, 1-Dichloroethane						
	1, 1-Dichlor-äthan						
	Äthylidenchlorid						
$C_2H_4Cl_2$	Ethylene dichloride	$CH_2Cl\text{-}CH_2Cl$	98.947	83.7	1.257	226	100
	1, 2-Dichloroethane						
	Ethylene chloride						
	Elayl chloride						
	Oil of the Dutch chemists						
	Dichloroethane						
	Dutch liquid						
	1, 2-Dichlor-äthan						
	Äthylendichlorid						
	Äthylenchlorid						
	Öl der holländischen chemiker						
	Elaylchlorid						
C_2H_4BrCl	Ethylene chlorobromide	$CH_2Br\text{-}CH_2Cl$	143.405	103.7	1.79	143	100
	1-Bromo-2-chloroethane						
	2-Chlor-1-Brom-äthan						
	Äthylenchlorobromid						
$C_2H_3Cl_3$	Trichloroethane	$CH_2ClCHCl_2$	133.397	113.5	1.443	404	100
	1, 1, 2-Trichloroethane						
	Ethylene monochlorochloride						
	Monochloroethylene chloride						
	Monochlorinated Dutch liquid						
	Vinyltrichloride						
	1, 1, 2-Trichlor-äthan						
$C_2H_2Cl_4$	*sym.*-Tetrachloroethane	$CHCl_2CHCl_2$	167.85	146.3	1.600	384	100
	1, 1, 2, 2-Tetrachloroethane						
	Acetylene tetrachloride						

	Tetrachloroethane						
	1, 1, 2, 2-Tetrachlor-äthan						
	Acetylentetrachlorid						
C_2HCl_5	Pentachloroethane	$CHCl_2CCl_3$	202.298	162	1.709	342	100
	Pentachlor-äthan						
C_2Cl_6	Hexachloroethane	CCl_3CCl_3	236.75	185	2.091	[1]500	0
	Perchloroethane						
	Carbon trichloride						
	Carbon hexachloride						
	Tetrachloroethylene dichloride						
	Hexachlor-äthan						
	Perchloräthan						
C_3H_7Cl	*n*-Propylchloride	$CH_3CH_2CH_2Cl$	78.512	46.6	.890	445	100
	1-Chloropropane						
	α-Chloropropane						
	1-Chlor-propan						
	α-Chlor-propan						
	Propylchlorid						
C_3H_7Cl	*Iso*propyl chloride	$CH_3CHClCH_3$	78.512	36.5	.860	430	100
	2-Chloropropane						
	β-Chloropropane						
	2-Chlor-propan						
	β-Chlor-propan						
	*Iso*propylchlorid						
$C_3H_6Cl_2$	Propylene chloride	$CH_3CHClCH_2Cl$	112.962	96.8	1.166	140	100
	1, 2-Dichloropropane						
	Propylene dichloride						
	α-β-Dichloropropane						
	1, 2-Dichlor-propan						
	αβ-Dichlor-propan						
	Propylendichlorid						
	Propylenchlorid						
$C_3H_6Cl_2$	Trimethylene chloride	$ClCH_2CH_2CH_2Cl$	112.962	125	1.201	330	100
	1, 3-Dichloropropane						
	Trimethylene dichloride						
	1, 3-Dichlor-propan						
	αγ (oder ω.ω′-) Dichlor-propan						
	Trimethylendichlorid						
	Trimethylenchlorid						
C_4H_9Cl	*n*-Butyl chloride	$CH_3CH_2CH_2CH_2Cl$	92.527	78	.884	265	100
	1-Chlorobutane						
	1-Chlor-butan						
	n-Butylchlorid						
	prim.-Butylchlorid						
C_4H_9Cl	*tert.*-Butyl chloride	$(CH_3)_3CCl$	92.527	51	.840	34	100
	2-Chloro-2-methylpropane						
	β-Chlor-*iso*butane						
	2-Chlor-2-methylpropan						
	β-Chlor-*iso*butan						
	tert.-Butylchlorid						
	Trimethylchlormethan						

[1] The maximum dosage tested.

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigants, and percentage mortality of weevils after exposure for 24 hours*—Continued

Empirical formula	Compound with synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity 20°/4°	Minimum lethal dosage of fumigant	Weevils killed after exposure for 24 hours
				° *C.*		*Mg. per liter*	*Per cent*
$C_4H_8Cl_2$	*n*-Butylidene chloride 1, 1-Dichlorobutane 1, 1-Dichlor-butan Butylidenchlorid	$CH_3CH_2CH_2CHCl_2$	126.98	113–115	1.1	220	100
$C_5H_{11}Cl$	*Iso*amyl chloride 4-Chloro-2-methylbutane 4-Chlor-2-methylbutan *Iso*amylchlorid	$(CH_3)_2\,CHCH_2CH_2Cl$	106.54	99.1	.893	107	100
$C_2H_2Cl_2$	Dichloroethylene 1, 2-Dichloroethene Acetylene dichloride $\alpha\,\beta$-Dichloroethylene 1.2-Dichlor-äthen *sym.*-oder $\alpha\,\beta$-Dichlor-äthylen Acetylen-dichlorid	$CHCl=CHCl$	96.931	[3] 55	1.25	600	100
C_2HCl_3	Trichloroethylene Trichlor-äthan Trichlor-äthylen	$CHCl=CCl_2$	131.38	88	1.477	650	100
C_2Cl_4	Tetrachloroethylene Tetrachloroethene Perchlorethylene Carbon bichloride Carbon dichloride Tetrachlor-äthen Tetrachlor-äthylen Perchloräthylen	$Cl_2C=CCl_2$	165.83	120.8	1.623	649	100
CH_3I	Methyl iodide Iodomethane Jodmethan Methyljodid	CH_3I	141.96	42.6	2.279	[2] 46	100
CH_2I_2	Methylene iodide Diiodomethane Dijodmethan Methylenjodid	CH_2I_2	267.88	[4] 180	3.325	[2] 67	100
CHI_3	Iodoform Triiodomethane Methenyl iodide	CHI_3	393.80	([4])	4.1	[1] 500	0

	Formyl triiodide						
	Trijodmethan						
	Methenyljodid						
	Jodoform						
C_2H_5I	Ethyl iodide	CH_3CH_2I	155.97	72.2	1.933	[2] 39	100
	Iodoethane						
	Monoiodoethane						
	Jod-äthan						
	Äthyljodid						
C_3H_7I	*n*-Propyl iodide	$CH_3CH_2CH_2I$	169.99	102.4	1.747	[1] 35	100
	1-Iodopropane						
	α-Iodopropane						
	1-Jod-propan						
	α-Jod-propan						
	n-Propyljodid						
	prim.-Propyljodid						
C_3H_7I	*Iso*propyl iodide	$(CH_3)_2CHI$	169.99	89.5	1.703	68	100
	2-Iodopropane						
	β-iodopropane						
	2-Jod-propan						
	β-Jod-propan						
	*Iso*propyljodid						
	sek.-Propyljodid						
C_4H_9I	*n*-Butyl iodide	$CH_3CH_2CH_2CH_2I$	184.00	127	1.617	97	100
	1-Iodobutane						
	1-Jod-butan						
	n-Butyljodid						
	prim.-Butyljodid						
C_4H_9I	*Iso*butyl iodide	$(CH_3)_2CHCH_2I$	184	120.4	1.605	64	100
	1-Iodo-2-methylpropane						
	α-Iodo-*iso*butane						
	1-Iod-2-methylpropan						
	α-Jod-*iso*butan						
	*Iso*butyljodid						
C_4H_9I	*sec.*-Butyl iodide	$CH_3CHICH_2CH_3$	184	117.5	1.595	64	100
	2-Iodobutane						
	Methylethylcarbiniodide						
	2-Jod-butan						
	sek.-Butyljodid						
	Methyläthylcarbinjodid						
C_4H_9I	*tert.*-Butyl iodide	$(CH_3)_3CI$	184	98–99	1.370	256	100
	2-Iodo-2-methylpropane						
	β-Iodo-*iso*butane						
	Trimethylcarbiniodide						
	2-Jod-2-methyl propan						
	β-Jod-*iso*butan						
	tert.-Butyljodid						
	Trimethylcarbinjodid						

[1] The maximum dosage tested. [2] The minimum concentration tested. Boiling point—cis., 60; trans., 48. [4] Decomposes.

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigants, and percentage mortality of weevils after exposure for 24 hours*—Continued

Empirical formula	Compound with synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity 20°/4°	Minimum lethal dosage of fumigant	Weevils killed after exposure for 24 hours
				° C.		*Mg. per liter*	*Per cent*
$C_5H_{11}I$	*Iso*amyl iodide	$(CH_3)_2CHCH_2CH_2I$	198.02	148.0	1.510	151	100
	4-Iodo-2-methylbutane						
	4-Jod-2-Methylbutan						
	*Iso*amyljodid						
C_3H_5I	Allyl iodide	$CH_2{=}CHCH_2I$	167.97	103.1	1.848	[1] 37	100
	3-Iodopropylene						
	3-Iodopropene						
	γ-Iodopropylene						
	3-Jod-propen-(1)						
	γ-Jod-propylen						
	Allyljodid						
CH_4O	Methyl alcohol	CH_3OH	32.031	64.5	.792	[1] 396	0
	Methanol						
	Carbinol						
	Wood alcohol						
	Wood spirit						
	Wood naphtha						
	Methyl hydroxide						
	Methyl hydrate						
	Columbian spirits						
	Columnian spirits						
	Methylalkohol						
	Holzgeist						
C_2H_6O	Ethyl alcohol	CH_3CH_2OH	46.046	78.5	.789	[1] 790	40
	Ethanol						
	Grain alcohol						
	Fermentation alcohol						
	Cologne spirit						
	Spirits of wine						
	Äthanol						
	Äthylalkohol						
	Weingeist						
C_3H_8O	*n*-Propyl alcohol	$CH_3CH_2CH_2OH$	60.062	97.8	.804	[1] 402	60
	1-Propanol						
	Ethyl carbinol						
	Propyl alcohol						
	Propanol-(1)						

	α-Oxy-propan						
	Äthyl-carbinol						
	prim.-Propylalkohol						
	n-Propylalkohol						
C_3H_8O	*Iso*propyl alcohol	$CH_3CHOHCH_3$	60.062	82.3	.786	220	100
	2-Propanol						
	Dimethyl carbinol						
	*Iso*propanol						
	Propanol-(2)						
	β-Oxy-propan						
	Dimethyl carbinol						
	sek.-Propylalkohol						
	*Iso*propylalkohol						
$C_4H_{10}O$	*n*-Butyl alcohol	$CH_3CH_2CH_2CH_2OH$	74.077	117.7	.810	[1]405	0
	1-Butanol						
	Propyl carbinol						
	Butanol-(1)						
	α-Oxy-butan						
	Propyl-carbinol						
	prim.-Normalbutylalkohol						
	n-Butylalkohol						
$C_4H_{10}O$	*Iso*butyl alcohol	$(CH_3)_2CHCH_2OH$	74.077	107.3	.802	160	100
	2-Methyl-1-propanol						
	*Iso*propylcarbinol						
	2-Methyl-propanol-(1)						
	α-Oxy-β-methyl-propan						
	*Iso*propyl-carbinol						
	prim.-*Iso*butylalkohol						
	*Iso*butylalkohol						
$C_4H_{10}O$	*sec.*-Butyl alcohol	$CH_3CH(OH)CH_2CH_3$	74.077	99.5	.808	162	100
	2-Butanol						
	Methylethylcarbinol						
	Butylene hydrate						
	Butanol-(2)						
	β-Oxy-butan						
	Methyl-äthyl-carbinol						
	sek.-Normalbutylalkohol						
	sek.-Butylalkohol						
$C_4H_{10}O$	*tert.*-Butyl alcohol	$(CH_3)_3COH$	74.077	82.8	.789	79	100
	2-Methyl-2-propanol						
	Trimethylcarbinol						
	Dimethyl ethanol						
	2-Methyl-propanol-(2)						
	β-Oxy-β-methyl-propan						
	tert.-*Iso*butylalkohol						
	tert.-Butylalkohol						

[1] The maximum dosage tested.

The minimum concentration tested.

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigants, and percentage mortality of weevils after exposure for 24 hours*—Continued

Empirical formula	Compound with synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity 20°/4°	Minimum lethal dosage of fumigant	Weevils killed after exposure for 24 hours
				° C.		*Mg. per liter*	*Per cent*
$C_5H_{12}O$	*n*-Amyl alcohol 1-Pentanol Butyl carbinol Pentanol-(1) α-Oxy-pentan Butyl-carbinol *prim.*-Normalamylalkohol *n*-Amylalkohol	$CH_3(CH_2)_3CH_2OH$	88.092	137.9	0.817	[1]409	0
$C_5H_{12}O$	*Iso*amyl alcohol 2-Methyl-4-butanol *Iso*butyl carbinol Fermentation amyl alcohol Fusel oil Grain oil Potato spirit 2-Methyl-butanol-(4) *prim.*-*Iso*amylalkohol *Iso*amylalkohol	$(CH_3)_2CHCH_2CH_2OH$	88.092	130.5	.812	195	100
$C_5H_{12}O$	*sec.*-Amyl alcohol 2-Pentanol Methylpropyl carbinol Pentanol-(2) β-Oxy-pentan Methyl-propyl-carbinol *sek.*-Normalamylalkohol	$CH_3CH(OH)CH_2CH_2CH_3$	88.092	119.5	.809	194	100
$C_5H_{12}O$	Diethyl carbinol 3-Pentanol Pentanol-(3) γ-Oxy-pentan Diäthylcarbinol	$(C_2H_5)_2CHOH$	88.092	115.6	.815	196	100
$C_5H_{12}O$	*tert.*-Amyl alcohol 2-Methyl-2-butanol Dimethylethyl carbinol Amylene hydrate 2-Methyl-butanol-(2) Dimethyl-äthyl-carbinol *tert.*-Amylalkohol Amylenhydrat	$(CH_3)_2C(OH)CH_2CH_3$	88.092	101.8	.809	65	100

$C_5H_{12}O$	*sec.*-Butyl carbinol 2-Methyl-1-butanol Methylethylcarbincarbinol Inactive amyl alcohol Amyl alcohol, active Amyl hydrate 2-Methyl-butanol-(1) Sekundärbutylcarbinol Methyläthylcarbincarbinol d-Amyl alcohol	$CH_3CH_2CH(CH_3)CH_2OH$	88.092	128	.816	163	100
$C_6H_{14}O$	*n*-Hexyl alcohol 1-Hexanol Pentyl carbinol Hexanol-(1) α-Oxy-hexan Pentylcarbinol *prim.*-*n*-Hexylalkohol	$CH_3(CH_2)_4CH_2OH$	102.11	155.8	.820	[1] 410	0
$C_6H_{14}O$	Methylbutyl carbinol 2-Hexanol Hexanol-(2) β-Oxy-hexan *sec.*-*n*-Hexyl alcohol	$CH_3CH(OH)(CH_2)_3CH_3$	102.11	131.9	.803	64	100
$C_6H_{14}O$	Dimethyl *n*-propyl carbinol 2-Methyl-2-pentanol β-Oxy-β-methyl pentane 2-Methyl-pentanol-(2) β-Oxy-β-methyl-pentan Dimethylpropylcarbinol	$(CH_3)_2C(OH)CH_2CH_2CH_3$	102.11	122	.823	66	100
$C_7H_{16}O$	*n*-Heptyl alcohol 1-Heptanol Heptylic alcohol Heptanol-(1) α-Oxy-heptan *prim.*-*n*-Heptylalkohol	$CH_3(CH_2)_5CH_2OH$	116.12	175.8	.817	[1] 409	0
$C_7H_{16}O$	Di-*n*-propyl carbinol 4-Heptanol δ-Oxy-heptane Heptanol-(4) δ-Oxy-heptan Dipropyl-carbinol	$(CH_3CH_2CH_2)_2CHOH$	116.12	155.4	.820	[1] 410	30
$C_7H_{16}O$	Triethyl carbinol 3-Ethyl-3-pentanol 3-Äthyl-pentanol-(3) γ-Oxy-γ-äthyl-pentan Triethyl-carbinol	$(CH_3CH_2)_3COH$	116.12	142	.840	134	100
$C_8H_{18}O$	*n*-Octyl alcohol 1-Octanol α-Oxy-octane Octanol-(1) α-Oxy-octan *prim.*-*n*-Octylalkohol	$CH_3(CH_2)_6CH_2OH$	130.14	194	.827	[1] 414	0

[1] The maximum dosage tested.

