THE EFFECT OF LOW TEMPERATURE AND STARVATION ON THE SURVIVAL AND DEVELOPMENT OF THE GERMAN COCKROACH BLATTELLA GERMANICA (L.)

A Thesis

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ABSTRACT

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Immature stages of the German cockroach, Blattella germanica (L.) are able to survive a starvation period up to 64 days but do not moult into later instars. First instar nymphs did not moult at 15.6°C., however, at 21.1°C. they developed to adults in about seven months. A temperature of 4.4°C. is fatal if cockroaches are exposed to it for three days. However, these insects can recover from undercooling temperatures as low as -10°C., if removed to room temperature immediately after freezing commences. Since the cockroaches are able to supercool momentarily to approximately -10°C. while a longer exposure to 4°C. is fatal, it can be assumed that the undercooling temperature cannot be used as an index of cold-hardiness for this species. Cooling infested dwellings below 4°C. for 3 days will kill the nymphs and adults. Eggs are more cold-hardy and must be chilled to about -7°C. for 24 hours for complete mortality.

On restricted diets, female cockroaches kept at 10°C. had a significantly higher per cent fat content than those kept at 26.7°C. There was no decrease in the body weight and per cent of body water when cockroaches were provided water only.

ACKNOWLEDGEMENTS

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INTRODUCTION

The German Cockroach, Blattella germanica (L.) is widespread in distribution (Metcalfe, Flint & Metcalfe). It frequents warm, inhabited places such as homes, restaurants, warm storage warehouses and has become a general nuisance. Because of its presence, public places such as restaurants, hotels, bakeries or wherever food is handled may be forced to close down (Food and Drug Act). Even after insecticide treatment one can never be sure of its extermination. Since this insect has become established so securely in a climate as severe as in certain parts of Canada, one wonders whether it might be tolerant to low temperatures. It's ability to survive occasional circumstances when food is limited or completely lacking is also of interest.

Early workers have studied the survival and development of this insect under starvation and low temperature conditions. However, their work was limited to higher temperatures (72°F. to 80°F.) and involved only the adult stage. In this thesis, an attempt has been made to determine the survival of various life stages of the German cockroach under inadequate food conditions and low temperatures, and to determine from this information whether the German cockroach could be controlled without the use of poisonous chemicals.

The survival of an insect living under adverse conditions is important in the population dynamics of that species. On the assumption that the species is able to resume development and population increase

after optimum conditions have returned, the pattern of mortality during sub-optimal conditions will determine how soon a population can build up again.

The Scope of the Study

There are two objectives in this study: (1) to determine the effect of exposure to low temperatures on the survival and development of Blattella germanica (L.); (2) to determine the role of developmental temperatures, humidity, sex and food regimes on the survival of the various stages of the German cockroach. The results of these studies could furnish pertinent information as to a method of controlling the German cockroach without the use of chemicals.

The Organization of the Thesis

The thesis is divided into two sections. The first section deals with the survival and development of the different life stages of the German cockroach under low temperature conditions. The second section describes the effects of various feeding regimes on the survival of the different instars of the cockroach.

LITERATURE REVIEW

Survival at Low Temperatures

The survival of the German cockroach at low temperatures has not been previously investigated thoroughly. Mellanby (1939, 1940) showed that activity of insects at low temperatures was modified by their previous thermal history. Colhoun (1954) demonstrated that adult male German cockroaches previously kept at 15°C. remained mobile at 5°C. Those acclimatized at 25°C. and 35°C. were immobilized below 6°C. and 8°C. respectively. Colhoun (1954) points out that a limit to acclimatization occurs at temperatures below 15°C. Colhoun (1960) also stated that the mean survival time of the male roach increased from approximately 6 days to 14 days at 7°C. after acclimatization at 15°C. as compared to acclimatization at 35°C.

Hatchability of Detached Oothecae

The effects of various temperatures and humidities on the hatch of eggs from manually detached oothecae have received some attention from early authors but unfortunately the results and interpretations are confusing. According to Ross (1929) when 9-day or older oothecae were removed from females, the eggs hatched if the egg cases were kept under "cool humid" conditions. Younger oothecae failed to hatch under any conditions. Parker and Campbell (1940) observed that hatching would occur even when the oothecae were detached two to four days after they were first noticeably extruded. However, for a high percentage of hatch

the egg cases had to be in contact with physiological saline solution isotonic to the female hemolymph.

The effect of humidity on the hatching of oothecae was studied by Roth and Willis (1955). At 30% relative humidity and 27-29°C. the hatch was low unless oothecae were removed about one day prior to dropping of the egg case by the female. At 90% relative humidity a high percentage of hatch occurred only if the egg cases were one or seven and more days old when removed from the females. Two to six-day old egg capsules failed to hatch under any condition when manually removed. These authors interpreted these results on the basis of water loss by the oothecae. The slowest rate of water loss occurs in oothecae which are one-day old when detached, and the greatest rate of water loss occurs in eggs which are four to six days old at the time of removal from the female. It is strange that the one-day old eggs yielded a high hatch because they still had to undergo the two to six-day period of high water loss without the protective mechanism of the female body.

Survival on Restricted Diets

There is relatively little information on the ability of German cockroaches to survive under conditions of partial or complete starvation. Willis and Lewis (1957) recorded the longevity of adult male and female German cockroaches at 27°C. and 40% relative humidity and of females only at the same temperature but at 70% relative humidity. The insects were placed on restricted diets of dry dog food only, water only, or neither food nor water. The mean duration of survival of females at 40%

relative humidity was 12, 42, and 13 days under the respective feeding regimes. The males survived approximately 9 days on all the above restricted diets. At 70% relative humidity the longevity of the females was 18, 28 and 28 days respectively. No reason is given why the females survived for 42 days at 40% relative humidity on a water diet and only 28 days at 70% relative humidity on the same diet.

SECTION I

THE SURVIVAL AND DEVELOPMENT OF THE GERMAN COCKROACH UNDER LOW TEMPERATURES

Materials and Methods

The survival and development of the different life stages of the German cockroach at low temperatures were studied by three methods: (1) by determining the time required to complete development at various temperatures and also the threshold development temperature; (2) by determining the survival of each life stage after exposure to low temperatures; (3) by determining the hatchability of eggs at various low temperatures.

One to two-day old nymphs were used to determine rate of development at different temperatures. Ten nymphs were placed at each temperature in plastic containers 6 inches in diameter and 2 1/2 inches in height. An inverted beaker of water in a Petri dish and dog meal provided the source of water and food necessary for normal development. Five temperatures from 4.4°C. to 26.7°C. at 5.6°C. intervals were used. Unfortunately, due to fungus growing on the food at the high humidity many of the results were discarded and only the reliable results will be discussed below.

For the low temperature exposure experiments the nymphal instar stages were divided into three categories; early instar (1st and 2nd instars); mid instar (3rd and 4th instars); and late instar (5th and 6th instars). The adult stages were also divided into three groups: adult

males, adult females, and gravid females. Ten insects from each category were subjected to low temperatures of -1.1°C., 1.7°C., and 4.4°C. for a 1-day and a 3-day exposure period. One day was allotted for recovery at 26.7°C. before mortality counts were made.

The survival of eggs at low temperatures was determined by manually removing the oothecae from females and exposing the eggs to the same temperatures as the other life stages. Each egg band was placed in a 1-inch square plastic box with screened air openings on each side. A saturated atmosphere was adequate for a complete hatch of eggs at 26.7°C. Therefore, a saturated atmosphere was used for each temperature. Thirty per cent relative humidity was used for determining the effect of humidity on the survival and hatch of the eggs. For determining the cold-hardiness of the eggs the oothecae were placed at -1.1°C. and -6.7°C. and removed periodically to 26.7°C. and contact moisture for hatching.

Results and Discussion

(1) Development at Low Temperatures

Gould and Deay (1940) found that at an average temperature of 24.4°C. development of the cockroach from first instar to adult required from 54 to 215 days. The lowest temperature that these authors used was 22.9°C. In this study both the survival at low temperatures and the threshold temperature for development of the German cockroach were studied. At 4.4°C. first instar nymphs survived for only three days. At 10°C. the first instar nymphs lived for 25 days but did not develop beyond the first instar. Nymphs at 15.6°C. lived for about seven months but did not develop beyond the second instar. When reared at 21.1°C. first instar nymphs developed into adults in about seven months but only 20 per cent survived. At 26.7°C. development from egg to adult required less than two months. The threshold developmental temperature would, therefore, be somewhere between 15.6°C. and 21.1°C.

(2) Survival at Low Temperatures

The data summarized in Table I show that the nymphs and adults of the German cockroach are not able to survive for any appreciable period at 4.4°C. One hundred per cent mortality occurs after a three-day exposure to this temperature. At -1.1°C. complete mortality occurs after a one-day exposure. After one day at 1.7°C. mortality is about 10% or less for all the stages except adult males of which 75% die. The eggs of the German cockroach are much more resistant to cold than the nymphs and adults are. The eggs will survive after seven days at -1.1°C. but one day at -6.7°C. is fatal.

TABLE I

THE MORTALITY OF GERMAN COCKROACHES WHEN EXPOSED TO LOW TEMPERATURES

Instar	Exposure Time (days)	Per cent Mortality		
		-1.1°C.	1.7°C.	4.4°C.
Early	1	100	10.0	5.0
	3	100	100	100
Mid	1	100	10.0	10.0
	3	100	100	100
Late	1	100	0.0	0.0
	3	100	100	100
Adult Male	1	100	75.0	10.0
	3	100	100	100
Adult Female	1	100	5.0	0.0
	3	100	100	100
Pregnant Female	1	100	0.0	0.0
	3	100	100	100

These results suggest an effective method of control of the German cockroach during the winter. If the temperature within a building could be lowered to about -6.0°C. (21°F.) for about 24 hours then all the life stages of the cockroach could be killed. With suitable precautions as to plumbing and certain freezable household items, this method of control does not seem unrealistic.

Although the cockroach survives up to three days at 4.4°C. (Table I) it was of interest to determine the degree of resistance of this insect to sudden and severe drops in temperature. To do this the roaches were exposed to approximately -35°C. and the temperature at which ice crystals began to form in their tissues was determined. This temperature is termed the undercooling or supercooling temperature. As soon as the undercooling temperature was reached the insect was removed from the chilling bath and allowed to thaw out and recover at room temperature. Table II summarizes the results.

Table II shows that these insects freeze at temperatures from approximately -6.0°C. to - 10.0°C. These temperatures are considerably lower than those required for mortality at the longer periods of exposure. Therefore, the undercooling point could not be used as a measure of cold hardiness in this species. Table II also shows that some of the cockroaches recovered after they were removed from the chilling bath and placed at 26.7°C.

(3) Feeding Temperature Threshold

It was previously mentioned that even at temperatures of 15.6°C. development of first instar nymphs did not progress beyond the second

TABLE II

THE AVERAGE UNDERCOOLING TEMPERATURE AND RECOVERY OF THE DIFFERENT LIFE STAGES OF THE GERMAN COCKROACH

Instar	Average U.T. (-°C.)	Per cent Recovery
First	-7.7	10.0
Second	-9.2	10.0
Third	-8.2	30.0
Fourth	-7.5	40.0
Fifth	-7.8	10.0
Sixth	-9.0	20.0
Adult	-6.6	20.0

instar in seven months. At 21.1°C. the same period was required for development from first instar to adult. This extremely slow growth could have been due to insufficient feeding by the insect at the lower temperatures. This aspect was investigated and feeding temperature thresholds of adult cockroaches were determined. Temperatures from 4.4°C. to 26.7°C., at 5.6°C. intervals were used. Unsexed adult insects deprived of food and water for two days were tested in an apparatus shown in Figure 1. One insect was placed in each compartment. Standardized capillary tubes filled to a marked level with a 10% aqueous sugar solution contained from 20 to 25 milligrams of solution. Each container with its two insects was placed in its respective temperature for conditioning for one hour before the sugar solution was introduced. The results are summarized in Table III.

After a one-hour and sixteen-hour feeding period adult German cockroaches consumed food at each temperature from 4.4°C. to 26.7°C. The amount of intake of sugar solution increased with temperature. The capillary tubes contained a maximum of 20 to 25 milligrams of the solution and complete intake occurred after 16 hours at 21.1°C. and 26.7°C. The evaporation from a control capillary tube at each temperature was negligible. Adult German cockroaches are, therefore, capable of feeding to a limited extent even at temperatures which are low enough to kill them after three days of exposure. No attempt was made to determine the threshold temperatures for feeding on dry food matter.

The slow development at 15.6°C. and 21.1°C. might be attributed to the direct effects of temperature rather than inadequate feeding by the nymphs.

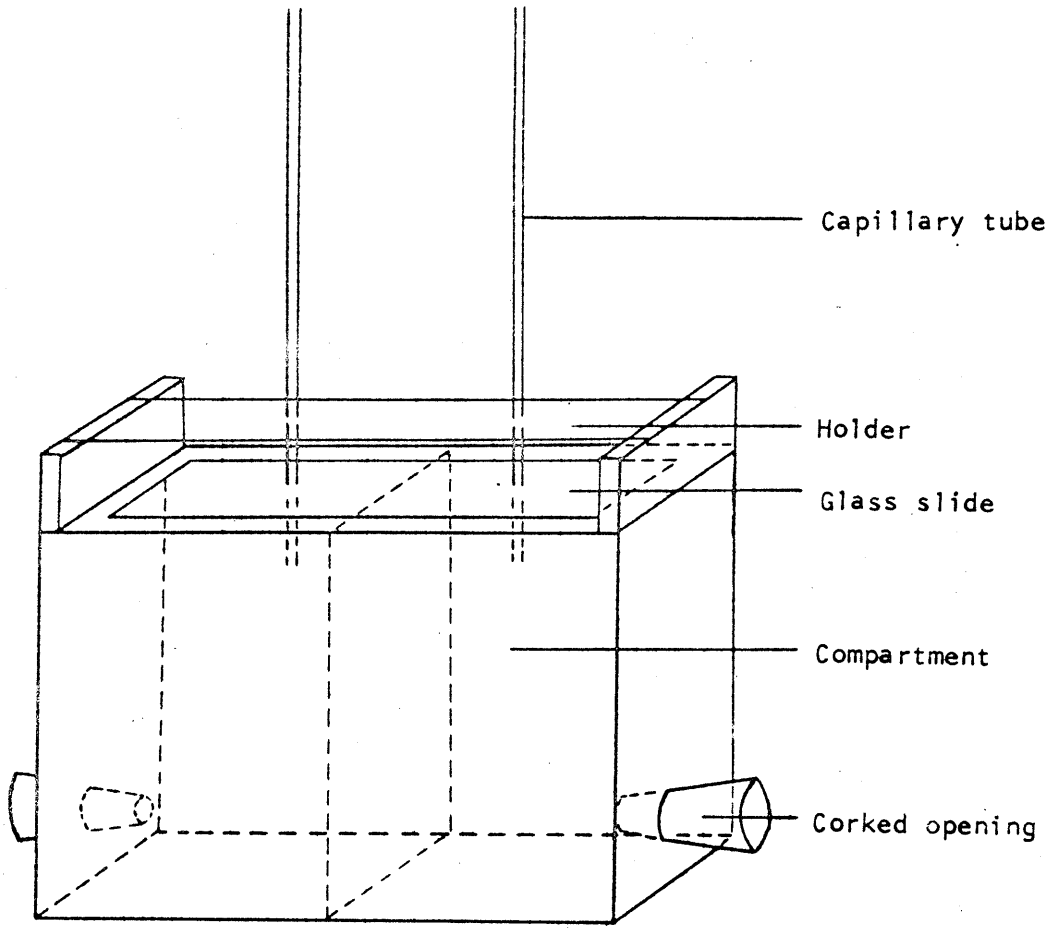


FIGURE 1. A TWO COMPARTMENT PLASTIC BOX USED TO DETERMINE INDIVIDUAL VOLUMES OF A 10% SUGAR SOLUTION CONSUMED BY THE GERMAN COCKROACH. (after BRACKEN, 1960).

TABLE III

THE AMOUNT OF 10% AQUEOUS SUGAR SOLUTION CONSUMED BY STARVED GERMAN COCKROACHES AT DIFFERENT TEMPERATURES

(10 insects tested at each temperature)

Temperature	Average Intake in Milligrams	
	After 1 hr.	After 16 hrs.
4.4°C.	1.14	6.49
10.0°C.	2.16	11.11
15.6°C.	9.97	19.68
21.1°C.	10.13	25.27 ✱
26.7°C.	14.89	24.57 ✱

✱ Cockroaches consumed all the sugar solution in the capillary tube.

SECTION II

THE SURVIVAL OF THE GERMAN COCKROACH ON VARIOUS DEFICIENT DIETS

Materials and Methods

The effect of an inadequate food regime on the survival of the German cockroach was determined by comparing the longevities of each life stage on the respective diets. The effect of different temperatures and humidities was also studied for each sex and life stage.

The required instar groups for this study were obtained by rearing the insects in large culture boxes at 26.7°C. on a diet of dog food[1] and water, prior to being subjected to the restricted diets. The insects were sexed by a method described by Ross and Cockran (1960). Humidity was controlled by the use of potassium hydroxide solutions placed in desiccators (Peterson, 1953). Two humidities, 70% and 30% relative humidity and two temperatures, 26.7°C. and 10°C. were used to determine differences in survival of the various instars. Test cages were 3 x 3 x 1 inch square plastic boxes lined on the bottom with coarse paper and covered by a plastic top through which a hole had been drilled for ventilation. Ten insects of each life stage were used for each treatment. The three food conditions were: food only, water only, neither food nor water. The control diet included both the dog meal and

[1]Gaines dog meal

water. Mortality checks were made twice weekly. At the higher temperature and humidity food was changed whenever fungal growth was noticed.

