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LIFE HISTORY OF THE IMPORTED *SCYMNUS (NEPHUS) REUNIONI* [*COL. : COCCINELLIDAE*] PREDATOR OF MEALYBUGS

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The life history of *Nephus reunioni*, introduced from the Reunioni island has been studied. Optimum temperature for the development of the entomophagous insect is 24-25° C. In this case the population has the highest survival at preimaginal stages, life duration of adults and reproductive capacity. The rate of population growth was calculated by the formula :

$$W = \exp \frac{\ln R_0}{T},$$

were R_0 - reproduction coefficient, T - generation development time. W shows the daily increase in the predator population and is maximum at 29 ° C. *N. reunioni* is capable of successfully developing within the wide range of relative humidity. Relative humidity of 55 ± 5 % is optimum for development of the population. Due to its ecological plasticity *N. reunioni* can be used in biological control of mealybugs on a much greater area than the earlier introduced *Cryptolaemus montrouzieri* (Mulsant).

KEY-WORDS : *Scymnus (Nephus) reunioni*, mealybugs, life history, predator, longevity.

Several mealybugs are pests of citrus, fruit trees, ornamental plants and vine in the USSR : *Pseudococcus fragilis* Brain (= gahani Green), *P. obscurus* Essig (= *maritimus* Ehrhorn), *P. comstocki* Kuwana, *Trionymus diminutus* Leonardi, *Planococcus citri* Risso, *Pl. ficus* Signoret (= *vitis* Nietner), *Antonina crawi* Cockerell. Their high harmfulness is to a great extent due to the absence of effective entomophagous insects which could reduce their number. Therefore the introduction of parasites and predators of adventive mealybugs is carried out in the U.S.S.R. A successful establishment of a number of introduced entomophagous insects has resulted in a sharp reduction of harmfulness of *P. comstocki, P. fragilis., P. obscurus* (**Smetnik & Izhevsky**, 1979). A few species of mealybugs still remain important pests. Among those are *P. citri* and *P. ficus* which injure vine, fig, glasshouse and indoor plants in the Transcaucasus, the Crimea and the Middle Asia. Early introduced *Chalcidoidea (Leptomastidea abnormis* Girault and *Leptomastix dactylopii* Howard) and *Coccinellidae* [*Cryptolaemus montrouzieri* (Mulsant)] to control these pests had not been established.

At present, *C. montrouzieri* is used by the method of seasonal colinization in a number of regions of the Transcaucasus. However, this species is ineffective in arid districts of the Transcaucasus and the Middle Asia, where damage made by mealybugs manifests itself to the greatest extent. Therefore, searches for new entomophagous insects and their introduction are being carried out.

The present paper describes the biology of a coccinellid, *N. reunioni*, predator of *P. citri* and *P. ficus*.

MATERIALS AND METHODS

N. reunioni was described as a new species in 1974 (**Chazeau** *et al.*, 1974). The biological material was sent to the U.S.S.R. by Dr. **A. Panis** (Zoology and Biological Control Station, Antibes, France) in 1978 at Dr. **T. V. Timofeeva**'s request (Laboratory of Biological Methods, Batumi). In 1979 we received this material from Dr. T. V. Timofeeva for our research. *N. reunioni* was reared on *P. citri* using etiolated potato seedlings, similarly to the procedure used for *C. montrouzieri* (**Fisher**, 1963).

When studying the effect of temperature and humidity on *N. reunioni* development, the 1st instar larvae were placed singly in test-tubes and supplied with abundant food. Duration of development, mortality at each stage, sex ratio and reproduction coefficient were recorded. These tests have been made at the temperatures of 11, 16, 21, 26, 31, 36 and 41 (± 1 °C.), 30, 40, 50, 60, 70, 80, 90 and 100 (± 5 %) RH and a light-dark cycle of 16 : 8 h. RH was made with the help of KOH solutions. There were 25-30 replications in each test.

During the investigation of adult survival, oviposition dynamics and embryonic development time the following procedure was used. Thirty newly emerged adults (F_0) were placed in cages and supplied with food (mealybugs on potato) in which they were kept for week. Then they were transferred to identical cages. The procedure of sequential transfer of beetles (F_0) was repeated untill they died. Time of larvae hatch and emergence of adults of the next generation (F_1) was recorded. Sex ratio of F_0 and F_1 was simultaneously determined. The fecundity was estimated by the quantity of larvae of the 1st instar, provided that the survival at the embryonic stage was 90 % which was a normal value for laboratory population of *Coccinellidae* (verbal report, **Kuznetsov**). The experiment was conducted at 21 and 26 °C and 55 ± 5 % RH.