Table 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigants, and percentage mortality of weevils after exposure for 24 hours*—Continued

Empirical formula	Compound with synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity 20°/4°	Minimum lethal dosage of fumigant	Weevils killed after exposure for 24 hours
				° C.		*Mg. per liter*	*Per cent*
$C_8H_{18}O$	dl-*sec.*-Octyl alcohol 2-Octanol Methyl *n*-hexyl carbinol β-Oxy-octane Capryl alcohol Caprylic alcohol *Sec.*-octylic alcohol Octoic alcohol Octanol-(2) β-Oxy-octan Methyl-hexyl-carbinol *sek.*-*n*-Octylalkohol Caprylalkohol	$CH_3CH(OH)CH_2CH_2CH_2CH_2CH_3$	130.14	178.5	0.819	164	100
$C_9H_{20}O$	*n*-Nonyl alcohol 1-Nonanol α-Oxy-nonane Nonanol-(1) α-Oxy-nonan *prim.*-*n*-Nonylalkohol	$CH_3(CH_2)_7CH_2OH$	144.15	215	.828	[1] 414	0
C_3H_6O	Allyl alcohol 1-Propene-3-ol Vinyl carbinol Propen-(1)-ol-(3) γ-Oxy-propylen Allylalkohol	$CH_2{=}CHCH_2OH$	58.046	97.0	.855	171	100
C_2H_5BrO	Ethylene bromohydrin 2-Bromoethyl alcohol 2-Brom-äthanol-(1) Glykolbromhydrin β-Brom-äthylalkohol	CH_2BrCH_2OH	124.955	150.3	1.655	337	100
C_2H_5ClO	Ethylene chlorohydrin 2-Chloroethyl alcohol 2-Chlor-äthanol-(1) β-Chlor-α-oxy-äthan β-Chlor-äthylalkohol Glykolchlorhydrin Äthylenchlorhydrin	CH_2ClCH_2OH	80.497	128.8	1.213	242	100

C_3H_7ClO	Propylene chlorohydrin	$CH_3CHClCH_2OH$	94.512	134	1.102	89	100
	2-Chloropropyl alcohol						
	2-Chlor-propanol-(1)						
	β-Chlor-α-oxy-propan						
	β-Chlor-propylalkohol						
	prim.-Propylenchlorhydrin						
C_3H_7ClO	Trimethylene chlorohydrin	$CH_2ClCH_2CH_2OH$	94.512	160-162	1.132	[1] 566	0
	3-Chlor-propanol-(1)						
	γ-Chlor-α-oxy-propan						
	γ-Chlor-propylalkohol						
C_3H_5ClO	Epichlorohydrin	CH_2Cl | CH | >O CH_2	92.497	117	1.184	[2] 24	100
	α-Epichlorohydrin						
	Chlor-methyl-2-äthylen-oxyd						
$C_4H_7Cl_3O$	1, 1, 1-Trichloro-*tert.*-butyl alcohol	$(CH_3)_2C(OH)CCl_3$	177.43	166.4	------	[1] 500	20
	1, 1, 1-Trichlor-2-methyl-propanol-(2)						
	α-α-α-Trichlor-β-oxy-methylpropan						
	Acetonchloroform						
	Chloretone						
	Acetone chloroform						
	tert.-Trichlorobutyl alcohol						
$C_4H_{11}NO$	β-Dimethylamine ethyl alcohol	$CH_2(CH_3)_2NCH_2OH$	------	135	.8866	[1] 443	0
	Dimethyl-(β-oxy-äthyl)amin						
$C_4H_{10}O$	Diethyl ether	$C_2H_5OC_2H_5$	74.077	34.5	.714	[1] 357	10
	Ether						
	Sulphuric ether						
	Ethyl oxide						
	Anaesthesia ether						
	Ethyl ether						
	Aether						
$C_5H_{12}O$	Methyl *n*-butyl ether	$CH_3OC_4H_9$	88.092	70.3	.764	382	100
$C_6H_{14}O$	Ethyl *n*-butyl ether	$C_2H_5OC_4H_9$	102.11	91.4	.752	226	100
$C_6H_{14}O$	Methyl *n*-amyl ether	$CH_3OC_5H_{11}$	102.11	88.5	.754	226	100
$C_6H_{14}O$	*n*-Propyl ether	$C_3H_7OC_3H_7$	102.11	89	.747	224	100
	Dipropyl ether						
$C_6H_{14}O$	*Iso*propyl ether	$(CH_3)_2CHOCH(CH_3)_2$	102.11	68.7	.735	353	100
	Di*iso*propyl ether						
$C_8H_{18}O$	*n*-Butyl ether	$C_4H_9OC_4H_9$	130.14	140.9	.769	[1] 385	60
$C_{10}H_{22}O$	*n*-Amyl ether	$C_5H_{11}OC_5H_{11}$	158.17	190	.774	[1] 387	0
$C_{10}H_{22}O$	*Iso*amyl ether	$((CH_3)_2CHCH_2CH_2)_2O$	158.17	172.2	.783	[1] 397	0
	Di*iso*amyl ether						
	Amyl oxide						
	Amyl ether						
	Diamyl ether						
	Amylic ether						
$C_5H_{10}O$	Ethyl allyl ether	$C_2H_5OCH_2CH=CH_2$	86.077	67.6	.765	[1] 383	90
$C_4H_{10}O_2$	Ethyl ne glycol monoethyl ether	$CH_2OHCH_2OC_2H_5$	90.077	135.3	.935	[1] 468	0
	Glycol ethyl ether						

[1] The maximum dosage tested.

[2] The minimum concentration tested.

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigants, and percentage mortality of weevils after exposure for 24 hours*—Continued

Empirical formula	Compound with synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity 20°/4°	Minimum lethal dosage of fumigant	Weevils killed after exposure for 24 hours
				°C.		*Mg. per liter*	*Per cent*
C_2H_4O	Ethylene oxide α-β-Oxido-äthan	CH_2 | >O CH_2	44.031	10.7	0.887	[2] 20	100
C_3H_6O	Propylene oxide α-Propylene oxide Methyl-äthylenoxyd	CH_3CH | >O CH_2		35	.90	54	100
C_2H_5ClO	Chloromethyl ether Chloromethyl methyl ether	CH_2ClOCH_3	80.497	59.5	1.063	[1] 532	0
$C_2H_4Cl_2O$	*sym.*-Dichloromethyl ether Dichloromethyl ether	CH_2ClOCH_2Cl	114.947	106	1.315	658	100
C_4H_9BrO	β-Bromoethyl ethyl ether 2-Bromoethyl ethyl ether	$CH_2BrCH_2OCH_2CH_3$	152.99	128.2	1.370	[2] 27	100
$C_4H_8Cl_2O$	β-β-Dichloroethyl ether 2-Chloroethyl ether	$CH_2ClCH_2OCH_2CH_2Cl$	142.98	178	1.213	[2] 24	100
$C_4H_8Cl_2O$	α-β-Dichloroethyl ether 1, 2-Dichloroethyl ethyl ether α-β-Dichlor-diäthyläther α-β-Dichlor-(α-äthoxy)-äthan Dichloroether Dichloroethyl oxide	$CH_2ClCH_2ClOCH_2CH_3$	142.98	145	1.174	188	100
$C_3H_8O_2$	Methylal Methylene dimethyl ether Formal Methylenedimethyl ester Methylendimethylate	$CH_2(OCH_3)_2$	76.062	44	.862	[1] 431	40
$C_5H_{12}O_2$	Ethylal Methylene diethyl ether	$CH_2(OC_2H_5)_2$	104.09	89	.851	340	100
$C_6H_{14}O_2$	Acetal Ethidene diethyl ether Diethylacetal Ethylidenediethylic ether Diethylaldehyde	$CH_3CH(OC_2H_5)_2$	118.11	102.2	.831	332	100
$C_4H_{10}O_2$	Dimethylacetal Acetaldehyde dimethyl acetal α-α-Dimethoxy-äthan Äthylidendimethyläther Ethylidenedimethyl ester	$CH_3CH(OCH_3)_2$	90.077	64.4	.866	346	100

CH_2O	Formaldehyde Methanal Oxomethan Ameisensäurealdehyd Oxymethylene Formalin Formalith Formic aldehyde	HCHO	30.015	21		[1] 200	0
C_2H_4O	Acetaldehyde Äthanal Oxoäthan Essigsäurealdehyd Leichter säuerstoffäther Ethylaldehyde Acetic aldehyde Ethanal Aldehyde	CH_3CHO	44.031	20.2	.781	469	100
C_3H_6O	Propionaldehyde Propanal α-Oxo-propan Propyl aldehyde Propionic aldehyde Propylic aldehyde	CH_3CH_2CHO	58.046	48.8	.807	[1] 404	0
C_4H_8O	*n*-Butyraldehyde Butanal α-Oxo-butan	$CH_3CH_2CH_2CHO$	72.062	75.7	.817	[1] 409	0
C_4H_8O	*Iso*butyraldehyde Methyl propanal α-Oxo-β-methyl-propan *Iso*butyl aldehyde *Iso*butyryl aldehyde	$(CH_3)_2CHCHO$	72.062	61	.794	79	100
$C_5H_{10}O$	*Iso*valeraldehyde 2-Methyl-4-butanal δ-Oxo-β-methyl-butan *Iso*propylacetaldehyde *Iso*valeric aldehyde *Iso*valeral	$(CH_3)_2CHCH_2CHO$	86.077	92.5	.803	[1] 402	90
$C_7H_{14}O$	Heptaldehyde Oenanthol Oenanthic aldehyde Heptanal Heptoic aldehyde Oenanthal α-Oxo-heptan Önanthaldehyd Önanthol	$C_6H_{13}CHO$	114.11	155	.850	[1] 425	0
C_2HCl_3O	Chloral Trichloroacetaldehyde 2,2,2-Trichlor-äthanol-(1) Trichloroacetic aldehyde	CCl_3CHO	147.38	98.1	1.512	454	100

[1] The maximum dosage tested.

[2] The minimum concentration tested.

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigants, and percentage mortality of weevils after exposure for 24 hours*—Continued

Empirical formula	Compound with synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity 20°/4°	Minimum lethal dosage of fumigant	Weevils killed after exposure for 24 hours
				° *C.*		*Mg. per liter*	*Per cent*
C_3H_4O	Acrolein Propenal γ-Oxo-propylen Acrylaldehyde Acrylic aldehyde Acraldehyde	$CH_2{=}CHCHO$	56.031	52.5	0.841	168	100
$C_6H_{10}O$	α-Methyl-β-ethylacrolein 1-Ethyl-2-methylacrolein 2-Methyl-penten-(2)-al-(1)	$CH_3CH_2CH{=}C(CH_3)CHO$	98.077	137.3	.858	257	100
C_4H_6O	Crotonaldehyde Buten-(2)-al-(1) α-Oxo-β-butylen β-Methylacrolein	$CH_3CH{=}CHCHO$	70.046	104	.859	344	100
C_3H_6O	Acetone Dimethyl ketone Propanone β-Oxo-propan Dimethylketal Ketopropane Methylacetyl Pyroacetic ether	CH_3COCH_3	58.046	56.1	.7915	396	100
C_4H_8O	Ethyl methyl ketone Butanone β-Oxo-butan β-Keto-butan Äthyl-acetyl Propionsäure-methylketon Methylethyl ketone	$C_2H_5COCH_3$	72.062	79.6	.805	242	100
$C_5H_{10}O$	Diethyl ketone 3-Pentanone γ-Oxo-pentan *sym.*-Dimethyl-acetone Propion Metacetone Propione Ethyl propionyl	$C_2H_5COC_2H_5$	86.077	101.7	.814	163	100

$C_5H_{10}O$	Methyl *n*-propyl ketone	$CH_3COC_3H_7$	86.077	101.7	.812	97	100
	2-Pentanone						
	β-Oxo-pentan						
	Propyl-acetyl						
	Buttersäure-methylketon						
	Äthyl-aceton						
$C_6H_{12}O$	Methyl *n*-butyl ketone	$CH_3COC_4H_9$	100.09	127.2	.830	83	100
	2-Hexanone						
	β-Oxo-hexan						
	n-Valeriansäure-methylketon						
$C_6H_{12}O$	Methyl *iso*butyl ketone	$CH_3COCH_2CH(CH_3)_2$	100.09	119	.803	64	100
	2-Methyl-4-pentanone						
	δ-Oxo-β-methyl-pentan						
	*Iso*propylaceton						
$C_7H_{14}O$	Dipropyl ketone	$C_3H_7COC_3H_7$	114.11	143.5	.821	131	100
	4-Heptanone						
	δ-Oxo-heptan						
	Di-*n*-propyl ketone						
	Butyron						
$C_7H_{14}O$	Methyl *n*-amyl ketone	$CH_3COC_5H_{11}$	114.11	150	.822	230	100
	2-Heptanone						
	β-Oxo-heptan						
$C_9H_{18}O$	Di-*n*-butyl ketone	$C_4H_9COC_4H_9$	142.14	175	.827	[1] 410	0
	5-Nonanone						
	ε-Oxo-nonan						
	Dibutylketon						
$C_{11}H_{22}O$	Di-*n*-amyl ketone	$C_5H_{11}COC_5H_{11}$	170.17	226.3	.826	[1] 413	0
	6-Undecanone						
	ζ-Oxo-undecan						
	Capron						
	Diamyl ketone						
C_3H_5ClO	Chloroacetone	$CH_2ClCOCH_3$	92.497	121	1.162	116	100
	Chloropropanone						
	α-Chlor-β-oxo-propan						
	Acetonylchloride						
	Monochloroacetone						
	Monochlorinated acetone						
$C_6H_{10}O$	Mesityl oxide	$(CH_3)_2=C=CHCOCH_3$	98.077	135	.863	52	100
	2-Methyl-2-penten-4-one						
	*Iso*propyliden-aceton						
$C_4H_6O_2$	Diacetyl	$CH_3COCOCH_3$	86.046	88	.975	[1] 488	0
	Butandion						
	β-γ-Dioxo-butan						
	Dimethyl glyoxal						
$C_5H_8O_2$	Acetylacetone	$CH_3COCH_2COCH_3$	100.062	137	.976	195	100
	Pentandion-(2,4)						
	β-δ-Dioxo-pentan						
	Diacetylmethan						

[1] The maximum dosage tested.

