Susceptibility of *Culex tritaeniorhynchus* and six other mosquitos to insecticides in Korea

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RÉSUMÉ

Cette première étude détaillée de la sensibilité des moustiques aux insecticides en Corée a montré clairement que Culex tritaeniorhynchus *était résistant au DDT et au lindane. Dans les zones rurales, aucune résistance des* Culex, Anopheles *et* Aedes *aux insecticides organophosphorés n'est encore apparue, et cela en dépit de fréquentes applications d'insecticides agricoles aux cultures de riz. Le produit de la concentration et du temps (CT), déduit de deux sortes d'expériences de test d'adultes, montre un même ordre de grandeur de toxicité des insecticides envers* Culex tritaeniorhynchus.

ABSTRACT.

This first detailed study on the susceptibility of mosquitos to insecticides in Korea has revealed the resistance of Culex tritaeniorhynchus *to DDT and lindane. In rural areas, organophosphorus resistance in culex, anopheline and aedes species has not yet occurred despite frequent pesticide applications to rice. The product of concentration and time (CT), derived from two adult test procedures, gave the same order of insecticide toxicity for* Culex tritaeniorhynchus.

Presented herein are the results of 175 larval susceptibility tests and 132 adult tests obtained in Korea against seven species of mosquitos from August 1969 to September 1972. The test methods employed, using 13 organophosphorus insecticides, three chlorinated hydrocarbons and one carbamate, were those recommended by the World Health Organization (1970). These results will enable comparisons to be made to susceptibility levels reported elsewhere and also provide base-lines for future work in Korea. BROWN and PAL (1971) have reviewed the resistance of mosquitos to insecticides on a world-wide basis.

SPECIES

The vector of Japanese encephalitis, *Cu. tritaeniorhynchus summorosus* was exposed in 33 % of the 307 tests. Other species tested of public health importance or interest were *Cu. pipiens pallens* (31 %), *An. sinensis* (11 %), *Ae. togoi* (8 %) and *Ae. vexans* (7 %). A few tests included *Cu. vagans* and *Cu. orientalis.*

LOCALITIES

Specimens were obtained from 15 localities. There provided adequate country-wide representation except for the eastern region and areas north of Seoul. A species was exposed to one of the standard WHO test procedures when sufficient numbers had been collected. Since a short time was spent in most localities, only a few insecticides could normally be tested.

About 65 % of all tests were made at the four study sites of the WHO Japanese Encephalitis Vector Research Unit (J.E.V.R.U.), which are described in an unpublished document (WHO/VBC/71.332). Briefly, Sintaein is located in an important rice growing area 215 km south of Seoul, and 32 % of all the tests occurred there. Sasang is a suburb of Pusan located near the Nak Tong river 330 km southeast of Seoul (15 % of tests). Another site is Paju located in a small rice growing area 25 km north of Seoul (10 %), whereas Banpo Dong is a suburb of Seoul located 2 km south of the Han river (8 %).

These 15 localities, as shown below, may be useful in planning future tests.

(1) Seoul suburbs south of Han river: Banpo Dong and Kimpo.

(2) Seoul suburbs north of Han river: Rockbon Dong, Nokbun Dong and Soo Saik.

(3) Pusan suburb near Nak Tong river: Sasang.

(4) Rice growing areas near Seoul: Paju and Seiryu Dong (Suwon).

(5) Rice growing areas in Cholla Pukdo Province: Sintaein, Kim Je and Kwang Hwal.

(6) Coastal areas: Byon San (Cholla Pukdo) and Kajawa Dong (Inchon).

(7) Offshore Islands: Cheju Do and Wi Do.

INSECTICIDES

When ample specimens had been obtained in breeding sites or from animal bait, fenitrothion was normally the first insecticide to be tested. It presently is the most frequently applied pesticide in Korea. It is therefore the compound of choice, followed by malathion and fenthion, in screening for organophosphorus-resistance. About 20 % of all tests were made with fenitrothion.

Naled (Dibrom) also has popular usage in Korea but for thermal fogging against mosquitos and for controlling caterpillars on pine trees. Aerial ULV applications are occasionally made. Although some mosquito larvae were tested against naled, the susceptibility levels of the adult populations have yet to be determined. One thermal fogging experiment using caged *Cu. tritaeniorhynchus* adults has shown that naled can provide good control at about one-third the effective malathion dosage (WHO/VBC/72.424).

Some tests were made with rice pest control materials, namely EPN, phenthoate (Cidial) and methyl parathion. Less toxic and less popular materials in this category are trichlorfon (Dipterex) and diazinon. Several other organophosphorus materials were tested because they were used in local vector control operations (e. g. dichlorvos) or else they offered promise as improved vector control replacements (e. g. chlorpyrifos, trade name Dursban). Future tests should include difenphos (Abate).

The three common chlorinated hydrocarbons were used and also the carbamate, propoxur. Except for OMS-1424 (2-Diethylamino-6-methylpyrimidin-4-yl dimethyl phosphorothionate) all the insecticides tested are fairly well known.

TEST PROCEDURES.

All specimens were normally field-collected and immediately tested, except for colony strains utilized during the cold months (November-March). The temperature during the tests normally ranged from 23 to 27 °C and the relative humidity from 65 to 85 %. Data for many tests were forwarded to WHO headquarters in Geneva for computer analysis, and the results are presented in various issues of the *WHO Information Circular on Insecticide* Resistance. The number of adults exposed are shown in Tables 5 and 6, and 300 or more specimens were normally used in each larval test. When the control mortalities exceeded 20 %, the tests were discarded.

