

CERTAIN BIOLOGICAL COMPARISONS OF RESISTANT AND
"NON-RESISTANT STRAINS OF THE GERMAN COCKROACH,
BLATTELLA GERMANICA (LINNAEUS)

by

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INTRODUCTION

The first report of resistance to a chemical poison in an insect species was that of the San José scale to lime sulfur in the State of Washington in 1908 (Melander, 1914). Prior to 1945, only 12 species of insects had shown resistance. Most of these were in the United States. By 1959, however, 122 cases had been reported from different areas of the world, and this number was about equally divided between insects of medical and those of agricultural importance. Each year more insects are added to the list of those which have developed resistance. Resistance to the chlorinated hydrocarbons occurred as early as 1947, and resistance to organic phosphate insecticides has greatly increased in the past four or five years. Natural populations of the German cockroach have exhibited resistance to chlorinated hydrocarbons for the past eight or nine years.

Many investigators have found differences in resistant strains of insects which they have attempted to associate with the development of resistance. Workers have reported variable results in comparing the incubation period, developmental period, adult longevity, fecundity, morphology, and other characteristics of resistant and non-resistant strains of insects. Differences between strains according to these criteria have been reported, although it is not clear whether many of these trait differences are causes or effects of the resistance factor or factors.

This study was undertaken to investigate certain differences between resistant and non-resistant strains of the German cockroach,

Blattella germanica (L.). Specifically, it was designed to compare the lengths of incubation and nymphal development, and the adult longevity of the strains; incidental information on the sex ratio and the number of non-hatching egg cases produced by the females of the different strains was also obtained.

REVIEW OF LITERATURE

Incubation Period: The incubation period of normal German cockroaches has been studied by several workers. Rau (1944) reported, after observing 12 females, that the egg cases were carried from 6 to 16 days with an average of 10 days. Of 13 egg cases produced by offspring of these, reckoning from the time the egg cases first protruded, 8 had an incubation period of 11 to 13 days, and 5 had a 12-day incubation period. Roth and Willis (1952) found that the female carried the oötheca about 13 days and that the eggs hatched about 16 days after copulation, the egg cases having developed 2 to 3 days after copulation. They found that a virgin female 8 days after its last molt usually developed an egg case which collapsed and was unproductive. Willis et al. (1958) reported that the females carried the oöthecae an average of 16.9 ± 1.5 days, and the average incubation period was 17.2 ± 0.1 days.

Pimentel et al. (1951) examined DDT-resistant house flies as to certain bionomic factors and found no statistical difference in comparing their time of incubation with that of a normal strain.

Lehr and Smith (1957) found no difference in the incubation period when they compared malathion-resistant and non-resistant strains of the two-spotted spider mite complex.

Developmental Period: The nymphal developmental period of the German cockroach is lengthened by isolation of individuals (Pettit, 1940); this is due to the absence of jostling and mutual stimulation. The males in this study appeared to mature earlier than the females.

Rau (1944) found the roaches from 3 hatching egg cases to become adults in 53, 54, and 56 days, respectively. Noland et al. (1949) found that those roaches fed a diet of pulverized dog biscuits and kept at a temperature of about 30 degrees C. matured in an average of 40 days. The two sexes seemed to mature at the same rate. Willis et al. (1958) found the average nymphal developmental period of nymphs reared in groups to be 41.3 ± 0.5 days for the females and 40.1 ± 0.6 days for the males. These roaches were reared at 30 degrees C. with uncontrolled humidity.

Variable observations have been made by workers comparing the larval developmental periods of resistant and non-resistant house flies. Bruce (1949) stated that the life cycle of DDT-resistant house flies seemed to be one or two days longer than that of the normal strain. Pimentel et al. (1951) found a significantly longer larval period in the DDT-resistant strain when it was compared with a normal strain. March and Lewallen (1950) used 23 generations in comparing DDT-resistant and non-resistant house flies as to the differences in the length of the life cycle. No significant differences could be found, although a greater than 300-fold resistance was present. Babers et al. (1953) found no significant differences in comparing six susceptible and two resistant strains of house flies as to the length of the larval period.

Lehr and Smith (1957) found no significant difference in the developmental period after comparing malathion-resistant and non-resistant strains of the two-spotted spider mite.

Adult Longevity: According to Willis and Roth (1958), the range of

adult lifespan of normal German cockroaches was from 97 to 180 days in the females, with most of them living 150 to 170 days. The males lived 128 ± 8.0 days. Roth and Willis (1956) found that virgin females lived for an average of 156 ± 5.9 days.

Pimentel et al. (1951) found no statistical difference in longevity between DDT-resistant and normal strains of house flies. Afifi and Knutson (1956) likewise found no statistical differences between strains when comparing the longevity of the F_2 and F_3 progeny from a dieldrin-treated strain with the F_2 and F_3 from an untreated strain. Also, they found no significant differences between strains when longevity and average weight were correlated. Ouye and Knutson (1957) found that malathion-treated larvae developed into adults which lived only 82 percent as long as the untreated. Hunter et al. (1958) found DDT-resistant female house flies to have a 15 percent shorter than normal lifespan after treatment with DDT, but they found no significant difference in lifespan upon comparing diazinon-treated, DDT-resistant house flies with a normal strain. After the workers treated susceptible flies with the two insecticides, no significant difference was found. Hunter et al. (1959) examined the DDT-45 strain (resistant to DDT, Dilan, dieldrin, and DDVP), and the Roberds strain (resistant to DDT and dieldrin) after treating the females with DDT or diazinon. A shorter adult lifespan occurred in the DDT- and the diazinon-treated females. Varzandeh et al. (1954) examined seven strains of house flies, three susceptible and four resistant, for several vigor traits, including longevity. The strains had variable backgrounds. The workers concluded that the

inheritance of the resistance factor is independent of the factors associated with vigor.

Knutson (1955), after collecting and rearing a wild strain of Drosophila, treated the insects with a sublethal dosage of dieldrin. Slightly greater longevity occurred in the dieldrin-treated flies.

Fecundity: Girault (1911) counted the combined eggs from 20 egg cases of normal German cockroaches. The maximum number produced was 48 per egg case, the minimum 34, with the average being 40.5 per egg case. Roth and Willis (1952) found that, of 28 copulations by normal German cockroaches, egg cases were formed in 26 (93 percent) of the instances, and 22 (85 percent) of these egg cases were fertile.

Pimentel et al. (1951) compared the number of eggs laid, the number hatched, and the time of hatching of the eggs from a DDT-resistant strain of house flies with those from a non-resistant strain and found no statistical differences. Babers et al. (1953) compared the viability of eggs produced by six susceptible and two resistant strains of house flies and found no significant difference. Varzandeh et al. (1954) found no significant difference in egg production or egg hatchability upon examining three susceptible and four resistant strains of house flies. Afifi and Knutson (1956) subjected parent generations of the house fly to topical application of dieldrin to produce 60 to 90 percent mortality and found that the F_1 generation produced 70 percent more eggs. The F_2 and F_3 progeny did not produce a significantly different number of eggs than did the untreated controls. Adult house

flies from malathion-treated larvae produced only 93 percent as many eggs as the untreated (Ouye and Knutson, 1957). Treated adults produced 12 percent more eggs than the untreated; however, the eggs showed two percent less hatchability. Hunter et al. (1959) found that fewer eggs were laid by two resistant strains after treatment with DDT or diazinon.