RESULTS AND DISCUSSION

1. Survival on Restricted Diets

The effects of sex, temperature and various restricted feeding regimens on the survival of the different instars of the German cockroach are shown in detail in Figures 2 to 29 and summarized in Tables IV and V. The term "starved" is used to imply that a restricted diet, whether dry food alone, or water alone or no food and no water was offered to the cockroaches. A legend is used to explain the lines on each of the graphs.

Table IV shows the maximum survival of German cockroaches under the various treatments to which they were subjected. The maximum survival is important from a practical consideration because even one living gravid female can start an infestation. Table V shows the longevity of 50 per cent of the individuals. These data indicate the survival potential of the population as a whole rather than a few hardy individuals.

Data from Tables IV and V show that male and female cockroaches lived roughly twice as long at 10°C. as at 26.7°C. when water was provided. When water was not provided, longevity was reduced in all treatments by about one-third whether food was or was not provided. There was an exception at 10°C. and 70% relative humidity. This is of practical importance since no eggs were produced and most of the cockroaches failed to survive for 40 days under the conditions at which they were tested.

TABLE IV

THE MAXIMUM LONGEVITY IN DAYS OF THE DIFFERENT INSTARS OF THE GERMAN COCKROACH ON RESTRICTED DIETS

Food Regime	Instar	26.7°C.				10°C.				Averages
		70%		30%		70%		30%		
		♂	♀	♂	♀	♂	♀	♂	♀	
Water Only	1st	18*		4*		18*		**		13.3
	2nd	11	11	11	11	17	38	31	31	20.1
	3rd	18	18	18	18	32	43	47	64	32.3
	4th	16	12	19	23	23	42	29	29	24.1
	5th	16	16	19	19	42	29	23	26	23.7
	6th	27	14	27	11	27	36	29	29	25.0
	Adult	8	20	11	29	22	29	22	36	22.1
Average		16.0	15.1	17.5	18.5	27.1	36.1	30.1	35.8	24.5
Food Only	1st	18*		4*		18*		12*		17.3
	2nd	14	14	7	11	24	24	14	17	15.6
	3rd	22	18	17	17	43	50	29	22	27.2
	4th	23	16	26	26	29	42	16	23	25.1
	5th	29	23	29	26	42	29	16	23	27.1
	6th	27	27	34	30	36	39	14	14	27.6
	Adult	12	19	11	22	18	46	19	36	22.8
Average		21.1	19.6	20.6	22.0	32.0	38.3	18.0	22.6	24.3
No Food No Water	1st	12*		4*		18*		12*		15.3
	2nd	11	11	7	10	14	24	14	14	13.1
	3rd	18	25	17	21	36	29	19	23	23.5
	4th	16	16	19	23	29	46	16	23	23.5
	5th	23	23	23	26	42	19	19	19	24.3
	6th	27	27	27	27	39	11	10	27	24.3
	Adult	8	21	11	22	11	25	15	29	17.7
Average		17.1	20.5	17.3	21.5	28.5	25.6	16.5	22.5	21.2

* Unsexed

** Nymphs died prior to testing

TABLE V

DAYS REQUIRED FOR 50% MORTALITY OF THE DIFFERENT INSTARS OF THE GERMAN COCKROACH ON RESTRICTED DIETS

Food Regime	Instar	26.7°C.				10°C.				Average
		70% R.H.		30% R.H.		70% R.H.		30% R.H.		
		♂	♀	♂	♀	♂	♀	♂	♀	
Water Only	1st	13*		2*		10*		15*		13.3
	2nd	2	6	2	5	13	22	11	5	7.0
	3rd	11	14	3	13	11	11	22	23	16.0
	4th	6	8	3	10	7	23	5	22	10.5
	5th	13	14	14	13	10	13	12	7	12.0
	6th	6	6	7	4	8	7	10	12	7.5
	Adult	5	6	5	13	8	12	7	22	9.7
Average		7.1	9.0	5.6	9.6	9.5	14.6	11.1	13.5	10.0
Food Only	1st	6*		2*		8*		7*		5.7
	2nd	11	10	3	6	16	7	9	12	9.2
	3rd	10	11	8	5	11	8	13	6	9.0
	4th	4	4	9	9	12	14	6	14	9.0
	5th	18	17	23	18	15	16	9	9	15.6
	6th	4	6	8	4	7	4	2	6	5.1
	Adult	10	12	8	11	11	15	9	14	11.2
Average		9.5	10.0	9.8	8.8	12.0	10.6	8.0	10.1	9.8
No Food No Water	1st	3*		2*		8*		7*		5.2
	2nd	6	5	2	7	12	14	7	7	7.5
	3rd	6	12	7	8	26	16	6	12	11.6
	4th	5	4	9	3	5	32	4	18	10.0
	5th	14	14	18	13	19	10	8	12	16.0
	6th	9	3	9	10	11	3	7	6	7.2
	Adult	5	8	6	14	6	8	7	15	8.6
Average		7.5	7.6	8.5	9.1	13.1	13.8	6.5	11.6	9.7

* Unsexed

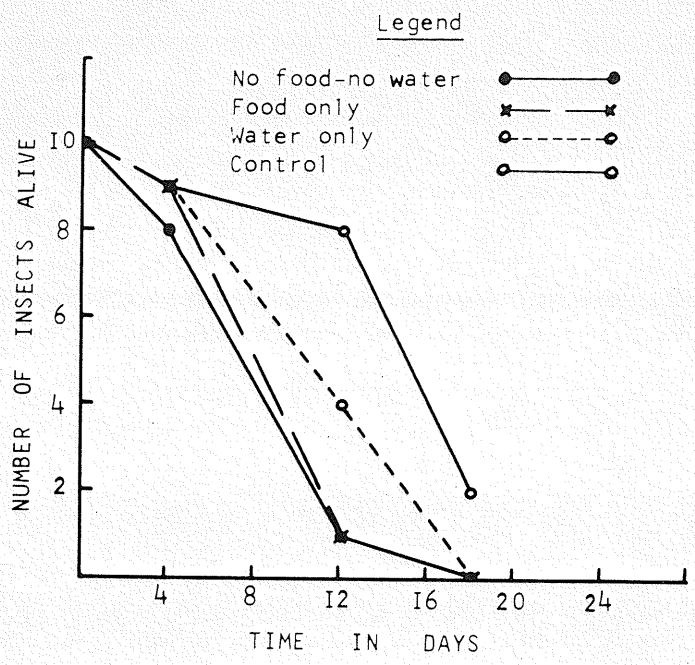


FIGURE 2

THE SURVIVAL OF FIRST INSTAR NYMPHS OF Blattella germanica (Linn.) STARVED AT 10°C AND 70% R.H.

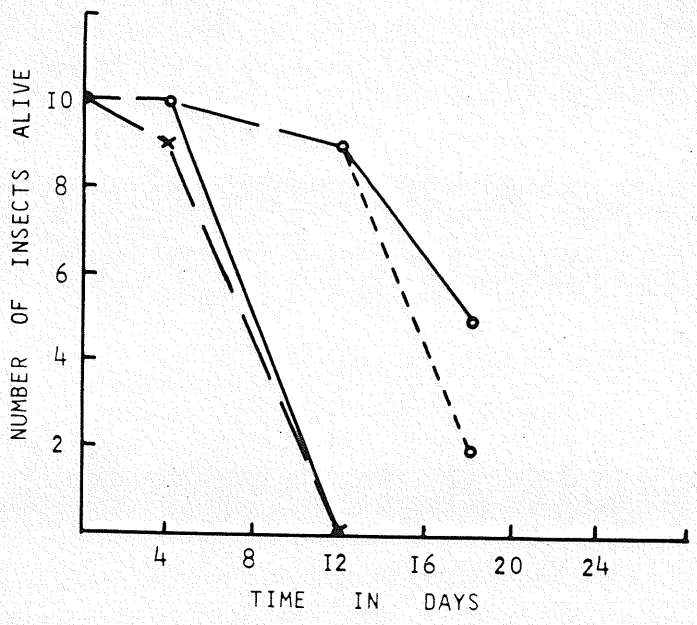


FIGURE 3

THE SURVIVAL OF FIRST INSTAR NYMPHS OF Blattella germanica (Linn.) STARVED AT 10°C AND 30% R.H.

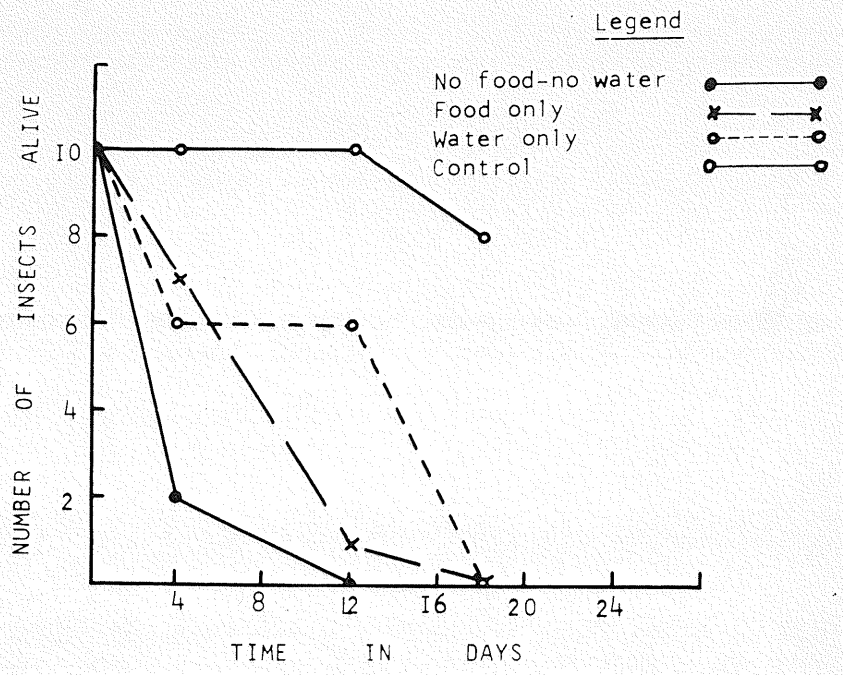


FIGURE 4

THE SURVIVAL OF FIRST INSTAR NYMPHS OF Blattella germanica (Linn.) STARVED AT 26.7°C AND 70% R.H.

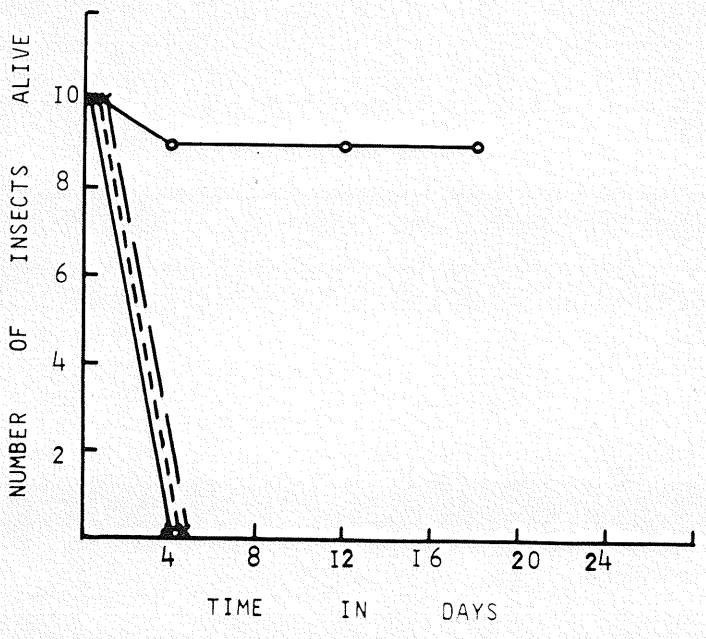


FIGURE 5

THE SURVIVAL OF FIRST INSTAR NYMPHS OF Blattella germanica (Linn.) STARVED AT 26.7°C AND 30% R.H.

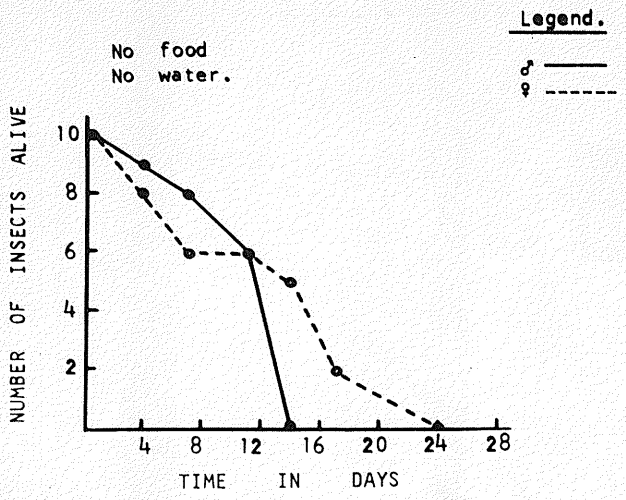


FIGURE 6 a.

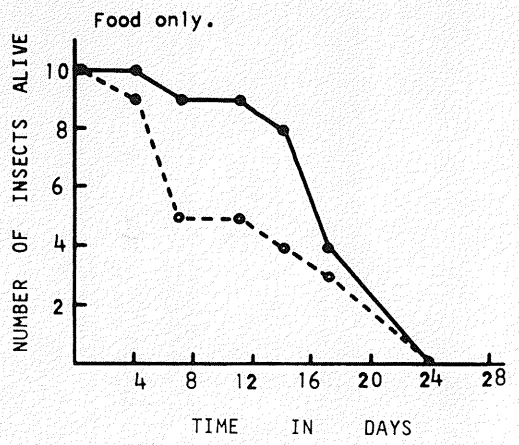


FIGURE 6 b.

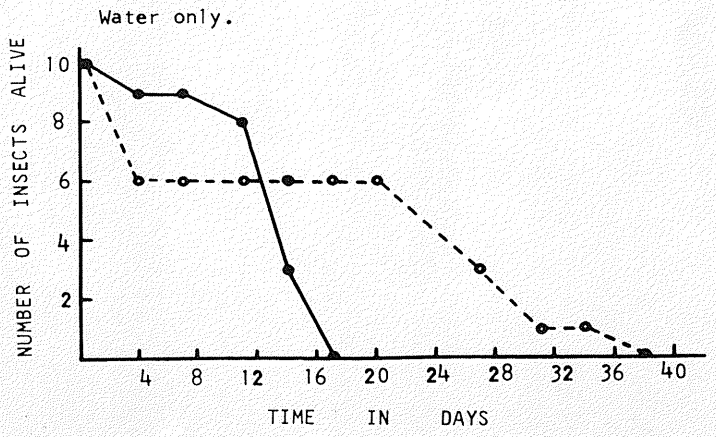


FIGURE 6 c.

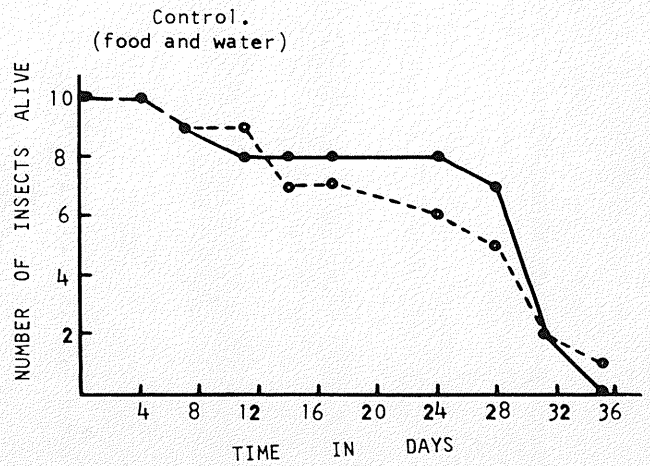


FIGURE 6 d.

FIGURE 6

THE SURVIVAL OF SECOND INSTAR NYMPHS OF Blattella germanica (Linn.) STARVED AT 10°C AND 70% R.H.

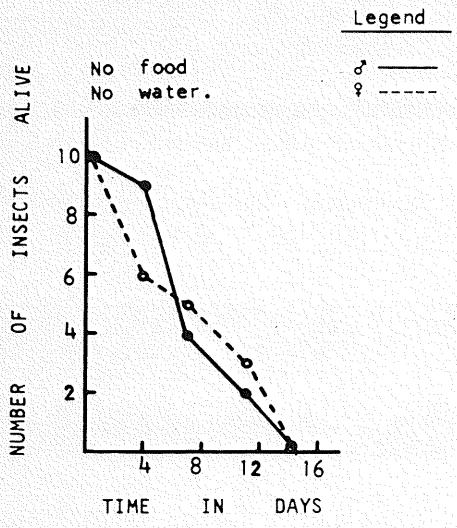


FIGURE 7 a.

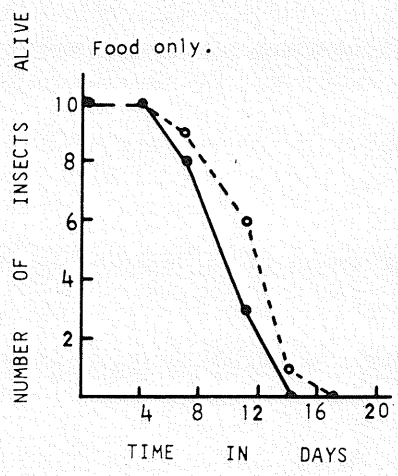


FIGURE 7 b.