Larvae.

For each concentration, at least two replicates of 25 third and fourth instar larvae were exposed for 24 h in plastic containers. These held 249 ml of water to which 1 ml of toxicant in ethanol had been added. Stock solutions of fenitrothion, malathion, fenthion, Dursban, bromophos, diazinon and the three chlorinated hydrocarbons were supplied by WHO. With the other compounds, ethanol solutions were prepared from technical material. Mortalities were recorded after 24 h exposures, and the regression lines were derived from at least three mortality points between 10 and 90 %.

Adults.

The impregnated papers and standard test kits were supplied by WHO. Two methods of testing were employed and two or more replicates of 26 engorged females were normally used for each concentration or exposure period. The mosquitos were transferred to clean holding tubes after exposure to the toxicant, and the percentage mortality determined 24 h later.

MULTIPLE - CONCENTRATION EXPOSURE. The well known WHO adult test for obtaining the percentage LC_{50} and percentage LC_{95} was used mainly in 1970. The specimens were exposed for 60 minutes to the following insecticides and concentrations: fenitrothion (.025, .1, .4, 1.6 %), malathion (.4, .8, 1.6, 3.2, 6.4, 12.8 %), fenthion (.2, 14, 18, 1.6, 3.2 %), DDT (.25, .5, 1.0, 2.0, 4.0 %), dieldrin (.2, .4, .8, 1.6, 4.0 %) and propoxur (.025, .1, .4, 1.6 %).

MULTIPLE-TIME EXPOSURE. A relatively new, recommended WHO procedure for obtaining the LT_{50} and LT_{95} in minutes was used in 1971 and 1972. Here, the regression lines were derived from the mortalities obtained at different exposure times to the same concentration of insecticide.

CT PRODUCTS. Although both adult test procedures could not be carried out simultaneously, the products of concentration and time (CT) are given for *Cu. tritaeniorhynchus*. ARIARATNAM and BROWN (1969) show the calculation procedure for *Cu. pipiens fatigans* exposed to DDT.

RESULTS.

Larvae.

FENITROTHION AND MALATHION. Table 1 shows the results obtained with seven species; and no resistance is indicated. With *Cu. tritaeniorhynchus*, the highest LC_{95} values to fenitrothion and malathion are only .038 ppm and .062 ppm, respectively. Moreover, the susceptibility levels in the two principal cities are similar to those in the rice growing and coastal areas. Apparently, there are not enough tests in each locality in each year to warrant a statistical analysis. In any case, the results could not provide a basis for concluding resistance.

TABLE 1. — Showing susceptibility levels of fourth instar larvae to fenitrothion and Malathion

Locality	Date	LC_{50} ppm	LC_{95} ppm
Fenitrothion			
Cu. tritaeniorhynchus			
Sasang	10.70	.0051	.0096
Sasang	8.71	.012	.029
Sasang	9.72	.0038	.023
Sintaein	8.70	.0080	.017
Sintaein	8.71	.0080	.020
Sintaein	8.72	.0044	.011
Banpo Dong	9.71	.010	.038
Kimpo	9.72	.0038	.023
Moo Reung Ri	10.70	.0058	.011
Chido	10.70	.0070	.011
Kajawa Dong	10.70	.0021	.0056
Cu. pipiens pallens			
Sasang	8.71	.0042	.039
Sasang	8.72	.0068	.026
Kim Je	4.70	.015	.032
Sintaein	9.70	.0039	.0061
Sintaein	6.71	.012	.023
Rockbon Dong	3.70	.012	.022
Nokbun Dong	6.72	.0026	.0064
Chido	12.70	.0058	.0088
Cu. vagans			
Banpo Dong	6.71	.0036	.0090
Banpo Dong	6.72	.0012	.0032
Cu. orientalis			
Paju	7.70	.0048	.016
An. sinensis			
Chido	10.70	.17	.75
Sintaein	8.72	.035	.12
Ae. togoi			
Byon San	5.70	.012	.020
Ae. vexans			
Banpo Dong	5.72	.0029	.0042

Locality	Date	LC_{50} ppm	LC_{95} ppm
Malathion			
Cu. tritaeniorhynchus			
Sasang	7.71	.014	.036
Sasang	9.72	.0096	.050
Sintaein	7.70	.0024	.036
Sintaein	8.71	.017	.046
Sintaein	8.72	.027	.062
Banpo Dong	9.71	.021	.068
Kimpo	9.72	.0030	.023
Paju	9.69	.021	.048
Chido	10.70	.018	.052
Cu. pipiens pallens			
Sasang	8.71	.079	.17
Sintaein	8.69	.050	.13
Sintaein	6.71	.075	.20
Sintaein	9.71	.047	.15
Kim Je	4.70	.051	.088
Rockbon Dong	2.70	.041	.059
Soo Saik	3.70	.060	.10
Chido	12.70	.091	.14
Cu. vagans			
Paju	7.70	.013	.026
Banpo Dong	6.71	.012	.023
Cu. orientalis			
Paju	7.70	.016	.037
An. sinensis			
Sintaein	8.70	.084	.17
Sintaein	8.72	.015	.072
Chido	10.70	.12	.20
Ae. togoi			
Byon San	8.69	.023	.063
Byon San	5.70	.018	.052