Knutson (1955) treated a wild strain of Drosophila with a sub-lethal dosage of dieldrin and found that the survivors produced 7.6 percent more eggs than the untreated controls.

Lehr and Smith (1957) found that a malathion-resistant strain of the two-spotted spider mite laid more eggs than a non-resistant strain.

In a study of BHC- and DDT-resistant strains of the German cockroach, Grayson (1953) found a significant decrease ($P > .01$) in the number of nymphs produced by the DDT-resistant strain. Grayson (1954) also found that fewer nymphs were produced by chlordane-resistant females than normal females ($P > .05$).

Ouye and Knutson (1957) treated adult house flies with malathion and found the number of larvae produced by them to exceed those of the untreated by two percent at pupation.

Knutson (1955) found that a dieldrin-treated strain of Drosophila produced 5.6 percent more larvae and 5.7 percent more pupae than the untreated controls.

Populations: Pimentel et al. (1951) found no significant differences in the sizes of DDT-resistant and non-resistant house fly popula-

tions at the peak of emergence; no differences were found in the percent successful in emerging. Babers et al. (1953) could find no significant differences correlated with resistance in comparing six susceptible and two resistant house fly strains as to the number of adults resulting from 500 eggs. Malathion-treated adult house flies theoretically produced 12 percent more progeny than the untreated (Ouye and Knutson, 1957). The emergence of progeny from the pupae of treated parents was one percent less than that from the untreated parents. DDT-resistant house flies produced 34 percent fewer progeny after a sublethal dosage of DDT (Hunter et al., 1958); after diazinon application, 21 percent fewer were produced. DDT-treated susceptible house flies showed an increase in fertility and fecundity; diazinon-treated susceptible flies showed increased fecundity but decreased fertility. DDT and diazinon treatment of susceptible flies resulted in 18 percent and 1 percent increases, respectively, in potential progeny (Hunter et al. 1958). A significantly higher fertility was found in the diazinon-treated, DDT-45 strain which was resistant to DDT, Dilan, dieldrin, and DDVP (Hunter et al., 1959). Significantly fewer female progeny were produced in the DDT-treated females of the Roberds strain, which was resistant to DDT and dieldrin.

A wild strain of Drosophila produced 5.8 percent more adults after a sublethal dosage of dieldrin (Knutson, 1955). The slightly greater longevity which occurred allowed an extended egg-laying period, and thus more progeny.

Lehr and Smith (1957) discovered no significant difference in the number of progeny produced by malathion-resistant and non-resistant

strains of the two-spotted spider mite complex.

Morphological Differences: Hough in 1928 tested two strains of the codling moth and found that the Colorado strain was more successful in entering sprayed fruit; this was later attributed to a resistance factor in the Colorado strain. Hough (1929) found no morphological differences, however, in examining the two strains.

Grayson (1953), in a study of BHC- and DDT-resistant strains of the German cockroach, determined that the size of the egg cases in the latter showed a highly significant decrease in size in both length and width over the normal strain. The BHC-resistant strain had significantly smaller oöthecae, but the difference was less than in the case of the DDT-resistant strain. Grayson (1954) found the egg cases of a chlordane-resistant strain of the German cockroach to be significantly smaller than the normal ($P > .05$). Mahan and Grayson (1956) compared certain morphological characteristics of DDT-, chlordane-, and lindane-resistant strains of the German cockroach with a normal strain. The total length, the width of the head, the width of the pronotum, and the length of the pronotum were compared. In general, the males and females from the resistant strains were smaller. Significant differences were found in all instances except the total length of the males and females of the lindane strain and the pronotum length of the females in the chlordane strain.

March and Lewallen (1950) compared tarsal segments in DDT-resistant and non-resistant strains of the house fly. They could find no

difference correlated with resistance. Bigelow and LeRoux (1954) found distinct morphological differences between DDT- and non-resistant house flies. They examined four characters: the maximum width of the second abdominal sternite, the maximum length of the second abdominal sternite, the width of the frons between the ptilinal sutures at the level of the boundary between the second and third antennal segments, and the length of the terminal segment of the right antenna measured along the anterior surface. Lichtwardt et al. (1955) found a DDT-resistant strain that developed an incomplete or "broken" subcostal wing vein, but this was not linked to the resistance factor (Lichtwardt 1956). Sokal and Hunter (1955) examined about 1000 flies from 9 strains of house flies and measured 16 morphological characters. Four ratios were computed from these. These workers could determine no correlation of morphological characters and resistance. Morrison (1957) examined 25 specimens of each sex from 19 different strains of house fly to determine if there was any correlation between the ratio of width to length of the second abdominal sternite and resistance. He found much variation, but generally, large ratios were associated with the DDT-resistant strains and small ratios with the normal strain.

Lehr and Smith (1957) could find no difference in morphology when comparing malathion-resistant and non-resistant strains of the two-spotted spider mite complex.

Weight Differences: Variable results have been obtained by workers studying the weights of resistant and normal insects. In examining the

codling moth, the recently hatched Colorado strain (resistant) larvae exceeded the Virginia strain (non-resistant) larvae in weight at average humidity and atmospheric pressure (Hough, 1934); however, in a saturated climate they weighed the same. The Virginia strain showed a greater weight loss under starvation conditions (Hough 1934). The eggs of the more resistant moths were the heavier (Hough, 1943).

Adults of DDT- and chlordane-resistant strains of the German cockroach were of lower weight than those of a normal strain (Grayson, 1953; Grayson, 1954).

Pimentel et al. (1951) could find no statistical differences in comparing the pupal weights of DDT-resistant house flies to those of normal house flies. Flies surviving DDT exposure were found to be heavier by McKenzie and Hoskins (1954). Varzandeh et al. (1954) could find no significant differences in pupal or adult weights when three susceptible and four resistant strains of house flies were compared. The F₂ progeny from dieldrin-treated parents were significantly heavier than the F₂ from the untreated parents (Afifi and Knutson, 1956). No significant difference could be found in correlating weight and longevity.

Age and Resistance: Tuma (1938) tested the susceptibility of different age groups of the German cockroach with an aliphatic thiocyanate and with a formulation containing 0.03 percent pyrethrins. The roaches of 17 weeks of age were the least susceptible.

Pimentel et al. (1951) discovered that the earliest pupating larvae of a DDT-resistant strain of house fly were more susceptible than

those maturing later. Decker and Bruce (1952) found that the more susceptible flies emerge first from heterogeneous cultures; this was confirmed by Johnston et al. (1954). Decker and Bruce (1952) also found that cultures developed from the first eggs produced showed much less DDT resistance than did those which emerged one or two days later. McKenzie and Hoskins (1954) divided two strains of house flies into three groups each; these included a check group, a group selected on the basis of 50 percent pupating early and 50 percent pupating late, and a group treated with DDT in the larval medium. The workers found the later pupating flies to have the higher LD₅₀.