In processing of data obtained standard methods of mathematical statistics were used, namely dispersive and correlative analysis as well as the method of Lesly's matrices (**Williamson**, 1972). The best approximating function was calculated by the least squares method. All the calculations were made using NAIRI- 2 computer.

RESULTS

TEMPERATURE EFFECT

Observation of *N. reunioni* development at different temperatures (tables 1, 2, 3) showed that lower temperature threshold for the development of larvae, prepupa and pupa stages falls within the range of 7 - 10 °C and for eggs 15 - 17 °C. The dependence of duration at preimaginal stage (d_0) on temperature (t) is approximated by hyperbola (table 3, fig. 1). The sum of effective temperatures for *N. reunioni* development from egg to adult is 469.5 °C.

The dependence of *N. reunioni* survival at preimaginal stages (b_0) on temperature is approximated by the second order parabola (fig. 2). The development of *N. reunioni* is possible at temperatures ranging from 11.9 to 40.7 °C. The maximum survival (0.66) over the period of preimaginal development is observed at 24.9 °C (for larvae 25.1 °C., for pupa and prepupa 23.5 °C).

According to the experimental data, the temperature at preimaginal development affects the adult longevity, female fecundity and even sex ratio. The dependence of the average (d_i) and maximum (d_i max) adult longevity of *N. reunioni* upon temperature conditions of preimaginal development (t) is approximated by the quadratic parabolae, respectively :

$$d_i = -98.85 + 15.14t - 0.316t^2 \quad (1)$$

and

$$d_i \max = -176.56 + 25.90t - 0.544t^2 \quad (2)$$

TABLE 1

Duration of N. reunioni *development at different temperatures and relative humidity of 55 ± 5 %*

Temperature (°C)	Initial specimen number	Duration of development (days)							
		Larva instars					prepupa	pupa	from 1 st instar larva to adult
		1	2	3	4	1-4			
11	30	30,0 ± 2,2	28,0 ± 2,5	28,6 ± 2,8	49,5 ± 5,5	136,0 ± 7,3	16,9 ± 1,5	26,8 ± 2,1	179,7 ± 11,3
16	27	6,3 ± 0,9	6,5 ± 1,0	6,6 ± 0,9	7,9 ± 1,1	27,2 ± 1,4	4,0 ± 0,5	18,5 ± 1,3	49,7 ± 8,3
21	25	5,2 ± 0,5	5,2 ± 0,5	5,3 ± 0,5	5,1 ± 0,8	20,8 ± 1,4	2,3 ± 0,2	9,8 ± 0,4	33,0 ± 3,8
26	25	3,2 ± 0,9	2,7 ± 0,4	3,0 ± 0,5	3,1 ± 0,5	11,9 ± 1,0	1,9 ± 0,3	6,4 ± 0,6	20,2 ± 1,4
31	27	2,8 ± 0,5	2,7 ± 0,5	2,5 ± 0,4	3,1 ± 0,4	11,2 ± 0,9	1,7 ± 0,2	5,6 ± 0,5	18,5 ± 2,0
36	30	2,8 ± 0,2	2,7 ± 0,3	2,5 ± 0,3	2,7 ± 0,2	10,7 ± 0,7	1,5 ± 0,1	4,3 ± 0,3	16,5 ± 1,4

TABLE 2

Survival of N. reunioni *at different temperatures and relative humidity of 55 ± 5 %*

Temperature (°C)	Initial specimen number	Survival (proportion of 1)							
		Larva instars					prepupa	pupa	from 1st instar larva to adult
		1	2	3	4	1-4			
11	30	0,43	0,73	0,77	0,87	0,21	0,69	0,78	0,11
16	27	0,67	0,87	0,95	1,00	0,55	1,00	0,95	0,52
21	25	0,75	0,93	1,00	0,94	0,65	1,00	0,93	0,61
26	25	0,77	0,94	1,00	1,00	0,72	0,93	1,00	0,67
31	27	0,73	0,86	0,94	1,00	0,59	0,94	0,94	0,52
36	30	0,60	1,00	0,94	1,00	0,57	0,88	0,64	0,32
41	30	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