TABLE 2. — Showing susceptibility levels of fourth instar larvae to eleven organophosphorus insecticides

Locality	Date	LC50 ppm	LC95 ppm
Fenthion			
Cu. tritaeniorhynchus			
Sasang	8.71	.0018	.0053
Sasang	9.72	.0066	.021
Sintaein	8.70	.0017	.0033
Sintaein	8.71	.0047	.010
Sintaein	8.72	.0027	.0074
Banpo Dong	9.71	.0056	.022
Cu. pipiens pallens			
Rockbon Dong	3.70	.074	.13
Soo Saik	12.70	.0028	.0048
Rockbon Dong	7.72	.0027	.0052
Sintaein	8.69	.0020	.0045
Kim Je	4.70	.0077	.038
Sintaein	9.71	.0030	.015
Cu. vagans			
Paju	7.70	.0019	.0047
Banpo Dong	5.72	.0022	.0031
Ae. vexans			
Paju	6.70	.0019	.0044
Ae. togoi			
Byon San	8.69	.0012	.0028
Byon San	5.70	.014	.021

Locality	Date	LC50 ppm	LC95 ppm
Naled			
Cu. tritaeniorhynchus			
Sasang	8.71	.010	.020
Sasang	9.72	.021	.095
Sintaein	8.71	.0044	.010
Sintaein	9.71	.027	.088
Sintaein	8.72	.0065	.037
Banpo Dong	9.71	.0044	.043
Kimpo	9.72	.0032	.0056
Cu. pipiens pallens			
Soo Saik	12.70	.032	.045
Sintaein	7.71	.013	.027
Sintaein	12.70	.028	.047
Sasang	8.72	.022	.048
Cu. vagans			
Banpo Dong	6.71	.0046	.0090
Trichlorfon			
Cu. tritaeniorhynchus			
Sasang	8.71	.019	.19
Sintaein	8.73	.18	.48
Cu. pipiens pallens			
Nokbun Dong	6.72	.25	.82
Soo Saik	12.70	.50	.73
Sintaein	6.71	.14	.34

Locality	Date	LC50 ppm	LC95 ppm
Chlorpyritos			
Cu. tritaeniorhynchus			
Sasang	7.71	.00055	.0019
Sasang	9.72	.0014	.0042
Sintaein	8.71	.00022	.00072
Sintaein	8.72	.00028	.0013
Banpo Dong	9.71	.00032	.00072
Kimpo	9.72	.00054	.0015
Cu. pipiens pallens			
Rockbon Dong	2.70	.00044	.00076
Soo Saik	3.70	.00061	.0011
Kim Je	4.70	.00058	.0011
Sintaein	6.71	.00035	.00068
Sintaein	9.71	.00031	.0013
Ae. togoi			
Byon San	5.70	.00048	.0016
Dichlorvos			
Cu. tritaeniorhynchus			
Rockbon Dong	7.70	.014	.024
Rockbon Dong	7.72	.016	.027
Sintaein	7.70	.018	.034
Ae. togoi			
Byon San	7.70	.039	.094

TABLE 2. — *(Continued)*

Locality	Date	LC50 ppm	LC95 ppm
EPN			
Cu. tritaeniorhynchus			
Sasang	8.71	.00075	.0031
Sintaein	9.71	.00055	.0011
Banpo Dong	9.71	.0011	.0034
Cu. pipiens pallens			
Soo Saik	12.70	.0012	.0043
Sintaein	12.70	.0020	.0035
Chido	12.70	.0012	.0026
OMS - 1424			
Cu. tritaeniorhynchus			
Sasang	8.72	.0065	.020
Cu. pipiens pallens			
Nokbun Dong	6.72	.0034	.0095
Cu. vagans			
Banpo Dong	5.72	.00092	.0016

Locality	Date	LC50 ppm	LC95 ppm
Phenthoate			
Cu. tritaeniorhynchus			
Sasang	8.71	.00072	.0017
Sintaein	9.71	.00089	.0043
Banpo Dong	9.71	.0013	.0032
Cu. pipiens pallens			
Soo Saik	12.70	.011	.023
Sintaein	12.70	.012	.028
Diazinon			
Cu. tritaeniorhynchus			
Sintaein	8.72	.019	.038
Cu. pipiens pallens			
Rockbon Dong	2.70	.030	.14
Nokbun Dong	6.72	.016	.027
Kim Je	4.70	.041	.092
Ae. togoi			
Byon San	8.69	.0068	.025
Byon San	5.70	.010	.027

Locality	Date	LC50 ppm	LC95 ppm
Methyl parathion			
Cu. tritaeniorhynchus			
Sasang	8.71	.00054	.0039
Sintaein	8.72	.0028	.0066
Cu. pipiens pallens			
Rockbon Dong	7.72	.0020	.0038
Sintaein	12.70	.0017	.0042
Bromophos			
Cu. pipiens pallens			
Rockbon Dong	2.70	.0053	.0088
Soo Saik	3.70	.0051	.0087
Sintaein	6.71	.0079	.023
Ae. togoi			
Byon San	5.70	.0047	.0081

Both *Cu. tritaeniorhynchus* and *Cu. pipiens pallens* show a similar response to fenitrothion but not to malathion. The LC_{95} values of the latter species to malathion normally fall between .1 ppm and .2 ppm in the cities and elsewhere.