MATERIALS

The strains of the German cockroach used in this study were available in the entomology laboratories of the Virginia Agricultural Experiment Station of the Virginia Polytechnic Institute, Blacksburg, Virginia. These included strains resistant to DDT, chlordane, and lindane, and a non-resistant strain. The DDT- and the lindane-resistant strains arose from placing the roaches under selection pressure to these insecticides in the laboratory. The chlordane-resistant strain was obtained from Corpus Christi, Texas, in 1952, the resistance having developed as a result of sustained use of chlordane in control of German cockroaches. A high level of resistance was maintained in all strains by periodic exposure to the appropriate insecticide in the laboratory.

Containers used for the roaches during the study were wide-mouth, quart-capacity jars which were $6\frac{1}{2}$ inches high and $3\frac{3}{8}$ inches in diameter. These were greased with petroleum jelly on the inside for an inch or more around the top to prevent the roaches from climbing out. A resting surface was provided by a section of screen wire bent into the shape of the letter "T" and notched at the top for holding a one-ounce salve box of water. Gallon-capacity battery jars, eight inches high and six inches in diameter, were prepared similarly except for larger screen wire sections, about six inches high, and larger salve boxes. These were used in the incubation study to rear and separate out the young female German cockroaches producing egg cases. They were also used in the early part of the adult longevity study.

The jars were labeled with a number and the name of the strain. Food and water were supplied. The food consisted of dry pellets of dog food. Into the salve tin was placed a crumpled square of paper toweling to enable any roaches falling into the water to climb out. The jars were covered with squares of cheese cloth held in place by rubber bands. Two rubber bands per jar were used in the event one should break. Handling of jars was facilitated by placing them in wooden trays. Glass or plastic vials were used in transferring roaches, and an aspirator was used in removing excess roaches.

During the course of the study, except for periods of observation and recording, the jars of cockroaches were kept in a walk-in cabinet maintained at approximately 30 degrees C. and 65 percent relative humidity.

METHODS

Incubation of Eggs: Half-grown to last-instar nymphs of each strain of the German cockroach were caught with a vial and put into gallon containers prepared as described. Each strain was allotted two such jars, and approximately 200 nymphs were placed in each one, making a total of 400 nymphs under observation for each strain. As the nymphs matured, careful observation was begun in order to be able to remove each female as it produced an egg case. Upon forming an egg case, each female was placed in a quart jar accompanied by a male. These were provided with food and water, and daily observations of the egg cases were made in order to determine the exact date of hatching. It was planned to obtain observations from about 125 egg cases from each strain.

Development of Nymphs: Isolated females carrying egg cases were kept under observation in order to obtain known dates of emergence of nymphs. Soon after hatching, all roaches were removed from each jar except approximately 10 nymphs. The removal was done with an aspirator. Daily observations were made to determine the date of maturation of each roach. Adult roaches were removed and the sex and the number of days between hatching and maturity was recorded for each. The plan was to obtain 50 hatching egg cases from each strain, one from each of 50 separate female roaches. This should give approximately 500 nymphs per strain from which developmental data might be obtained.

Longevity of the Adults: Half-grown to last-instar nymphs were placed in gallon-capacity battery jars prepared as described. As soon as they matured, they were placed in quart containers, with up to 10 being placed in one jar. Vials were used for the transfers. The date of maturation was recorded. Both sexes were put together in the jar, and no individual of one sex was allowed to remain in a jar without an individual of the opposite sex being introduced. Equal numbers of the two sexes were placed in each jar when feasible.

Observations were made once every two days with occasional daily observations. Dead roaches were removed from the jars after the sex and date of mortality of each was recorded. It was planned to collect over 100 roaches of each sex from each strain, making a grand total of well over 300 roaches in this study.

RESULTS

Incubation Period of Eggs: The hatching egg cases observed included 122 from the normal strain, 128 from the DDT-resistant strain, 148 from the chlordane-resistant strain, and 161 from the lindane-resistant strain, making a total of 559 egg cases.

The egg cases of the normal strain all hatched within 16 to 19 days after formation, indicating a high degree of homogeneity. Conversely, the resistant strains showed more heterogeneity (fig. 1, and table 1). The time of hatching of the strains varied from 15 to 23 days in the chlordane-resistant strain to 15 to 20 days in the DDT-resistant strain. The egg cases of the lindane-resistant strain hatched in from 15 to 21 days. In all four strains the largest number of hatching egg cases occurred in the eighteenth day.

The DDT-resistant strain was found to be highly significantly different from the other resistant strains when compared using the simple "t" test (table 2).

The mortality of the females carrying the egg cases was recorded. The DDT-resistant strain showed the highest mortality, with 12.7 percent of the females dying. A relatively low mortality of encapsulated females was found in the other strains. Female mortality in the lindane strain was 3.9 percent, in the normal strain 3.0 percent, and in the chlordane strain 2.1 percent.

Data were obtained on the numbers of non-hatching egg cases. The DDT strain had the lowest reproductive potential with 23.3 percent failing to hatch. In the chlordane-resistant strain 7.6 percent failed

to hatch; in the normal strain 4.7 percent failed, and in the lindane strain 2.8 percent failed to hatch.

Development of Nymphs: The number of nymphs maturing as females included 271 from the normal strain, 228 from the chlordane-resistant strain, 233 from the DDT-resistant strain, and 293 from the lindane-resistant strain. The males included 280 normal, 213 chlordane-resistant, 246 DDT-resistant, and 286 lindane-resistant individuals.

A high degree of heterogeneity was found in the lindane- and DDT-resistant strains when they were compared with the other two. This was evident in both the females and the males (fig. 2 and fig. 3). The females of the chlordane-resistant strain were quite similar to normal females, and the difference was barely significant; no significant difference was found in comparing the developmental periods of the males of these two strains.

Of sixteen comparisons between sexes within strains and between strains, 12 showed significant differences (table 4). In general, the females matured sooner in all strains, although the time difference was small (table 3). The males and females of the chlordane-resistant strain on the average matured earlier than those of the other strains except for the normal strain males. The nymphal developmental periods ranged within 28 and 47 days.

The sex ratios of the strains approached unity in all instances. They were as follows: normal strain, 1.07 females to 1 male, chlordane-resistant strain, .94 females to 1 male, DDT-resistant strain, 1.02

females to 1 male, and lindane-resistant strain, .97 females to 1 male.

Longevity Study: The number of adult males and females, respectively, observed for longevity included 125 and 179 from the normal strain, 122 and 144 from the chlordane-resistant strain, 151 and 172 from the DDT-resistant strain, and 109 and 140 from the lindane-resistant strain. The longevity of females in all three resistant strains showed considerable heterogeneity when compared with normal strain females (fig. 4). The DDT-resistant strain, which had the highest order of resistance of the resistant strains, was the most heterogeneous. The resistant females all lived longer on the average than the normal females (table 5). The longest-lived individual was a female of the chlordane-resistant strain which lived 208 days, while two females in the DDT-resistant strain lived over 200 days. A highly significant difference was found in comparing the longevity of the females of the resistant strains with that of the normal strain (table 6). Also, a highly significant difference was found in comparing the DDT-resistant strain with the lindane-resistant strain. The females of the DDT-resistant strain had the longest average longevity (66.41 ± 3.33 days). The chlordane- and lindane-resistant females had a longer adult lifespan (58.85 ± 3.41 days and 54.82 ± 2.71 days, respectively) than normal females (43.37 ± 2.20 days). There was no significant difference when comparisons were made of the longevity of the males from the different strains (table 7). Their lifespans were quite similar (fig. 5), with most of them living around 100 days (table 5).