TABLE 3

Calculated data on the influence of temperature (t) on N. reunioni *development*

Indices	Egg	Larva	Prepupa	Pupa	Whole generation
Calculated lower temperature threshold of development (c, °C)	16,40 ± 1,06	8,44 ± 0,56	7,15 ± 0,30	9,23 ± 0,68	11,89 ± 0,73
The average duration of development (d_i, day)	$d_1 = \frac{99,85}{t - 16,40}$	$d_2 = \frac{236,97}{t - 8,44}$	$d_3 = \frac{37,48}{t - 7,15}$	$d_4 = \frac{116,01}{t - 9,23}$	$d_o = \frac{469,48}{t - 11,89}$
Approximation error (v_i, %)	3,22	3,31	2,10	3,71	3,09
Rate of development ($v_i = 1/d_i$, days^{-1})	$v_1 = 0,010t - 0,1642$	$v_2 = 0,0038t - 0,0260$	$v_3 = 0,0267t - 0,1907$	$v_4 = 0,0086t - 0,0795$	$v_o = 0,0021t - 0,0253$
Approximation error (v_i, %)	3,22	6,08	5,31	2,77	4,35
Upper temperature threshold of development (h, °C)	-	41,79 ± 2,63	41,23 ± 1,63	41,23 ± 1,63	40,73 ± 1,53
Accumulated temperatures (K, °C)	99,85	236,97	37,48	116,01	469,48

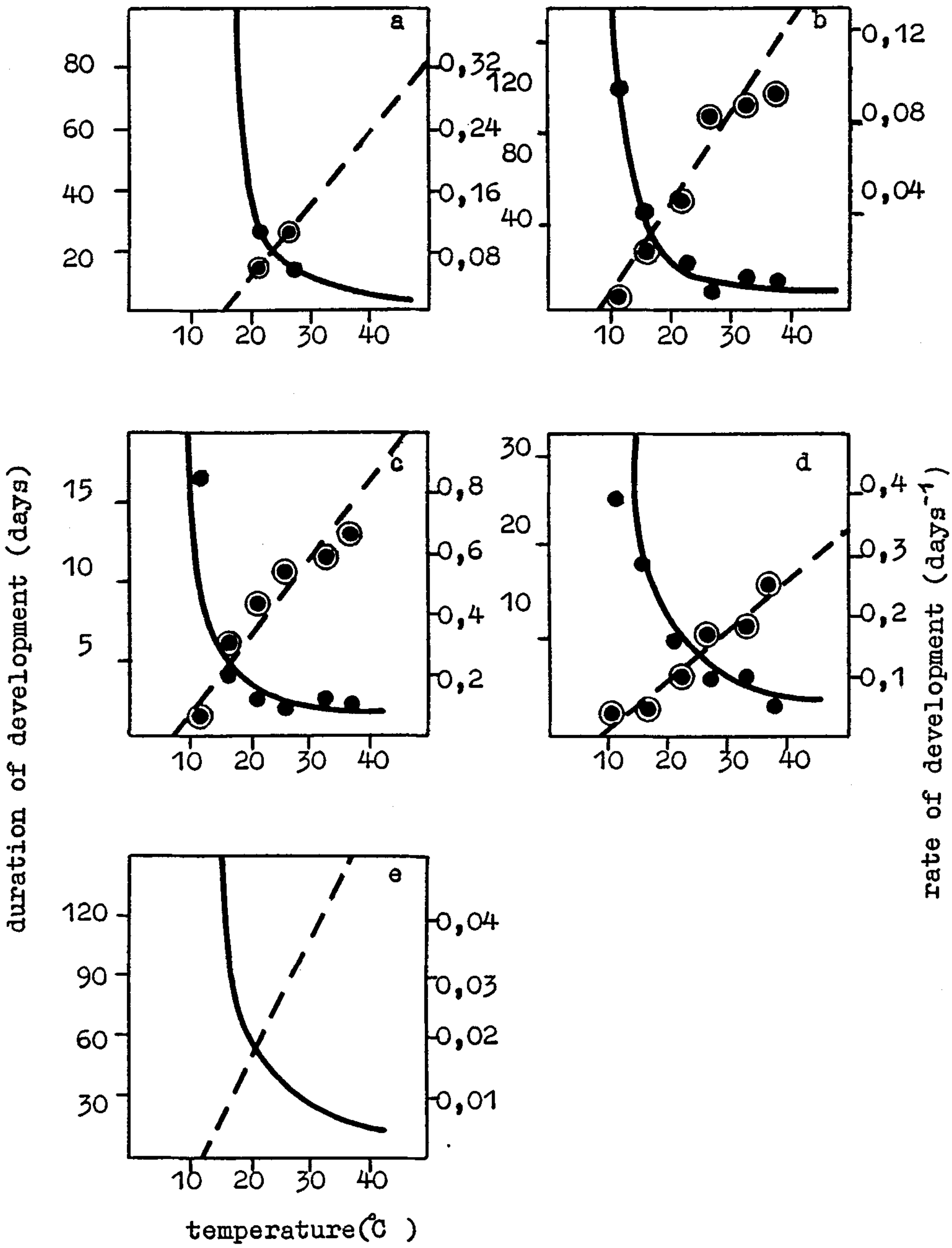

Fig. 1. Influence of temperature on duration (solid line) and rate (dotted line) of *N. reunioni* development (a -egg, b -larvae, c -prepupa, d -pupa, e -all preimaginal stages of development).