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigants, and percentage mortality of weevils after exposure for 24 hours*—Continued

Empirical formula	Compound with synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity 20°/4°	Minimum lethal dosage of fumigant	Weevils killed after exposure for 24 hours
				° C.		*Mg. per liter*	*Per cent*
CH_2O_2	Formic acid Methansäure Ameisensäure Acidum formicum Acid hydrogen carboxylic	$HCOOH$	46.015	100.5	1.220	[1]610	0
$C_2H_4O_2$	Acetic acid Äthansäure Methan-carbonsäure Essigsäure Acidum aceticum Acid methanecarboxylic Vinegar acid	CH_3COOH	60.031	118.1	1.049	[1]525	0
$C_2H_3ClO_2$	Chloroacetic acid Chloräthansäure Chloressigsäure Monochloroacetic acid	$CH_2ClCOOH$	94.481	189.5	1.370	[1]500	0
$C_3H_6O_2$	Propionic acid Propansäure Äthancarbonsäure Methylessigsäure Methylacetic acid Metacetonic acid Ethylcarbonic acid	CH_3CH_2COOH	74.046	141.1	.992	[1]496	0
$C_4H_8O_2$	*n*-Butyric acid Butansäure Propan-α-carbonsäure Äthyessigsäure *n*-Buttersäure Buttersäure Propylformic acid Butyric acid	$CH_3CH_2CH_2COOH$	88.062	163.5	.959	[1]480	0
$C_4H_8O_2$	*Iso*butyric acid Methylpropansäure Propan-β-carbonsäure Dimethylessigsäure *Iso*buttersäure	$(CH_3)_2CHCOOH$	88.062	154.4	.949	[1]475	0

$C_5H_{10}O_2$	*n*-Valeric acid Pentansäure Butan-α-carbonsäure Propylessigsäure *n*-Valeriansäure Propylacetic acid Normal valeric acid	$CH_3CH_2CH_2CH_2COOH$	102.08	187	.942	[1]471	0
$C_5H_{10}O_2$	*Iso*valeric acid 2-Methyl-butansäure-(4) β-Methyl-propan-α-carbonsäure β-Methyl-*n*-buttersäure *Iso*propylessigsäure *Iso*butylameisensäure *Iso*valeriansäure Pentoic acid, primary Valerianic acid Valeric acid, anhydrous. Valeric acid, monohydrate *Iso*butylcarbonyl	$(CH_3)_2CHCH_2COOH$	102.08	176.7	.937	[1]469	0
$C_5H_{10}O_2$	dl-Methylethylacetic acid 2-Methyl-butansäure-(1) Butan-β-carbonsäure α-Methyl-buttersäure Methyl-äthylessigsäure	$CH_3CH_2CH(CH_3)COOH$	102.08	174	.941	[1]471	0
$C_2H_2Br_2O$	Bromoacetyl bromide Bromäthanoylbromid Bromacetylbromid	$CH_2BrCOBr$	201.85	150	2.317	[1]1,159	0
$C_2H_2Cl_2O$	Chloroacetyl chloride Chloräthanoylchlorid Chloracetylchlorid	$CH_2ClCOCl$	112.931	105	1.495	[1]748	0
C_2HCl_3O	Dichloroacetyl chloride Dichloräthanoylchlorid Dichloracetylchlorid	$CHCl_2COCl$	147.38	108	1.56	[1]780	0
C_2Cl_4O	Trichloroacetyl chloride Trichloräthanoylchlorid Trichloracetylchlorid	CCl_3COCl	181.832	118	1.629	[1]815	0
C_3H_5ClO	Propionyl chloride Propanoylchlorid Propionylchlorid	C_2H_5COCl	92.497	80	1.065	[1]533	0
C_4H_7ClO	*n*-Butyryl chloride Butyryl chloride Butanoylchlorid Buttersäurechlorid Butyrylchlorid	C_3H_7COCl	106.51	102	1.028	[1]514	0
C_5H_9ClO	*n*-Valeryl chloride Pentanoylchlorid *n*-Valeriansäurechlorid *n*-Valerylchlorid	C_4H_9COCl	120.53	128	1.016	[1]508	0
C_5H_9ClO	*Iso*valeryl chloride 2-Methyl-butanoylchlorid-(4) *Iso*valeriansäurechlorid *Iso*valerylchlorid	$(CH_3)_2CHCH_2COCl$	120.53	113	.9887	[1]495	0

[1] The maximum dosage tested.

Table 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigants, and percentage mortality of weevils after exposure for 24 hours*—Continued

Empirical formula	Compound with synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity 20°/4°	Minimum lethal dosage of fumigant	Weevils killed after exposure for 24 hours
				° C.		*Mg. per liter*	*Per cent*
$C_2Cl_2O_2$	Oxalyl chloride Oxalsäuredichlorid Oxalylchlorid	$(COCl)_2$	126.916	64	1.488	[1] 744	30
$C_2H_4O_2$	Methyl formate Ameisensäuremethylester Methylformiat	$HCOOCH_3$	60.031	31.8	.975	39	100
$C_3H_6O_2$	Ethyl formate Ameisensäureäthylester Äthylformiat Formic ether	$HCOOC_2H_5$	74.046	54.3	.906	72	100
$C_4H_8O_2$	*n*-Propyl formate Propylformiat	$HCOOC_3H_7$	88.062	81.3	.901	72	100
$C_4H_8O_2$	*Iso*propyl formate *Iso*propylformiat	$HCOOCH(CH_3)_2$	88.062	71.3	.883	53	100
$C_5H_{10}O_2$	*n*-Butyl formate Butylformiat	$HCOOC_4H_9$	102.08	106.8	.911	109	100
$C_5H_{10}O_2$	*Iso*butyl formate *Iso*butylformiat	$HCOOCH_2CH(CH_3)_2$	102.08	98.2	.875	35	100
$C_7H_{16}O_3$	Ethyl orthoformate Triäthylester der orthoameisensäure Triäthylorthoformiat Orthoameisensäureäthylester Triäthoxy-methan	$HC(OC_2H_5)_3$	148.12	145.9	.897	90	100
$C_6H_{12}O_2$	*Iso*amyl formate Ameisensäure*iso*amylester *Iso*amylformiat Amyl formate	$HCOOCH_2CH_2CH(CH_3)_2$	116.09	123.5	.871	70	100
$C_4H_6O_2$	Allyl formate Ameisensäureallylester Allylformiat	$HCOOCH_2CH{=}CH_2$	86.046	83	.948	38	100
$C_2H_3ClO_2$	Methyl chloroformate Methyl chlorocarbonate Kohlensäuremethylesterchlorid Chlorameisensäuremethylester Methylchlorformiat	$ClCOOCH_3$	94.481	71.4	1.236	198	100
$C_3H_5ClO_2$	Ethyl chloroformate Ethyl chlorocarbonate	$ClCOOC_2H_5$	108.497	95	1.139	251	100

	Kohlensäureäthylesterchlorid Chlorameisensäureäthylester Carbäthoxychlorid Chlorkohlensäureäthylester						
$C_3H_4Cl_2O$	β-Chloroethyl chloroformate Chlorameisensäure-(β-chlor-äthyl)-ester	$ClCOOCH_2CH_2Cl$		150–160	1.2	480	100
$C_4H_7ClO_2$	*n*-Propyl chloroformate *n*-Propylchlorocarbonate Chlorameisensäurepropylester	$ClCOOCH_2CH_2CH_3$	122.51	116	1.083	[1] 542	20
$C_4H_6Cl_2O_2$	γ-Chloropropyl chloroformate γ-Chloropropyl chlorocarbonate	$ClCOOCH_2CH_2C$	156.96	58–60 (8 mm.)	1.2	[1] 600	10
$C_4H_7ClO_2$	*Iso*propyl chloroformate *Iso*propyl chlorocarbonate Chlorameisensäure*iso*propylester	$ClCOOCH(CH_3)_2$	122.512	53–54 (160 mm.)	1.08	[1] 540	70
$C_5H_9ClO_2$	*n*-Butyl chloroformate *n*-Butyl chlorocarbonate	$ClCOOCH_2CH_2CH_2CH_3$	136.53	138.9	1.078	[1] 539	0
$C_5H_9ClO_2$	*Iso*butyl chloroformate *Iso*butyl chlorocarbonate Chlorameisensäure*iso*butylester	$ClCOOCH_2CH(CH_3)_2$	136.53	130	1.040	[1] 520	20
$C_6H_{11}ClO_2$	*Iso*amyl chloroformate *Iso*amyl chlorocarbonate Chlorameisensäure*iso*amylester	$ClCOOCH_2CH_2CH(CH_3)_2$	150.54	156	1.024	[1] 512	0
$C_3H_6O_2$	Methyl acetate Essigsäuremethylester Methylacetat	CH_3COOCH_3	74.046	57.1	.933	187	100
$C_4H_8O_2$	Ethyl acetate Acetic ether Essigäther Äthylacetat Essigsäureäthylester Aether aceticus Vinegar naphtha	$CH_3COOCH_2CH_3$	88.062	77.1	.899	180	100
$C_5H_{10}O_2$	*n*-Propyl acetate *n*-Propyl-acetat	$CH_3COOCH_2CH_2CH_3$	102.08	101.6	.887	89	100
$C_5H_{10}O_2$	*Iso*propyl acetate *Iso*propylacetat	$CH_2COOCH(CH_3)_2$	102.08	89	.877	110	100
$C_6H_{12}O_2$	*n*-Butyl acetate *n*-Butyl-acetat	$CH_3COOCH_2CH_2CH_2CH_3$	116.09	126.5	.882	212	100
$C_6H_{12}O_2$	*Iso*butyl acetate *Iso*butylacetat	$CH_3COOCH_2CH(CH_3)_2$	116.09	118.3	.871	87	100
$C_6H_{12}O_2$	*sec.*-Butyl acetate *sek.*-Butyl-acetat	$CH_3COOCH(CH_3)CH_2CH_3$	116.09	112.2	.870	122	100
$C_7H_{14}O_2$	*Iso*amyl acetate *Iso*amyl-acetat Amyl acetate Banana oil Amylacetic ether	$CH_3COOC_5H_{11}$	130.11	142.5	.875	175	100
$C_9H_{18}O_2$	*n*-Heptyl acetate *n*-Heptyl-acetat	$CH_3COOC_7H_{15}$	158.14	191.5	.874	[1] 437	0

[1] The maximum dosage tested.

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigants, and percentage mortality of weevils after exposure for 24 hours*—Continued

Empirical formula	Compound with synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity 20°/4°	Minimum lethal dosage of fumigant	Weevils killed after exposure for 24 hours
				°C.		*Mg. per liter*	*Per cent*
$C_{10}H_{20}O_2$	*sec.*-Octyl acetate Methylhexylcarbin-acetat Capryl-acetat	$CH_3COOCH(CH_3)(CH_2)_5CH_3$	172.15	193	0.87	[1] 435	0
$C_3H_5BrO_2$	Bromomethyl acetate Essigsäure-(brom-methyl)-ester	CH_3COOCH_2Br	152.95	130-133	1.5	[1] 750	60
$C_4H_7BrO_2$	2-Bromoethyl acetate β-Bromo ethyl acetate β-Brom-äthyl-acetat	$CH_3COOCH_2CH_2Br$	166.971	70 (27 mm.)	1.514	[2] 30	100
$C_4H_7ClO_2$	2-Chloroethyl acetate β-Chloro ethyl acetate β-Chlor-äthyl-acetat	$CH_3COOCH_2CH_2Cl$	122.51	145	1.178	47	100
$C_5H_9BrO_2$	3-Bromopropyl acetate γ-Bromo propyl acetate	$CH_3COOCH_2CH_2CH_2Br$	180.987	--------	1.2	[1] 600	0
$C_3H_5BrO_2$	Methyl bromoacetate	$CH_2BrCOOCH_3$	152.95	------	1.5	[2] 30	100
$C_4H_7BrO_2$	Ethyl bromoacetate Bromessigester	$CH_2BrCOOCH_2CH_3$	166.97	159	1.514	[2] 30	100
$C_3H_5ClO_2$	Methyl chloroacetate Methyl-chloracetat	$CH_2ClCOOCH_3$	108.497	130	1.22	73	100
$C_4H_7ClO_2$	Ethyl chloroacetate Äthyl-chloracetat	$CH_2ClCOOCH_2CH_3$	122.51	145.5	1.159	93	100
$C_5H_9ClO_2$	*Iso*propyl chloroacetate *Iso*propylchloracetat	$CH_2ClCOOCH(CH_3)_2$	136.526	149.5	1.09	[2] 22	100
$C_6H_{11}ClO_2$	*sec.*-Butyl chloroacetate *sek.*-Butyl-chloracetat	$CH_2ClCOOCH(CH_3)CH_2CH_3$	150.534	167.5	1.06	66	100
$C_6H_{11}ClO_2$	*n*-Butyl chloroacetate	$CH_2ClCOOCH_2CH_2CH_2CH_3$	150.534	175	1.081	216	100
$C_4H_6Cl_2O_2$	Ethyl dichloroacetate	$CHCl_2COOCH_2CH_3$	156.96	158.2	1.282	256	100
$C_4H_5Cl_3O_2$	Ethyl trichloroacetate	$CCl_3COOCH_2CH_3$	191.41	168	1.383	692	100
$C_5H_9BrO_2$	Ethyl 1-bromopropionate Ethyl α-bromopropionate dl-α-Brom-propionsäureäthylester 2-Brom-propansäure-(1)-äthylester	$CH_3CHBrCOOCH_2CH_3$	180.99	160	1.393	84	100
$C_5H_9BrO_2$	Ethyl 2-bromopropionate Ethyl β-bromopropionate 3-Brom-propansäure-(1)-äthylester β-Brom-propionsäureäthylester	$CH_2BrCH_2COOCH_2CH_3$	180.99	135-136 (50 mm.)	1.4	[1] 700	80
$C_5H_9ClO_2$	Ethyl 2-chloropropionate Ethyl β-chloropropionate	$CH_2ClCH_2COOCH_2CH_3$	136.54	162.5	1.114	[1] 557	90