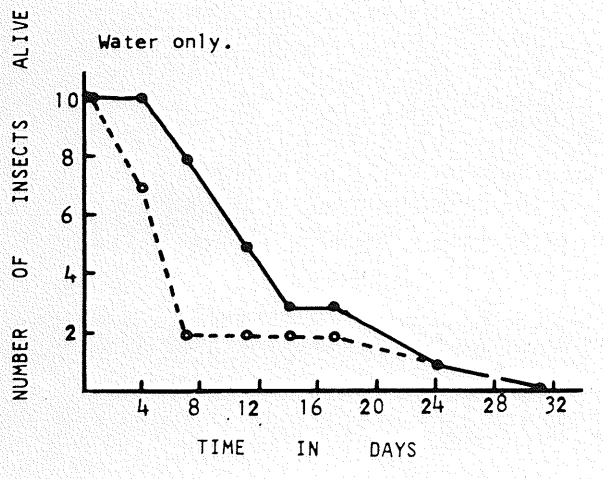


FIGURE 7 c.

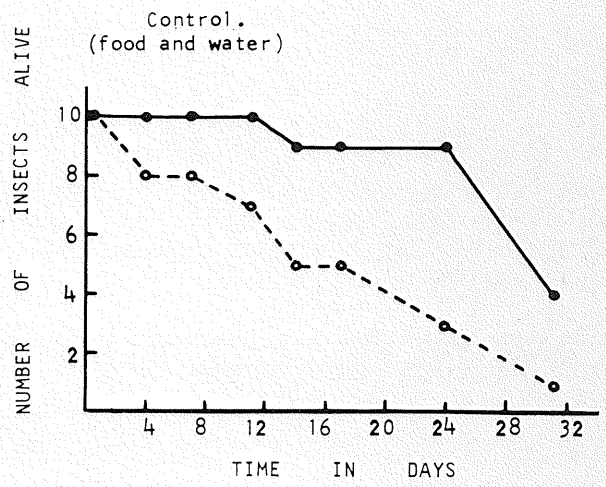


FIGURE 7 d.

FIGURE 7

THE SURVIVAL OF SECOND INSTAR NYMPHS OF Blattella germanica (Linn.) STARVED AT 10°C AND 30% R.H.

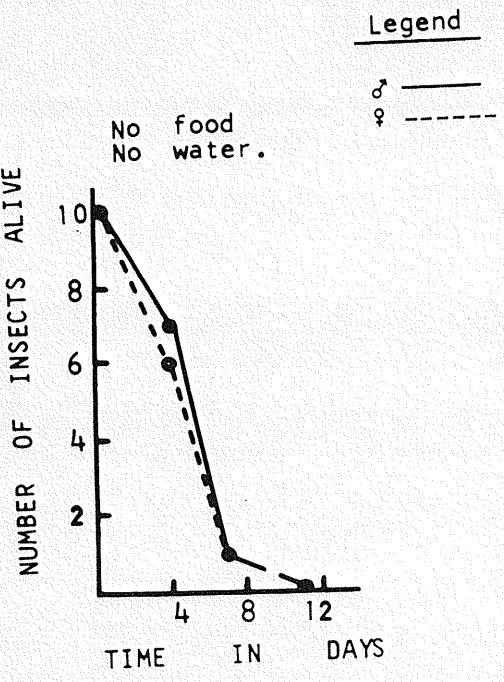


FIGURE 8 a.

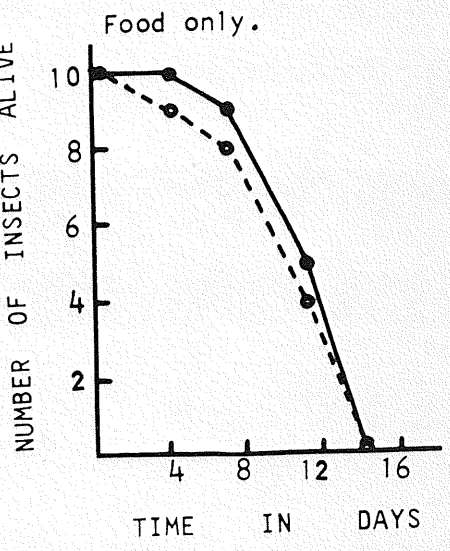


FIGURE 8 b.

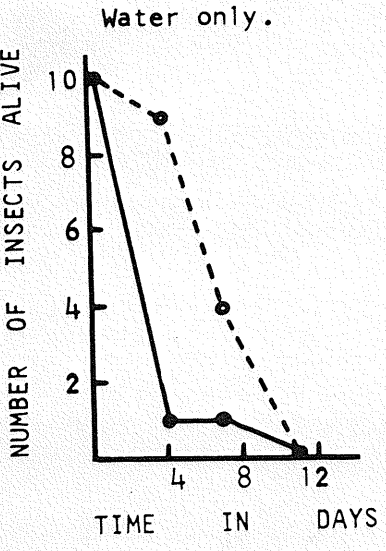


FIGURE 8 c.

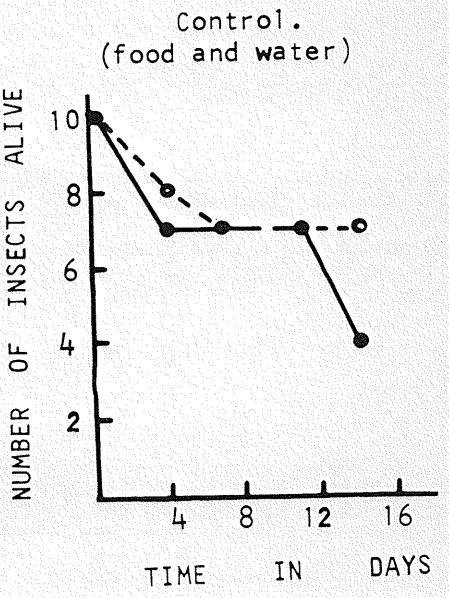


FIGURE 8 d.

FIGURE 8

THE SURVIVAL OF SECOND INSTAR NYMPHS OF Blattella germanica (Linn.) STARVED AT 26.7°C AND 70% R.H.

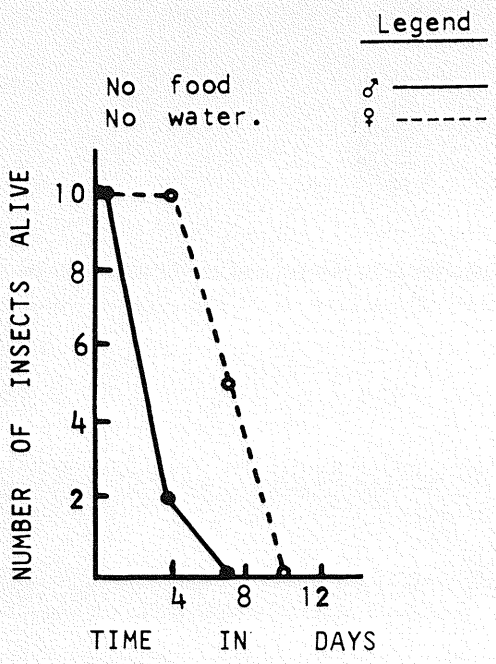


FIGURE 9 a.

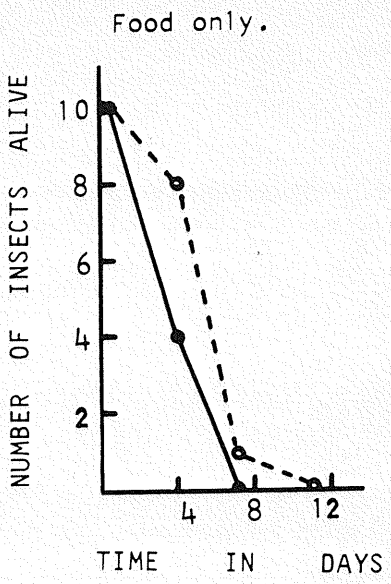


FIGURE 9 b.

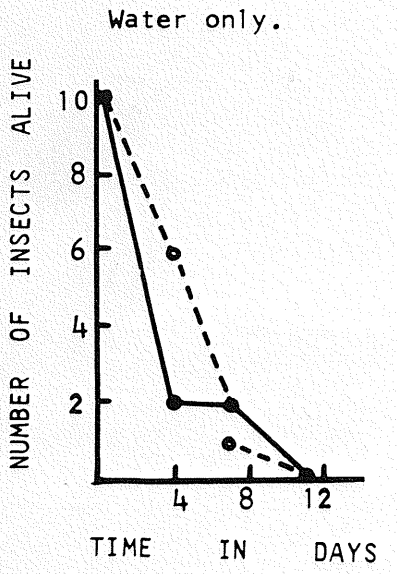


FIGURE 9 c.

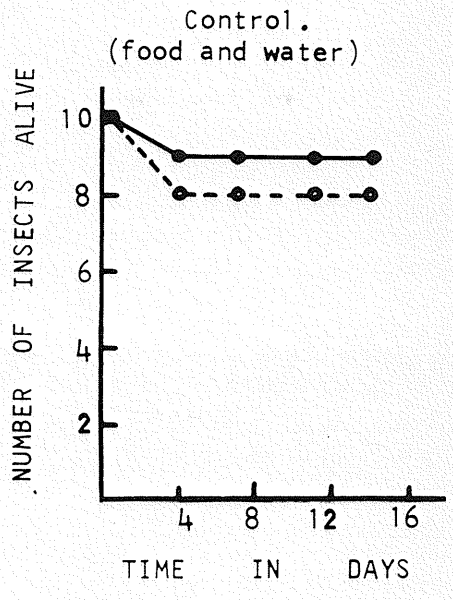


FIGURE 9 d.

FIGURE 9

THE SURVIVAL OF SECOND INSTAR NYMPHS OF Blattella germanica (Linn.) STARVED AT 26.7°C AND 30% R.H.

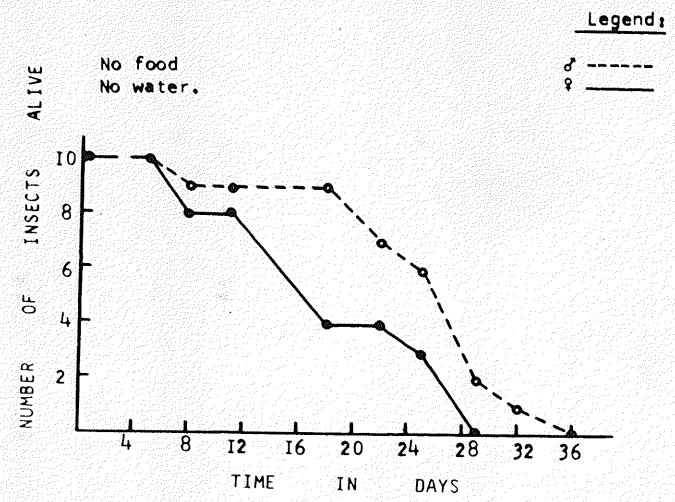
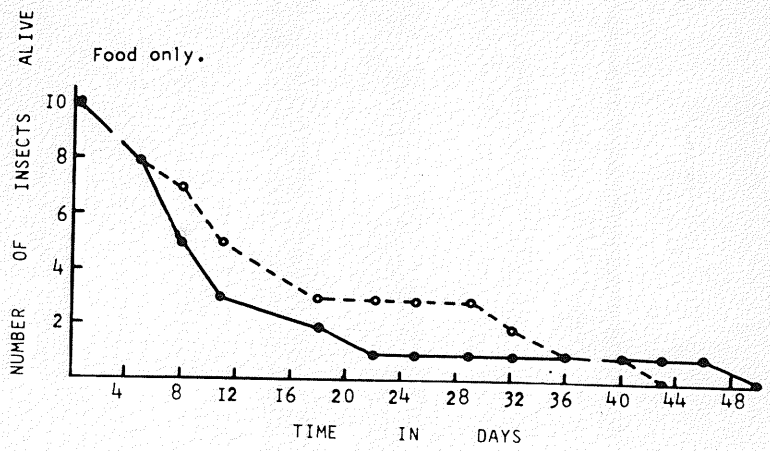


FIGURE 10 a.



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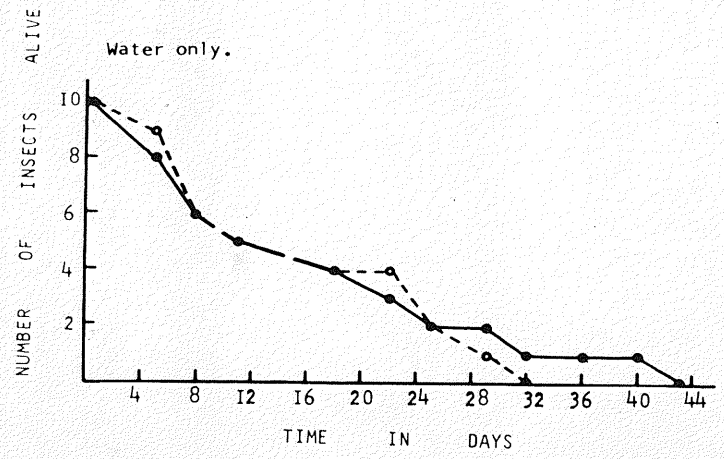


FIGURE 10 c.

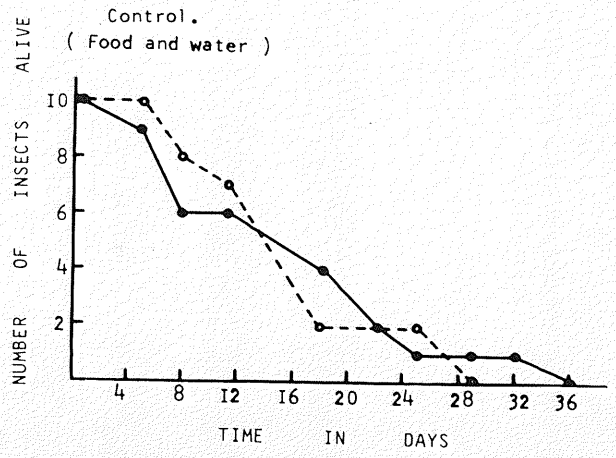


FIGURE 10 d.

FIGURE 10

THE SURVIVAL OF THIRD INSTAR NYMPHS OF Blattella germanica (Linn.) STARVED AT 10°C AND 70% R.H.

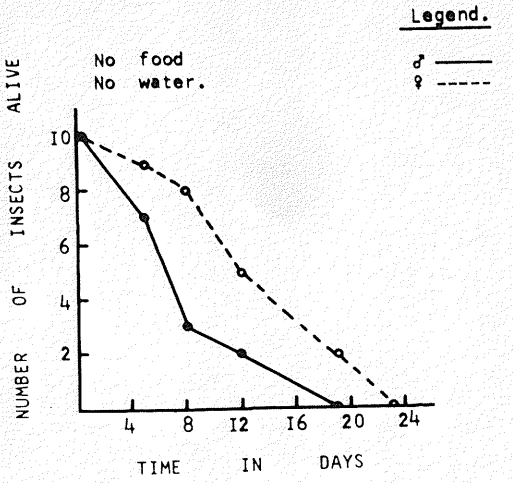


FIGURE 11 a.

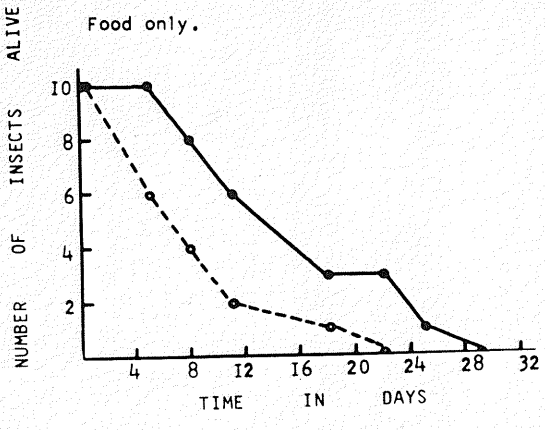


FIGURE 11 b.

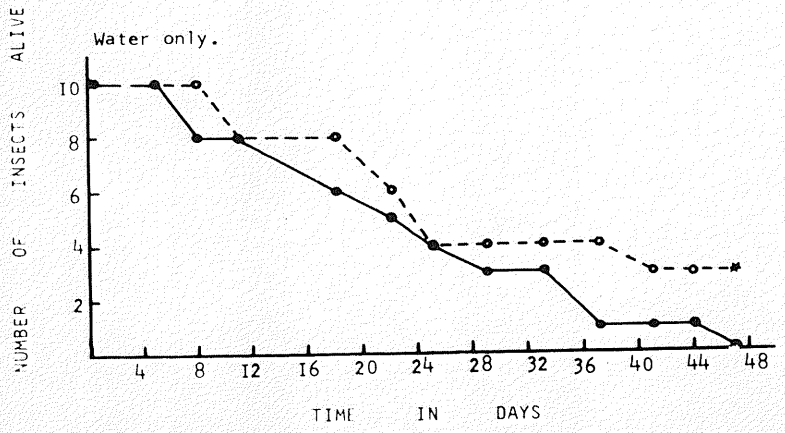


FIGURE 11 c.