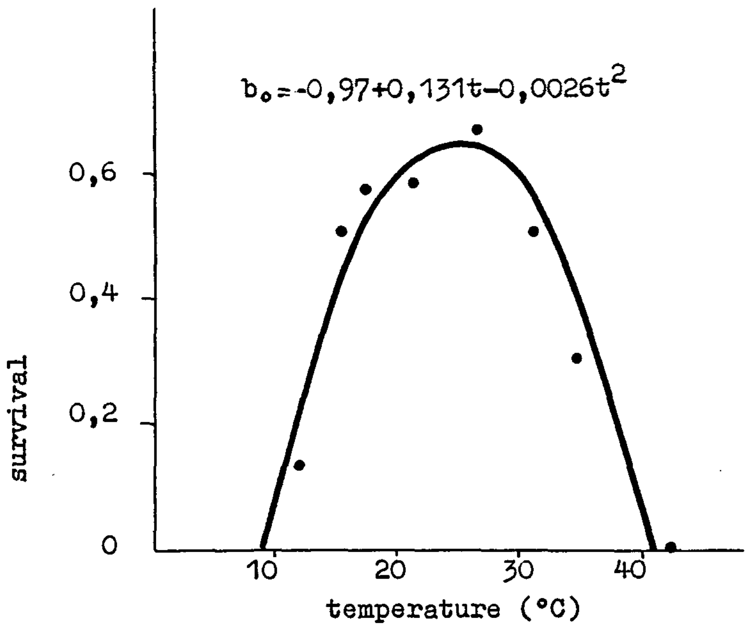

Fig. 2. Influence of temperature on survival of *N. reunioni* during the development from the 1st instar larva to adult (air humidity - 55 ± 5 %).

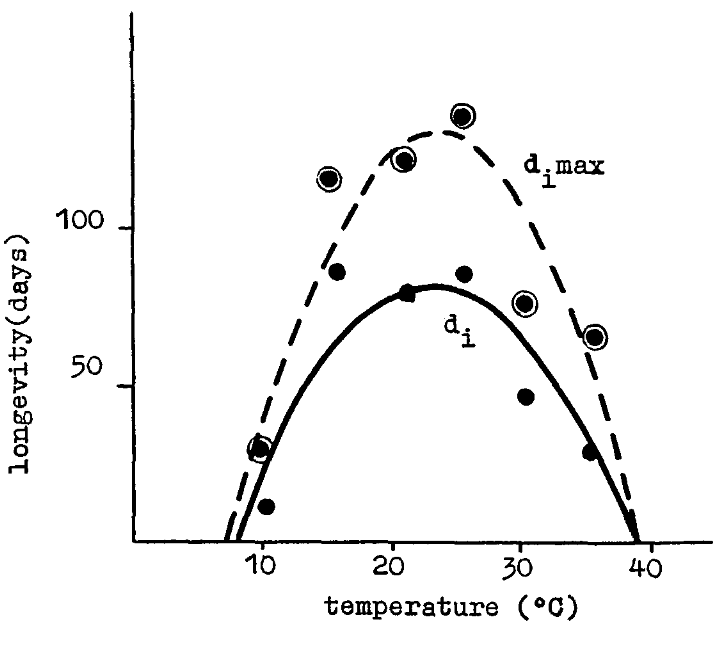

Fig. 3. Dependence of the average (solid line) and maximum (dotted line) adult longevity of *N. reunioni* on temperature during preimaginal development.

The analysis of equations (1) and (2) showed that the longest duration of adult life at preimaginal stages observed at 23.9 °C, the average life time being 82.6 days and maximum 132.0 days. The maximum duration of adult life was recorded at 25 °C and was 165 days.

The dependence of proportion of females in *N. reunioni* population (f) on temperature of preimaginal development is approximated by the second order parabola (fig. 4a). Analysis of the parabola showed that the minimum proportion of females was observed after the development at 24.9 °C and made 0.52 (sex ratio close to 1 : 1). At higher and lower temperature at the preimaginal development, the proportion of females increases and sex ration reaches 3 : 1 and more. Perhaps, it is connected with the higher survival of females under unfavourable conditions.