TABLE 1. The Incubation Periods of Eggs from Resistant and Normal Strains

Strain	No. of Egg Cases	Average ^o Incubation Period (Days)
Lindane-Resistant	161	17.96 \pm .09
Chlordane-Resistant	148	18.18 \pm .08
DDT-Resistant	128	17.57 \pm .09
Normal	122	18.00 \pm .06

^o \pm Standard error of the mean

TABLE 2. Calculated "t" Values for Comparisons of Incubation Periods of Eggs of Resistant and Normal Strains

Lindane			
1.73	Chlordane		
3.02 ^o	4.95 ^o	DDT	
.33	1.73	3.93 ^o	Normal

^o Significantly different at $P > 0.01$ ("t" values in table were 2.58 in all instances at the 99% confidence level)

TABLE 3. The Nymphal Developmental Periods of Resistant and Normal Strains

Strain	Sex	No. of Individuals	Nymphal Developmental Period(Days)		
			Max.	Min.	Ave. ^o
Lindane-Resistant	F	293	46	28	34.98 \pm .24
Chlordane-Resistant	F	228	45	28	32.33 \pm .19
DDT-Resistant	F	233	46	29	35.46 \pm .23
Normal	F	271	45	29	33.16 \pm .20
Lindane-Resistant	M	286	47	29	35.13 \pm .19
Chlordane-Resistant	M	213	45	30	33.41 \pm .17
DDT-Resistant	M	246	46	30	36.06 \pm .23
Normal	M	280	46	30	33.68 \pm .13

^o \pm Standard error of the mean

TABLE 4. Calculated "t" Values for Comparisons of Nymphal Developmental Periods of Resistant and Normal Strains

Lindane Males	Lindane Females	Chlordane Males	Chlordane Females	DDT Males	DDT Females	Normal Males	Normal Females
.51	---	---	---	---	---	---	---
6.87**	---	4.26**	---	---	---	---	---
---	8.69**	---	---	---	---	---	---
3.14**	---	9.32**	---	---	---	---	---
---	1.48	---	10.55**	1.86	---	---	---
6.28**	---	1.26	---	8.90**	---	---	---
---	5.86**	---	2.97**	---	7.61**	2.17*	---

- * Significantly different at $P > .05$ ("t" values in table ranged from 1.96 to 1.97 at the 95% confidence level)
- ** Significantly different at $P > 0.01$ ("t" values in table ranged from 2.58 to 2.59 at the 99% confidence level)

TABLE 5. Adult Longevity of Males and Females in Resistant and Normal Strains

Strain	Sex	No. of Individuals	Longevity (Days)	
			Maximum	Average °
Lindane-Resistant	F	140	180	54.82 ± 2.71
Chlordane-Resistant	F	144	208	58.85 ± 3.41
DDT-Resistant	F	172	203	66.41 ± 3.33
Normal	F	179	168	43.37 ± 2.20
Lindane-Resistant	M	109	118	40.49 ± 1.80
Chlordane-Resistant	M	122	98	37.60 ± 1.46
DDT-Resistant	M	151	102	39.91 ± 1.63
Normal	M	125	102	37.06 ± 1.98

° ± Standard error of the mean

TABLE 6. Calculated "t" Values for Comparisons of Longevity of Females of Resistant and Normal Strains

Lindane			
2.70°	DDT		
.92	1.59	Chlordane	
3.28°	5.77°	3.81°	Normal

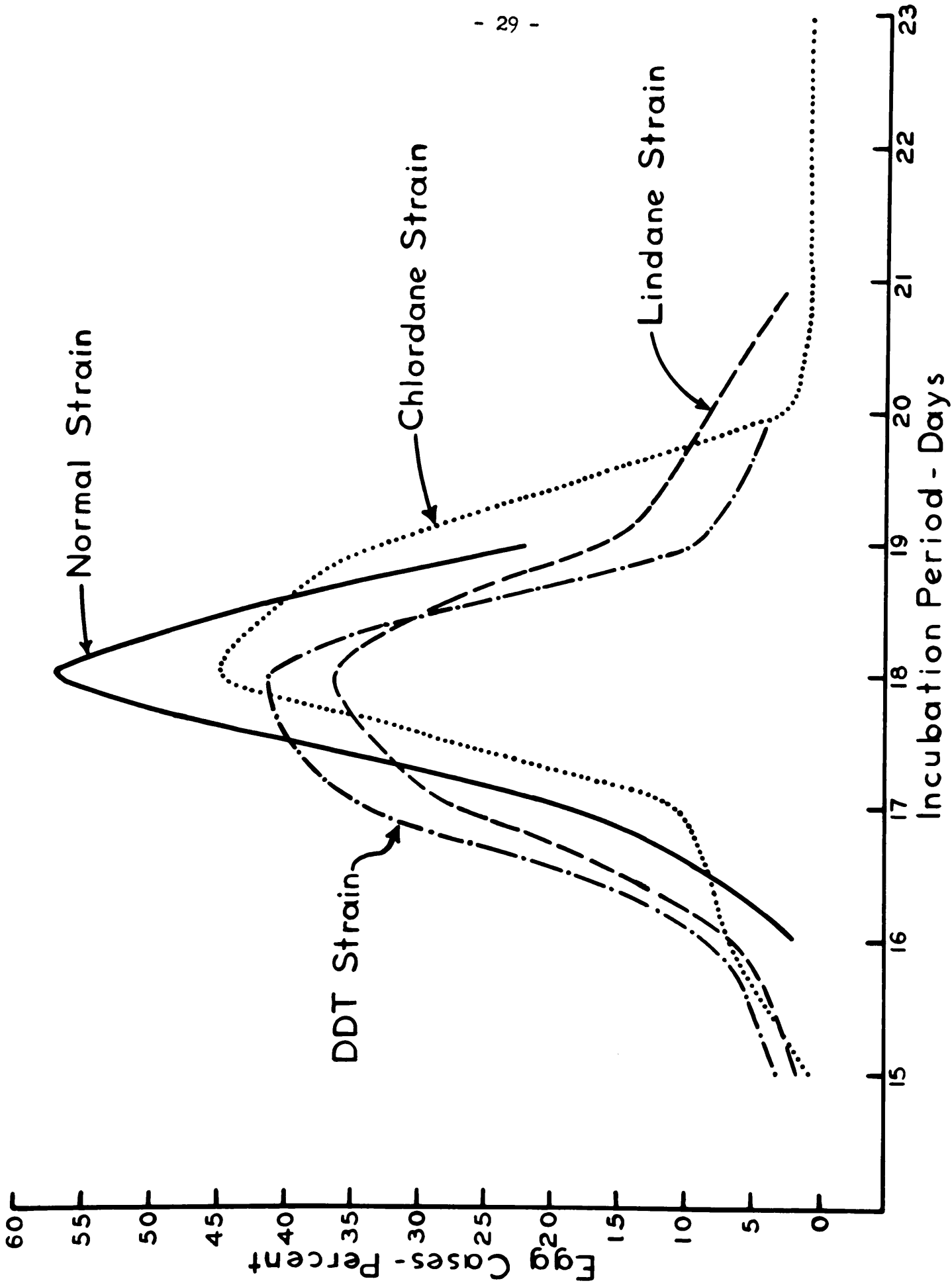
° Significantly different at $P > 0.01$ ("t" values in table were 2.58 in all instances at the 99% confidence level)