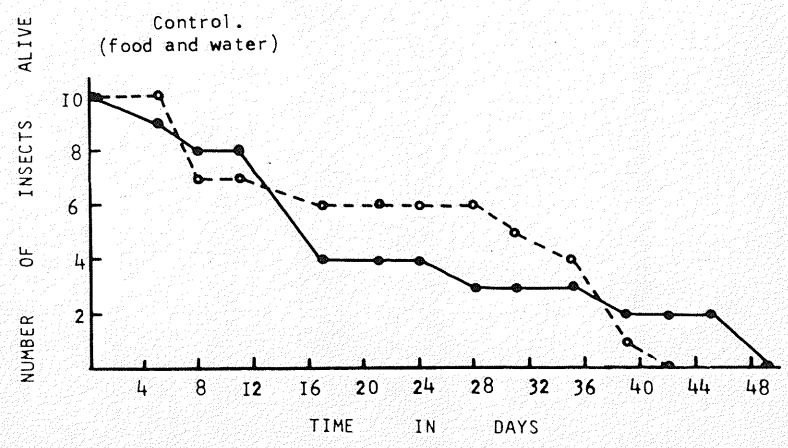


FIGURE 11 d.

FIGURE 11

THE SURVIVAL OF THIRD INSTAR NYMPHS OF Blattella germanica (Linn.)

STARVED AT 10°C AND 30% R.H. ✱ One ♀ survived 64 days.

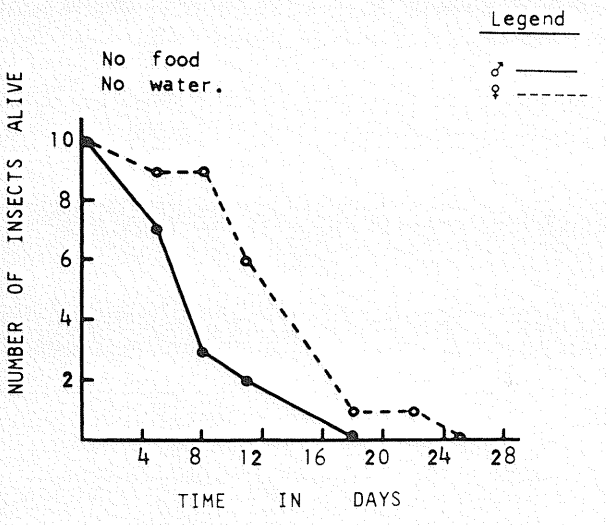


FIGURE 12 a.

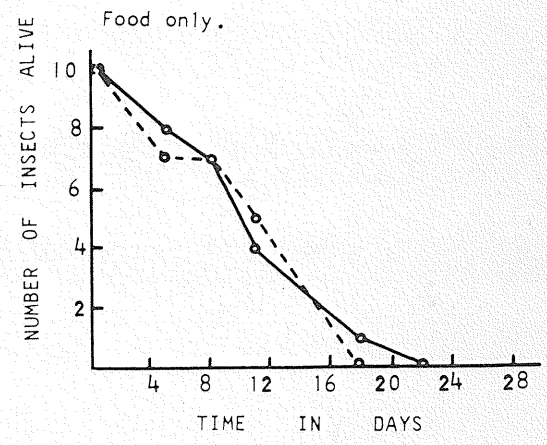


FIGURE 12 b.

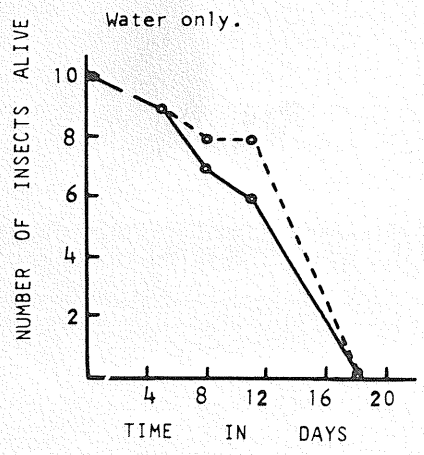


FIGURE 12 c.

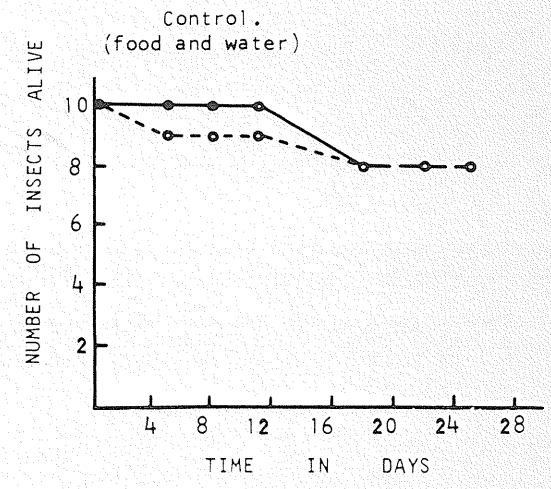


FIGURE 12 d.

FIGURE 12

THE SURVIVAL OF THIRD INSTAR NYMPHS OF Blattella germanica (Linn.) STARVED AT 26.7°C AND 70% R.H.

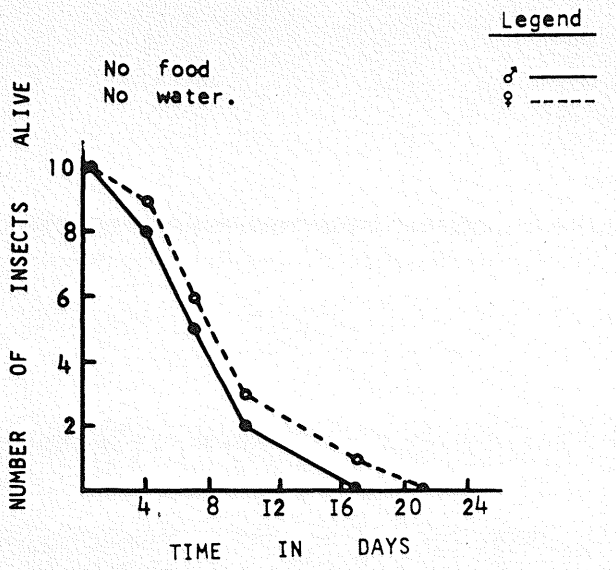


FIGURE 13 a.

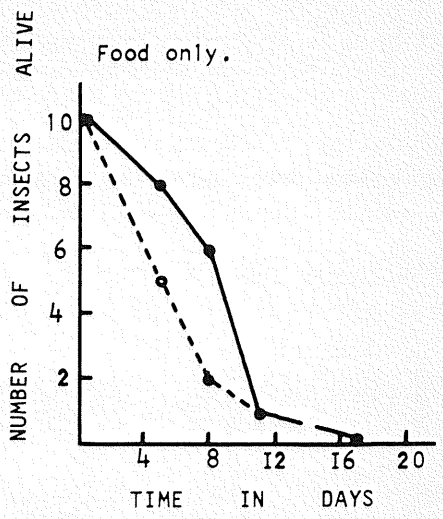


FIGURE 13 b.

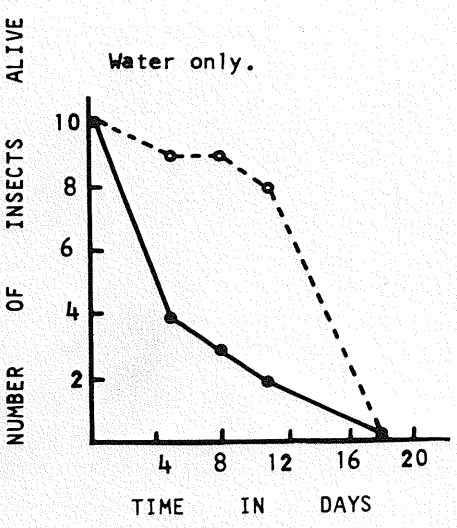


FIGURE 13 c.

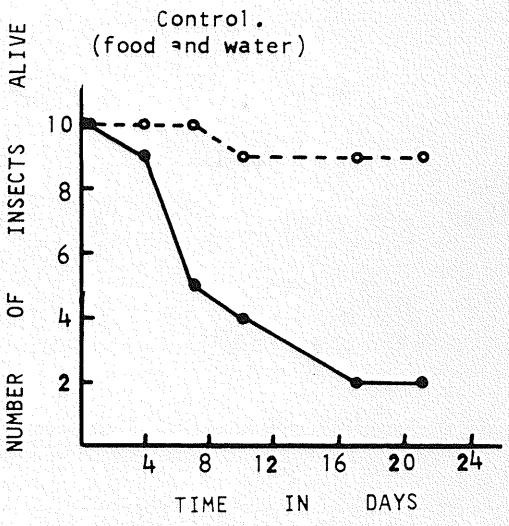


FIGURE 13 d.

FIGURE 13

THE SURVIVAL OF THIRD INSTAR NYMPHS OF Blattella germanica (Linn.) STARVED AT 26.7°C AND 30% R.H.

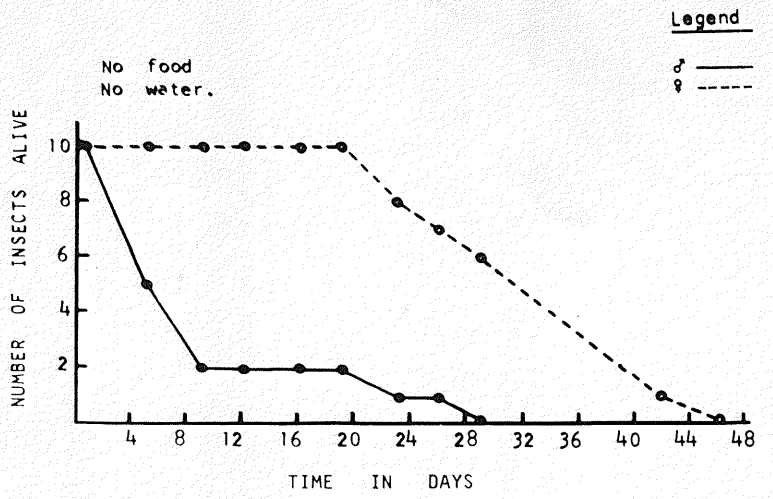


FIGURE 14 a.

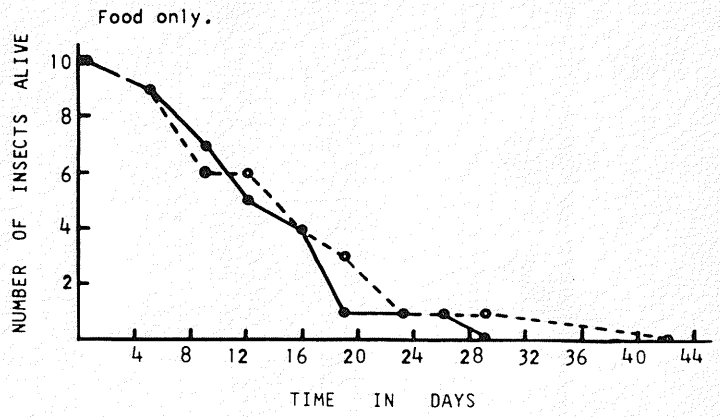


FIGURE 14 b.

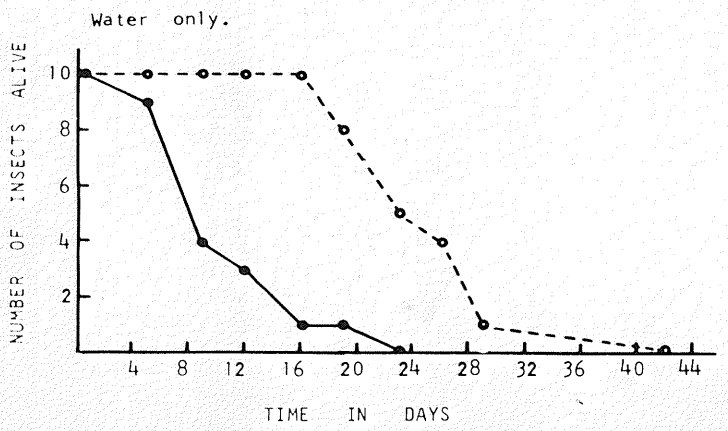


FIGURE 14 c.

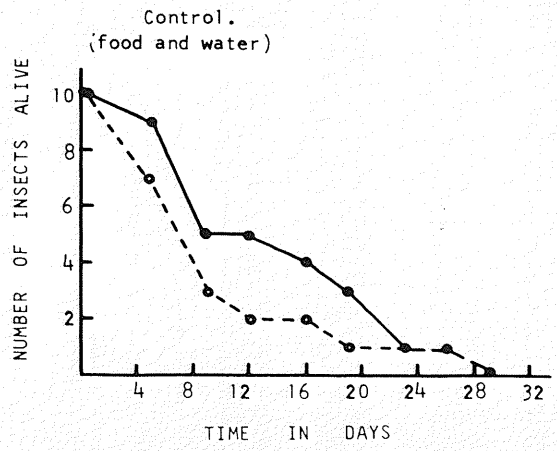


FIGURE 14 d.

FIGURE 14

THE SURVIVAL OF FOURTH INSTAR NYMPHS OF Blattella germanica (Linn.)

STARVED AT 10°C AND 70% R.H.

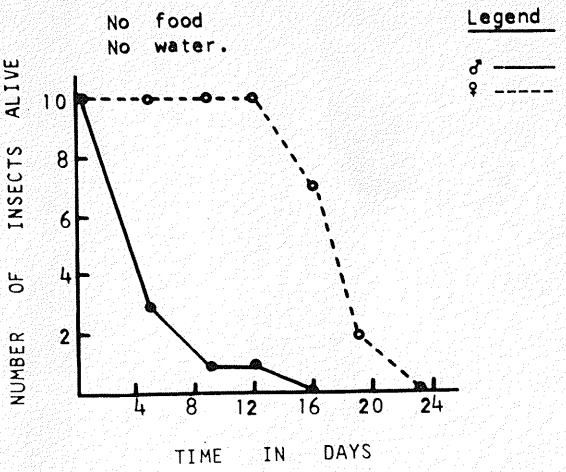


FIGURE 15 a.

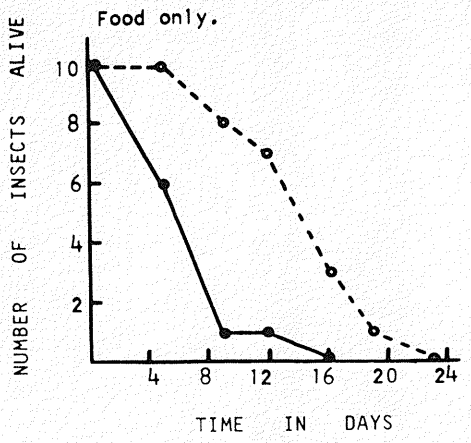


FIGURE 15 b.

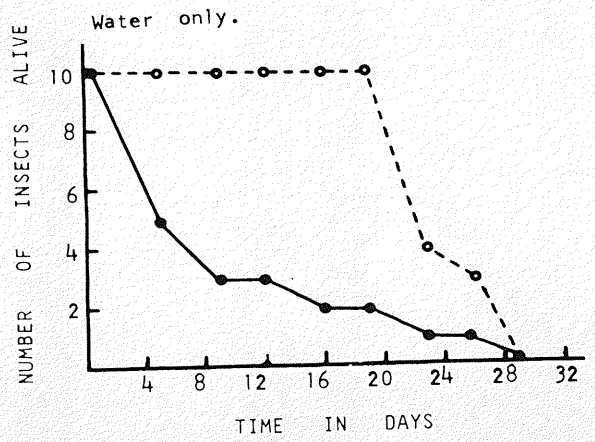


FIGURE 15 c.

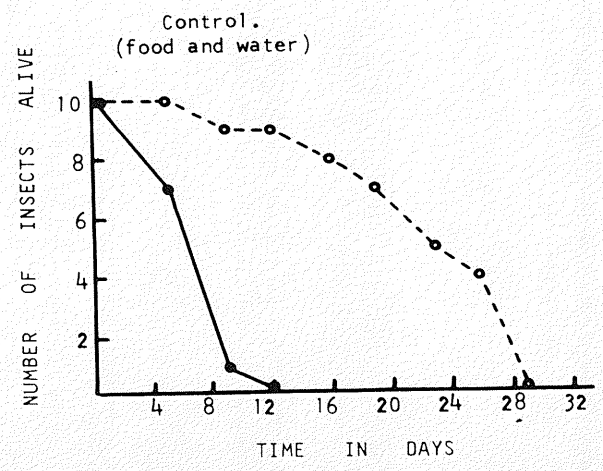


FIGURE 15 d.

FIGURE 15

THE SURVIVAL OF FOURTH INSTAR NYMPHS OF Blattella germanica (Linn.) STARVED AT 10°C AND 30% R.H.

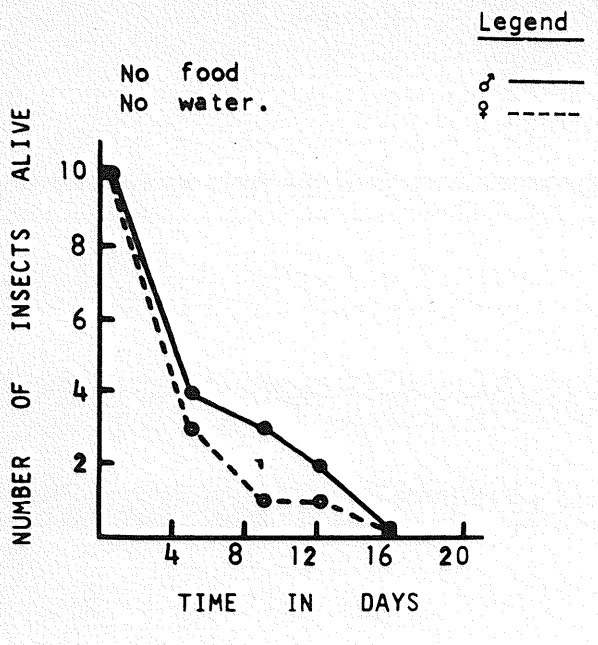


FIGURE 16 a.