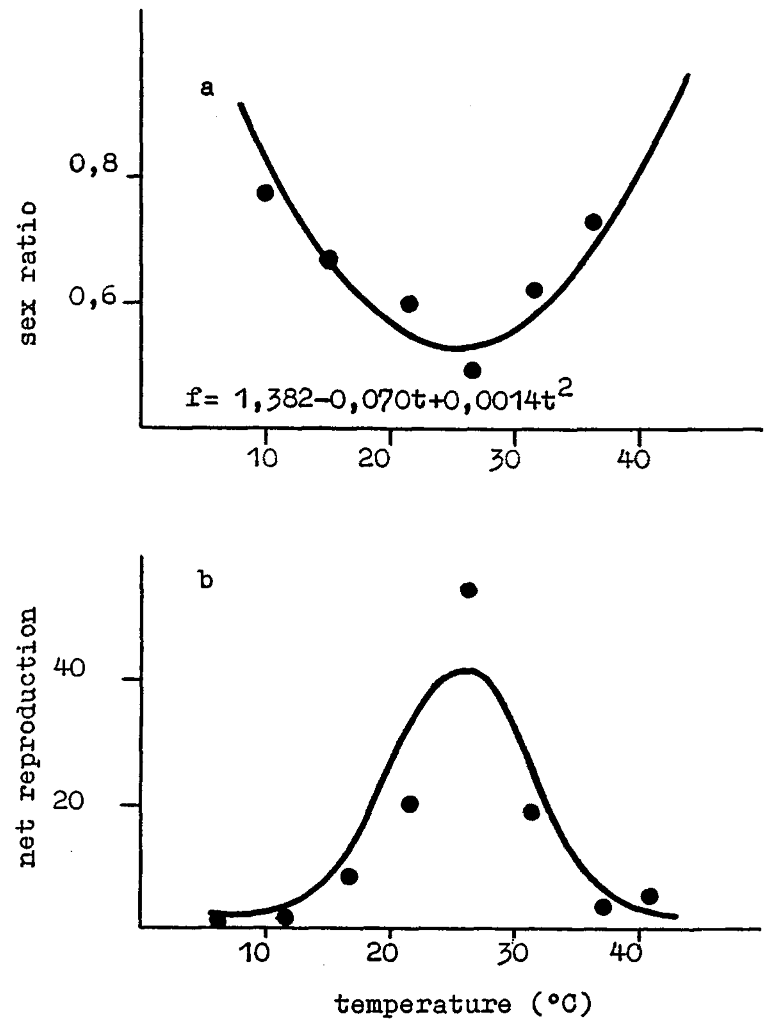

Fig. 4. Dependence of sex ratio (a) and reproduction coefficient of *N. reunioni* on temperature during preimaginal development.

The dependence of *N. reunioni* reproduction coefficient (R_0) on temperature at preimaginal development is approximated by the equations :

$$R_0 = 1.1061\,e - 8.058 + 0.945\,t - 0.0191\,t^2 \quad (3).$$

The analysis of equation (3) showed that the reproduction coefficient of *N. reunioni* is maximum after the preimaginal development at 24.9 °C and equals 41.5 (fig. 4b).

Our studies indicate that the temperature of 24 – 25 °C is optimal for the development of *N. reunioni*. In this case the predator has maximum survival both in preimaginal stages and adults and highest reproductive capacity.

Air humidity effect

N. reunioni is capable of successful developing over a wide range of relative air humidity. The dependence of survival upon relative air humidity (P) within the period from first instar larva to the adult is approximated by the second order parabola (fig. 5a). The analysis of the equation showed that *N. reunioni* survival is maximum (0.57) at the relative humidity of 52.2 %. Only at air humidity less than 10 % and more than 95 % the predator mortality exceeds 80 %. Air humidity does not practically affect the development of eggs, prepupae and pupae.

Air humidity over 50 % does not exercise significant influence on duration of *N. reunioni* development. At air humidity less than 50 % the duration of the development increases. This relation is approximated by the first order hyperbola (fig. 5b). Successful development of *N. reunioni* is possible at air humidity from 10 to 95 %. Optimum humidity for the development is 55 ± 5 %. Thus, optimum conditions for the development of *N. reunioni* are 24 – 25 °C and 55 ± 5 % RH.

Development under optimum conditions

N. reunioni females oviposit into egg clusters of mealybugs. The predator eggs are hardly distinguished from the eggs of prey in colour and size, therefore it is extremely difficult to find them. The larva feeds on eggs, larvae and females of a mealybug ; four instars. With abundance of food the predator larvae, regardless of it develops within age, prefers feeding on the 3rd instar larvae and eggs of prey. Even newly hatched larvae are able to feed on large mealybug females. While feeding, the larva of the predator penetrates into prey nibbling from below and sucks it out. After completing its development the larva of the 4th instar attaches itself with the abdominal end to substrate. In 2-3 days pupation occurs. The exuviae of larva serves as shelter for pupa. Young beetles leave their shelters in 1 or 2 days after emergence. Then they begin feeding and mating. The beetles prefer to feed on the larvae of junior instars and on eggs of mealybugs. Cannibalims in *N. reunioni* has not been recorded. Oviposition begins on the 5th or the 6th day after the emergence of beetles and continues till their death. During the life of beetles more than one mating takes place.