	3-Chlor-propansäure-(1)-äthylester						
	β-Chlor-propionsäureäthylester						
$C_5H_7NO_2$	Ethyl cyanoacetate	$CH_2(CN)COOC_2H_5$	113.06	206	1.063	[1] 532	0
	Malonsäure-äthylester-nitril						
	Cyanessigsäure-äthylester						
	Cyanessigester						
$C_4H_8O_2$	Methyl propionate	$CH_3CH_2COOCH_3$	88.062	79.9	.917	183	100
	Methylpropionat						
$C_5H_{10}O_2$	Ethyl propionate	$CH_3CH_2COOCH_2CH_3$	102.08	99.1	.891	125	100
	Äthylpropionat						
$C_6H_{12}O_2$	*n*-Propyl propionate	$CH_3CH_2COOCH_2CH_2CH_3$	116.09	123.4	.883	124	100
	Propylpropionat						
$C_7H_{14}O_2$	*n*-Butyl propionate	$CH_3CH_2COOC_4H_9$	130.11	146	.883	[1] 442	60
	Butylpropionat						
$C_7H_{14}O_2$	*Iso*butyl propionate	$CH_3CH_2COOCH_2CH(CH_3)_2$	130.11	136.8	.869	174	100
	*Iso*butylpropionat						
$C_8H_{16}O_2$	*Iso*amyl propionate	$CH_3CH_2COOC_5H_{11}$	144.12	160.2	.870	435	100
	*Iso*amylpropionat						
$C_4H_8O_3$	Methyl lactate	$CH_3CH(OH)COOCH_3$	104.062	144.8	1.08	[1] 540	0
	α-Oxo-propionsäuremethylester						
	Milchsäuremethylester						
$C_5H_{10}O_3$	Ethyl lactate	$CH_3CH(OH)COOC_2H_5$	118.08	154	1.031	[1] 516	0
	α-Oxo-propionsäure-äthylester						
	Milchsäureäthylester						
$C_5H_{10}O_2$	Methyl *n*-butyrate	$CH_3CH_2CH_2COOCH_3$	102.08	102.3	.898	180	100
	Methylbutyrat						
$C_6H_{12}O_2$	Ethyl *n*-butyrate	$CH_3CH_2CH_2COOCH_2CH_3$	116.09	121.3	.870	264	100
	Äthylbutyrat						
	Butyric ether						
$C_7H_{14}O_2$	*n*-Propyl *n*-butyrate	$CH_3CH_2CH_2COOC_3H_7$	130.11	143	.879	[1] 440	40
	Propyl *n*-butyrate						
	Propylbutyrat						
$C_8H_{16}O_2$	*n*-Butyl *n*-butyrate	$CH_3CH_2CH_2COOC_4H_9$	144.12	166.4	.872	[1] 436	0
	Butyl *n*-butyrate						
	Butylbutyrate						
$C_8H_{16}O_2$	*Iso*butyl *n*-butyrate	$C_3H_7COOCH_2CH(CH_3)_2$	144.12	156.9	.866	[1] 433	0
	*Iso*butylbutyrat						
$C_9H_{18}O_2$	*Iso*amyl *n*-butyrate	$C_3H_7COOC_5H_{11}$	158.14	178.6	.882	[1] 441	10
	*Iso*amylbutyrat						
$C_6H_{12}O_2$	Ethyl *iso*butyrate	$(CH_3)_2CHCH_2COOC_2H_5$	116.09	111.7	.871	87	100
	Äthyl*iso*butyrat						
	*Iso*butyric ether						
$C_8H_{16}O_2$	*Iso*butyl *iso*butyrate	$(CH_3)_2CHCH_2COOCH_2CH(CH_3)_2$	144.12	148.7	.875	263	100
	*Iso*butyl*iso*butyrat						
$C_6H_{12}O_2$	Methyl *n*-valerate	$C_4H_9CO_2CH_3$	116.09	127.3	.910	255	100
	Methylvalerianat						
$C_7H_{14}O_2$	Ethyl *n*-valerate	$C_4H_9CO_2CH_2CH_3$	130.11	145.5	.877	[1] 439	70
	Äthylvalerianat						
	Ethyl valerianate						
	Ethyl valeriate						

[1] The maximum dosage tested.

[2] The minimum concentration tested.

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigants, and percentage mortality of weevils after exposure for 24 hours*—Continued

Empirical formula	Compound with synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity 20°/4°	Minimum lethal dosage of fumigant	Weevils killed after exposure for 24 hours
				° C.		*Mg. per liter*	*Per cent*
$C_6H_{18}O_2$	*n*-Butyl *n*-valerate	$C_4H_9CO_2C_4H_9$	158.14	185.8	0.885	[1] 443	0
	Butylvalerianat						
$C_7H_{14}O_2$	Ethyl *iso*valerate	$(CH_3)_2CHCH_2CO_2C_2H_5$	130.11	135	.866	173	100
	Äthyl *iso*valerianat						
$C_8H_{16}O_2$	*n*-Propyl *iso*valerate	$(CH_3)_2CHCH_2CO_2C_3H_7$	144.12	155.9	.863	[1] 432	0
$C_9H_{18}O_2$	*Iso*butyl *iso*valerate	$(CH_3)_2CHCH_2CO_2CH_2CH(CH_3)_2$	158.14	168.5	.854	[1] 427	0
$C_{10}H_{20}O_2$	*Iso*amyl *iso*valerate	$(CH_3)_2CHCH_2CO_2CH_2CH_2CH(CH_3)_2$	172.15	194	.870	[1] 435	0
$C_7H_{14}O_2$	Methyl *n*-caproate	$C_5H_{11}COOCH_3$	130.11	149.5	.904	[1] 452	0
	Hexansäuremethylester						
	Pentan-α-carbonsäuremethylester						
	Normalcapronsäuremethylester						
	Methylcapronat						
$C_8H_{16}O_2$	Ethyl *n*-caproate	$C_5H_{11}COOC_2H_5$	144.12	166.6	.875	[1] 438	0
	Äthylcapronat						
	Ethyl caproate						
	Ethyl capronate						
	Caproic ether						
	Capronic ether						
$C_8H_{16}O_2$	Methyl *n*-heptylate	$C_6H_{13}COOCH_3$	144.12	172.1	.881	[1] 441	0
	Önansäuremethylester						
	Heptansäuremethylester						
	Hexan-α-carbonsäuremethylester						
$C_9H_{18}O_2$	Ethyl *n*-heptylate	$C_6H_{13}COOC_2H_5$	158.14	187.1	.872	[1] 436	0
	Oenanthic ether						
	Cognac oil						
	Oenanthylic ether						
	Önansäureäthylester						
	Heptansäureäthylester						
	Hexan-α-carbonsäureäthylester						
$C_9H_{18}O_2$	Methyl caprylate	$C_7H_{15}COOCH_3$	158.14	192.9	.887	[1] 444	0
	Octansäuremethylester						
	Heptan-α-carbonsäuremethylester						
	n-Caprylsäuremethylester						
	n-Octylsäuremethylester						
$C_4H_6O_4$	Dimethyl oxalate	$(COOCH_3)_2$	118.046	163.3	1.120	[1] 500	0
	Methyl oxalate						

	Oxalsäuredimethylester Dimethyloxalat						
$C_6H_{10}O_4$	Diethyl oxalate Ethyl oxalate Oxalsäurediäthylester Diäthyloxalat	$(COOC_2H_5)_2$	146.08	186.1	1.080	[1] 540	
$C_{12}H_{22}O_4$	Di*iso*amyl oxalate *Iso*amyl oxalate Di*iso*amyloxalat	$(CH_3)_2CHCH_2CH_2O_2CCO_2CH_2CH_2CH(CH_3)_2$	230.17	265	.968	[1] 484	0
$C_3H_6O_3$	Dimethyl carbonate Methyl carbonate Dimethylcarbonat	$CO(OCH_3)_2$	90.046	89.7	1.069	[1] 535	90
$C_5H_{10}O_3$	Diethyl carbonate Ethyl carbonate Carbonic ether Diethylcarbonic ether Diäthylcarbonat	$CO(OC_2H_5)_2$	118.08	125.8	.979	196	100
$C_7H_{14}O_3$	Di-*n*-propyl carbonate Dipropylcarbonat	$CO(OC_3H_7)_2$	146.11	168.2	.968	[1] 484	0
$C_9H_{18}O_3$	Di-*n*-butyl carbonate Dibutylcarbonat	$CO(OC_4H_9)_2$	174.14	207.7	.924	[1] 462	0
$C_9H_{18}O_3$	Di*iso*butyl carbonate Di*iso*butylcarbonat	$CO((CH_3)_2CHCH_2)_2$	174.14	190.3	.919	[1] 460	10
$C_{11}H_{22}O_3$	Di*iso*amyl carbonate Di*iso*amylcarbonat	$CO(OC_5H_{11})_2$	202.17	228.7	.912	[1] 456	0
$C_6H_{10}O_4$	Ethylidene diacetate Diacetat des Acetaldehydhydrats Äthylidenglykol-diacetat Äthylidendiacetat	$CH_3CH(CH_3COO)_2$	146.08	169	.852	[1] 426	0
$C_7H_{12}O_2$	Ethyl β-β dimethyl acrylate 2-Methyl-buten-(2)-säure-(4)-äthylester β-Methyl-α-propylen-α-carbonsäure-äthylester β-β-Dimethyl-acrylsäure-äthylester	$(CH_3)_2C{=}CHCOOC_2H_5$	128.09	155	.922	203	100
$C_6H_{10}O_3$	Ethyl acetoacetate β-Keto-buttersäure-äthylester Acetessigsäureäthylester Acetessigester Diacetic ether	$CH_3COCH_2COOC_2H_5$	130.08	180	1.025	[1] 513	0
CH_5N	Methylamine (33 per cent in water) Aminomethan Carbinamin Methylamin	CH_3NH_2	31.047	−6.5	------	[1] 167	0
C_2H_7N	Ethylamine Aminoäthan Äthylamin	$CH_3CH_2NH_2$	45.062	16.6	.689	[1] 345	0
C_3H_9N	*n*-Propylamine 1-Amino-propan α-Amino-propan Propylamin	$CH_3CH_2CH_2NH_2$	59.077	48.7	.719	[1] 360	0

[1] The maximum dosage tested.

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigants, and percentage mortality of weevils after exposure for 24 hours*—Continued

Empirical formula	Compound with synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity 20°/4°	Minimum lethal dosage of fumigant	Weevils killed after exposure for 24 hours
				°C.		*Mg. per liter*	*Per cent*
C_3H_9N	*Iso*propylamine	$(CH_3)_2CHNH_2$	59.077	34	0.694	278	100
	2-Amino-propan						
	β-Amino-propan						
	*Iso*propylamin						
$C_4H_{11}N$	*n*-Butylamine	$CH_3CH_2CH_2CH_2NH_2$	73.093	76	.740	[1]370	0
	1-Amino-butan						
	α-Amino-butan						
	prim.-Normalbutylamin						
	Butylamin						
$C_4H_{11}N$	*Iso*butylamine	$(CH_3)_2CHCH_2NH_2$	73.093	68	.736	294	100
	1-Amino-2-methyl-propan						
	α-Amino-β-methyl-propan						
	*Iso*butylamin						
$C_4H_{11}N$	*sec.*-Butylamine	$CH_3CHNH_2CH_2CH_3$	73.093	63	.718	215	100
	2-Amino-butan						
	β-Amino-butan						
	Methylethylcarbin-amin						
	sek.-Normalbutylamin						
	sek.-Butylamin						
$C_5H_{13}N$	*n*-Amylamine	$CH_3CH_2CH_2CH_2CH_2NH_2$	87.108	104	.766	[1]383	0
	1-Amino-pentan						
	α-Amino-pentan						
	prim.-Normalamylamin						
	n-Amylamin						
$C_5H_{13}N$	*Iso*amylamine	$CH_3CH(CH_3)CH_2CH_2NH_2$	87.108	95	.751	300	100
	4-Amino-2-methyl-butan						
	δ-Amino-β-methyl-butan						
	*Iso*butylcarbinamin						
	*Iso*amylamin						
C_3H_7N	Allylamine	$CH_2{=}CHCH_2NH_2$	57.062	53.2	.761	[1]381	50
	3-Amino-propen-(1)						
	γ-Amino-α-propylen						
	Allylamin						
C_2H_7N	Dimethylamine (33 per cent in water)	$(CH_3)_2NH$	45.062	7.4	.680	[1]340	0
	Dimethylamin						

$C_4H_{11}N$	Diethylamine Diäthylamin	$(C_2H_5)_2NH$	73.093	56.0	.711	142	100
$C_6H_{15}N$	Di-*n*-propylamine Dipropylamin	$(C_3H_7)_2NH$	101.12	110.7	.738	221	100
$C_6H_{15}N$	Di*iso*propylamine Di*iso*propylamin	$\left(\begin{matrix}CH_3\\CH_3\end{matrix}\right\}CH\Big)_2NH$	101.12	84	.722	72	100
$C_8H_{19}N$	Di-*n*-butylamine Dibutylamin	$(C_4H_9)_2NH$	129.15	161	.74	[1] 370	90
$C_8H_{19}N$	Di*iso*butylamine Di*iso*butylamin	$((CH_3)_2CHCH_2)_2NH$	120.15	138.8	.745	224	100
$C_{10}H_{23}N$	Di*iso*amylamine Di*iso*amylamin	$((CH_3)_2CHCH_2CH_2)NH$	157.19	190	.767	[1] 384	0
$C_6H_{11}N$	Diallylamine Diallylamin	$(CH_2=CHCH_2)_2NH$	97.86	111	.72	288	100
C_3H_9N	Trimethylamine (33 per cent in water) Trimethylamin	$(CH_3)_3N$	59.077	3.5	.662	[1] 331	0
$C_6H_{15}N$	Triethylamine Triäthylamin	$(C_2H_5)_3N$	101.12	89.5	.728	218	100
$C_9H_{21}N$	Tri-*n*-propylamine Tripropylamin	$(C_3H_7)_3N$	143.17	156	.757	227	100
$C_{12}H_{27}N$	Tri-*n*-butylamine Tributylamin	$(C_4H_9)_3N$	185.22	214	.778	[1] 389	0
$C_{15}H_{33}N$	Tri*iso*amylamine Tri*iso*amylamin	$(C_5H_{11})_3N$	227.26	237	.785	[1] 393	0
$C_{14}H_{13}NO$	Tetramethylammonium hydroxide 10 per cent Tetramethylammoniumhydroxid	$(CH_3)_4NOH$	91.108	([4])	----------	[1] 50	0
C_2H_3N	Acetonitrile Methyl cyanide Äthannitril Acetonitril Methylcyanid	CH_3CN	41.031	82	.783	[1] 392	90
C_3H_5N	Propionitrile Ethyl cyanide Propannitril Propionitril Äthylcyanid	CH_3CH_2CN	55.047	97.1	.783	235	100
C_4H_7N	*n*-Butyronitrile *n*-Propyl cyanide Butannitril Butyronitril Propylcyanid	$CH_3CH_2CH_2CN$	69.062	118	.794	238	100
C_5H_9N	*n*-Valeronitrile *n*-Valeryl nitrile Pentannitril *n*-Valeriansäurenitril *n*-Valeronitril	$CH_3CH_2CH_2CH_2CN$	83.077	141	.801	224	100
$C_6H_{11}N$	*Iso*capronitrile 2-Methyl-pentannitril-(5) *Iso*butylessigsäurenitril *Iso*capronitril	$(CH_3)_2CHCH_2CH_2CN$	97.09	155.5	.806	81	100

[1] The maximum dosage tested.