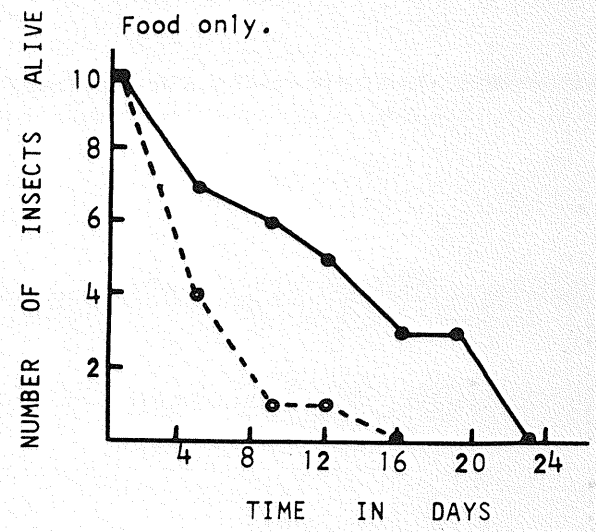


FIGURE 16 b.

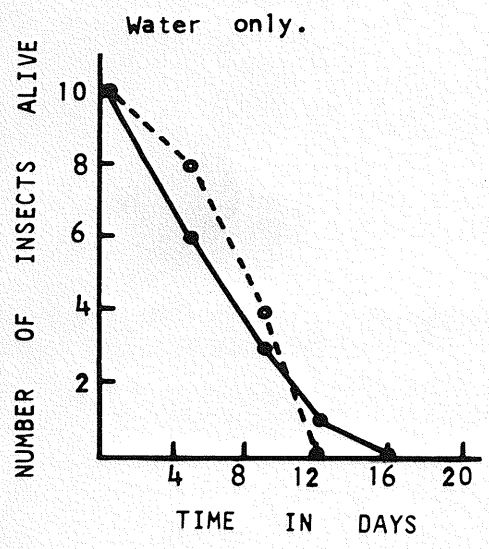


FIGURE 16 c.

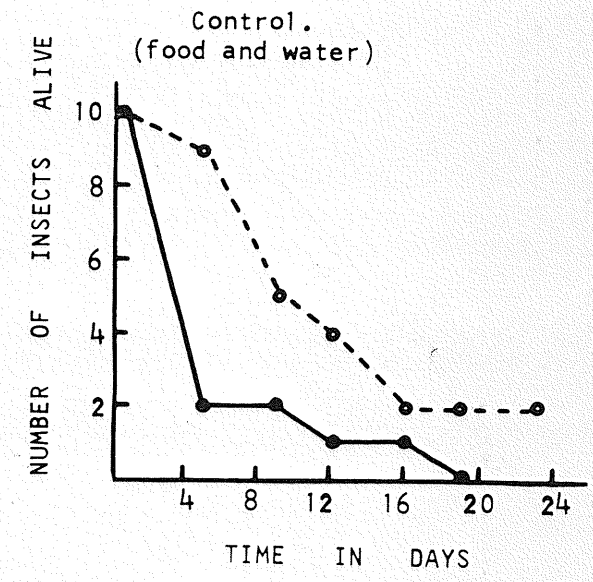


FIGURE 16 d.

FIGURE 16

THE SURVIVAL OF FOURTH INSTAR NYMPHS OF Blattella germanica (Linn.) STARVED AT 26.7°C AND 70% R.H.

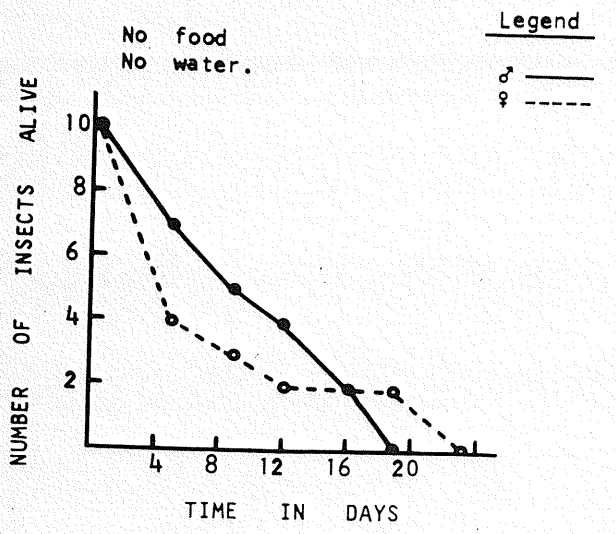


FIGURE 17 a.

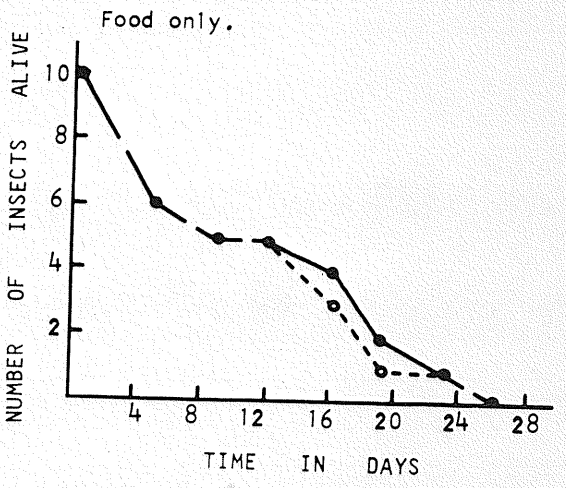


FIGURE 17 b.

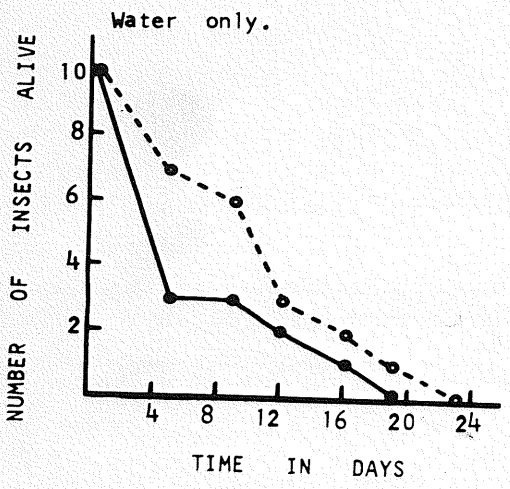


FIGURE 17 c.

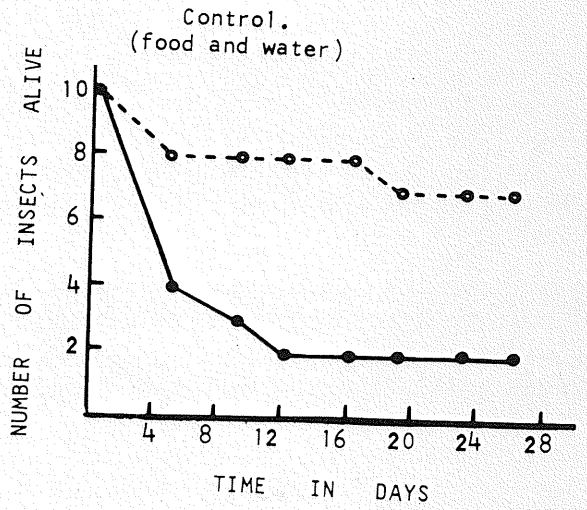


FIGURE 17 d.

FIGURE 17

THE SURVIVAL OF FOURTH INSTAR NYMPHS OF Blattella germanica (Linn.) STARVED AT 26.7°C AND 30% R.H.

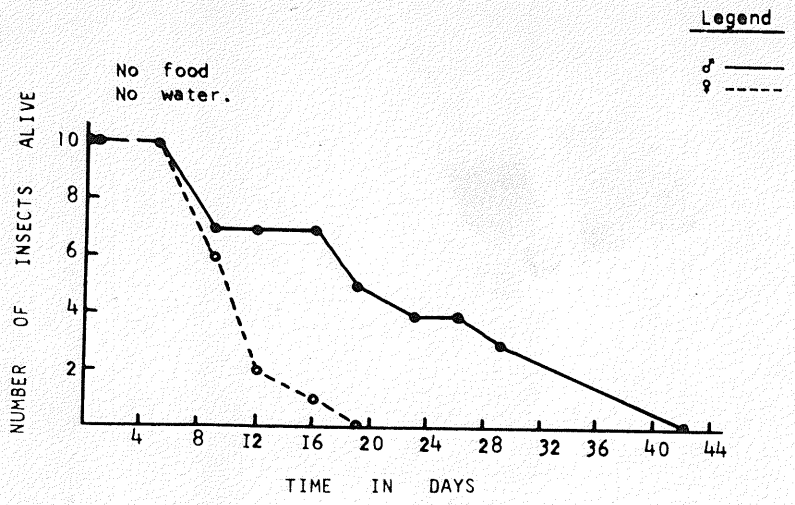


FIGURE 18 a.

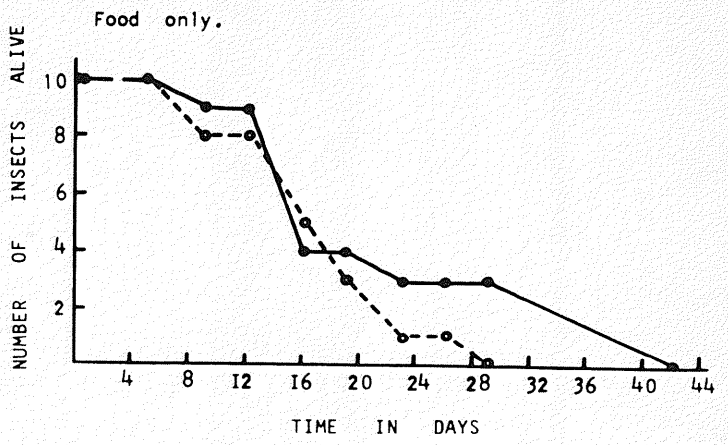


FIGURE 18 b.

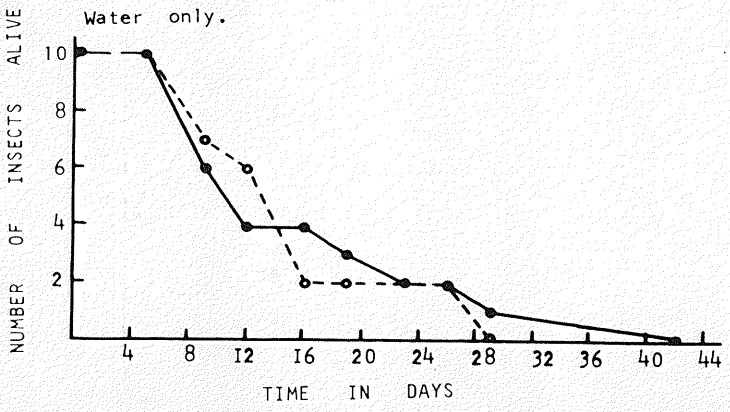


FIGURE 18 c.

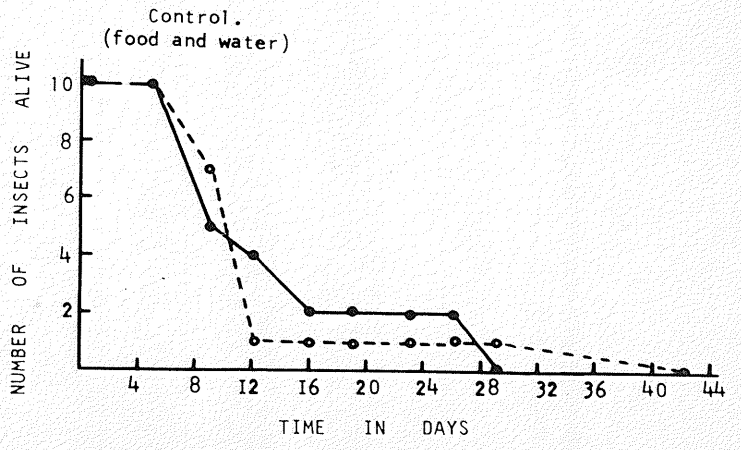


FIGURE 18 d.

FIGURE 18

THE SURVIVAL OF FIFTH INSTAR NYMPHS OF Blattella germanica (Linn.)

STARVED AT 10°C AND 70% R.H.

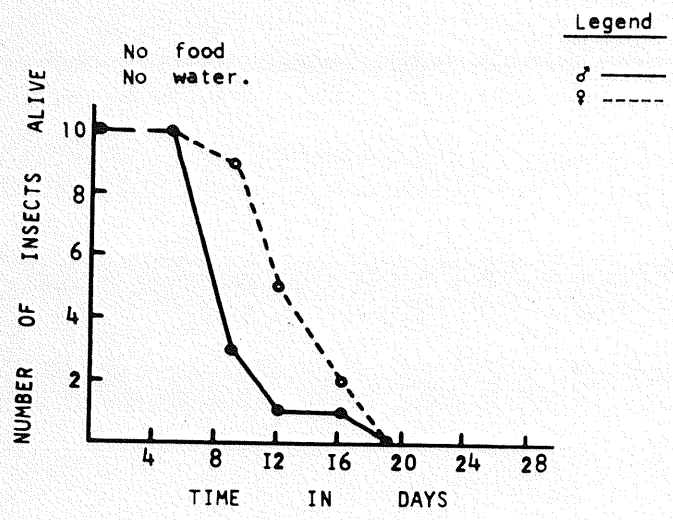


FIGURE 19 a.

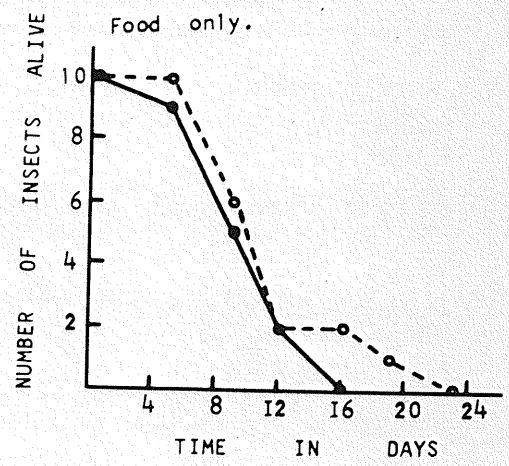


FIGURE 19 b.

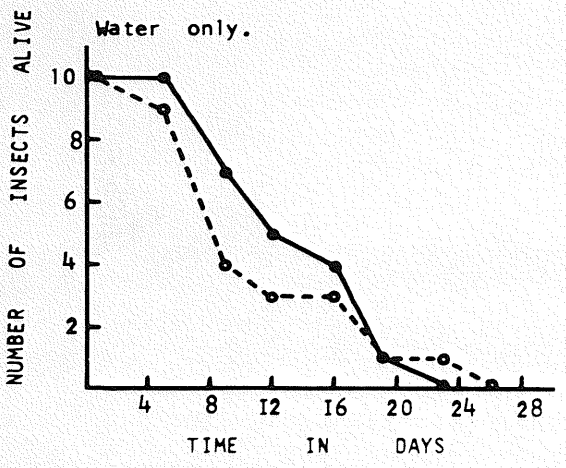


FIGURE 19 c.

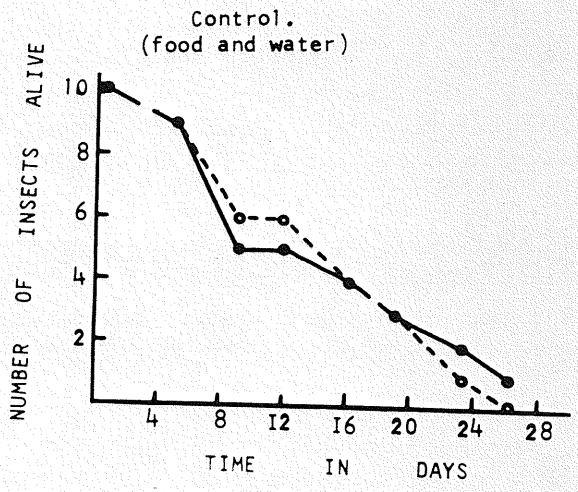


FIGURE 19 d.

FIGURE 19

THE SURVIVAL OF FIFTH INSTAR NYMPHS OF Blattella germanica (Linn.) STARVED AT 10°C AND 30% R.H.

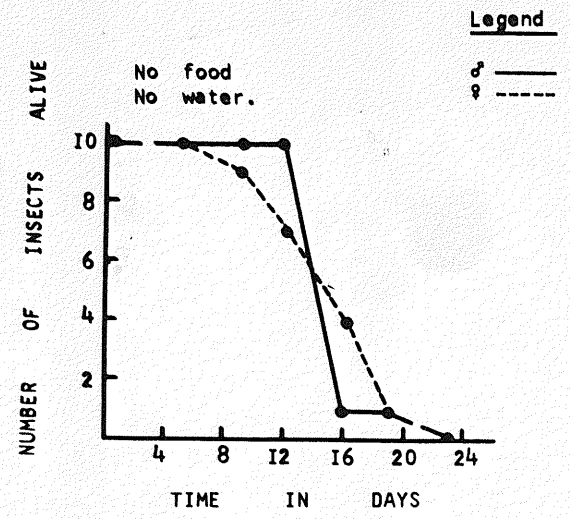


FIGURE 20 a.