The limited data obtained with *An. sinensis* suggest tolerance to fenitrothion. However, the highest LC_{95} value (.75 ppm) to fenitrothion was obtained late in the season at Chido on the island of Wi Do, where organophosphorus pesticides are not extensively used.

OTHER ORGANOPHOSPHORUS MATERIALS. Table 2 shows the results obtained with 11 compounds. With fenthion, the high LC_{95} value of .13 ppm was obtained in only one test with colonized *Cu. pipiens pallens*. This high figure was not obtained in subsequent tests, using field specimens. THOMAS (1970) however reported *Cu. pipiens fatigans* to be resistant to fenthion at two localities in Kuala Lumpur, in which case the LC_{95} values were between .15 and .2 ppm.

TABLE 3. — Showing susceptibility levels of fourth instar larvae to DDT, Dieldrin and Lindane

Locality	Date	LC_{50} ppm	LC_{95} ppm
DDT			
Cu. tritaeniorhynchus			
Sasang	8.71	.13	1.0
Sintaein	8.69	1.2	>2.5
Sintaein	9.71	.18	.73
Sintaein	8.72	.45	3.4
Banpo Dong	9.71	.16	.80
Paju	9.69	.11	.97
Chido	10.70	.042	.19
Cu. pipiens pallens			
Rockbon Dong	2.70	.26	.95
Soo Saik	3.70	.067	.52
Sintaein	8.69	.090	.58
Sintaein	9.71	.064	.20
Kim Je	4.70	.095	.24
Chido	12.70	.093	.20
Ae. togoi			
Byon San	8.69	.012	.071
Byon San	5.70	.020	.031
Dieldrin			
Cu. tritaeniorhynchus			
Sasang	8.71	.25	.54
Sintaein	8.69	.22	.60
Sintaein	9.71	.13	.44
Banpo Dong	9.71	.21	.58
Paju	9.69	.14	.23
Cu. pipiens pallens			
Rockbon Dong	2.70	.0030	.032
Sintaein	8.69	.0057	.031
Kim Jo	4.70	.0040	.017
Ae. vexans			
Paju	6.70	.0012	.0034
Ae. togoi			
Byon San	5.70	.00097	.0045
Cu. vagans			
Paju	7.70	.0014	.0027
Cu. orientalis			
Sintaein	6.70	.0062	.011
Lindane			
Cu. tritaeniorhynchus			
Sasang	8.71	.099	.37
Sintaein	9.71	.19	1.3
Sintaein	8.72	.70	3.3
Banpo Dong	9.71	.17	.75
Paju	9.69	.11	.22
Chido	10.70	.061	.14
Cu. pipiens pallens			
Rockbon Dong	2.70	.039	.11
Sintaein	8.69	.14	.49
Sintaein	9.71	.046	.45
Kim Jo	4.70	.080	.18
An. sinensis			
Sintaein	6.70	.13	.42
Chido	10.70	.17	.99
Ae. vexans			
Paju	6.70	.0088	.031
Ae. togoi			
Byon San	8.69	.015	.059
Byon San	5.70	.0069	.023
Cu. vagans			
Paju	6.70	.0093	.021
Sintaein	6.70	.018	.048
Banpo Dong	6.71	.0064	.017
Cu. orientalis			
Paju	7.70	.0021	.0067

With trichlorfon, the LC_{95} values for *Cu. tritaeniorhynchus* and *Cu. pipiens pallens* range from .19 ppm to .82 ppm. There seems to be a natural refractoriness of *Cu. pipiens* to this insecticide. For example, GAHAN and NOE (1956) reported a LC_{50} of .32 ppm for *Cu. pipiens fatigans* in the United States, whereas in the WHO stage I insecticide tests at the Riverside Laboratory, the LC_{50} for the same species exceeded 1 ppm trichlorfon.

EPN, phenthoate and methyl parathion were found to be very toxic to larvae, but less so than chlorpyrifos. These results are consistent with previously reported (WHO/VBC/71.270) field observations which showed that the application rates used for rice pest control are presently about five to 10 times higher than required for mosquito larval control.

CHLORINATED HYDROCARBONS. The results in Table 3 suggest DDT and lindane resistance in *Cu. tritaeniorhynchus* at Sintaein. *Cu. pipiens pallens* appears, except at Rockbon Dong, to show only its natural tolerance to these insecticides. The few tests made with dieldrin suggest tolerance in *Cu. tritaeniorhynchus* but susceptibility in *Cu. pipiens pallens*. With *An. sinensis*, tolerance to lindane is indicated. Moderate to highly developed organochlorine-resistance is not apparent among the different species tested.

AVERAGE LC_{50} AND LC_{95} VALUES. These are shown for six of the organophosphorus insecticides and the three chlorinated hydrocarbons tested against *Cu. tritaeniorhynchus* (Table 4). Although these data are derived from tests in different localities and years, they should be useful for comparing future test results. Shown also are the highest values recorded in individual tests.

With the organophosphorus materials, the average values indicate that fenitrothion, malathion and naled have somewhat similar larvicidal activity. Dursban and EPN are the most toxic, followed by fenthion.

Adults.