[4] Decomposes.

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigants, and percentage mortality of weevils after exposure for 24 hours*—Continued

Empirical formula	Compound with synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity 20°/4°	Minimum lethal dosage of fumigant	Weevils killed after exposure for 24 hours
				° C.		*Mg. per liter*	*Per cent*
$C_3H_2Cl_3NO$	Chloral cyanohydrin 2, 2, 2-Trichlorolactic nitrile	$Cl_3CCH(OH)CN$	174.40	220	----------	[1] 500	0
$C_3H_3N_3O_3$	Cyanuric acid	$(HCNO)_3$	120.047	----------	----------	[1] 500	0
CH_3NO_2	Nitromethane Nitromethan	CH_3NO_2	61.031	101.9	1.139	[1] 570	90
$C_2H_5NO_2$	Nitroethane Nitro-äthan	$CH_3CH_2NO_2$	75.047	114.8	1.056	211	100
$C_4H_9NO_2$	*n*-Butyl nitrite *n*-Butylester der saltpetrigen säure	$CH_3CH_2CH_2CH_2ONO$	103.077	75	.911	91	100
$C_5H_{11}NO_2$	*Iso*amyl nitrite *Iso*amylester der saltpetrigen säure *Iso*amylnitrit Amylnitrit	$(CH_3)_2CHCH_2CH_2ONO$	117.09	99	.872	87	100
$C_2H_5NO_3$	Ethyl nitrate Äthylester der saltpetersäure Äthylnitrat Saltpeteräther	$CH_3CH_2ONO_2$	91.047	88.7	1.105	[1] 553	80
$C_5H_{11}NO_3$	*Iso*amyl nitrate *Iso*amylester der saltpetersäure *Iso*amylnitrat	$(CH_3)_2CHCH_2CH_2ONO_2$	133.09	148	.996	230	100
$C_5H_9NO_2$	Diacetyl monomethoxime	$CH_3COC(NOCH_3)CH_3$	115.08	125–127	.9	90	100
CH_5NO	α-Methylhydroxylamine O-Methylhydroxylamin α-Methylhydroxylamin Methoxylamin	CH_3ONH_2	47.047	----------	.9	90	100
C_2H_6S	Ethyl mercaptan Äthanthiol Äthylmercaptan	C_2H_5SH	62.111	36.2	.840	[2] 17	100
C_3H_8S	*n*-Propyl mercaptan Propanthiol-(1) *prim.*-Propylmercaptan *n*-Propylmercaptan	$CH_3CH_2CH_2SH$	76.127	68	.8	48	100
C_3H_8S	*Iso*propyl mercaptan Propanthiol-(2) *sek.*—Propylmercaptan *Iso*propylmercaptan	$(CH_3)_2CHSH$	76.127	60	.8	160	100

$C_4H_{10}S$	*n*-Butyl mercaptan Butanthiol-(1) *prim.*-Normalbutylmercaptan *n*-Butylmercaptan	C_4H_9SH	90.142	98	.836	67	100
$C_4H_{10}S$	*Iso*butyl mercaptan 2-Methyl-propanthiol-(1) *Iso*butyl-mercaptan	$(CH_3)_2CHCH_2SH$	90.142	88	.836	33	100
$C_5H_{12}S$	*Iso*amyl mercaptan 2-Methyl-butanthiol-(4) *Iso*amylmercaptan	$C_5H_{11}SH$	104.16	129.5	.835	84	100
C_2H_6S	Methyl sulphide Dimethylsulfid	$(CH_3)_2S$	62.111	36.2	.849	425	100
$C_4H_{10}S$	Ethyl sulphide Diäthyl-sulfid	$(C_2H_5)_2S$	90.142	91.6	.837	419	100
$C_6H_{14}S$	*n*-Propyl sulphide Dipropylsulfid	$(C_3H_7)_2S$	118.17	142	.814	244	100
$C_8H_{18}S$	*Iso*butyl sulphide Di*iso*butylsulfid	$((CH_3)_2CHCH_2)_2S$	146.20	171	.836	334	100
$C_6H_{10}S$	Allyl sulphide Diallylsulfid	$(CH_2{=}CHCH_2)_2S$	114.14	138.7	.888	[1] 444	60
$C_2H_6S_2$	Methyl disulphide Dimethyldisulfid	CH_3SSCH_3	94.176	118	1.046	[2] 21	100
$C_4H_{10}S_2$	Ethyl disulphide Diäthyl-disulfid	$C_2H_5SSC_2H_5$	122.21	153.5	.993	79	100
$C_4H_{10}Se$	Ethyl selenide Diäthyl-selenid	$(C_2H_5)_2Se$	137.28	108	1.230	246	100
C_2H_4OS	Thioacetic acid Thioessigsäure Thiacetsäure Äthanthiolsäure	CH_3COSH	76.096	93	1.074	215	100
$SOCl_2$	Thionyl chloride	$SOCl_2$	118.981	78.8	1.638	655	100
$C_4H_9O_2ClS$	*n*-Butanesulphochloride Butan-sulfonsäure-(1) chlorid Butan-α-sulfonsäure	$CH_3CH_2CH_2CH_2SO_2Cl$		96	1.2	[1] 600	0
$C_3H_6S_3$	Dimethyl-trithiocarbonate	$SC(SCH_3)_2$	138.24	204.5	1.159	[1] 600	20
$C_7H_{16}S_2$	Mercaptol	$(CH_3)_2C(SC_2H_5)_2$	160.22	191	<1.	[1] 600	0
CCl_4S	Perchloromethyl mercaptan	CCl_3SCl	185.90	149	1.718	240	100
C_2H_3NS	Methyl thiocyanate Thiocyansäure-methylester Rhodanmethan Methylthiocyanate Methylrhodanid	CH_3SCN	73.096	133	1.068	64	100
C_3H_5NS	Ethyl thiocyanate Thiocyansäure-äthylester Rhodanäthan Äthylrhodanid	C_2H_5SCN	87.112	144.4	.996	100	100
C_4H_7NS	*Iso*propyl thiocyanate Thiocyansäure-*iso*propylester *Iso*propylrhodanid	$(CH_3)_2CHSCN$	101.127	149–151	.963	[2] 19	100

[1] The maximum dosage tested.

[2] The minimum concentration tested.

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigants, and percentage mortality of weevils after exposure for 24 hours*—Continued

Empirical formula	Compound with synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity 20°/4°	Minimum lethal dosage of fumigant	Weevils killed after exposure for 24 hours
				° C.		*Mg. per liter*	*Per cent*
C_2H_5NS	Ethyl *iso*thiocyanate Thiokohlensäure-äthylimid Äthyl*iso*thiocyanat Äthylsenföl	C_2H_5NCS	87.112	132	0.995	[1] 20	100
C_4H_5NS	Allyl*iso*thiocyanate Allyl*iso*thiocyanat Allylsenföl	$CH_2{=}CHCH_2NCS$	99.112	150.7	1.01	[1] 20	100
$C_4H_{10}O_3S$	Ethyl sulphite Diethyl sulfite Diäthylester der schwefligen säure Diäthylsulfite	$(C_2H_5)_2SO_3$	138.14	161.3	1.077	108	100
$C_2H_6O_4S$	Methyl sulphate Dimethylsulfat	$(CH_3)_2SO_4$	126.111	188.8	1.333	667	100

[1] The minimum concentration tested.

DISCUSSION OF RESULTS

In considering the results of the fumigation tests upon weevils in ½-liter glass flasks, it should be borne in mind that the tests were conducted in the presence of a relatively large quantity of wheat, which has a large absorptive capacity for the vapors of many compounds. The minimum lethal dosage is greater, therefore, than if no wheat were present.

The exact minimum lethal concentration of compounds in the vapor phase would have to be determined in the absence of wheat or any other absorptive material, and under carefully controlled conditions of temperature and humidity, and to compare the toxicity of compounds accurately the concentration of vapor should be expressed in terms of gram-molecules per liter, or molar percentage. The minimum lethal dose of each compound as determined in these tests, however, includes the true minimum lethal concentration of vapor plus the quantity of material absorbed by the wheat plus the quantity that failed to volatilize. The tests in this series were made for the sole purpose of rapidly surveying the field of possible fumigants suitable for the destruction of insects in grain, but it is believed that the following information obtained on the relations between the chemical-physical properties of organic compounds and their toxicity to rice weevils is of value.

On account of the experimental error of the tests, results within 20 per cent of each other are rated as equal.

RELATIVE TOXICITY OF THE ALIPHATIC COMPOUNDS TESTED

Hydrocarbons

Of nine hydrocarbons tested, only two, *n*-heptane and diisobutylene, killed all the weevils, and even these were not highly toxic. Aliphatic hydrocarbons of the methane or ethylene series do not appear promising as grain fumigants.

Bromides

Under the conditions of the test the order of toxicity of the bromine substitution products of hydrocarbons is as follows:

Of methane, carbon tetrabromide > bromoform > methylene bromide.
Of ethane, ethylene > ethyl > ethylidene.
Of propane, *n*-propyl > 1, 2-dibromo > *iso*propyl.
Of butane, *tert.*-butyl > *n*-butyl = *iso*butyl > *iso*butylene > *sec.*-butyl.
Of the straight chain bromides, *n*-propyl = *n*-butyl > ethyl.

The alkylene radical appears to be more toxic than the corresponding alkyl one; for example, the toxicity of allyl bromide is greater than that of *n*-propyl bromide.

Two of the bromides, *tert.*-butyl and allyl bromides, killed 100 per cent of the weevils at the minimum [3] dosage tried.

Tetrabromoethane, 1, 2-dibromobutane, 2, 3-dibromobutane, and 1, 2, 3-tribromobutane did not kill all the weevils at the maximum [4] dosage tried.

[3] The minimum dosage of each compound tested was 0.02 c. c. per liter.
[4] The maximum dosage of each compound tested was 0.50 c. c. per liter.

Chlorides

The order of toxicity of the chlorine substituted hydrocarbons is as follows:

Of methane, chloroform>methylene chloride>carbon tetrachloride.
Of ethane, ethylene dichloride>penta=tetra=trichloroethane>ethylidene chloride>hexachloroethane.
Of propane, 1, 2-dichloro>1, 3-dichloro>*n*-propyl=*iso*propyl.
Of butane, *tert.*-butyl>1, 1-dichloro =*n*-butyl.
Of ethene, dichloro=trichloro=tetrachloro.

The following relations are also significant:

*Iso*amyl>*n*-butyl>*n*-propyl.
1, 2-Dichloroethane>1, 1-dichloroethene.
Trichloroethane>trichloroethene.
Tetrachloroethane>tetrachloroethene.

Only one aliphatic chloride tested, hexachloroethane, failed to kill 100 per cent of the weevils at the maximum dosage used.

Iodides

Five of the twelve aliphatic iodides tested killed all weevils at the minimum dosage tried. Iodoform was the only iodide that did not kill all weevils at the maximum dosage tested.

The comparative toxicity of the iodides is as follows:

n-Propyl>*iso*propyl.
*Iso*butyl=*sec.*-butyl>*n*-butyl.
n-Propyl>*n*-butyl>*iso*amyl.

In toxicity to weevils, chlorides, bromides, and iodides rank as follows:

Comparative Toxicity of Chlorides, Bromides, and Iodides

Substitution product of—	Derivative	Order of toxicity
Methane	Di	Iodide>chloride>bromide.
	Tri	bromide>chloride.
	Tetra	bromide>chloride.
Ethane	Mono	Iodide>bromide.
	1, 1-Di	bromide=chloride.
	1, 2-Di	bromide>chloride.
Propane	Mono (1)	Iodide>bromide>chloride.
	Mono (2)	Iodide>bromide>chloride.
	1, 2-Di	bromide=chloride.
Butane	*n*-Butyl	Iodide=bromide>chloride.
	*Iso*butyl	Iodide>bromide.
	sec.-Butyl	Iodide>bromide.
	tert.-Butyl	bromide>chloride.
Pentane	*Iso*amyl	Chloride>bromide=iodide.

Ethylene dibromide>ethylene chlorobromide>ethylene dichloride.

Alcohols

Twenty-four alcohols were tested. Ten, namely, methyl, ethyl, *n*-propyl, *n*-butyl, *n*-amyl, *n*-hexyl, *n*-heptyl, di-*n*-propyl carbinol, *n*-octyl, and *n*-nonyl alcohols, failed to kill all the weevils at the maximum dosage tried. The order of toxicity of the other alcohols is as follows:

tert.-Amyl=methylbutylcarbinol=dimethyl *n*-propyl carbinol> *tert.*-butyl > triethylcarbinol > *iso*butyl = *sec.*-butyl = *sec.*-butylcarbinol = *sec.*-octyl = allyl > *iso*amyl = *sec.*-amyl = diethylcarbinol = *iso*propyl.

None of the straight chain primary alcohols was effective in killing weevils. The branched chain primary alcohols (*iso*butyl alcohol, *iso*amyl alcohol, and *sec.*-butyl carbinol) were effective, but less so than the secondary and tertiary alcohols with the same number of carbon atoms. Of the 5 most toxic alcohols, 4 are tertiary, and 1 is a secondary alcohol.

The following orders of toxicity were ascertained:

*Iso*propyl > *n*-propyl.
tert.-Butyl > *iso*butyl = *sec.*-butyl > *n*-butyl.
tert.-Amyl > *sec.*-butylcarbinol > *iso*amyl = *sec.*-amyl = diethylcarbinol > *n*-amyl.
Methylbutylcarbinol = dimethyl-*n*-propylcarbinol > *n*-hexyl.
Triethylcarbinol > di-*n*-propylcarbinol or *n*-heptyl alcohol.
sec.-Octyl > *n*-octyl.
Allyl > *iso*propyl > *n*-propyl.
Primary alcohols, *iso*butyl = *sec.*-butylcarbinol > *iso*amyl.
Secondary alcohols, methylbutylcarbinol > *sec.*-butyl = *sec.*-octyl > *sec.*-amyl = diethylcarbinol = *iso*propyl.
Tertiary alcohols, *tert.*-Amyl = dimethyl-*n*-propylcarbinol > triethylcarbinol.

Halogen Substituted Alcohols

The comparative toxicity of the halogen substituted alcohols is as follows:

Epichlorohydrin > propylene chlorohydrin > ethylene chlorohydrin > ethylene bromohydrin > trimethylene chlorohydrin or trichloro-*tert.*-butyl alcohol.