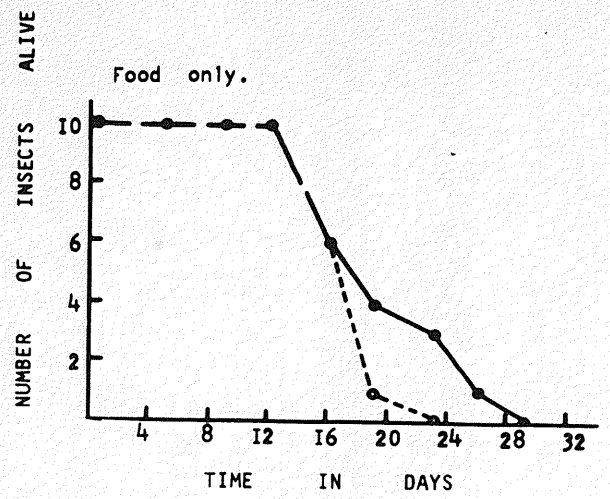


FIGURE 20 b.

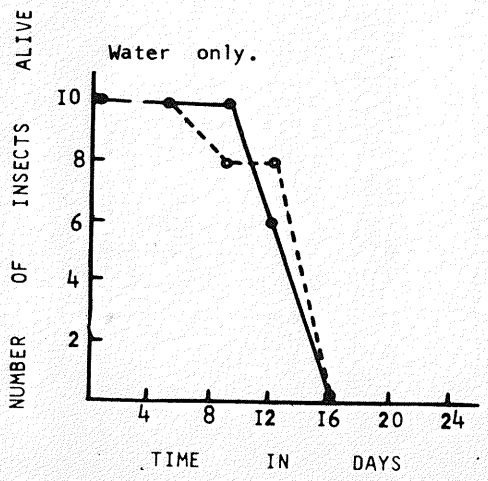


FIGURE 20 c.

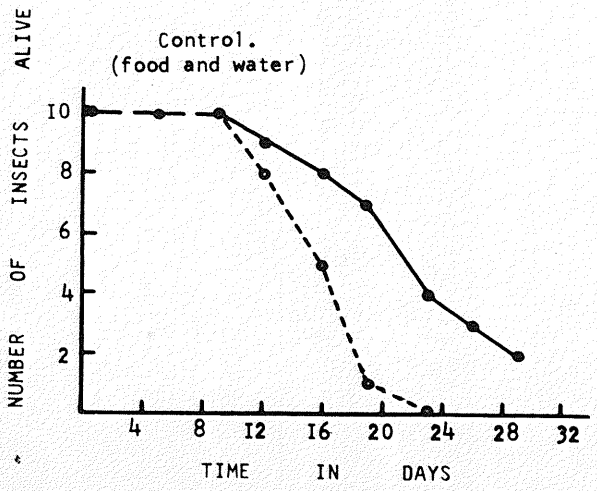


FIGURE 20 d.

FIGURE 20

THE SURVIVAL OF FIFTH INSTAR NYMPHS OF Blattella germanica (Linn.) STARVED AT 26.7°C AND 70% R.H.

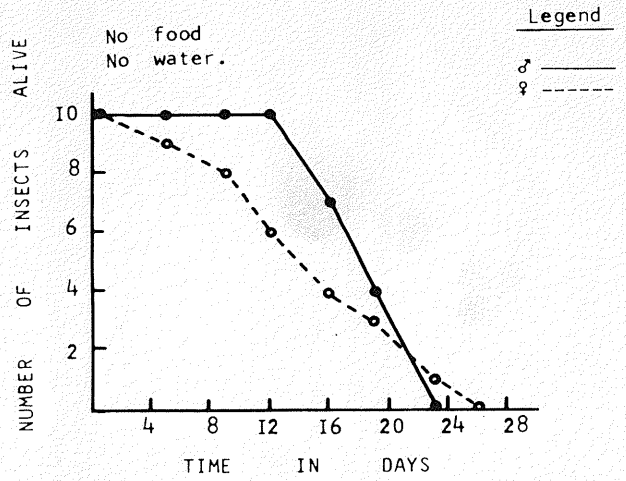


FIGURE 21 a.

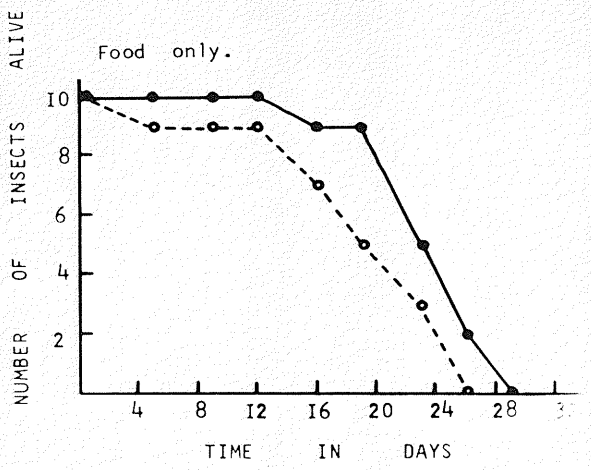


FIGURE 21 b.

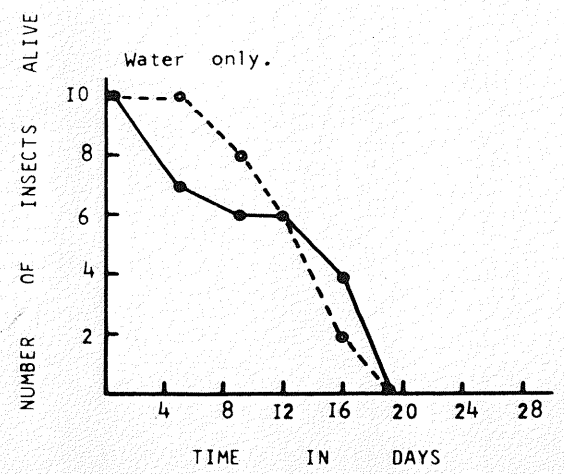


FIGURE 21 c.

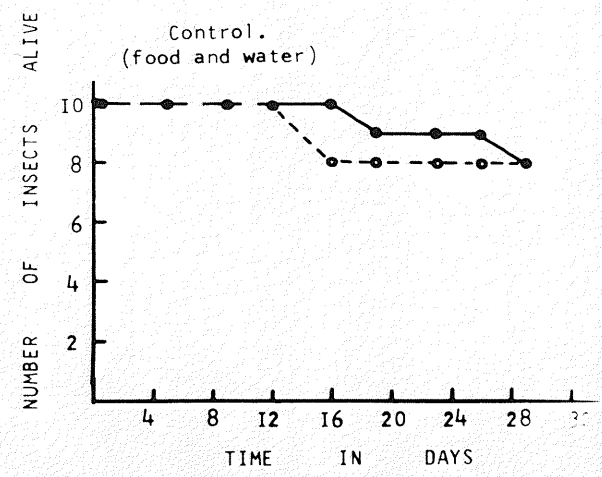


FIGURE 21 d.

FIGURE 21

THE SURVIVAL OF FIFTH INSTAR NYMPHS OF Blattella germanica (Linn.) STARVED AT 26.7°C AND 30% R.H.

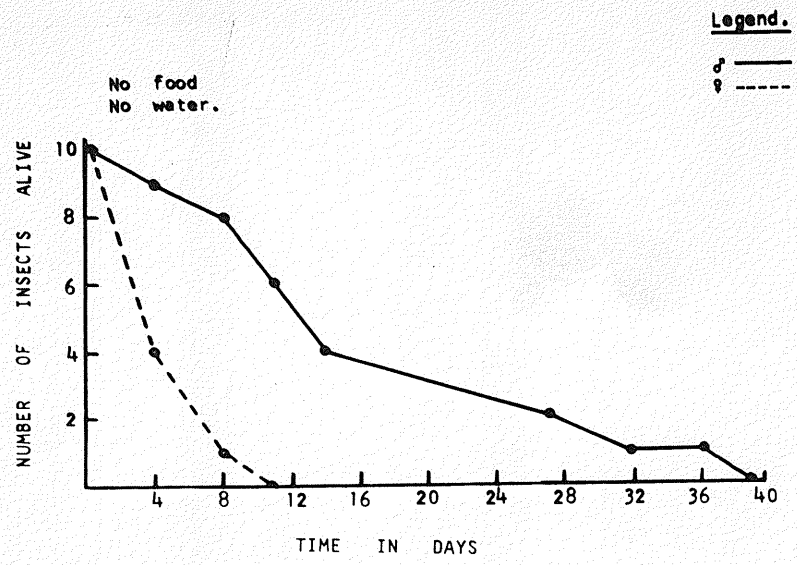
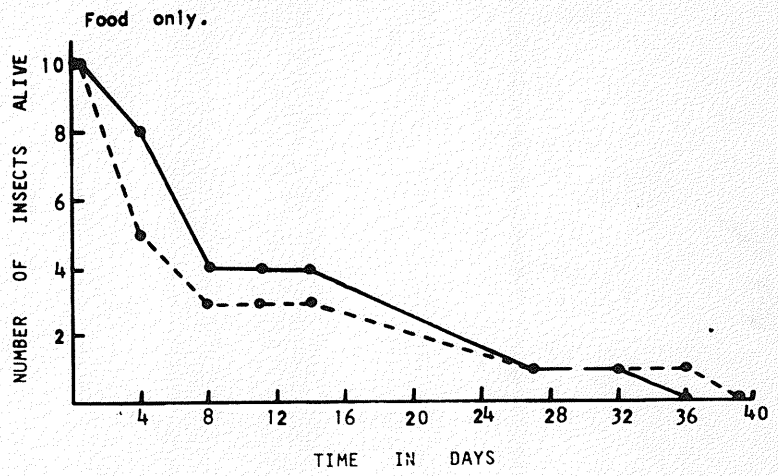


FIGURE 22 a.



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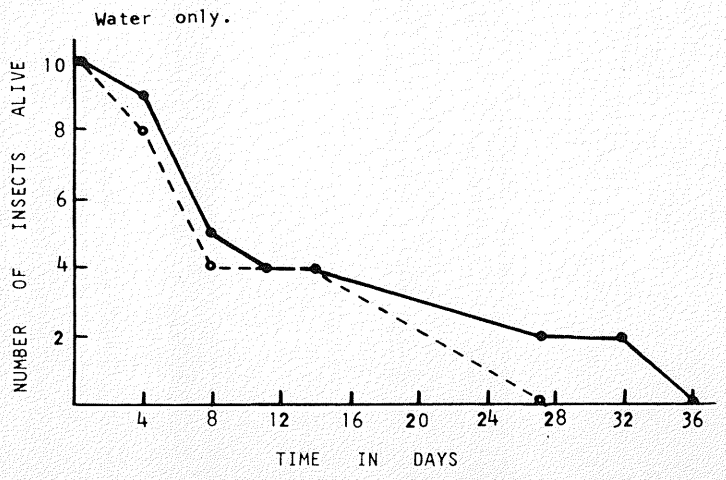

FIGURE 22 c.

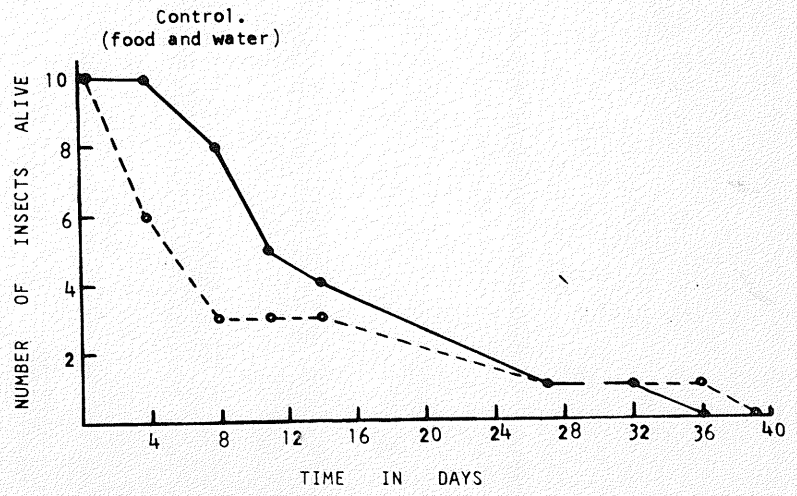

FIGURE 22 d.

FIGURE 22

THE SURVIVAL OF SIXTH INSTAR NYMPHS OF Blattella germanica (Linn.) STARVED AT 10°C AND 70% R.H.

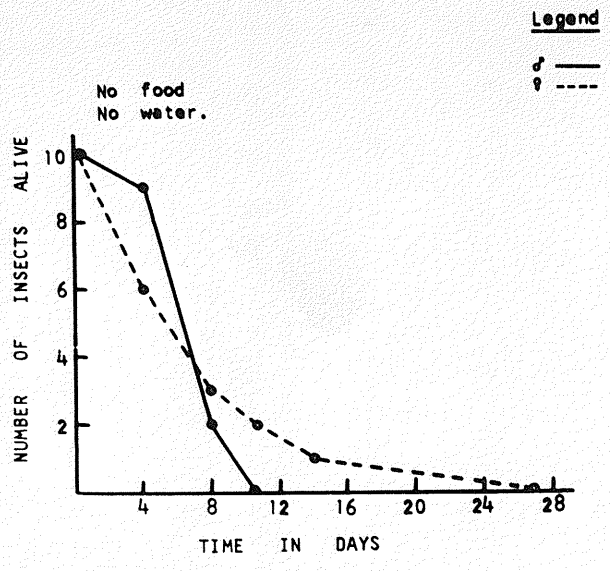

FIGURE 23 a.

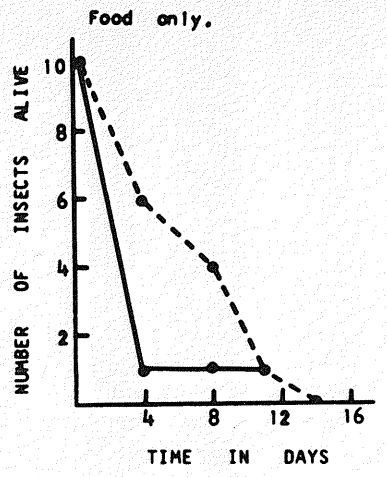

FIGURE 23 b.

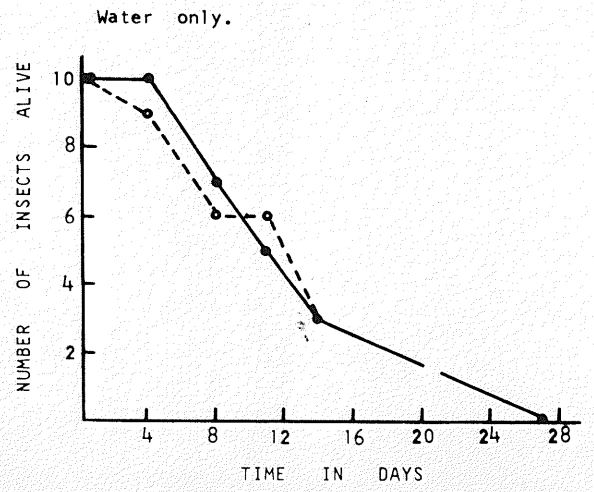

FIGURE 23 c.

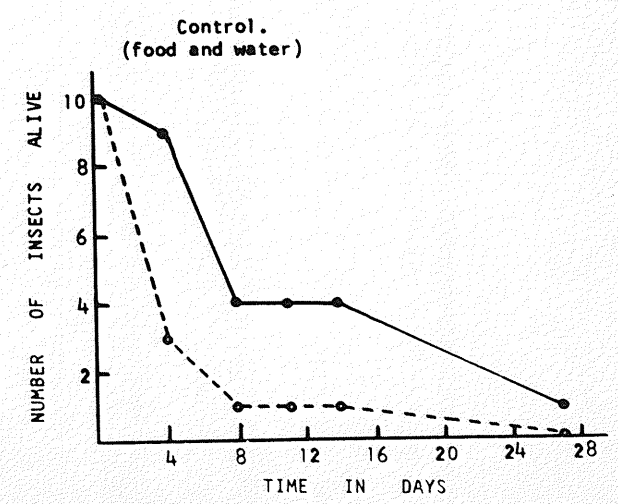

FIGURE 23 d.

FIGURE 23

THE SURVIVAL OF SIXTH INSTAR NYMPHS OF Blattella germanica (Linn.) STARVED AT 10°C AND 30% R.H.

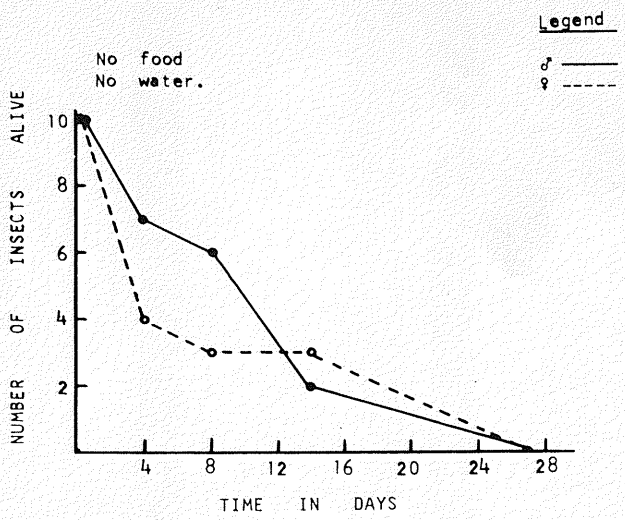

FIGURE 24 a.