TABLE 7. Calculated "t" Values for Comparisons of Longevity of Males of Resistant and Normal Strains

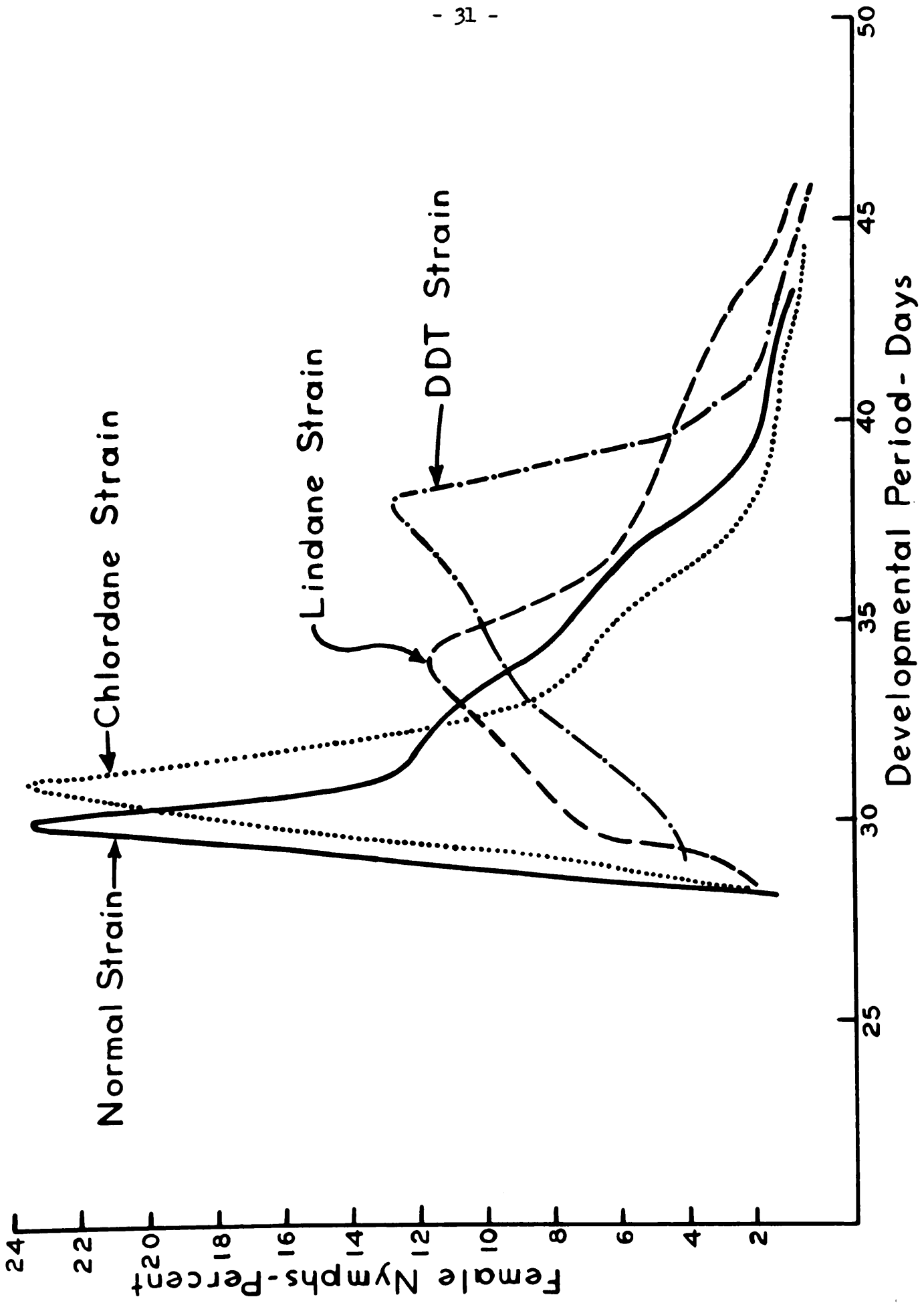
Lindane			
.24	DDT		
1.25	1.06	Chlordane	
.97	1.12	.22	Normal

° "t" values in table were 2.58 in all instances at the 99% confidence level

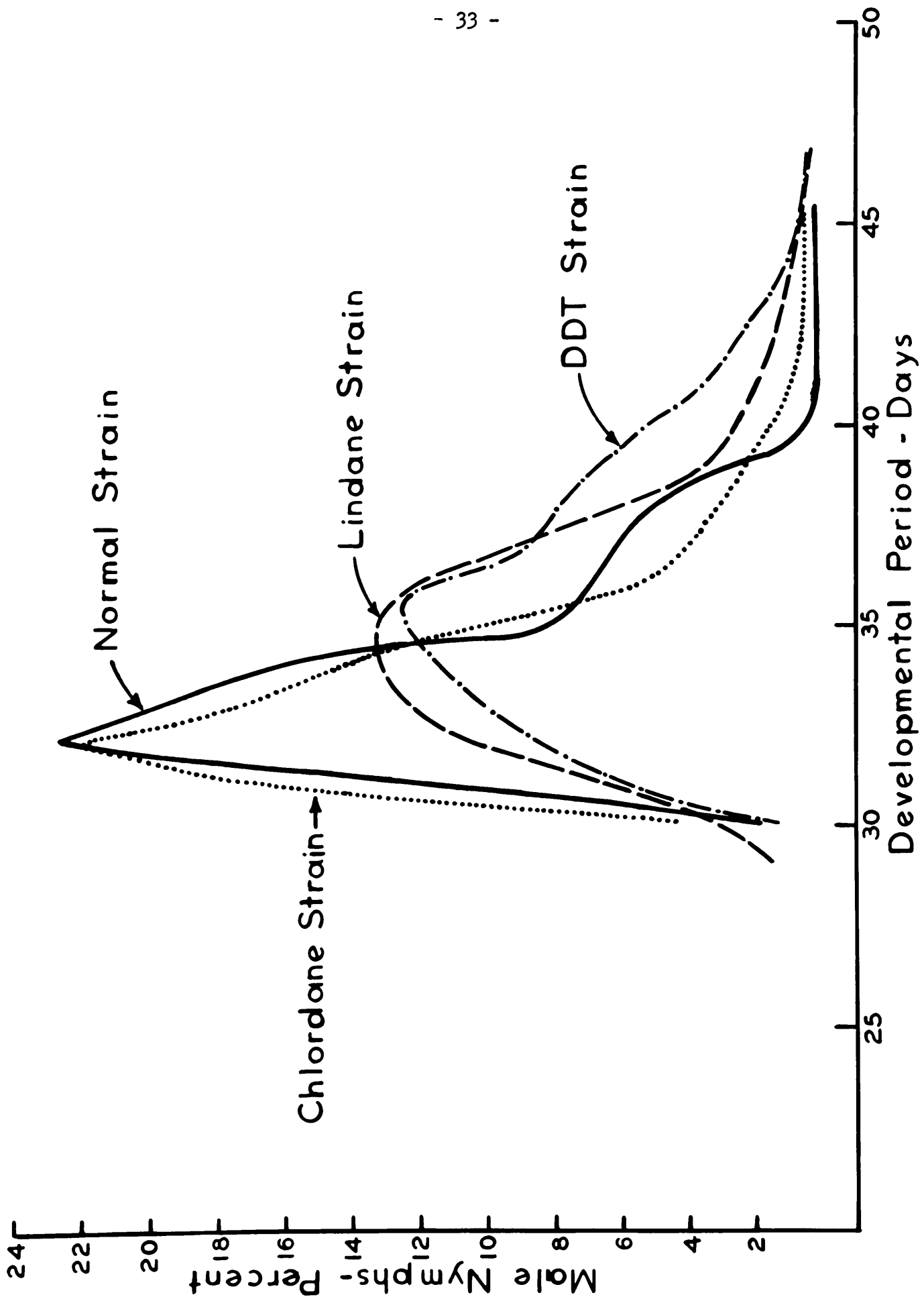
**FIGURE 1. The Incubation Periods of Egg Cases from
Resistant and Normal Strains**