Epichlorohydrin was effective at the minimum dosage tried, but trimethylene chlorohydrin and trichloro-*tert.*-butyl alcohol failed to kill all weevils even at the rate of 0.50 c. c. per liter. The substitution of chlorine or bromine for hydrogen in ethyl and *n*-propyl alcohols resulted in an increase in their toxicity to weevils covered with wheat.

Amino Alcohols

β-Dimethylamino ethyl alcohol, the only amino alcohol tested, failed to kill all weevils when applied at the rate of 0.50 c. c. per liter.

Ethers

As a class, the ethers were weak in insecticidal action. Of 11 tested, 8 failed to kill all weevils at the maximum dosage of 0.50 c. c. per liter. The toxicity of the others may be compared as follows:

Di-*n*-propyl = methyl-*n*-amyl = ethyl-*n*-butyl > di*iso*propyl = methyl-*n*-butyl.
Di-*n*-propyl > di*iso*propyl.

There is no consistent relation between the toxicity of the ethers and their corresponding alcohols. For example,

*Iso*propyl alcohol > di*iso*propyl ether, but
Di-*n*-propyl ether > *n*-propyl alcohol.

Oxides

The two oxides tested were highly toxic to weevils in wheat. Ethylene oxide has such a high vapor pressure at room temperature (25° C.) that it was difficult accurately to pipette small quantities of it. Its exact toxic dosage is shown by the tests in the 500-cubic-foot fumigating vault, p. 49.

HALOGEN SUBSTITUTED ETHERS

Of five halogen substituted ethers tested, two, 2-bromoethyl ethyl ether and 2-chloroethyl ether, killed at the minimum dosage tried. Chloromethyl methyl ether failed to kill all weevils at the maximum dosage, and the dichloromethyl ether had low toxicity.

The position of the substituting halogen atoms affects the toxicity of the compound. For example, 2-chloroethyl ether is much more toxic than 1, 2-dichloroethyl ethyl ether.

ACETALS

Ethylal, acetal, and dimethylacetal are about equally toxic, the minimum lethal dosage of each being 340 mg. per liter. Methylal failed to kill all weevils at the maximum dosage of 0.50 c. c. per liter.

ALDEHYDES

Formaldehyde, applied as the aqueous solution formalin, propionaldehyde, *n*-butyraldehyde, *iso*valeraldehyde, and heptaldehyde failed to kill all weevils at the maximum dosage.

*Iso*butyraldehyde is the most toxic of the aldehydes tested.

The following relations were determined:

*Iso*butyraldehyde > crotonaldehyde > *n*-butyraldehyde.
Acrolein > propionaldehyde.
Acrolein > crotonaldehyde.

KETONES

The order of toxicity of the ketones follows:

Dipropyl ketone > diethyl ketone > dimethyl ketone.

Di-*n*-butyl and di-*n*-amyl ketones did not kill all weevils at the dosage of 0.50 c. c. per liter.

Methyl *iso*butyl ketone > methyl *n*-butyl ketone = methyl *n*-propyl ketone > methyl *n*-amyl ketone = ethyl methyl ketone > dimethyl ketone.

Of all the ketones tested, mesityl oxide is the most toxic to weevils in wheat.

One of the two diketones tried, diacetyl, failed to kill all weevils at the maximum dosage.

ACIDS

Not one of the nine acids tested killed any weevils at the maximum dosage of 0.50 c. c. per liter. The vapors of these acids appear to be taken up by wheat and thus fail to reach the weevils underneath.

ACID CHLORIDES AND BROMIDES

Nine compounds of the acid chloride and bromide class killed no weevils when tested in a dosage of 0.50 c. c. per liter. Wheat appears to retain the vapors of these compounds in the same manner that it does those of the acids.

ESTERS

FORMATES

The order of toxicity of the formates is as follows:

Methyl = *iso*butyl = allyl > *iso*propyl > ethyl = *n*-propyl = *iso*amyl > *n*-butyl.
Ethyl orthoformate is slightly less toxic than ethyl formate.

CHLOROFORMATES

Nine chloroformate compounds were tested. Methyl chloroformate was found to be more toxic than ethyl chloroformate and this in turn was more toxic than *n*-propyl chloroformate.

β-Chloroethyl chloroformate is less toxic than ethyl chloroformate.

Six chloroformates failed to kill all weevils in wheat even at the maximum dosage.

ACETATES

Ten esters of acetic acid were tried. Two, namely, *n*-heptyl and *sec.*-octyl acetates, failed to kill all weevils at the maximum dosage of 0.50 c. c. per liter. The order of toxicity of the others is:

*Iso*butyl = *n*-propyl > *sec.*-butyl = *iso*propyl > *iso*amyl = methyl = ethyl = *n*-butyl.

HALOGENATED ESTERS OF ACETIC ACID

Bromomethyl and 3-bromopropyl acetates did not kill all the weevils at the maximum dosage. 2-Bromoethyl acetate killed 100 per cent of the weevils at the minimum dosage applied. The toxicity of 2-bromomethyl is greater than that of 2-chloroethyl.

ESTERS OF HALOGENATED ACETIC AND PROPIONIC ACIDS

The following are the orders of toxicity found for the esters of halogenated acetic and propionic acids:

Methyl bromoacetate > methyl chloroacetate.
Ethyl bromoacetate > ethyl chloroacetate.
Methyl chloroacetate > ethyl chloroacetate > *n*-butyl chloroacetate.
Ethyl chloroacetate > ethyl dichloroacetate > ethyl trichloroacetate.
Ethyl 1-bromopropionate > ethyl 2-bromopropionate.
Ethyl bromoacetate > ethyl 1-bromopropionate.

CYANOACETATES

The only ester of cyanoacetic acid tried, ethyl cyanoacetate, failed to kill 100 per cent of the weevils at the maximum dosage.

PROPIONATES

Among the propionates the following order of toxicity was observed:

Ethyl = *n*-propyl > methyl = *iso*butyl > *iso*amyl.

n-Butyl propionate failed to kill all weevils at the maximum dosage.

LACTATES

Two esters of lactic (α-hydroxypropionic acid) were tested, methyl and ethyl. Both proved ineffective at the maximum concentration of 0.50 c.c. per liter.

n-BUTYRATES

Four esters of *n*-butyric acid, *n*-propyl, *n*-butyl, *iso*butyl, and *iso*amyl, failed to kill all weevils at the maximum dosage used. Of the other two, the toxicity of the methyl is greater than that of the ethyl.

*ISO*BUTYRATES

Two esters of *iso*butyric acid were tested. The ethyl is more toxic than the *iso*butyl.

n–VALERATES

The methyl ester was the only *n*–valerate that gave a 100 per cent kill. Ethyl and *n*–butyl *n*–valerates were ineffective.

*ISO*VALERATES

The ethyl ester was effective, but the *n*–propyl, *iso*butyl, and *iso*amyl esters failed to kill at the maximum dosage of 0.50 c.c. per liter.

CAPROATES, HEPTYLATES, AND CAPRYLATES

None of the methyl and ethyl esters of the caproic, heptylic, and caprylic acids killed 100 per cent of the weevils at the maximum dosage of 0.50 c. c. per liter.

OXALATES

Neither the dimethyl, diethyl, nor di*iso*amyl esters killed any weevils even at the maximum dosage.

CARBONATES

Six esters of carbonic acid were tested. Only the diethyl ester gave a 100 per cent kill.

DIACETATE AND ACETOACETATE

Ethylidene diacetate and ethyl acetoacetate were ineffective.

ACRYLATE

The only ester of an unsaturated acid that was tried, ethyl β–β–dimethyl acrylate, was effective at a dosage of 203 mg. per liter.

Comparison of Toxicity of Methyl, Ethyl, and *Iso*butyl Esters

The relative toxicity of the methyl, ethyl, and *iso*butyl esters of different fatty acids is shown in Table 2, which gives the minimum lethal dosage of each.

Table 2.—*Toxicity of methyl, ethyl, and* iso*butyl esters of certain fatty acids to rice weevils buried in wheat*

Acid	Minimum lethal dosage (mg. per liter) for 24 hours' exposure of—			Acid	Minimum lethal dosage (mg. per liter) for 24 hours' exposure of—		
	Methyl ester	Ethyl ester	*Iso*butyl ester		Methyl ester	Ethyl ester	*Iso*butyl ester
	Mg.	*Mg.*	*Mg.*		*Mg.*	*Mg.*	*Mg.*
Formic	39	72	35	*n*–Valeric	255	(1)	(2)
Acetic	157	180	87	*Iso*valeric	(2)	173	(1)
Propionic	183	125	174	*n*–Caproic	(1)	(1)	(2)
n–Butyric	180	204	(1)	*n*–Heptylic	(1)	(1)	(2)
*Iso*butyric	(2)	87	263	Caprylic	(1)	(2)	(2)

[1] Five-tenths cubic centimeters, approximately 450 mg., did not kill 100 per cent of the weevils.
[2] Not tested.

From the data in Table 2 it is evident that the esters of formic acid are markedly more toxic to weevils in wheat than are the esters of the higher acids.

The esters of the branched chain acids are more toxic than those of the corresponding straight chain acids having the same number of carbon atoms. For example,

Ethyl *iso*butyrate>ethyl *n*–butyrate.
*Iso*butyl *iso*butyrate>*iso*butyl *n*–butyrate.
Ethyl *iso*valerate>ethyl *n*–valerate.

Effect of Halogen Substitution in Esters

IN THE ACID RADICAL

The esters of chloroformic acid are decidedly less toxic to weevils covered with wheat than are the corresponding esters of formic acid. This is attributed to the great instability of the chloroformates. Apparently most of their vapors are absorbed by the wheat before they come in contact with the weevils. For instance,

Methyl formate>methyl chloroformate.
Ethyl formate>ethyl chloroformate.

The introduction of a single chlorine or bromine atom in acetic acid greatly increases the toxicity of the esters. For example:

Methyl chloroacetate>methyl acetate.
Ethyl chloroacetate>ethyl acetate.

The introduction of two or three chlorine atoms in acetic acid, however, decreases the toxicity of the esters. In that case the following is the order of toxicity:

Ethyl chloroacetate>ethyl acetate>ethyl dichloroacetate>ethyl trichloroacetate.

The introduction of a single bromine atom in the alpha position into propionic acid increases the toxicity of the ethyl ester, but in the beta position decreases the toxicity.

Ethyl 1–bromopropionate>ethyl propionate>ethyl 2–bromopropionate.

IN THE ALKYL RADICAL

No consistent relations in toxicity seem to hold when halogen is substituted in the alkyl radical.

Methyl acetate>bromomethyl acetate.
Propyl acetate>3–bromopropyl acetate, but
2–Bromo and 2–chloroethyl acetates>ethyl acetate.

The following comparison shows this inconsistency:

2–Chloroethyl acetate>ethyl chloroacetate, but
Methyl bromoacetate>bromomethyl acetate.

Amines

PRIMARY AMINES

None of the primary amines exhibits much toxicity to weevils in wheat. The following comparisons were made:

*Iso*propyl>*n*–propyl.
sec.–Butyl>*iso*butyl>*n*–butyl.
*Iso*amyl>*n*–amyl.

Four out of ten primary amines failed to kill all weevils when applied at the rate of 0.50 c. c. per liter.

SECONDARY AMINES

The following order of toxicity of the secondary amines was observed:

Di*iso*propyl>diethyl>di-*n*-propyl=di*iso*butyl>diallyl.
Di*iso*butyl>di-*n*-butyl.

TERTIARY AMINES

Three out of five tertiary amines tested, namely, trimethyl, tri-*n*-butyl, and tri*iso*amylamines, failed to kill all the weevils. Triethyl and tri-*n*-propylamines are about equally toxic.

QUATERNARY AMINES

The only quaternary ammonium derivative tested, tetramethylammonium hydroxide, failed to kill any weevils in wheat at the maximum dosage of 0.50 c. c. per liter.

COMPARISON OF PRIMARY, SECONDARY, AND TERTIARY AMINES

An exact comparison of the amines can not be made, because so many tested failed to kill 100 per cent of the weevils. The toxicity of diethylamine, however, is greater than that of triethylamine, which in turn is greater than the toxicity of monoethylamine. In general, the secondary amines appear to be more toxic than the primary or tertiary amines.

NITRILES

The nitriles are toxic in the following order:

*Iso*capro>*n*-valero=propio=*n*-butyro.

Acetonitrile was not effective in killing 100 per cent of the weevils in wheat at the maximum dosage.

Chloral cyanohydrin and cyanuric acid killed no weevils at the maximum dosage.

NITRO COMPOUNDS, NITRITES, NITRATES, OXIMES, AND HYDROXYLAMINES

In toxicity the nitro compounds, nitrites, nitrates, oximes, and hydroxylamines rank as follows:

Nitroethane>Nitromethane.
n-Butyl nitrite=*iso*amyl nitrite.
*Iso*amyl nitrate>ethyl nitrate.
*Iso*amyl nitrite>*iso*amyl nitrate.

Diacetyl monomethoxime and α-methylhydroxylamine are about equally toxic, the minimum lethal dosage of each being 90 mg. per liter.

MERCAPTANS

As a class, the mercaptans are extremely toxic. Ethyl mercaptan killed all the weevils in wheat at the minimum dosage tried, 0.02 c. c. per liter. The order of toxicity of the mercaptans is as follows:

Ethyl>*iso*butyl>*n*-propyl>*n*-butyl>*iso*amyl>*iso*propyl.

As shown in Table 3, the mercaptans are much more toxic to weevils in wheat than are the corresponding alcohols.

TABLE 3.—*Toxicity of mercaptans and alcohols to rice weevils buried in wheat*

Radical	Minimum lethal dosage (mg. per liter) for 24 hours' exposure of—		Radical	Minimum lethal dosage (mg. per liter) for 24 hours' exposure of—	
	Mercaptan	Alcohol		Mercaptan	Alcohol
	Mg.	*Mg.*		*Mg.*	*Mg.*
Methyl	(1)	(1)	*n*-Butyl	67	(1)
Ethyl	[3] 17	(2)	*Iso*butyl	33	160
n-Propyl	48	(2)	*Iso*amyl	84	195
*Iso*propyl	160	220			

[1] Not tested.
[2] Five-tenths cubic centimeter, approximately 400 mg., did not kill 100 per cent of the weevils.
[3] Minimum dosage tried.

SULPHIDES

The comparative toxicity of the sulphides is as follows:

n-Propyl>*iso*butyl>ethyl=methyl>allyl.

The sulphides are distinctly less toxic to weevils in wheat than are the corresponding mercaptans. For example,

Ethyl mercaptan (17)[5]>diethyl sulphide (419).[6]
n-Propyl mercaptan (48)[6]>dipropyl sulphide (244).[6]
*Iso*butyl mercaptan (33)[6]>di*iso*butyl sulphide (334).[6]

DISULPHIDES

Only two disulphides were tested, methyl and ethyl. The methyl is more toxic than the ethyl.

The disulphides are much more toxic than the sulphides, but somewhat less toxic than the mercaptans. For example,

Methyl disulphide>methyl sulphide.
Ethyl mercaptan>ethyl disulphide>ethyl sulphide.

SELENIDES

The only selenide tested, ethyl selenide, was more toxic than the corresponding sulphide, ethyl sulphide.