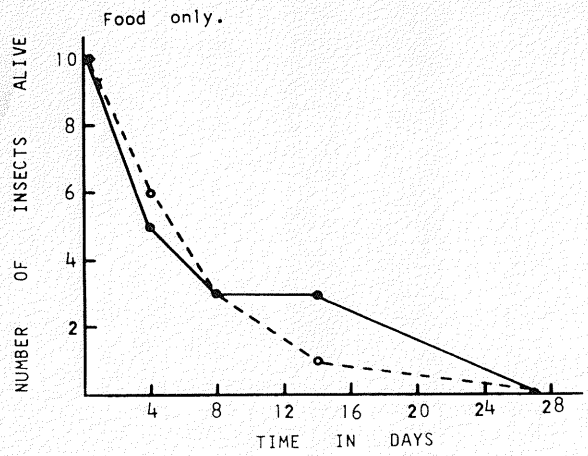

FIGURE 24 b.

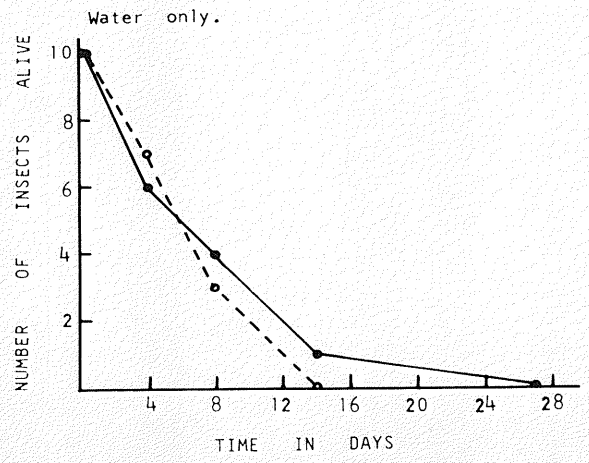

FIGURE 24 c.

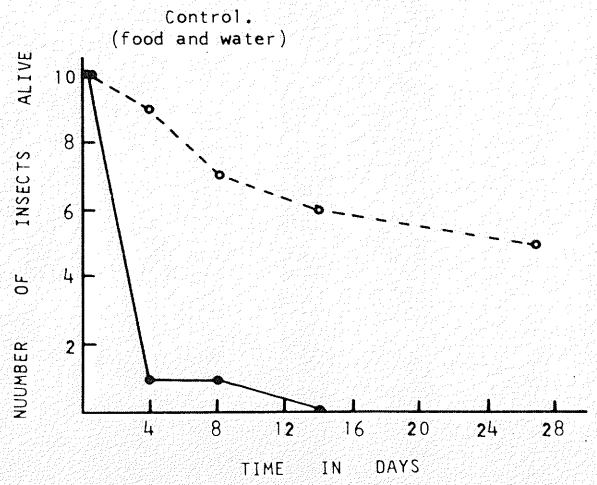

FIGURE 24 d.

FIGURE 24

THE SURVIVAL OF SIXTH INSTAR NYMPHS OF Blattella germanica (Linn.) STARVED AT 26.7°C AND 70% R.H.

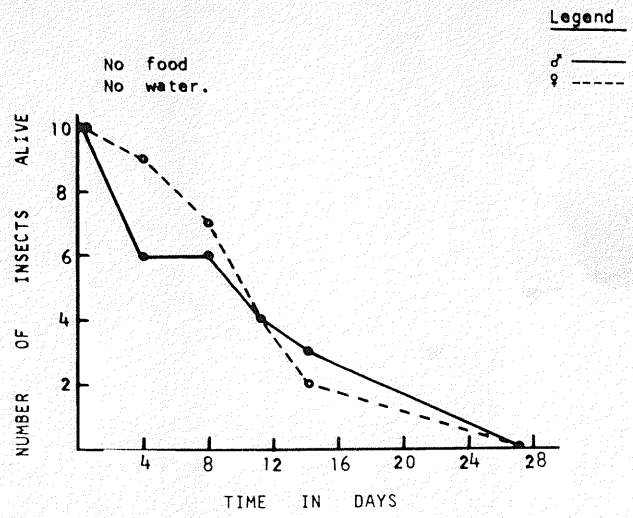

FIGURE 25 a.

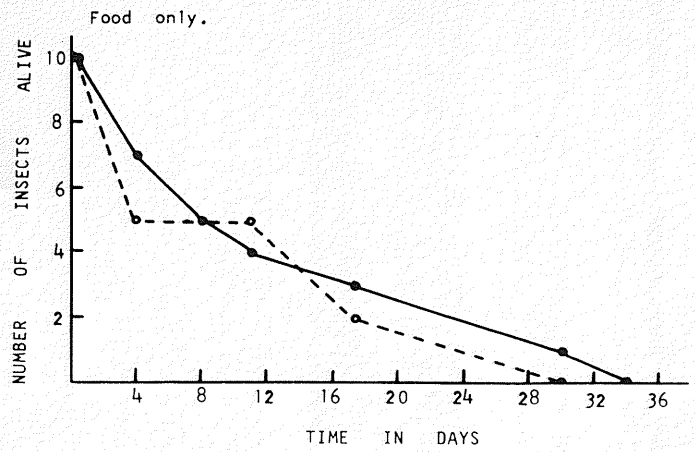

FIGURE 25 b.

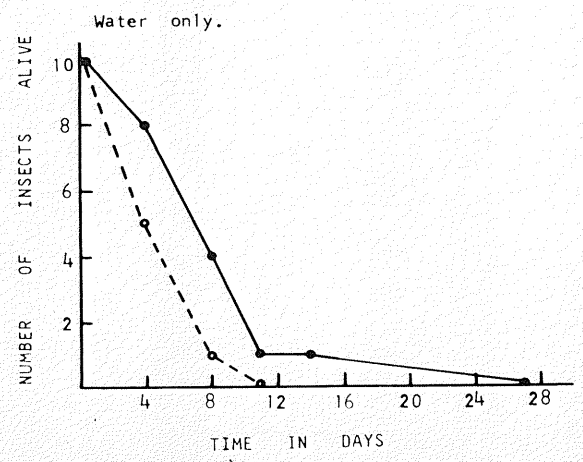

FIGURE 25 c.

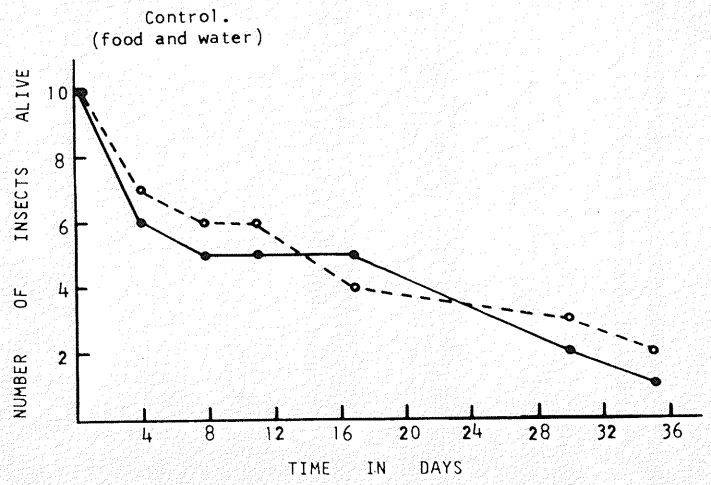

FIGURE 25 d.

FIGURE 25

THE SURVIVAL OF SIXTH INSTAR NYMPHS OF Blattella germanica (Linn.) STARVED AT 26.7°C AND 30% R.H.

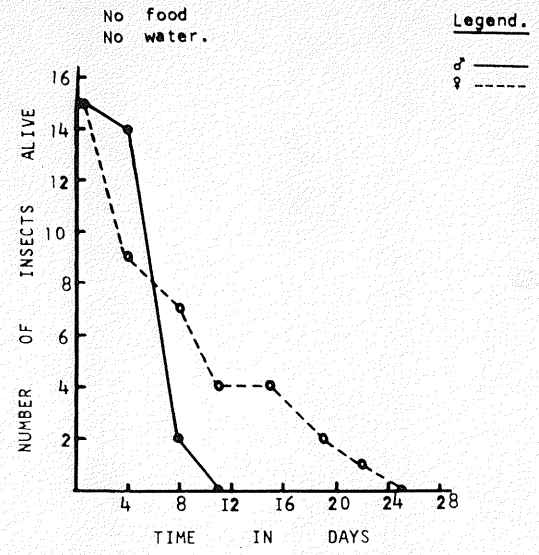

FIGURE 26 a.

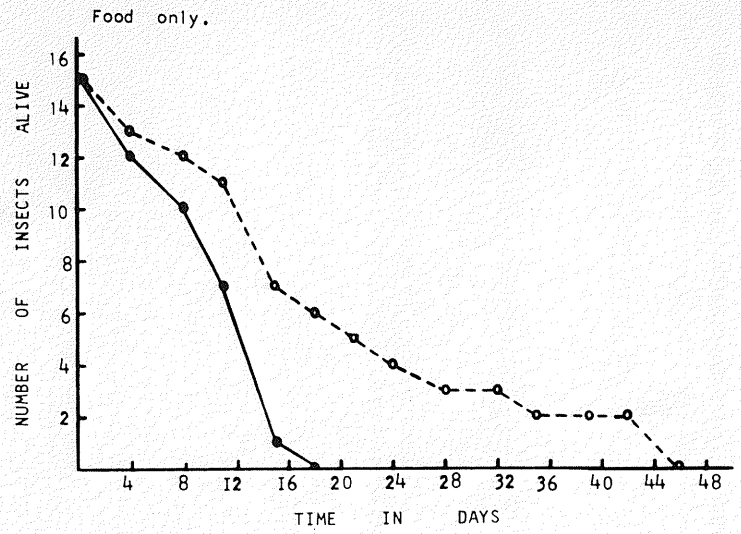

FIGURE 26 b.

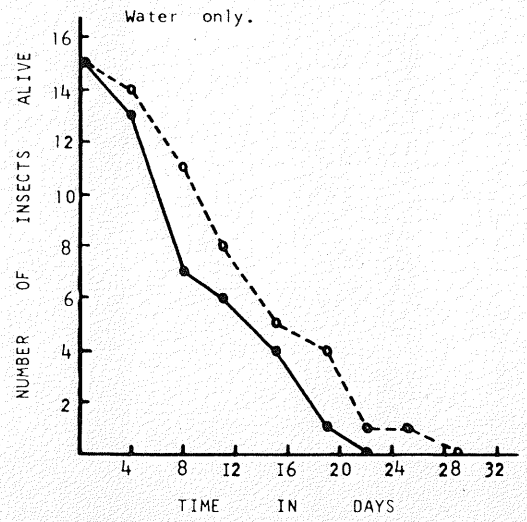

FIGURE 26 c.

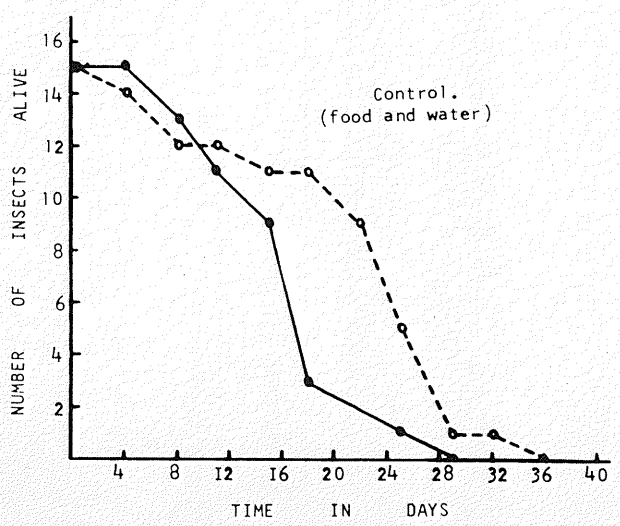

FIGURE 26 d.

FIGURE 26

THE SURVIVAL OF THE ADULT STAGE OF Blattella germanica (Linn.) STARVED AT 10°C AND 70% R.H.

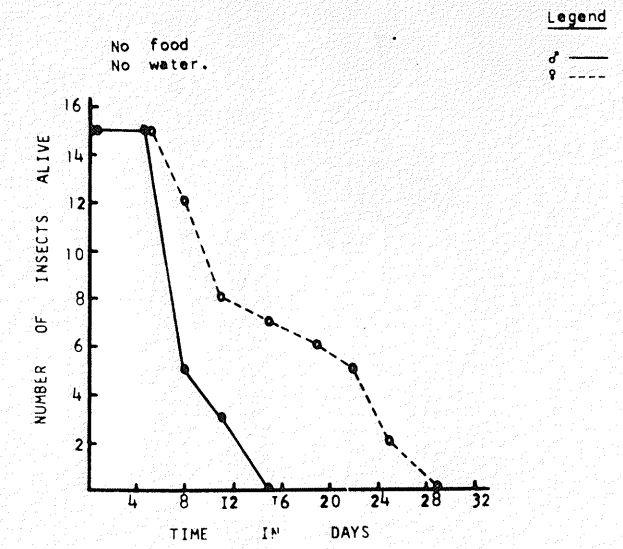

FIGURE 27 a.

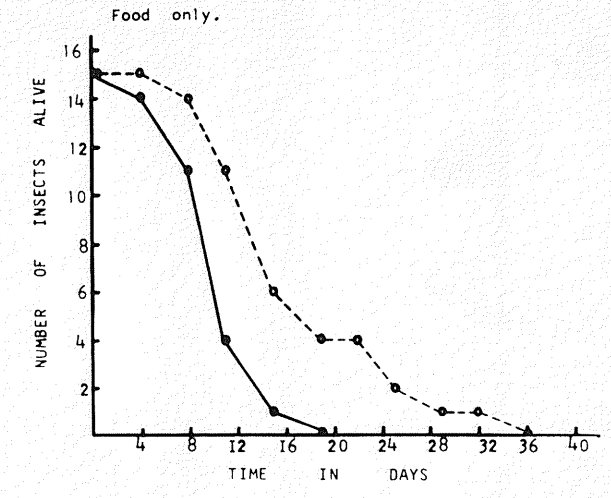

FIGURE 27 b.

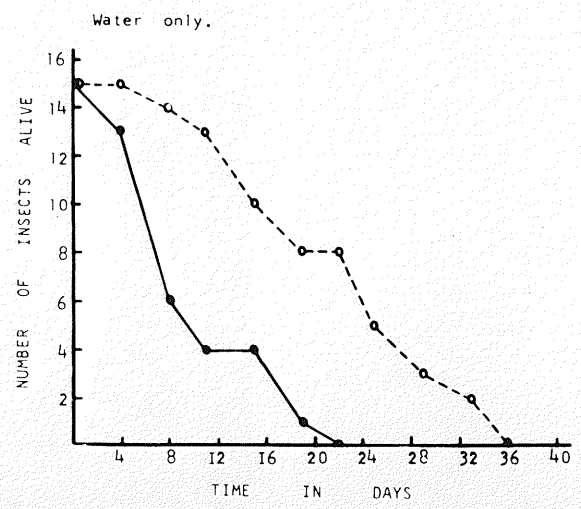

FIGURE 27 c.

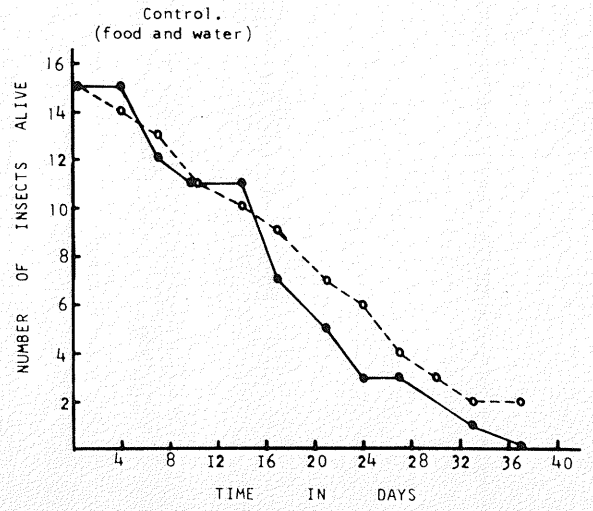

FIGURE 27 d.

FIGURE 27

THE SURVIVAL OF THE ADULT STAGE OF Blattella germanica (Linn.) STARVED AT 10°C AND 30% R.H.

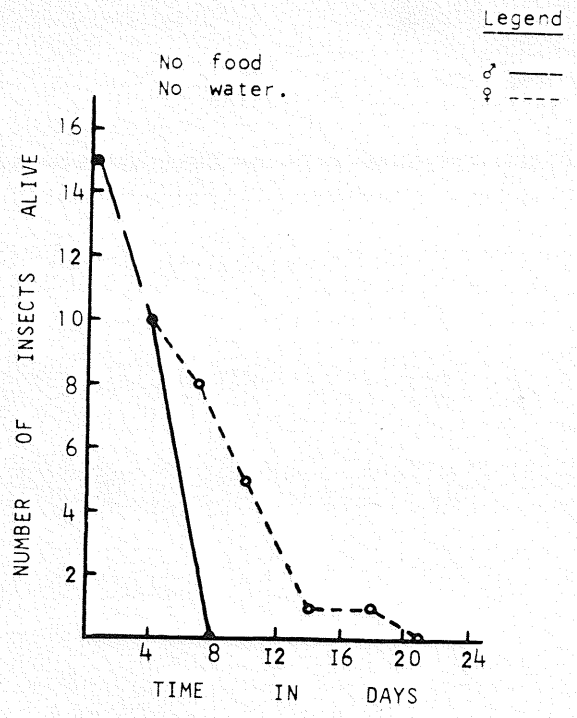

FIGURE 28 a.