The dependence of egg number laid by a female (m ♀ per day on its age (z, days since emergence) is approximated by the second order parabola (fig. 6a). The intensity of the egg laying reaches maximum on the 78th day of the female life (2.6 eggs/day). Average fecundity of the *N. reunioni* female is 177.1 eggs. The proportion of beetles survived to each age (Lz) reduces constantly. The reproduction coefficient and duration of generation development were calculated by the formula :

$$R_0 = {}_0\int^{\infty} m_x\, l_x\, d_x \quad (4)$$

and

$$T = \frac{{}_0\int^{\infty} x\, m_x\, l_x\, d_x}{R_0} \quad \text{(Pianka, 1978)} \quad (5)$$

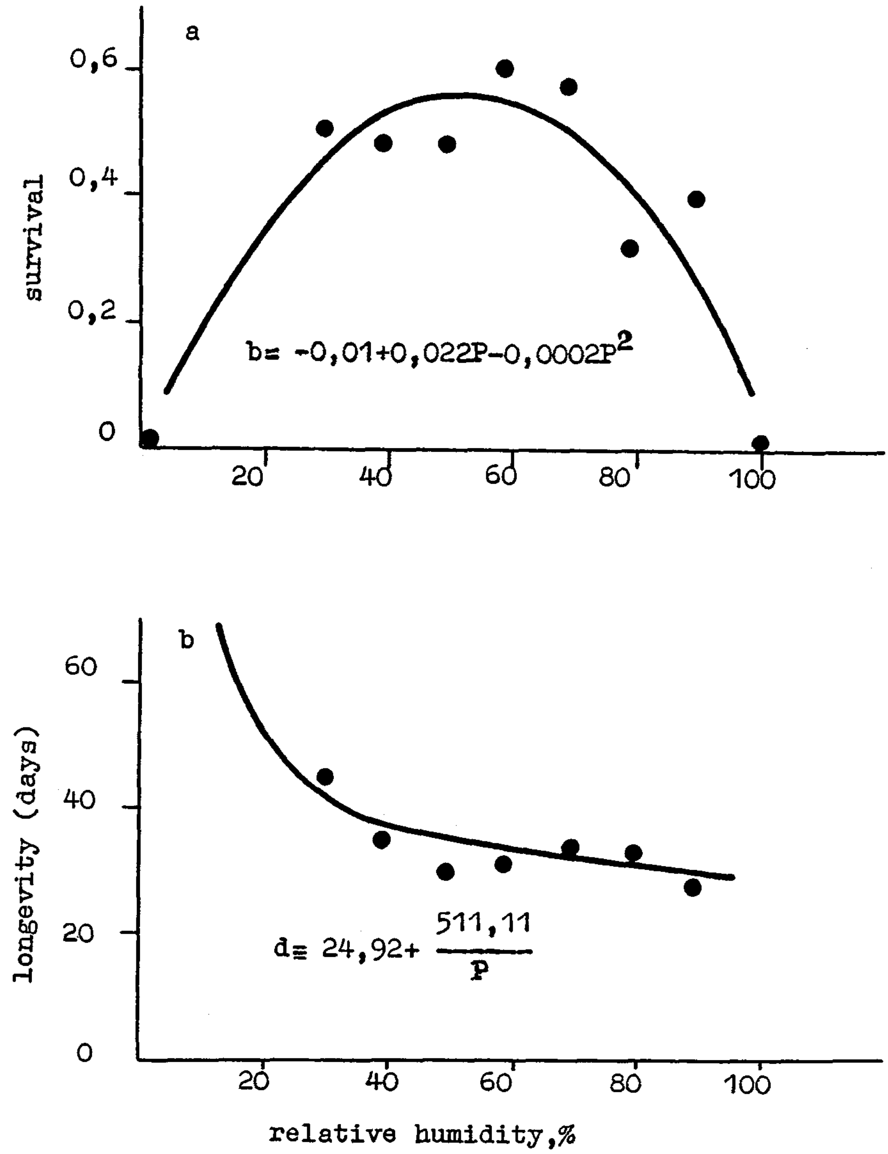

Fig. 5. Air humidity effect on survival (a) and duration on *N. reunioni* development from the 1st instar larvae to the adult (t = 21 °C).

where R_0 - reproduction coefficient, T – duration of generation development (days), x - entomophagous insect age beginning from egg laying (days), l_x - survival from x = 0 to x (share of 1), m_x - fecundity per day. The results of the calculations showed that the duration of the development of one *N. reunioni* generation under optimum conditions (24 - 25 °C, 55 ± 5 % RH) was 102.1 days, and the reproduction coefficient could be as high as 64.0.