MISCELLANEOUS SULPHUR COMPOUNDS

Butanesulphochloride, dimethyltrithiocarbonate, and mercaptol did not kill all weevils at the maximum dosage of 0.50 c. c. per liter.

The other sulphur compounds tested, namely, thioacetic acid, thionyl chloride, and perchloromethyl mercaptan, were only slightly to moderately toxic to weevils in wheat.

THIO- AND *ISO*THIOCYANATES

The following order of toxicity exists among the thiocyanates:

*Iso*propyl>methyl>ethyl.

[5] Minimum dosage tried. [6] Minimum lethal dosage.

The *iso*thiocyanates are more toxic than the corresponding thiocyanates, ethyl *iso*thiocyanate, for instance, being more toxic than ethyl thiocyanate.

Ethyl and allyl *iso*thiocyanates killed all weevils at the minimum dosage.

SULPHITES AND SULPHATES

Ethyl sulphite, the only sulphite tried, was more toxic to weevils in wheat than was methyl sulphate, the one sulphate tested.

COMPARATIVE TOXICITY OF ALKYLS

The difference in toxicity of the methyl, ethyl, and *n*-propyl derivatives is, in general, so slight that the results of the tests are not sufficiently accurate to establish the proper order of toxicity. Furthermore, these tests were made on a basis of milligrams per liter rather than milligram molecules per liter. It was noticed, however, that the *n*-propyl derivative is more toxic than the *iso*propyl derivative in the bromide, chloride, iodide, ether, acetate, and mercaptan, whereas the *iso*propyl derivative is more toxic in the alcohol, formate, primary amine, and secondary amine.

The general order of toxicity of the butyl derivatives is as follows:

tert.-Butyl > *iso*butyl = *sec.*-butyl > *n*-butyl.

Every *tert.*-butyl derivative tested (bromide, chloride, and alcohol) was more toxic than the corresponding *n*- and *sec.*-butyl derivatives.

The *iso*butyl derivative is more toxic than the *n*-butyl in the iodide, alcohol, aldehyde, ketone (methyl *iso*butyl ketone > methyl *n*-butyl ketone), formate, acetate, propionate, primary amine, secondary amine, and mercaptan. *n*-Butyl and *iso*butyl bromides are about equally toxic.

The unsaturated radical, allyl, appears to have more toxicity than the *n*-propyl radical.

The allyl is more toxic than the *n*-propyl in the bromide, alcohol, aldehyde, and formate, but *n*-propyl sulphide is more toxic than allyl sulphide.

MOST EFFECTIVE FUMIGANTS

The fumigants shown in these tests to be the most effective are grouped in the following list:

PART 1.—FUMIGANTS LETHAL IN THE MINIMUM DOSAGE APPLIED (0.02 C. C. PER LITER)

	Mg. per liter		Mg. per liter
Ethyl mercaptan ..... Less than ..	17	Allyl bromide .... Less than ..	28
*Iso*propyl thiocyanate ..... do	19	2-Bromoethyl acetate ..... do	30
Ethyl *iso*thiocyanate ...... do	20	Methyl bromoacetate ..... do	30
Allyl *iso*thiocyanate .... do	20	Ethyl bromoacetate .... do	30
Methyl disulphide .... do	21	*n*-Propyl iodide .... do	35
tert.-Butyl bromide .... do	24	Allyl iodide .... do	37
Epichlorohydrin .... do	24	Ethyl iodide .... do	39
2-Chloroethyl ether .... do	24	Methyl iodide .... do	46
2-Bromoethyl ethyl ether .. do	27	Methylene iodide .... do	67

Ten classes of compounds are represented in this list of 18 effective fumigants, namely, 2 bromides out of 20 tested; 5 iodides out of 12 tested; the 1 epichlorohydrin tested; 2 halogenated ethers out of 5 tested; 1 halogenated ester out of 4 tested; 2 esters of halogenated fatty acids out of 19 tested; 1 mercaptan out of 6 tested; 1 disulphide out of 2 tested; 1 thiocyanate out of 3 tested; and both *iso*thiocyanates tested.

Thirteen of these 18 compounds contain halogen, and the remaining 5 contain sulphur. Three of the sulphur compounds also contain nitrogen.

PART 2.—ADDITIONAL FUMIGANTS LETHAL IN DOSAGES LESS THAN 100 MG. PER LITER

	Mg. per liter		Mg. per liter
Ethylene oxide	20	Di*iso*propylamine	72
*Iso*butyl mercaptan	33	Methyl chloroacetate	73
tert.-Butyl chloride	34	*Iso*butyraldehyde	79
*Iso*butyl formate	35	*tert.*-Butyl alcohol	79
Allyl formate	38	Ethyl disulphide	79
Methyl formate	39	*Iso*capronitrile	81
2-Chloroethyl acetate	47	*n*-Propyl bromide	81
n-Propyl mercaptan	48	Methyl *n*-butyl ketone	83
Mesityl oxide	52	Ethyl 1-bromopropionate	84
*Iso*propyl formate	53	*Iso*amyl mercaptan	84
Propylene oxide	54	Ethyl *iso*butyrate	87
Carbon tetrabromide	60	*Iso*butyl acetate	87
*Iso*butyl iodide	64	Ethylene dibromide	87
sec.-Butyl iodide	64	*Iso*amyl nitrite	87
Methylbutylcarbinol	64	Propylene chlorohydrin	89
Methyl*iso*butyl ketone	64	*n*-Propyl acetate	89
Methyl thiocyanate	64	Diacetyl monomethoxime	90
tert.-Amyl alcohol	65	*a*-Methylhydroxylamine	90
Dimethyl *n*-propylcarbinol	66	Ethyl orthoformate	90
n-Butyl mercaptan	67	*n*-Butyl nitrite	91
*Iso*propyl iodide	68	Ethyl chloroacetate	93
*Iso*amyl formate	70	Methyl *n*-propyl ketone	97
Ethyl formate	72	*n*-Butyl iodide	97
n-Propyl formate	72	Ethyl thiocyanate	100

The effective compounds in part 2 of this list represent the following proportion of each class:

Three bromides out of 20 tested; 1 chloride out of 21 tested; 4 iodides out of 12 tested; 1 secondary alcohol out of 8 tested; 3 tertiary alcohols out of 11 tested; 4 ketones out of 11 tested; 1 secondary amine out of 8 tested; 2 nitrites out of 2 tested; 1 nitrile out of 5 tested; 8 formates (including 1 orthoformate) out of 9 tested; 2 acetates out of 10 tested; 1 *iso*butyrate out of 2 tested; 2 monochloroacetates out of 3 tested; 1 bromopropionate out of 2 tested; the 1 oxime tested; the 1 hydroxylamine tested; 1 halogenated ester out of 4 tested; 2 thiocyanates out of 3 tested; 4 mercaptans out of 7 tested; 1 disulphide out of 2 tested; and both oxides tested.

Of these 48 compounds, 13 contain halogen, 8 contain nitrogen, 7 contain sulphur, 2 contain both sulphur and nitrogen, and 22 contain only carbon, hydrogen, and oxygen.

Of the 309 compounds tested, 243 were either nontoxic under the conditions of the test, or more than 100 mg. per liter was required to kill the insects.

LEAST EFFECTIVE FUMIGANTS

The following materials failed to kill any weevils at the maximum dosage of 0.50 c.c. per liter: Decane, amylene, *sym.*-tetrabromoethane, 1, 2, 3-tribromobutane, hexachloroethane, iodoform, methyl alcohol, *n*-butyl alcohol, *n*-amyl alcohol, *n*-hexyl alcohol, *n*-heptyl alcohol, *n*-octyl alcohol, *n*-nonyl alcohol, trimethylene chlorohydrin, β-dimethylaminoethyl alcohol, di-*n*-amyl ether, di*iso*amyl ether, glycol ethyl ether, chloromethyl ether, formalin, propionaldehyde, *n*-butyraldehyde, heptaldehyde, di-*n*-butyl ketone, di-*n*-amyl ketone, diacetyl, formic acid, acetic acid, chloroacetic acid, propionic acid, *n*-butyric acid, *iso*butyric acid, *n*-valeric acid, *iso*valeric acid, dimethylethylacetic acid, bromoacetyl bromide, chloroacetyl chloride, di-chloroacetyl chloride, trichloroacetyl chloride, propionyl chloride, *n*-butyryl chloride, *n*-valeryl chloride, *iso*valeryl chloride, *n*-butyl chloroformate, *iso*amyl chloroformate, *n*-heptyl acetate, *sec.*-octyl acetate, γ-bromopropyl acetate, ethyl cyanoacetate, methyl lactate, ethyl lactate, *n*-butyl *n*-butyrate, *iso*butyl *n*-butyrate, *n*-butyl *n*-valerate, *n*-propyl *iso*valerate, *iso*butyl *iso*valerate, *iso*amyl *iso*valerate, methyl *n*-caproate, ethyl *n*-caproate, methyl *n*-heptylate, ethyl *n*-heptylate, methyl *n*-caprylate, methyl oxalate, ethyl oxalate, *iso*amyl oxalate, di-*n*-propyl carbonate, di-*n*-butyl carbonate, di*iso*amyl carbonate, ethylidene diacetate, ethyl acetoacetate, methylamine, ethylamine, *n*-propylamine, *n*-butylamine, *n*-amylamine, dimethylamine, di*iso*amylamine, trimethylamine, tri-*n*-butylamine, tri*iso*amylamine, tetramethylammonium hydroxide, chloral cyanohydrin, cyanuric acid, *n*-butanesulphochloride, and mercaptol.

These 85 nontoxic compounds represent the following proportion of the various classes: Two hydrocarbons out of 9 tested; 2 bromides out of 20 tested; 1 chloride out of 21 tested; 1 iodide out of 12 tested; 7 primary alcohols (all straight chain) out of 12 tested; 1 chlorohydrin out of 4 tested; the 1 amino alcohol tested; 3 ethers out of 11 tested; 1 chloro-ether out of 4 tested; 4 aldehydes out of 10 tested; 2 ketones out of 11 tested; 1 diketone out of 2 tested; the 9 acids tested; the 9 acid bromides and chlorides tested; 2 chloroformates out of 9 tested; 2 acetates out of 10 tested; 1 brominated ester out of 4 tested; the 1 cyanoacetate tested; both lactates tested; 2 *n*-butyrates out of 6 tested; 1 *n*-valerate out of 3 tested; 3 *iso*valerates out of 4 tested; both caproates tested; both heptylates tested; the 1 *n*-caprylate tested; the 3 oxalates tested; 3 carbonates out of 6 tested; the 1 diacetate tested; the 1 acetoacetate tested; 5 primary amines out of 10 tested; 2 secondary amines out of 8 tested; 3 tertiary amines out of 5 tested; the 1 tetramethylammonium derivative tested; the 1 cyanohydrin tested; the 1 cyanuric acid tested; the 1 sulphochloride tested; and the 1 miscellaneous sulphur compound tested.

CONCLUSIONS

A study of the 66 most toxic and the 85 least toxic compounds from a total of 309 tested against weevils in the presence of wheat under conditions where the compounds could come in contact with the weevils only in the vapor phase indicates:

Apparently no relation exists between the boiling point of compounds and their relative toxicity, except that most compounds of high boiling point (above 150° C.) have too low a vapor pressure at room temperature (25° C.) to furnish a toxic concentration of vapor.

Branched chain radicals are more toxic than are straight chain radicals.

Chemically inert compounds, that is, paraffin hydrocarbons, have but little toxicity.

Some compounds that are highly reactive chemically, such as aldehydes, acids, and acid chlorides, do not kill weevils in wheat, probably because they are absorbed by the wheat and fail to reach the insects.

Compounds belonging to the following classes are the most toxic: Iodides, bromides, mercaptans, thiocyanates, *iso*thiocyanates, disulphides, oxides, epichlorohydrin, halogenated ethers, halogenated esters, and formates.

GERMINATION TESTS

METHOD

In order to determine the usefulness of a fumigant, its effect upon the germinating quality of seeds must be known. To obtain information regarding the action upon wheat germination of the various compounds tested as fumigants for the rice weevil in this investigation, careful germination tests were made upon the wheat, before and after 24 hours' exposure to each fumigant. In most cases the fumigated wheat was treated with the maximum dosage of fumigant tested, namely, 0.5 c. c. per liter of space half filled with wheat, equivalent to 1.25 c. c. per kilogram of grain. These germination tests were made in duplicate upon 100 kernels of wheat by the seed testing laboratory, Bureau of Plant Industry.

EXPERIMENTAL RESULTS

The fumigants that lowered the comparative germination of wheat more than 10 per cent are given in Table 4.

TABLE 4.—*Fumigants that lower the germination of wheat 10 per cent or more of check*

Fumigant	Dosage applied	Minimum lethal dosage	Germination of fumigated wheat expressed as percentage of check
	Gm. per kg of wheat	*Gm. per kg. of wheat* [1]	*Per cent*
Allyl bromide	0.3	[2] 0.07	2
Do.	1.7	[2].07	4
Methyl iodide	.6	[2].115	1
Allyl iodide	.3	[2].090	86
Do.	1.4	[2].090	27
Methyl alcohol	3.5	>[3].99	89
Do.	13.1	>[3].99	80
Ethyl alcohol	10.3	>[3].98	50
n-Butyl alcohol	5.5	>[3]1.01	65
2-Bromoethyl alcohol	2.1	.84	50
α-Epichlorohydrin	1.5	[2].06	0
α-β-Dichloroethyl ether	.6	.47	78
Do.	1.5	.47	10
Ethylene oxide	.075	[2].05	0
Do.	4.4	[2].05	0
Propylene oxide	1.1	.13	0
Formalin	1.25	>[3]1.5	69
Acetaldehyde	2.0	>[3]1.17	0
Heptaldehyde	1.1	>[3]1.06	87
Acrolein	1.1	.42	1
Crotonaldehyde	1.1	.86	1
Chloroacetone	1.45	.29	0
Diacetyl	1.2	>[3]1.22	1
Formic acid	.5	>[3]1.5	89
*Iso*valeric acid	1.2	>[3]1.17	87
dl-Methylethylacetic acid	1.2	>[3]1.18	88

Fumigant	Dosage applied	Minimum lethal dosage	Germination of fumigated wheat expressed as percentage of check
	Gm. per kg. of wheat	*Gm. per kg. of wheat* [1]	*Per cent*
Chloroacetic acid	1.25	>[3]1.25	32
Bromoacetyl bromide	2.9	>[3]2.90	17
Chloroacetyl chloride	1.5	>[3]1.87	21
Dichloroacetyl chloride	1.5	>[3]1.95	85
Trichloroacetyl chloride	1.6	>[3]2.04	69
n-Butyryl chloride	1.3	>[3]1.28	69
n-Valeryl chloride	1.3	>[3]1.27	85
*Iso*valeryl chloride	1.2	>[3]1.24	88
Oxalyl chloride	1.9	>[3]1.86	68
Allyl formate	1.2	.1	87
Methyl chloroformate	.6	.5	68
Do.	1.5	.5	9
Ethyl chloroformate	.7	.63	42
n-Propyl chloroformate	3.4	>[3]1.30	13
n-Butyl chloroformate	1.3	>[3]1.35	74
*Iso*butyl chloroformate	1.3	>[3]1.3	76
Bromoethyl acetate	2.0	>[3]1.88	76
2-Bromoethyl acetate	2.0	[2].07	89
γ-Bromopropyl acetate	.7	>[3]1.5	78
Do.	1.5	>[3]1.5	68
Methyl monochloroacetate	.3	.18	13
Do.	1.5	.18	1
Ethyl monochloroacetate	.3	.23	10
Do.	1.5	.23	2
*Iso*propyl monochloroacetate	.3	[2].05	10

[1] Data in this column are calculated from figures in minimum-lethal-dosage column of Table 1.
[2] Minimum dosage tested, equivalent to 0.02 c. c. per liter or 0.05 c. c. per kilogram of wheat.
[3] Maximum dosage tested, equivalent to 0.5 c. c. per liter or 1.25 c. c. per kilogram of wheat.