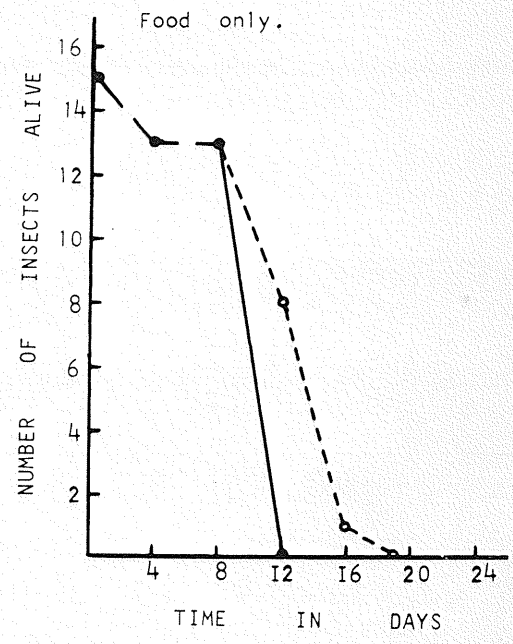

FIGURE 28 b.

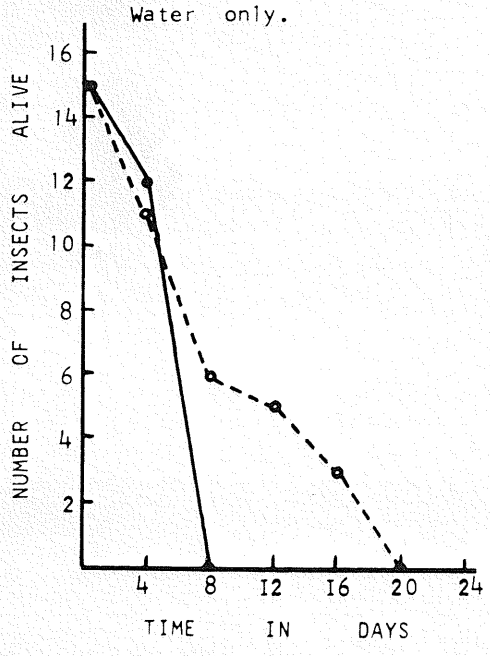

FIGURE 28 c.

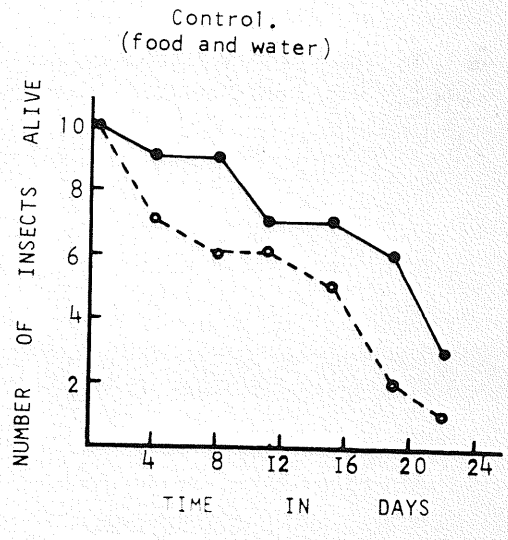

FIGURE 28 d.

FIGURE 28

THE SURVIVAL OF THE ADULT STAGE OF Blattella germanica (Linn.) STARVED AT 26.7°C AND 70% R.H.

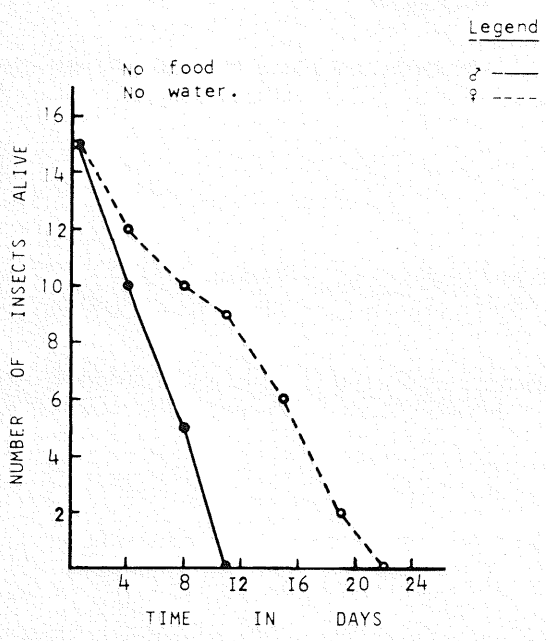

FIGURE 29 a.

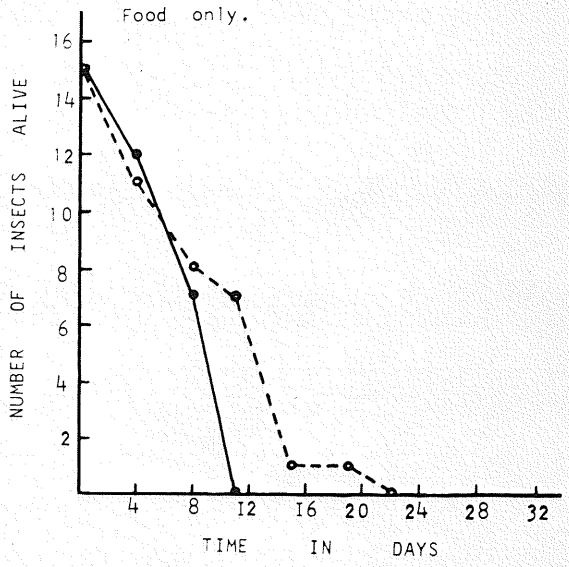

FIGURE 29 b.

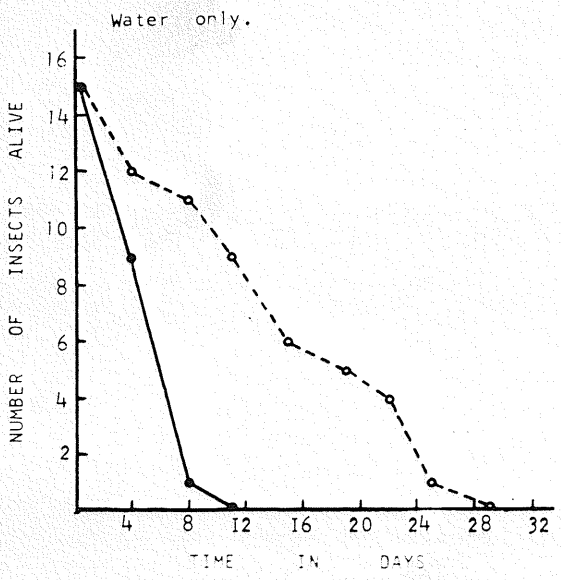

FIGURE 29 c.

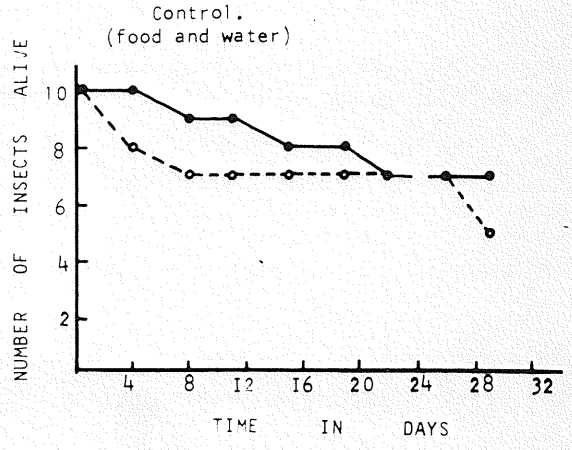

FIGURE 29 d.

FIGURE 29

THE SURVIVAL OF THE ADULT STAGE OF Blattella germanica (Linn.) STARVED AT 26.7°C AND 30% R.H.

(2) Fat and Water Loss

Some instars of the German cockroach survived long periods of starvation, as shown in Figures 2-29. Differences in survival indicate the role of temperature, humidity, sex, and food regimen. The ability of these insects to survive under starvation conditions must be attributed to some organic factor within the insect. One such factor could be the fat content. Since reserve fat is a major source of food and energy for the roaches when only water was available, its depletion would presumably result in death of the insect. This possibility was explored by extracting the ether soluble content from insects exposed to various starvation conditions. The per cent fat is calculated on the basis of the dry weight of the insect. A soxhlet extraction apparatus was used for fat extraction.

Water loss within the insect's tissues could also contribute to mortality when free water was not available. This would be expressed particularly at high temperatures and low humidities. The water content of the insects before and after treatment was obtained by dehydration under vacuum at 80°C. The fat and water content of cockroaches on various restricted diets is summarized in Table VI.

TABLE VI

THE PER CENT WATER AND FAT OF ADULT GERMAN COCKROACHES KEPT ON RESTRICTED DIETS AT 70% R.H.

Food Regime	Interval in Days	26.7°C. ♂ Average Weight (in Mg.)	26.7°C. ♂ % Moisture	26.7°C. ♂ % Fat	26.7°C. ♀ Average Weight (in Mg.)	26.7°C. ♀ % Moisture	26.7°C. ♀ % Fat	10°C. ♂ Average Weight (in Mg.)	10°C. ♂ % Moisture	10°C. ♂ % Fat	10°C. ♀ Average Weight (in Mg.)	10°C. ♀ % Moisture	10°C. ♀ % Fat
Control	0	54.5	62.0	3.9	77.3	65.0	9.6	54.5	62.0	3.9	77.3	65.0	9.6
	7	61.7	65.2	7.0	77.0	51.7	16.7	54.9	69.2	21.3	109.1	63.5	31.2
	15	59.6	66.6	1.5	64.2	56.9	1.1	50.7	73.2	2.2	103.2	65.1	21.7
	23	67.4	62.8	4.0	83.1	64.3	8.1	48.5	69.9	3.4	105.0	65.1	22.4
Water Only	0	54.5	62.0	3.9	77.3	65.0	9.6	54.5	62.0	3.9	77.3	65.0	9.6
	7	48.5	66.8	4.3	81.1	61.9	9.4	51.2	71.9	6.9	111.1	63.2	25.7
	15	-	-	-	86.5	67.6	1.1	54.6	74.0	1.4	103.7	65.2	26.3
	23	-	-	-	77.8	64.5	5.4	45.5	69.9	7.3	105.3	64.1	25.9
Food Only	0	54.5	62.0	3.9	77.3	65.0	9.6	54.5	62.0	3.9	77.3	65.0	9.6
	7	38.1	57.5	1.9	58.4	51.9	10.0	51.7	57.4	4.5	99.1	63.4	21.5
	15	-	-	-	56.5	60.2	0.0*	43.3	72.3	0.0*	95.4	62.1	16.6
	23	-	-	-	-	-	-	-	-	-	80.6	63.0	11.7
No Food	0	54.5	62.0	3.9	77.3	65.0	9.6	54.5	62.0	3.9	77.3	65.0	9.6
	7	36.5	56.4	5.0	60.9	58.3	15.7	55.4	62.8	9.2	100.4	62.3	29.0
No Water	15	-	-	-	65.5	59.5	7.5	48.3	67.9	1.3	85.2	66.2	22.6
	23	-	-	-	-	-	-	-	-	-	82.6	62.5	25.2

- No Survivors

* The author cannot explain the reason for a 0.0% fat content.

The results were analyzed by the factorial arrangement of treatments (Snedecor, 1957). The per cent fat and per cent water content of only the females was analyzed because the mortality of the males at 26.7°C. during the second week of the test was so high that enough replicates could not be obtained for reliable analysis.

Table VI A. The analysis of variance for per cent fat content of female German cockroaches kept on restricted diets for various durations (intervals).

Sources of Variance	df	SS	Mean Square	cal. F	Tabulated F Value (5%)
Replication	4	384.81			
Food regime (Treatment)	3	128.94	42.98	1.32	2.72
Interval (I)	2	1,883.29	941.64	28.88*	3.11
Temperature (T)	1	2,795.44	2,795.44	85.75*	3.96
TrT x I	6	454.39	75.73	2.32*	2.21
TrT x T	3	261.83	87.28	2.68	2.72
I x T	2	1,847.70	923.85	28.34*	3.11
TrT x I x T	6	0	0		
Error	84	2,738.22	32.60		

Table VI B. The analysis of variance for per cent water content of female German cockroaches kept on restricted diets for various durations (intervals) at 26.7°C.

Sources of Variance	df	SS	Mean Square	Cal. F	Tabulated F Value (5%)
Replication	4	49.66	12.42	.14	
Food regime (Treatment)	3	516.88	172.29	2.00	2.86
Interval (I)	2	502.46	251.23	2.91	3.26
I x TrT	6	286.55	47.76	.55	2.36
Error	36	3,105.50	86.26		

On the basis of analysis of variance (Table VI A and VI B) the female cockroaches kept at 10°C. had a significantly higher per cent fat content over a fifteen-day period than those kept at 26.7°C. There appeared to be a rise in per cent fat at 10°C. but a decrease at 26.7°C. The greater metabolic activity at the higher temperature could account for the decrease in per cent fat. Since no females in the experiment laid eggs except in the control, egg production did not contribute to any difference in percentage of fat in the females.

There was no decrease in the per cent of water and body weight over the fifteen-day test period even at the higher temperature when water was provided. The data are not sufficiently extensive to provide an estimate of the loss of body weight during the test period. However, it must be inferred that body weight was lost on the restricted diets.

(3) Oviposition Under Starvation Conditions

Under starvation conditions female German cockroaches were unable to form eggs. Although sexes were kept separate in the test experiments, the females already would have been mated in the cultures. At 26.7°C. and adequate diet the females developed egg capsules and the nymphs hatched successfully. At 10°C. and adequate diet the females did not develop eggs. No egg capsules developed under restricted diets at any temperature.

(4) Water Loss in the Oothecae

As was mentioned under the review of literature previous authors (Ross, 1929 etc.) were in disagreement as to the most suitable time for manually removing oothecae and as to the adequate temperature and humidity conditions required for successful hatching of the eggs.

Roth and Willis (1955) showed that water loss from the oothecae was least on the first and seventh day of their appearance on the females. When the egg capsules were removed on the first and after the seventh day and maintained at 90% relative humidity and 80°F., there was about a 50% hatch. Egg capsules removed on the second to sixth day did not hatch.

In this study the egg capsules were removed when they were one day old and placed at several temperatures and humidities. The water loss was determined at each temperature and humidity (Table VII).

Ninety-six per cent hatch occurred in 13 to 17 days at 26.7°C. and saturated conditions. No hatching occurred at 10°C. or lower.

TABLE VII

THE TOTAL WEIGHT LOSS OF ONE-DAY OLD GERMAN COCKROACH OOTHECAE WHEN EXPOSED TO VARIOUS TEMPERATURES AND HUMIDITIES OVER A 13-DAY PERIOD

	Per Cent Weight Loss					
Relative Humidity	26.7°C.	21.1°C.	15.6°C.	10°C.	4.4°C.	-1.1°C.
30%	34.1	34.2	26.9	18.9	8.8	8.9
Saturated	6.3	10.4	6.8	3.9	3.8	4.1

Table VII shows that a considerable loss of water occurs at 30% relative humidity at high temperatures. No hatch occurred at this humidity at temperatures from 26.7°C. to -1.1°C. Under saturated conditions the water loss was much lower. It is presumed that the loss in weight was entirely due to water loss.

It was also interesting to note that by removing the one-day old oothecae the females produced more oothecae in a given time than they would have, had the eggs been laid normally. For example a group of five females produced only 13 oothecae in 62 days when they were deposited normally. Another group of five females produced 23 oothecae in the same period when the oothecae were removed at one day of age. A sample of 10 egg capsules taken from both groups averaged 35 eggs per capsule.

SUMMARY AND CONCLUSIONS

The survival and development of the German cockroach at low temperatures and survival on restricted diets was studied.

Development to maturity at 21.1°C. takes about seven months, but the mortality is about 80%. First instar nymphs do not moult at 15.6°C. even though they can survive up to seven months at this temperature. At 26.7°C. development is complete in less than 2 months.

Three days of exposure to 4.4°C. or one day at -1.1°C. is sufficient to cause 100% mortality of all stages except the egg stage. One day of exposure to -6.7°C. is sufficient for complete mortality of the egg stage. Undercooling temperatures of the German cockroach range from about -6.6°C. to -9.2°C. but are by no means a measure of cold hardiness of the insect.

The German cockroach can feed at 4.4°C. Three days of exposure to this temperature is lethal to the nymphal and adult stages. Temperatures lower than this were not tested for feeding responses because insects become immobilized.

Male and female cockroaches lived approximately twice as long at 10°C. as at 26.7°C. when water was provided. When water was not provided, longevity was reduced by about one-third in all treatments whether food was or was not provided. Female German cockroaches kept at 10°C. had a significantly higher per cent fat content than those kept at 26.7°C. over a fifteen day period on restricted diets. There was no decrease in the body weight and per cent of water over the same period

when water was provided. The data did not provide a reliable estimate of weight loss when water was not provided.

German cockroach oothecae when manually removed in the early stages, hatch successfully under saturated humidity at temperatures of 15.6°C., 21.1°C., and 26.7°C. but die at 30% relative humidity.

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