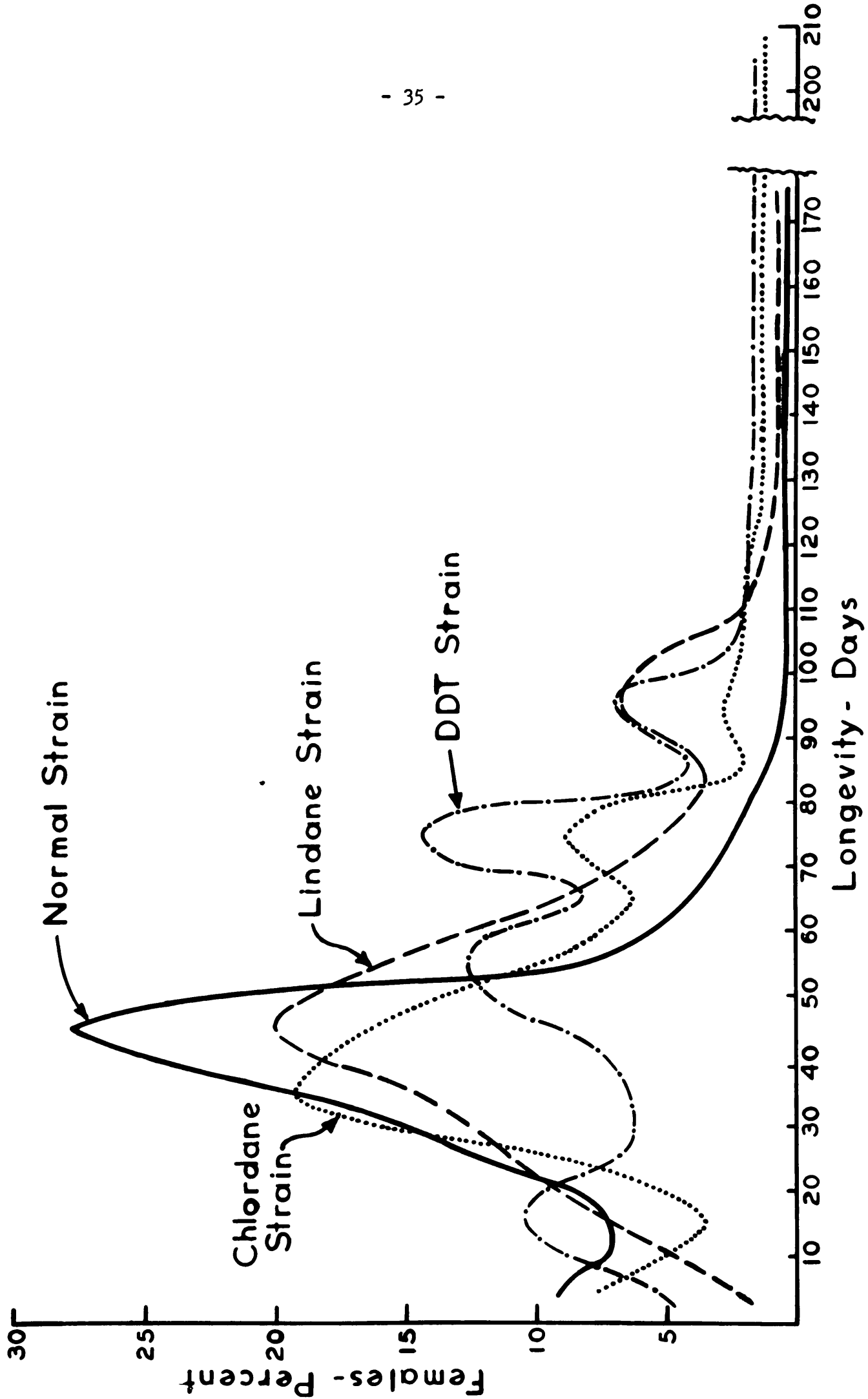
**FIGURE 2. The Nymphal Developmental Period
of Females from Resistant and
Normal Strains**



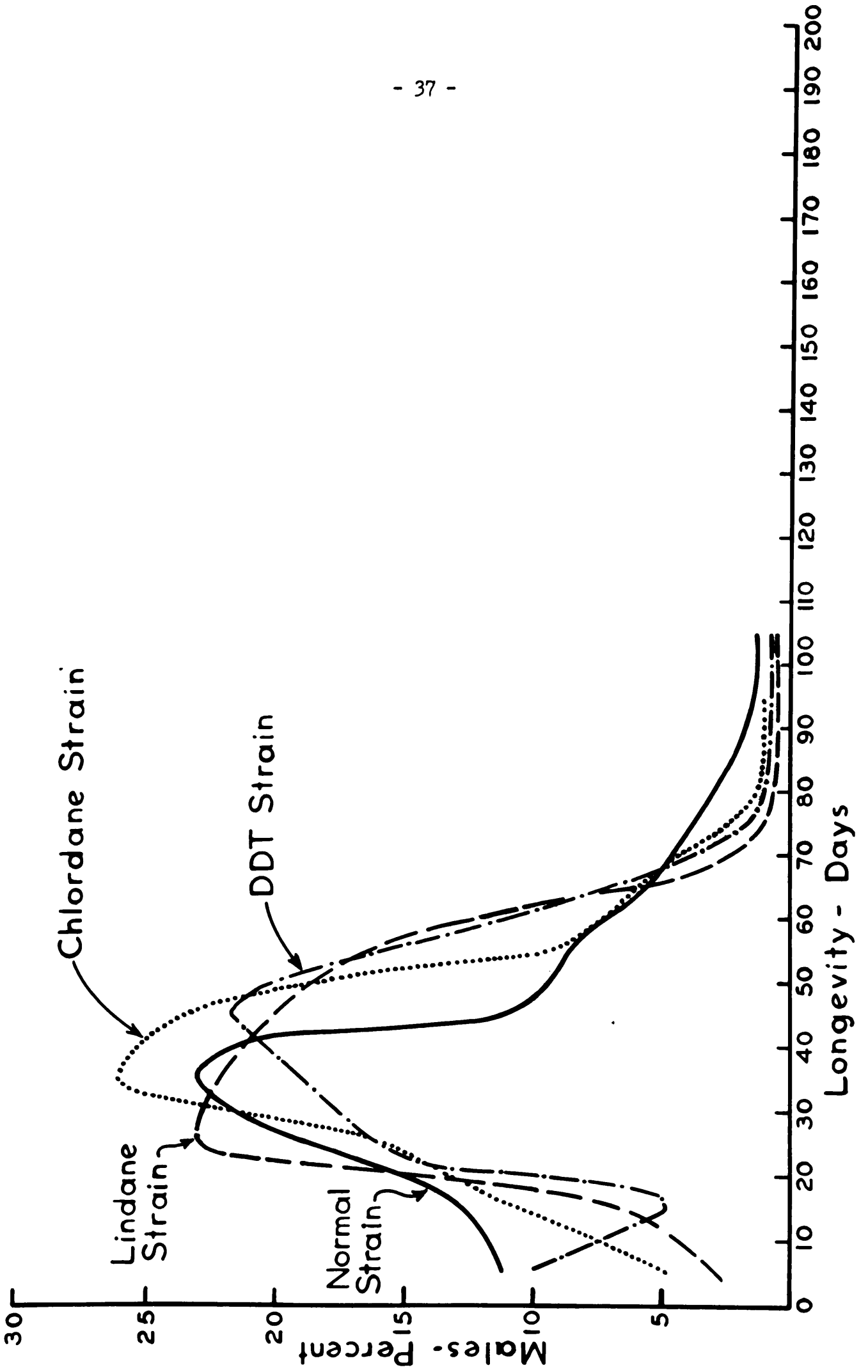
**FIGURE 3. The Nymphal Developmental Period
of Males from Resistant and
Normal Strains**