MULTIPLE-CONCENTRATION EXPOSURE. The results for the 60-minute exposure are shown in Table 5. With fenitrothion, additional LC_{95} values might have been obtained if the impregnated papers included 3.2 % as in the fenthion series. Although *Cu. tritaeniorhynchus* and

TABLE 4. — Showing summary results of nine larvciides tested against *Cu. tritaeniorhynchus* and *Cu. pipiens pallens*

Insecticide	Cu. tritaeniorhynchus			Cu. pipiens pallens		
	No. tests	Average LC_{50} ppm	Average LC_{95} ppm	No. tests	Average LC_{50} ppm	Average LC_{95} ppm
Fenitrothion	11	.0064 (.0021-.012)	.018 (.0056-.038)	8	.0078 (.0026-.015)	.020 (.0061-.039)
Malathion	9	.015 (.0024-.027)	.047 (.023-.068)	8	.062 (.041-.091)	.13 (.088-.20)
Fenthion	6	.0039 (.0017-.0066)	.012 (.0033-.022)	6	.015 (.0020-.074)	.033 (.0045-.13)
Naled	7	.012 (.0032-.027)	.044 (.0056-.095)	4	.024 (.022-.032)	.042 (.027-.048)
Chlorpyrifos	6	.00055 (.00022-.0014)	.0017 (.00072-.0042)	5	.00046 (.00031-.00061)	.00099 (.00068-.0013)
EPN	3	.00080 (.00055-.0011)	.0025 (.0011-.0034)	3	.0015 (.0012-.0020)	.0035 (.0026-.0043)
DDT	7	.33 (.042-1.2)	1.4 (.19-3.4)	6	.11 (.054-.26)	.45 (.20-.95)
Dieldrin	5	.19 (.13-.25)	.48 (.23-.60)	3	.0052 (.0040-.0060)	.027 (.017-.032)
Lindane	6	.22 (.061-.70)	1.0 (.14-3.3)	4	.076 (.039-.14)	.31 (.11-.49)

Range in parenthesis.

Cu. pipiens pallens larvae show a similar response to fenitrothion, the latter species is about three times more susceptible in the adult stage. With *An. sinensis*, the low mortality to adults is consistent with the fenitrothion tolerance indicated in larvae. In addition, unpublished JEVRU data show that adult densities of *An. sinensis* are at present much higher than those of *Cu. tritaeniorhynchus* in the Cholla rice belt area.

With malathion, the October 1970 data deserve comment. The LC_{95} values for *Cu. tritaeniorhynchus*, *Cu. pipiens pallens*, and *Cu. orientalis* are 7.6, 6.6 % and 8.7 % respectively. Here, the adults were reared from

TABLE 5. — Showing susceptibility levels of female adults exposed for one hour to several concentrations of insecticides (multiple-concentration exposure)

Locality	Dato	No. exposed	LC_{50} % con.	LC_{95} % con.
Fenitrothion				
	Cu. tritaeniorhynchus			
Sintaein	7.70	123	.4	1.2
Sintaein	3.72	250	1.3	>1.6
Kwang Hwal	8.70	73	.24	.91
Sasang	10.70	100	>1.6	-
Chido	10.70	117	.77	>1.6
	Cu. pipiens pallens			
Rockbon Dong	5.70	200	.20	.50
Sintaein	6.70	103	.45	.88
Sintaein	8.70	94	.17	.47
Sintaein	10.70	126	.53	.81
Paju	10.70	60	.13	.40
Nokbun Dong	3.72	270	.52	1.2
Nokbun Dong	6.72	250	.30	.85
	An. sinensis			
Sintaein	6.70	111	.60	>1.6
Sintaein	7.70	121	.24	1.4
Sintaein	8.70	66	.38	1.0
Sintaein	9.70	59	>1.6	-
Paju	6.70	160	.6	1.0
Kwang Hwal	8.70	77	>1.6	-
Chido	10.70	50	>1.6	-
	Ae. vexans			
Paju	6.70	120	.34	1.1
Sintaein	6.70	100	.40	1.5
Banpo Dong	6.72	250	.27	.58
	Ae. togoi			
Byon San	5.70	180	.065	.14
	Cu. orientalis			
Paju	7.70	150	.48	.82
Seiryu Dong	10.70	80	.28	.96
Sintaein	10.70	100	.85	>1.6
	Cu. vagans			
Paju	6.70	100	.41	.86

Locality	Date	No. exposed	LC_{50} % con.	LC_{95} % con.
Fenthion				
	Cu. tritaeniorhynchus			
Sintaein	8.70	87	.41	.96
Chido	10.70	109	1.5	2.5
	Cu. pipiens pallens			
Sintaein	8.69	200	.31	.48
Sintaein	6.70	127	.39	.72
Sintaein	10.70	100	.68	1.4
Rockbon Dong	5.70	250	.31	.59
Nokbun Dong	6.72	400	.40	.77
	An. sinensis			
Sintaein	6.70	114	1.7	3.1
Sintaein	7.70	157	.66	2.9
Paju	7.70	125	.93	1.9
Kwang Hwal	8.70	139	>3.2	-
	Ae. vexans			
Paju	6.70	150	.56	.93
Sintaein	6.70	153	.63	.92
Banpo Dong	6.72	350	.62	1.7
	Ae. togoi			
Byon San	8.69	200	.22	.37
Byon San	5.70	300	.35	.59
Dieldrin				
	Cu. tritaeniorhynchus			
Kwang Hwal	8.70	108	>4.0	-
Chido	10.70	178	>4.0	-
	Cu. pipiens pallens			
Rockbon Dong	4.70	370	.30	.88
Sintaein	6.70	218	.48	2.4
Sintaein	10.70	125	2.6	>4.0
Paju	10.70	80	.81	2.6
Nokbun Dong	6.72	350	1.6	>4.0
	An. sinensis			
Sintaein	6.70	164	2.0	>4.0
Paju	7.70	204	1.4	>4.0
Moo Reung Ri	10.70	55	>4.0	
Chido	10.70	55	>4.0	
	Ae. vexans			
Paju	6.70	150	.76	1.4
Sintaein	8.70	120	.17	.62
Banpo Dong	6.72	350	.82	1.55
	Ae. togoi			
Byon San	8.69	200	.87	1.5
Byon San	5.70	350	.098	.23
	Cu. orientalis			
Paju	6.70	125	.46	1.1