TABLE 4

Development matrix of the laboratory population of N. reunioni *under optimum conditions*

	EGG.	LARVA	PREPUPA AND PUPA	ADULT 1	2	3	4	5	6	7	8	9	10	11	12	13	14
Fecundity within 11 days (eggs)		–	–	1,118	4,795	7,871	10,347	12,221	13,495	14,168	14,241	13,713	12,584	10,855	8,525	4,996	1,355
egg	0,900	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
larva	–	0,734	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
prepupa and pupa	–	–	1,000	–	–	–	–	–	–	–	–	–	–	–	–	–	–
1	–	–	–	1,000	–	–	–	–	–	–	–	–	–	–	–	–	–
2	–	–	–	–	0,983	–	–	–	–	–	–	–	–	–	–	–	–
3	–	–	–	–	–	0,972	–	–	–	–	–	–	–	–	–	–	–
4	–	–	–	–	–	–	0,964	–	–	–	–	–	–	–	–	–	–
5	–	–	–	–	–	–	–	0,952	–	–	–	–	–	–	–	–	–
6	–	–	–	–	–	–	–	–	0,938	–	–	–	–	–	–	–	–
7	–	–	–	–	–	–	–	–	–	0,922	–	–	–	–	–	–	–
8	–	–	–	–	–	–	–	–	–	–	0,905	–	–	–	–	–	–
9	–	–	–	–	–	–	–	–	–	–	–	0,881	–	–	–	–	–
10	–	–	–	–	–	–	–	–	–	–	–	–	0,850	–	–	–	–
11	–	–	–	–	–	–	–	–	–	–	–	–	–	0,809	–	–	–
12	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0,686	–	–
13	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0,579	–
14	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0,219

Survival in stages (in parts from 1)

adults according to the age (up to 11 days)

In order to describe the growth of the laboratory population of *N. reunioni* under optimum conditions, Lesly's matix (table 4) was made. This matrix was taken as a basis for computer programme.

Eleven days were taken to be one step of the matrix. Within this period, on the average the development from an egg to a larva, from a larva to a prepupa and from a prepupa to an adult lasts. The adult life was divided into 14 steps of 11 days each. The results of the computation showed that under optimum conditions and abundant food the laboratory population of the predator grows exponentially (fig. 7a). In this case the population, initially represented by any ratio of stages and age, gradually reaches a stable age distribution (fig. 7b), at which per 1 adult there are 3.002 eggs, 1.606 larva and 0.701 prepupa and pupa. Age composition of adults also becomes gradually stable : 80.9 % are adults at the age up to 33 days, 15.9 % - at the age from 33 up to 66 days, 2.8 % from 66 up to 99 days, and the rest are older.