TABLE 4.—*Fumigants that lower the germination of wheat 10 per cent or more of check*—Continued

Fumigant	Dosage applied	Minimum lethal dosage	Germination of fumigated wheat expressed as percentage of check	Fumigant	Dosage applied	Minimum lethal dosage	Germination of fumigated wheat expressed as percentage of check
	Gm. per kg. of wheat	*Gm. per kg. of wheat* [1]	*Per cent*		*Gm. per kg. of wheat*	*Gm. per kg. of wheat*	*Per cent*
*Iso*propyl monochloroacetate	1.5	[1].05	4	Ethyl *n*-caproate	1.1	>[2]1.1	86
n-Butyl monochloroacetate	1.3	.5	6	Methyl oxalate	1.4	>[2]1.25	30
Ethyl dichloroacetate	1.6	.6	22	Ethyl oxalate	1.4	>[2]1.35	50
Ethyl trichloroacetate	1.7	1.7	88	*Iso*amyl oxalate	1.2	>[2]1.2	89
Methyl monobromoacetate	.4	[1].07	26	Diisoamylamine	.95	>[2].96	77
Do	1.9	[1].07	1	Triethylamine	.9	.55	80
Ethyl monobromoacetate	.4	[1].07	41	Tri-*n*-butylamine	1.0	>[2].97	84
Do	1.0	[1].07	4	Tri*iso*amylamine	1.0	>[2].98	71
Ethyl propionate	.7	.31	80	Ethyl nitrate	.8	>[2]1.38	2
Ethyl α-bromopropionate	1.0	.21	82	*n*-Butyl nitrite	1.1	.23	51
Do	1.7	.21	23	Methyl sulphide	1.1	1.06	89
*Iso*amyl *n*-butyrate	1.1	>[2]1.1	80	Thioacetic acid	1.3	.54	89
n-Butyl *n*-valerate	1.1	>[2]1.1	85	Thionyl chloride	2.0	1.64	0
				n-Butanesulphochloride	1.25	>[2]1.5	87
				Perchloromethyl mercaptol	1.25	.60	7
				Methyl sulphate	1.7	1.67	31

[1] Minimum dosage tested, equivalent to 0.02 c. c. per liter or 0.05 c. c. per kilogram of wheat.
[2] Maximum dosage tested, equivalent to 0.50 c. c. per liter or 1.25 c. c. per kilogram of wheat.

DISCUSSION OF RESULTS AND CONCLUSIONS

Several of the compounds tested, for example, acids and acid chlorides, injure the germination of wheat and are not effective against weevils.

Some of the compounds that lower the percentage germination of wheat were tested in excessive doses, for instance, α-epichlorohydrin.

Only a few of the materials that hold promise as insecticides must be used cautiously upon seed grain. These are certain iodides, halogenated alcohols, epichlorohydrin, halogenated ethers, oxides, and esters of halogenated fatty acids.

The bromides, with the exception of allyl bromide, chlorides, formates, sulphides, disulphides, thiocyanates, *iso*thiocyanates, and mercaptans, in dosages more than sufficient to kill all weevils in wheat do not injure the germination of the grain.

TESTS IN A 500-CUBIC-FOOT FUMIGATING VAULT [7]

METHOD

Of the 66 compounds that under laboratory conditions were 100 per cent toxic to the rice weevil at dosages less than 100 mg. per liter or 6.24 pounds per 1,000 cubic feet, only a few possess the desirable

[7] Detailed accounts of the tests with the most promising of the fumigants will be found in the following publications:
COTTON, R. T., and ROARK, R. C. ETHYLENE DICHLORIDE—CARBON TETRACHLORIDE MIXTURE; A NEW NONBURNABLE, NONEXPLOSIVE FUMIGANT. Jour. Econ. Ent. 20: 636–639. 1927.
——— and ROARK, R. C. FUMIGATION OF STORED-PRODUCT INSECTS WITH CERTAIN ALKYL AND ALKYLENE FORMATES. Indus. and Engin. Chem. 20: 380–382. 1928.
——— and ROARK, R. C. ETHYLENE OXIDE AS A FUMIGANT. Indus. and Engin. Chem. 20: 805. 1928.
ROARK, R. C., and COTTON, R. T. FUMIGATION TESTS WITH CERTAIN ALIPHATIC CHLORIDES. Jour. Econ. Ent. 21: 135–142. 1928.
——— and COTTON, R. T. INSECTICIDAL ACTION OF SOME ESTERS OF HALOGENATED FATTY ACIDS IN THE VAPOR PHASE. Indus. and Engin. Chem. 20: 512–514. 1928.

qualities of cheapness, effectiveness, commercial availability, and freedom from fire hazard and injurious effect upon man or merchandise.

Seventeen of the compounds that possess some or all of these qualifications were selected as worthy of further testing. A series of experiments with these was conducted in a commercial-type fumigating vault which was of very tight construction and had a capacity of 500 cubic feet. The fumigant to be tested was poured through a trap door in the top of the vault into a shallow trough suspended close to the ceiling. The vault was then closed for 24 hours. The insects used were the larvae of the clothes moth (*Tineola bisselliella*), of the black carpet beetle (*Attagenus piceus*), and of the furniture beetle (*Anthrenus vorax*), all species highly resistant to fumigants. The larvae were placed in cotton-stoppered vials and buried in pieces of overstuffed furniture. In all tests 20 specimens of the clothes moth and 50 specimens of each of the other species were used.

In addition to these tests comparative tests with carbon tetrachloride and carbon disulphide were made.

EXPERIMENTAL RESULTS

Table 5 contains data indicating the relative toxicity of the various compounds or mixtures of compounds tested. With the exception of carbon disulphide and ethylene oxide, the vapors of the compounds, or a mixture of a compound and carbon tetrachloride, used in the experiment are nonflammable and nonexplosive when heated to 122° F. and may therefore be considered as free from fire hazard.

TABLE 5.—*Results of fumigation tests on insects in a 500-cubic-foot vault*

Class	Fumigant				Temperature	Minimum lethal dosage for an exposure of 24 hours
	Compound	Parts by volume	Compound	Parts by volume		
					° F.	*Pounds for 1,000 cubic feet*
Chlorides	Carbon tetrachloride				85	30
	do	1	Ethylene dichloride	3	85	6
	do	1	do	3	65	12
	do	7	*tert.*-Butyl chloride	3	83	12
	Trichloroethylene				83	12
	Tetrachloroethylene				85	30
Iodides	Carbon tetrachloride	3	Ethyl iodide	1	85	5
Alcohols	do	7	*tert.*-Butyl alcohol	3	55	20
Oxides	Ethylene oxide				75	1
Formates	Carbon tetrachloride	7	*n*-Propyl formate	3	85	11
	do	3	*Iso*propyl formate	1	85	14
	do	3	*sec.*-Butyl formate	2	85	8
	do	3	*Iso*butyl formate	2	85	9
	do	3	*Iso*amyl formate	2	85	7
Acetates	do	7	*Iso*propyl acetate	3	83	15
Monochloroacetates.	Methyl monochloroacetate				83	1
	Ethyl monochloroacetate				83	2
	*Iso*propyl monochloroacetate				83	1½
Carbonates	Carbon tetrachloride	1	Diethyl carbonate	1	83	30+
Disulphides	Carbon disulphide				80	1½

DISCUSSION OF RESULTS AND CONCLUSIONS

The data in Table 5 show that several of the compounds are sufficiently toxic to be of value as fumigants. Ethylene oxide and methyl monochloroacetate appear to be the most toxic of the compounds tested, and when used in a tight vault compare favorably in toxicity with carbon disulphide. Others somewhat less toxic have advantages that compensate for the lower toxicity and enhance their value for fumigation of some types. Some of the advantages and limitations of these materials are discussed below.

CHLORIDES

The chlorides as a group are cheap, commercially available in large quantities, not highly toxic to man, and not readily flammable. They possess pleasant odors, and do not affect the germination of wheat. Of the several chlorides tested on a large scale, ethylene dichloride in a mixture of 3 volumes to 1 volume of carbon tetrachloride appears to be the most promising as a general fumigant. At 85° F. or over, a complete kill is obtained with 6 pounds of the mixture per 1,000 cubic feet of space. At lower temperatures a somewhat larger dose is required to give equally good results. The 3 to 1 mixture is nonflammable, nontoxic to man, and harmless to fabrics and furniture. It does not affect the germinating qualities of wheat, but gives to foodstuffs rich in oil a characteristic sweetish taste, which they are likely to retain for some time. In Industrial and Engineering Chemistry for February, 1930, ethylene dichloride in tank cars is quoted at 8 cents per pound, f. o. b.

Although more toxic than ethylene dichloride, *tert.*-butyl chloride requires a larger proportion of carbon tetrachloride to render it free from fire hazard, and it can not be used in metal-lined vaults because it attacks the metal.

Trichloroethylene is nonflammable and in the large scale tests proved to be about two and a half times as toxic as carbon tetrachloride at 80° F. or over. It should be valuable for combining with more toxic compounds to reduce the fire hazard.

Tetrachloroethylene, also nonflammable, is about as toxic as carbon tetrachloride.

IODIDES

Ethyl iodide, the only iodide tested on a large scale, is highly toxic, but owing to its high cost and the improbability of its being produced cheaply in the near future, it can not be considered a practical fumigant.

ALCOHOLS

Tertiary butyl alcohol is the most toxic of the alcohols tested. As the vapors are flammable, however, such a large proportion of carbon tetrachloride must be added to remove the fire hazard that the toxicity of the resulting mixture is reduced to a prohibitive extent.

OXIDES

Ethylene oxide shows promise of being an excellent all-purpose fumigant. A gas at ordinary temperatures, it is put up in liquid form under pressure. The gas is almost odorless, and so far as known has no injurious effect upon merchandise. Owing to its low boiling point, 10.7° C., it is effective at comparatively low temperatures, a feature that greatly enhances its value. The vapors are flammable and in high concentrations produce anaesthesia in man. In a concentration of 1 pound per 1,000 cubic feet, however, the fire and human hazards are negligible. The 1930 price of ethylene oxide is about $2 a pound in small quantities or 75 cents a pound in large quantities. It could probably be made to sell in large quantities at about 40 cents a pound.

FORMATES

The vapors of the lower alkyl formates are highly toxic to insects, and by admixture with carbon tetrachloride, formates that boil above 70° C. can be made free from fire hazard. The vapors are not injurious to the germinating power of grain and seem well adapted for the fumigation of foodstuffs. The esters of formic acid are now commercially available. When these formates are used as fumigants, a temperature of 75° F. or more is essential to obtain the best results.

ACETATES

Tests with *iso*propyl acetate indicated that so large a proportion of carbon tetrachloride must be added to obtain a mixture free from fire hazard that the effectiveness is reduced too low for practical purposes.

MONOCHLOROACETATES

The monochlorpacetates tested on a large scale are highly toxic at 80° F. and above. Owing to their high boiling point they are not efficient at low temperatures. Their vapors have a slightly irritating effect upon the eyes, but their lachrymatory power is much less than that of chloropicrin. Very little is known regarding the physiological action of monochloroacetic acid and its esters. The vapors of these esters, heated to 122° in admixture with air in a box will not propagate a flame when sparked and therefore may be said to be free from fire hazard. In small lots ethyl monochloroacetate has been quoted at from $1 to $1.50 a pound. It is believed that it could be manufactured in moderate quantities to sell at not more than 30 cents a pound. The methyl and *iso*propyl esters could probably be made to sell for not more than 50 cents a pound.

The results of germination tests on wheat fumigated with these monochloroacetates indicate that they have an injurious effect upon the germination.

CARBONATES

When mixed with a quantity of carbon tetrachloride sufficient to remove the fire hazard the vapors of diethyl carbonate are not toxic enough to be of commercial value.

SUMMARY

Three hundred and nine aliphatic compounds were tested against the rice weevil in ½-liter Erlenmeyer flasks half filled with wheat. Sixty-six of these compounds were lethal after an exposure of 24 hours, in dosages less than 100 mg. per liter or 6.24 pounds per 1,000 cubic feet, 18 of these being lethal in the minimum dosage tried, 0.02 c. c. per liter (1 to 4 pounds per 1,000 cubic feet).

The compounds showing the greatest toxicity are in the following classes: Iodides, bromides, mercaptans, thiocyanates, *iso*thiocyanates,

disulphides, oxides, epichlorohydrin, halogenated ethers, halogenated esters, and formates.

An analysis of the results obtained with the 66 most toxic and the 85 least toxic compounds tested indicates that there is no apparent relation between the boiling point of compounds and their relative toxicity, except that most compounds having a high boiling point (above 150° C.) have too low a vapor pressure at room temperature to furnish a toxic concentration; that branched chain radicals are more toxic than are straight chain radicals; that compounds which are inert chemically have little toxicity; and that some compounds highly reactive chemically do not kill weevils in wheat, probably because they are absorbed by the wheat and fail to reach the insects.

Germination tests with wheat showed that the chlorides, formates, sulphides, disulphides, thiocyanates, *iso*thiocyanates, and mercaptans in dosages more than sufficient to kill weevils do not injure the germination of the grain. The iodides, halogenated alcohols, epichlorohydrin, halogenated ethers, oxides, and esters of halogenated fatty acids are injurious to the germination of wheat and should be used with caution.

Many effective compounds are unavailable commercially or are too costly to be of practical value. Seventeen compounds showing promise of commercial value were tested in a 500-cubic-foot fumigation vault. Two of these, ethylene oxide and methyl monochloroacetate, were shown to be slightly more toxic than carbon disulphide. They were lethal at a dosage of 1 pound per 1,000-cubic feet. The ethyl and *iso*propyl esters of monochloroacetic acid were only slightly less toxic.

Ethylene dichloride in admixture with carbon tetrachloride in the ratio of 3 parts to 1 by volume was lethal at a dosage of 6 pounds per 1,000 cubic feet. Because of its low cost, effectiveness, and lack of fire hazard and toxicity to human beings, ethylene dichloride should be a useful fumigant.

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