TABLE 5. — *(Continued)*

Locality	Date	No. exposed	LC_{50} % con.	LC_{95} % con.
Malathion				
	Cu. tritaeniorhynchus			
Sintaein	7.70	84	.82	1.1
Chido	10.70	164	4.1	7.6
	Cu. pipiens pallens			
Sintaein	8.69	200	.95	1.5
Sintaein	6.70	120	1.2	1.9
Sintaein	10.70	175	3.5	6.6
Rockbon Dong	5.70	240	1.0	2.0
Nokbun Dong	6.72	350	1.6	2.2
	An. sinensis			
Sintaein	6.70	158	1.7	2.4
Paju	6.70	180	1.4	2.9
	Ae. vexans			
Paju	6.70	200	1.8	2.3
Sintaein	6.70	119	1.0	2.5
Sanpo Dong	6.72	325	.46	.96
	Ae. togoi			
Byon San	5.70	400	.51	.83
	Cu. orientalis			
Seiryu Dong	10.70	120	3.6	8.7
Propoxur				
	Cu. tritaeniorhynchus			
Sintaein	7.70	91	.081	.32
Chido	10.70	80	.14	.60
	Cu. pipiens pallens			
Sintaein	7.70	170	.17	.56
Nokbun Dong	6.72	350	.035	.088
	An. sinensis			
Sintaein	7.70	112	.047	.17
	Ae. vexans			
Sintaein	7.70	119	.047	.17
Banpo Dong	6.72	250	.050	.11
	Ae. togoi			
Byon San	7.70	118	.038	.075

Locality	Date	No. exposed	LC_{50} % con.	LC_{95} % con.
DDT				
	Cu. tritaeniorhynchus			
Sintaein	7.70	105	>4.0	
Chido	10.70	100	>4.0	
Banpo Dong	9.71	105	>4.0	
	Cu. pipiens pallens			
Sintaein	8.69	100	>4.0	
Rockbon Dong	4.70	375	>4.0	
Sintaein	6.70	185	>4.0	
Nokbun Dong	6.72	350	>4.0	
	An. sinensis			
Sintaein	7.70	131	1.3	4.0
Paju	7.70	125	1.7	4.0
Banpo Dong	9.71	120	1.7	>4.0
Sintaein	8.72	100	1.3	2.6
	Ae. vexans			
Paju	6.70	120	2.4	>4.0
Sintaein	7.70	94	1.7	3.2
Banpo Dong	6.72	250	2.6	>4.0
	Ae. togoi			
Byon San	8.69	200	2.2	>4.0
Byon San	5.70	225	1.5	3.0
	Cu. orientalis			
Paju	7.70	90	.79	3.9

larvae collected in three widely separated localities. However, adult populations of these species in the spring and summer months never showed this low level of susceptibility to any organophosphorus material tested. PENNINGTON (1968) in Okinawa found malathion resistance in *Cu. pipiens fatigans* and *Cu. tritaeniorhynchus*, but it was expressed in adults as well as larvae that survived concentrations of 1 ppm. Other results herein indicate susceptibility of *An. sinensis* to malathion but not to fenthion.

With DDT, *Cu. tritaeniorhynchus* and *Cu. pipiens pallens* show negligible mortality at the highest concentration (4 %), but since the exposure time was not increased above one hour, these results are considered to be inconclusive. The same pertains to *Cu. tritaeniorhynchus* and *An. sinensis* exposed to dieldrin. Crossing experiments in the laboratory, or longer exposure periods, are needed to clarify the type of adult response to the chlorinated hydrocarbons. On the other hand, *An. sinensis* shows susceptibility to DDT and *Cu. pipiens pallens* to dieldrin.

With propoxur, all the species tested were found to be susceptible.

MULTIPLE-TIME EXPOSURE. The results of the exposures to one concentration of insecticide are shown in Table 6. Two of the concentrations of fenitrothion used in 1972 were not made avaiiable in 1971. This posed some minor difficulties in comparing the results.

With *Cu. tritaeniorhynchus*, the exposure times to fenitrothion in 1972 normally had to be increased to obtain the same mortalities achieved in 1971 on papers having a lower percentage of active ingredient. However, more tests are required to determine whether this increase in exposure time is due to resistance or tolerance.

