In preliminary studies, human body lice maintained in the laboratory for many generations on lindane, Lauseto neu, and the pyrethrins developed much less resistance to these insecticides than has been developed to DDT. The lice developed no resistance to a pyrethrum-sulfoxide compound after 30 generations.

Resistance of Human Body Lice to Insecticides

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THAT INSECTS can develop resistance to insecticides has been known for approximately 50 years. However, the subject has been studied extensively in this country only during the last 6 years, following the development of resistance to DDT by houseflies. The literature on the development of insect resistance to insecticides has been reviewed by Babers (*1*) and Babers and Pratt (*2*). Several important references are given in the Yearbook of Agriculture for 1952.

The laboratory of the Entomology Research Branch of the United States Department of Agriculture conducted research at Orlando, Fla., from June 1951 to August 1954 on the resistance of the human body louse, *Pediculus humanus humanus* L., to DDT, lindane, Lauseto neu (chloromethyl *p*-chlorophenyl sulfone), pyrethrins, and pyrethrins plus sulfoxide (*n*-octyl sulfoxide of isosafrole).

Lindane, Lauseto neu, and pyrethrins were selected for study because of their general effectiveness against both normal and DDT-resistant lice. Lindane is of special interest because it has been adopted by the Armed Forces for the control of body lice in areas where resistance to DDT has developed.

The experimental development of resistance has usually been accomplished under laboratory conditions by selection. A concentration of toxicant that will cause moderate to high mortality is used, and the survivors serve as parents of the next generation. In some of the Orlando studies reported here the lice were exposed to very light deposits of insecticides which caused no apparent mortality or injury. The dosages varied with the insecticides, but most of them were approximately one-tenth those usually required to give a low mortality or moribundity.

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Previous Reports on DDT Resistance

A number of workers in the field and in the laboratory have reported on the development of DDT-resistant lice. Bushland and associates in 1945 (*3*) and Eddy and Bushland in 1948 (*4*) demonstrated that cloth impregnated

with a 0.05-percent DDT solution or treated with a powder containing 0.1 percent of DDT caused complete or nearly complete mortality of body lice in 24 hours. In 1950, King (*5*) reported that lice surviving single exposures to DDT at a concentration causing high mortality showed no resistance after several generations.

However, Hurlbut and associates in 1952 (*6*) failed to control lice on Korean military personnel with a powder containing 10 percent DDT and indicated that the failures were due to resistance. In the same year Barnett and Knoblock (*7*) showed that body lice in Japan were also resistant to DDT. Data on the susceptibility of the lice in Korea and Japan prior to the general use of DDT in those areas apparently were never obtained.

In 1953, Busvine (*8*) reported that a strain of lice from Egypt were resistant to DDT but susceptible to other insecticides. Hurlbut and associates (*9*) reported in 1954 that, after being in general use in Egypt since 1947, 10-percent DDT powder did not control lice any longer, and laboratory tests confirmed some degree of resistance to DDT.

Yasutomi (*10*) presented laboratory data in 1952 showing that body lice in Japan could develop considerable resistance to DDT in three generations and to BHC in two generations. The lice used by Yasutomi were obtained from vagrants in Ueno in Tokyo, Japan, and he assumed that they had had no previous exposure to either DDT or BHC. However, both chemicals had been available and rather widely used in Japan for several years.

The resistance of body lice in Korea to DDT and several other compounds was studied by Eddy in 1952 (*11*). He showed the lice in Korea to be at least 100 times more resistant to DDT than a laboratory strain of body lice maintained at Orlando, Fla. However, the resistance of the lice to certain other insecticides tested at the same time was not marked.

The resistant Korean lice were collected from prisoners of war who had been dusted with DDT from time to time during 6 to 9 months. In the tests made in Korea 10-percent DDT powder caused 60 percent mortality during a 24-hour exposure, which indicated that many insects in the population were susceptible.

Methods of Current Studies

For the current Orlando studies, two lots of lice highly resistant to DDT were obtained from Korea. The standard, or regular, colony was descended from lice collected in the United States before the advent of DDT.

The methods used for rearing the lice were essentially the same as those described by Culpepper (*12, 13*). The procedures described by Bushland and associates (*14*) and Eddy (*11*) were used to test the insecticides as cloth impregnants and as powders.

After rearing the resistant Korean lice for three generations without exposure to insecticides, a portion of one lot was maintained on cloth that had been impregnated with DDT by dipping it into a 0.01-percent solution in acetone. The remainders of the two lots were then combined and maintained on untreated cloth.

At first all Korean lice were fed twice daily on human subjects, but later they were fed on rabbits once each day. The standard colony had been fed on rabbits for a number of years.

Resistance to DDT

In the tests with the Korean lice maintained on cloth impregnated with 0.01 percent DDT, application of 10 percent DDT caused high but incomplete mortality during the first few generations. However, the resistance gradually increased, and by the 15th generation few or none of the lice were killed in 24 hours.

In another experiment 100 young adult body lice (50 of each sex) from the regular colony, which had had no previous contact with DDT, were placed on cloth impregnated with DDT by dipping it into a 0.001-percent solution. The lice were transferred to freshly impregnated cloth three times weekly. The resistance developed is shown in the table. Most of the data represent averages of 2 tests with 20 lice (10 of each sex) per test and an exposure period of 24 hours. The lice maintained on DDT showed slight resistance by the 5th generation and by the 8th generation were approximately five times as resistant as those of the regular colony. By the 16th generation resistance was very high, but could not be measured accurately as the highest test concentration of DDT (10 percent)

failed to kill all the lice. There was a slight additional increase in resistance by the 25th generation, after which this colony was discontinued.