**FIGURE 4. Longevity of Females from Resistant
and Normal Strains**



**FIGURE 5. Longevity of Males from Resistant
and Normal Strains**



DISCUSSION

The incubation periods of the eggs of the resistant strains were more variable or heterogeneous than those of the normal strain. In only the DDT-resistant strain, however, was the difference between incubation periods significant, and this difference extended to the other two resistant strains, as well as to the normal strain. The lengths of time required for development in the egg stage found in this study are in general agreement with those obtained by Willis et al. (1958) on a normal strain of the German cockroach reared under similar conditions, but differ from those obtained by Rau (1944) and Roth and Willis (1952).

The lindane- and DDT-resistant strains exhibited more heterogeneity during the period of nymphal development than either the normal or the chlordane-resistant strains. Both the lindane- and the DDT-resistant strains had significantly longer nymphal developmental periods than either the normal or the chlordane-resistant strains. The results obtained here on nymphal development are in fair agreement with those obtained by Noland et al. (1949) and Willis et al. (1958) when normal roaches were reared under conditions somewhat similar to those employed in this study. The time required for nymphal development reported by Rau (1944) was considerably longer than reported here.

The females of all the resistant strains exhibited more heterogeneity in adult longevity than did those of the normal strain. However, this was not true in the case of the males. The adult life-span of the females in the resistant strains was significantly longer

than that of normal females. Although the adult period of the males was longer in all three resistant strains, compared to normal males, the differences were not significant. The extensions in adult longevity of resistant strains were as follows: DDT > chlordane > lindane. This is of interest since the magnitude of resistance in these strains follows the same pattern. The average longevity of adult male and female German cockroaches reported here, from both resistant and normal strains, is considerably shorter than that reported by Willis and Roth (1958), although rearing conditions were similar.

One might attempt to correlate the development of resistance to DDT or lindane with increase in adult lifespan, increase in nymphal developmental period, or decrease in incubation period; however, such correlations may not be valid because the chlordane-resistant cockroaches had a longer incubation period, a shorter nymphal developmental period, but a longer adult period than the normal strain. Perhaps this apparent inconsistency could be explained by the fact that the DDT- and lindane-resistant strains were produced through laboratory selection, whereas the chlordane-resistant strain originated in the field. Brown (1959) has pointed out that resistant strains produced by selection in the laboratory may differ in genetic composition and phenotypic characteristics from those originating in the field. This could perhaps explain the difference between the chlordane-resistant and the other two resistant strains.

The sex ratio, which approached unity in all instances, was in accord with the findings of previous investigators (Hilchey and

Patton, 1952; Willis et al., 1958) who studied normal German cock-
roaches.

SUMMARY AND CONCLUSIONS

Comparisons were made of resistant and normal strains of the German cockroach to determine the presence of differences in incubation period, nymphal developmental period, and adult longevity. The cockroaches were reared in a walk-in cabinet maintained at approximately 30 degrees C. and 65 percent relative humidity. Techniques for rearing and handling are described.

In general, the resistant strains were more heterogeneous than the normal strain. The exceptions were the chlordane-resistant males and females in the nymphal developmental study and all the resistant males in the longevity study. Only the DDT-resistant strain was significantly different in the incubation period; the difference extended to the other resistant strains as well as to the normal strain. The DDT- and lindane-resistant strains had a significantly longer nymphal developmental period than the other two strains. Significantly greater longevity occurred in the females of the resistant strains than in females of the normal strain.

The DDT-resistant strain, which had the highest order of resistance, usually showed the greatest deviation from the normal; this included the greatest number of non-hatching egg-cases and the greatest mortality of encapsulated females. The resistant females followed an adult lifespan pattern of: DDT > chlordane > lindane; the order of magnitude of resistance followed a similar pattern.

Finally, this study indicated that, when comparisons were made of resistant and non-resistant German cockroaches, rather consistent

differences were found associated with the development of resistance in the strains which had laboratory-induced resistance (DDT- and lindane-resistant), but correlation was variable between the normal strain and the resistant strain which originated in the field (chlor-dane-resistant). The field-originated resistant strain was similar to the normal strain in average incubation and developmental periods, but similar to the other resistant strains in longevity.

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LITERATURE CITED

- Afifi, S.E.D., and H. Knutson. 1956. Reproductive potential, longevity, and weight of house flies which survived one insecticidal treatment. *Jour. Econ. Ent.* 49 (3): 310-313.
- Babers, F.H., J.J. Pratt, Jr., and M. Williams. 1953. Some biological variations between strains of resistant and susceptible house flies. *Jour. Econ. Ent.* 46: 914-915.
- Bigelow, R.S., and E.J. LeRoux. 1954. Distinct morphological differences between DDT-resistant and non-resistant strains of the house fly, Musca domestica L. *Canad. Ent.* 66: 78-86.
- Brown, A.W.A. 1959. Inheritance of insecticide resistance and tolerance. *Misc. Pub. Ent. Soc. Amer.* 1 (1): 20-26.
- Bruce, W.N. 1949. Latest report on fly control. *Pest Control.* 17 (6): 7, 28.
- Decker, G.C., and W.N. Bruce. 1952. House fly resistance to chemicals. *Amer. Jour. Trop. Med. Hyg.* 1: 395-403.
- Girault, A.A. 1911. Standards of the number of eggs laid by insects IX. *Ent. News.* 14.
- Grayson, J.M. 1953. Effects on the German cockroach of twelve generations of selection for survival to treatments with DDT and benzene hexachloride. *Jour. Econ. Ent.* 46 (1): 124-127.
- _____. 1954. Differences between a resistant and a non-resistant strain of the German cockroach. *Jour. Econ. Ent.* 47 (2): 253-256.
- Hilchey, J.D., and R.L. Patton. 1952. Effects of irregular sex ratios on growth response data from nutritional assays upon Blattella