The high LT_{95} values of 455 and 480 minutes for *Cu. tritaeniorhynchus* to 1.6 % fenitrothion occurred in two August 1972 tests. In West Africa, HAMON and SALES (1970) reported LT_{95} values of 102 minutes for *An. gambiae* and 178 minutes for *Cu. pipiens fatigans* to only .4 % fenitrothion. This somewhat " delayed " response of *Cu. tritaeniorhynchus* to fenitrothion was detected simul-

TABLE 6. — Showing susceptibility levels of female adults exposed to one concentration of insecticide (multiple-time exposure)

Concentration of insecticide used	Species exposed	Locality	Date	No. exposed	LT_{50} min.	LT_{95} min.
		Penitrothion				
1.6 %	Cu. tritaeniorhynchus	Sintaein	3.72	349	56	232
1.6 %	Cu. tritaeniorhynchus	Sintaein	8.72	302	130	455
1.6 %	Cu. tritaeniorhynchus	Sasang	8.72	450	38	460
1.6 %	Cu. pipiens pallens	Nokbun Dong	3.72	150	12	28
1.6 %	An. sinensis	Sintaein	8.72	249	52	270
1.0 %	Cu. tritaeniorhynchus	Sasang	7.71	350	18	95
1.0 %	Cu. pipiens pallens	Sasang	8.71	250	16	58
1.0 %	An. sinensis	Sasang	8.71	250	54	114
0.4 %	Cu. tritaeniorhynchus	Sintaoin	3.72	250	94	445
0,4 %	Cu. pipiens pallens	Nokbun Dong	3.72	150	65	105
0.1 %	Cu. tritaeniorhynchus	Sasang	7.71	250	325	780
0.1 %	Cu. tritaeniorhynchus	Sasang	8.72	400	1020	>1140
		Malathion				
5.0 %	Cu. tritaeniorhynchus	Sasang	7.71	426	22	55
5.0 %	Cu. tritaeniorhynchus	Sasang	8.72	300	40	70
5.0 %	Cu. tritaeniorhynchus	Sintaein	8.72	268	75	225
5.0 %	Cu. pipiens pallens	Sasang	8.71	200	9	27
5.0 %	An. sinensis	Sasang	8.71	200	17	31
5.0 %	An. sinensis	Sasang	8.72	96	16	83
5.0 %	An. sinensis	Sintaein	8.72	199	11	85
0.5 %	Cu. tritaeniorhynchus	Sasang	7.71	350	455	690
0.5 %	Cu. tritaeniorhynchus	Sasang	8.72	390	165	1320
		Fenthion				
2.5 %	Cu. tritaeniorhynchus	Sasang	7.71	350	35	112
2.5 %	Cu. tritaeniorhynchus	Sasang	8.72	200	36	122
2.5 %	Cu. tritaeniorhynchus	Sintaein	8.72	250	108	170
0.25%	Cu. tritaeniorhynchus	Sasang	7.71	200	540	930
0.25%	Cu. tritaeniorhynchus	Sasang	8.72	200	600	1440
		Propoxur				
.16%	Cu. tritaeniorhynchus	Sintaein	8.72	150	12	21
.10%	Cu. tritaeniorhynchus	Sasang	7.71	200	12	26
.10%	Cu. pipiens pallens	Sasang	8.71	200	16	27
.01%	Cu. tritaeniorhynchus	Sasang	7.71	300	38	59
.01%	Cu. tritaeniorhynchus	Sintaein	8.72	256	245	475
		Dieldrin				
4.0 %	Cu. tritaeniorhynchus	Sasang	7.71	250	174	460
		DDT				
4.0 %	Cu. tritaeniorhynchus	Sasang	7.71	350	108	900
4.0 %	An. sinensis	Sintaein	8.72	150	12	34

taneously in two widely separated and diverse localities; namely, Sasang (Pusan) at the southeastern tip of the Korea peninsula and Sintaein located 200 km to the northwest in the rice belt. However, in August 1972, wild adult females of *Cu. tritaeniorhynchus* confined in cages or loose in the natural environnemt, were susceptible to fenitrothion ULV applied at 438 ml/ha from a C-46 aircraft at Sasang (WHO/VBC/72.406).

CT PRODUCTS. Table 7 shows the results for *Cu. tritaeniorhynchus*. Using data from the multiple-concentration exposure tests, the product of percentage LC_{50} and minutes exposure indicate the following order of insecticide toxicity: propoxur, fenitrothion, fenthion, malathion, dieldrin or DDT. By multiple-time exposure, the product of LT_{50} in minutes and percentage concentration also shows that fenitrothion is more toxic than fenthion. Moreover, both methods give the same order of insecticide toxicity. The apparent superiority of fenitrothion over fenthion is interesting and not typical. With *An. sinensis*, malathion is superior to fenthion and also fenitrothion; and it may be recalled that these latter two compounds have very popular usage in Korea.