How much selection, or mortality of susceptible individuals, occurred during the first few generations and whether selection was primarily responsible for the degree of resistance developed were not determined. In subsequent tests to check on these points it was found that adult lice maintained on cloth treated with 0.001 percent DDT did not live quite as long as the controls or lay quite as many eggs. However, the difference did not appear to be sufficient to justify the conclusion that resistance was developed through selection alone.

Other tests indicated that nonresistant lice could be maintained on cloth treated with 0.0001 percent DDT with no more mortality than those maintained on untreated cloth. Accordingly, 2 colonies each with 200 newly hatched nymphs were established on this concentration of DDT and two on untreated cloth. Mortality through seven generations was less for lice exposed to DDT than for the controls. This study is being continued.

Loss of DDT Resistance

A portion of the resistant colony obtained from Korea was reared on untreated cloth to determine the number of generations required for the lice to lose their resistance. Loss of resistance was evident by the third generation and complete by the eighth.

After 17 generations had been maintained on cloth treated with 0.01 percent DDT, another portion of the resistant Korean colony was removed from DDT and reared on untreated cloth. The colony showed practically no loss of resistance after six generations but a considerable loss by the ninth generation. After 9 generations concentrations of 0.1, 1, and 10 percent of DDT caused 45, 75, and 75 percent knockdown and kill, respectively. Little or no further loss was indicated in tests of the 25th generation. Eventually the lice will probably lose their resistance, but apparently many generations will be required.

Lindane and Lauseto neu

Development of resistance to lindane and Lauseto neu was attempted by the method described above for DDT, that is, by continuously exposing the lice to sublethal concentrations of the insecticides. The concentrations used were 0.00005 percent for lindane and 0.0025 percent for Lauseto neu. The body lice used in these studies were from the Korean colony that had lost its resistance to DDT. In view of this, resistance to both insecticides, especially lindane, was expected to develop.

Lice of the fifth generation exposed to lindane and Lauseto neu showed no more than twice as much resistance as the regular colony. The

Relative susceptibility to DDT of normal body lice and lice maintained on cloth impregnated with 0.001-percent DDT solution for various numbers of generations

Percent concentration	Percent knockdown and mortality after indicated number of generations									
	5		8		12		16		25	
	DDT	Normal	DDT	Normal	DDT	Normal	DDT	Normal	DDT	Normal
10.0	------	--------	------	--------	90	--------	95	--------	90	--------
5.0	------	--------	------	--------	100	--------	88	--------	85	--------
1.0	------	--------	------	--------	100	--------	90	--------	70	--------
0.1	100	100	------	--------	90	--------	75	--------	55	--------
0.05	------	--------	100	--------	95	--------	65	100	75	--------
0.025	98	98	80	100	65	100	48	98	45	100
0.01	78	98	60	100	70	95	18	95	15	95
0.005	73	98	50	85	35	55	13	83	5	80
0.0025	45	93	40	45	0	45	0	65	0	10
0.001	10	43	10	5	0	5	3	5	0	0
Control (untreated)	------	13	------	0	------	0	------	0	------	0

lice have now been reared through 34 generations without any further increase in resistance to either material. The amount of resistance developed thus far is so slight that it seems well within the variation expected with any insecticide.

Pyrethrins and Pyrethrins Plus Sulfoxide

The lice used in studies with pyrethrins were taken from the regular colony, which had had no previous contact with DDT or other insecticides. As in the tests with the other materials, the lice were maintained on cloth treated with sublethal concentrations—0.001 percent of pyrethrins alone and 0.0001 percent of pyrethrins plus 0.001 percent of sulfoxide. No more than twofold resistance to pyrethrins was indicated in tests against different generations of lice up to and including the 17th, at which time the colony was discontinued. The pyrethrum-sulfoxide colony appeared to be no more resistant than the regular colony after 30 generations. Studies with this colony are being continued.

Summary

Studies were conducted on the development and loss of resistance of the body louse (*Pediculus humanus humanus* L.) to DDT, lindane, Lauseto neu (chloromethyl *p*-chlorophenyl sulfone), pyrethrins, and pyrethrins plus sulfoxide. The more important findings are:

1. Highly but not completely DDT-resistant body lice from Korea lost their resistance in 3 to 8 generations when maintained in a DDT-free environment.

2. DDT-resistant lice from Korea developed extreme resistance in 15 generations when maintained on cloth impregnated with a 0.01-percent DDT solution.

3. Extremely resistant lice lost approximately 75 percent of their resistance in 15 generations after being removed from contact with DDT.

4. Body lice from the regular colony, which had never been exposed to DDT, developed a high resistance in 25 generations when maintained on cloth impregnated with 0.001 percent of DDT. There was a very low mortality in the initial exposures, but resistance developed.

5. Body lice maintained for 34 generations on cloth impregnated with low concentrations of lindane and Lauseto neu and 17 generations on pyrethrins failed to develop more than twofold resistance to these insecticides. Lice maintained on pyrethrins plus sulfoxide failed to develop any resistance in 30 generations.

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