- germanica (L.). Boyce Thompson Inst. Contrib. 16: 455-459.
- Hough, W.S. 1928. Relative resistance to arsenical poisoning of two codling moth strains. Jour. Econ. Ent. 21 (2): 325-329.
- _____. 1929. Studies of the relative resistance to arsenical poisoning of different strains of codling moth larvae. Jour. Agri. Res. 38 (4): 245-256.
- _____. 1934. Colorado and Virginia strains of codling moth in relation to their ability to enter sprayed and unsprayed apples. Jour. Agri. Res. 48 (6): 533-553.
- _____. 1943. Development and characteristics of vigorous or resistant strains of codling moth. Va. Agri. Exp. Sta. Tech. Bull. 91, V.P.I., Blacksburg.
- Hunter, P.E., L.K. Cutkomp, and A.M. Kolkails. 1958. Reproduction in DDT- and diazinon-treated house flies. Jour. Econ. Ent. 51 (5): 579-582.
- _____. 1959. Reproduction following insecticidal treatment of two resistant strains of house flies. Jour. Econ. Ent. 52: 765-766.
- Johnston, E.F., R. Bogart, and A.W. Lindquist. 1954. The resistance to DDT by houseflies. Jour. Hered. 45: 177-182.
- Knutson, H. 1955. Modifications in fecundity and life span of Drosophila melanogaster Meigen following sublethal exposure to an insecticide. Ann. Ent. Soc. Amer. 48 (1-2): 35-39.
- Lehr, R. and F.F. Smith. 1957. The reproductive capacity of three strains of the two-spotted spider mite complex. Jour. Econ. Ent. 50 (5): 634-636.

- Lichtwardt, E.T., W.N. Bruce, and G.C. Decker. 1955. Notes on the inbreeding of house flies. Jour. Econ. Ent. 48: 301-303.
- Lichtwardt, E.T. 1956. Genetics of DDT-resistance of an inbred line of house flies. Jour. Hered. 47: 11-16.
- Mahan, J.G., and J.M. Grayson. 1956. Morphological comparisons of resistant and non-resistant strains of the German cockroach, Blattella germanica (L.). Va. Jour. Sci. pp. 166-169.
- March, R.B., and L.L. Lewallen. 1950. A comparison of DDT-resistant and non-resistant house flies. Jour. Econ. Ent. 43: 721-722.
- McKenzie, R.E., and W.M. Hoskins. 1954. Correlation between the length of the larval period of Musca domestica L. and resistance of adult flies to insecticides. Jour. Econ. Ent. 47: 984-992.
- Melander, A.L. 1914. Can insects become resistant to sprays? Jour. Econ. Ent. 7 (2): 167-173.
- Morrison, F.O. 1957. The ratio of the width to the length of the second abdominal sternite of the house fly. Jour. Econ. Ent. 50: 554-556.
- Noland, J.L., J.H. Lilly, and C.A. Baumann. 1949. A laboratory method for rearing cockroaches, and its application to dietary studies on the German cockroach. Ann. Ent. Soc. Amer. 42: 63-70.
- Ouye, M.T., and H. Knutson. 1957. Reproductive potential, longevity, and weight of house flies following treatments of larvae with malathion. Jour. Econ. Ent. 50 (4): 490-493.
- Pettit, L.C. 1940. The effect of isolation on growth in the cockroach, Blattella germanica (L.)(Orthoptera Blattidae) Ent. News. 51:293.

- Pimentel, D., J.E. Dewey, and H.H. Schwardt. 1951. An increase in the duration of the life cycle of DDT-resistant strains of the house fly. *Jour. Econ. Ent.* 44: 477-481.
- Rau, P. 1944. A note on the period of incubation of eggs of the cockroach, Blattella germanica L. *Canad. Ent.* 212.
- Roth, L.M., and E.R. Willis. 1952. A study of cockroach behavior. *Amer. Midland Naturalist.* 47: 66-100, 109-129.
- _____. 1956. Parthenogenesis in cockroaches. *Ann. Ent. Soc. Amer.* 49 (3): 195-204.
- Sokal, R.R., and P.E. Hunter. 1955. A morphometric analysis of DDT-resistant and non-resistant house fly strains. *Ann. Ent. Soc. Amer.* 48 (6): 499-507.
- Tuma, V. 1938. Roaches. A study of the relationship between the ages of cockroaches and their resistance to liquid insecticides. *Soap.* 14 (6): 109-111, 113, 115, 117, 151.
- Varzandeh, M., W.M. Bruce, and G.C. Decker. 1954. Resistance to insecticides as a factor influencing the biotic potential of the house fly. *Jour. Econ. Ent.* 47 (1): 129-134.
- Willis, E.R., G.R. Riser, and L.M. Roth. 1958. Observations on reproduction and development in cockroaches. *Ann. Ent. Soc. Amer.* 51 (1): 53-69.

VITA

Benjamin David Perkins, Jr. was born in Richmond, Virginia on May 15, 1935. He attended the public schools of that city. His enrollment at the University of Richmond in 1954 led to a B.A. degree in Biology from that institution in 1958. His interest in entomology was encouraged by investigation of the ecology of the cigarette beetle in tobacco storage warehouses in Durham, North Carolina during the summers of 1957 and 1958. This work was done as entomologist for Liggett and Myers Tobacco Co. in conjunction with the U.S.D.A. Stored Tobacco Insects Laboratory. In the fall of 1958, he enrolled at Virginia Polytechnic Institute, Blacksburg, Virginia, where he pursued a program leading to the degree of Master of Science with a major in Entomology.

A handwritten signature in cursive script, reading "B. David Perkins, Jr." The signature is written in dark ink and is centered below the typed text.

CERTAIN BIOLOGICAL COMPARISONS OF RESISTANT AND
NON-RESISTANT STRAINS OF THE GERMAN COCKROACH,
BLATTELLA GERMANICA (LINNAEUS)

Abstract

Strains of the German cockroach resistant to lindane, chlordane, and DDT were compared with a normal strain as to incubation period of eggs, developmental period of nymphs, and longevity of adults.

The resistant strains were more heterogeneous than the normal, with the exceptions of the chlordane-resistant males and females of the nymphal developmental study and all the resistant males in the longevity study. The incubation period of the DDT-resistant strain was shorter than that of the normal and the other two resistant strains. The DDT- and lindane-resistant strains had longer nymphal developmental periods than the other two strains. The resistant females lived significantly longer than the normal females. The sex ratio approached unity in all strains.

Correlation of resistance with differences found in this study gave variable results. The field-originated strain (chlordane-resistant) was similar to the normal strain in average length of incubation and nymphal developmental periods, but similar to the other resistant strains in longevity. On the other hand, rather consistent differences were found between the normal strain and those with laboratory-induced resistance (DDT and lindane strains).