In the multiple-time exposure tests, the results for fenthion and propoxur are somewhat constant regardless of the concentration used. But considerable variation occurs with fenitrothion and to a lesser extent with malathion. The highest CT products for fenitrothion pertain to the August 1972 tests previously discussed. In one test made with DDT at Sasang, *Cu. tritaeniorhynchus* is six times more susceptible than a DDT-tolerant strain of *Cu. pipiens fatigans* from Rangoon (ARIARATNAM and BROWN, 1969), although the larvae of both species have an identical response to DDT (LC_{50}, .13 ppm). How-

TABLE 7. — Showing concentration-time products (CT) derived from adult tests with *Cu. tritaeniorhynchus*

Insecticide	No. tests	Min. exposure	Average LC_{50}: % (range)	Average CT: % x min. (range)
		Multiple-concentration exposure		
Fenitrothion	4	60	.68(.24 - 1.3)	40 (14 - 48)
Malathion	2	60	2.5 (.82 - 4.1)	150 (49 - 246)
Fenthion	2	60	.95(.41 - 1.5)	57 (25 - 90)
Propoxur	2	60	.11(.081 - .14)	7 (5 - 8)
Dieldrin	2	60	>4.0	>240
DDT	3	60	>4.0	>240

Multiple-time exposure

% Insecticide	No. tests	Average LT_{50}: min. (range)	Average CT: % x min. (range)
1.6 % fenitrothion	3	74 (38 - 130)	118 (61 - 208)
1.0 % fenitrothion	1	18	18
0.4 % fenitrothion	1	94	38
0.1 % fenitrothion	2	672 (325 - 1020)	67 (33 - 102)
5.0 % malathion	3	46 (22 - 75)	230 (110 - 375)
0.5 % malathion	2	310 (165 - 455)	155 (83 - 228)
2.5 % fenthion	3	60 (35 - 103)	150 (88 - 270)
0.25% fenthion	2	570 (540 - 600)	142 (135 - 150)
0.16% propoxur	1	12	1.9
0.10% propoxur	1	12	1.2
0.01% propoxur	2	142 (38 - 245)	1.4 (.4 - 2.5)
4 % DDT	1	174	696
4 % dieldrin	1	108	432

ever, data are lacking from the Sintaein area, where *Cu. tritaeniorhynchus* larvae have survived DDT concentrations of 2.5 ppm.

By multiple-concentration exposure, the CT products for fenitrothion, fenthion and malathion are lower than those derived from the multiple-time exposure tests. Conversely, the values for propoxur are higher, whereas no meaningful comparisons are possible with the limited DDT and dieldrin data. By multiple-time exposure, dieldrin has been shown to be more toxic than DDT, whereas no distinction was possible by multiple concentration exposures of only 60 minutes.

DISCUSSION

We believe that organophosphorus-resistance is not clearly indicated in any *Culex* or *Aedes* species. *An. sinensis* may be naturally tolerant to fenitrothion, and *Cu. tritaeniorhynchus* seems comparatively resistant to DDT and lindane at only one locality.

These test procedures are not always expected to be sensitive enough to clearly distinguish tolerance from low levels of resistance. The few inconclusive test situations may be followed up with more detailed experimentation.

With larvae, only *Cu. tritaeniorhynchus* at Sintaein has LC_{50} values to DDT and lindane above .3 ppm. The other larval species have even lower LC_{50} values to all three chlorinated hydrocarbons. Undoubtedly, a greater reliance is now being placed on the organophosphorus materials in Korea. The susceptibility of *An. sinensis* adults to DDT is noteworthy because *vivax* malaria still occurs in certain areas. With the carbamate propoxur, all the species tested show considerable adult susceptibility.

The product of concentration and time (CT), derived from two adult test procedures, gives the same order of insecticide toxicity for *Cu. tritaeniorhynchus*. Propoxur, a fast acting compound with a low LT_{50} value, was found to be superior to fenitrothion as a residual adulticide (WHO/VBC/72.397), whereas fenitrothion was superior to malathion as a ULV aerial spray (WHO/VBC/72.406). These field studies are consistent with the CT data. For non-residual exterior space sprays, differences in the CT products could provide clues as to the dosage required for control once the effective field dosage of one compound has been established.

These susceptibility test procedures are expected to continue. Apart from the results obtained, any usually high *Cu. tritaeniorhynchus* density in a rice growing locality might be an unwelcome but useful sign for resistance. On the other hand, the high organophosphorus dosages at present being applied clearly exceed the larval LC_{100} values. These dosages could even be lethal to some individuals that eventually show resistance to one or more of the organophosphorus compounds.

Some opportunity for the selection of resistance might occur in previously treated water containing concentrations below 1 ppm, in which only a part of the population is killed. But the organophosphorus materials now being applied to the rice fields are not persistent. If larvae survive a fresh pesticide application, such as one from fenthion, that could suggest highly developed organophosphorus resistance warranting prompt clarification and testing.

It should be noted that the larval populations in Korea are often exposed to a variety of organophosphorus materials even during one rice growing season. Because these seasons are short, the present pesticide application shedules are probably frequent enough in many rural areas to account for the low adult densities of *Cu. tritaeniorhynchus*. Detailed studies might show that this species takes a longer time to complete its immature development than *An. sinensis*.

To sum up, the response of *Cu. tritaeniorhynchus* larvae to DDT in two tests, and to lindane in one test, appear to be the only probable cases of resistance revealed in this study.

ACKNOWLEDGEMENTS.

We thank Dr T. TADANO for the tests carried out during August 1969 and also Dr. R. J. TONN former project leader of JEVRU.

Mr. K. W. LEE, Mr. H. K. SHIN, Mr. H. I. REE and other JEVRU personnel kindly assisted in the collection of field specimens. During their visits to JEVRU, Dr. J. MOUCHET, Dr. Y. H. BANG and Dr. C. Y. CHOW offered valuable suggestions.

Manuscrit reçu au S.C.D.
le 4 décembre 1973.

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