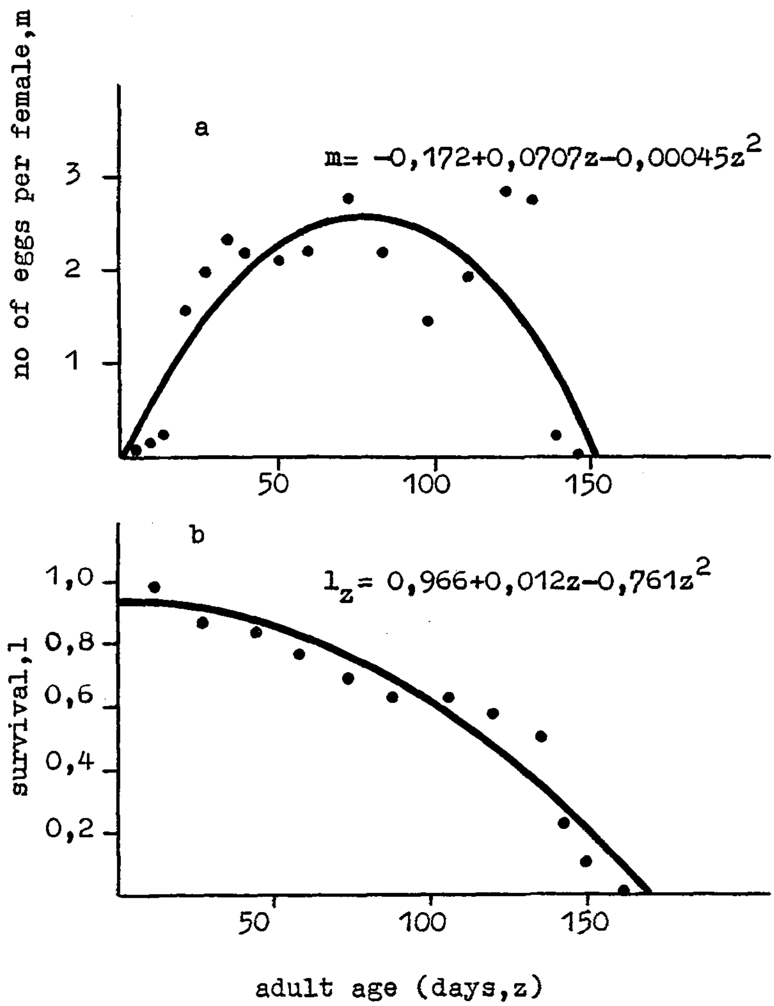

Fig. 6. Oviposition dynamics (a) and survival of *N. reunioni* adults under optimum conditions (24-25 °C, 55 ± 5 % RH).

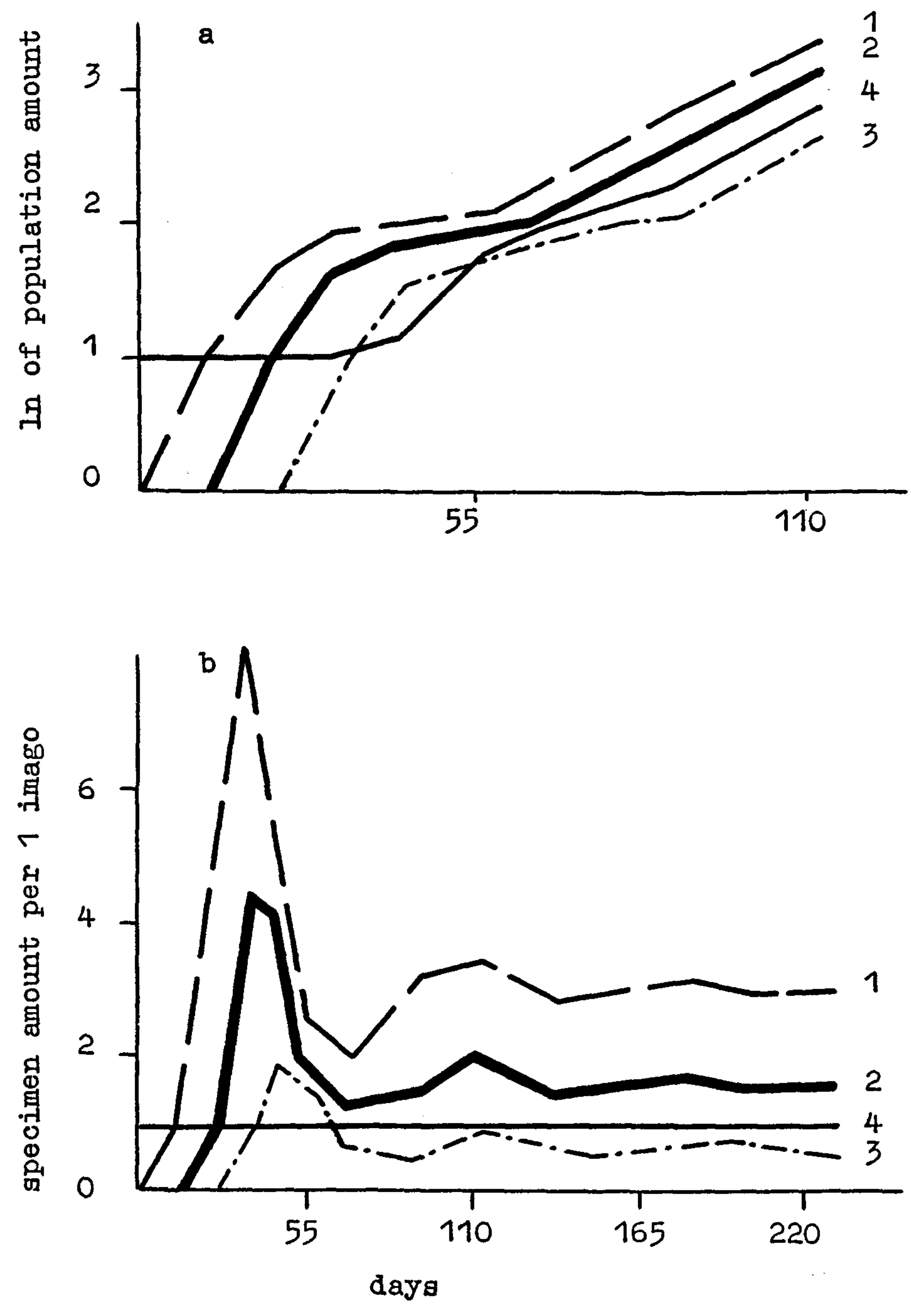

Fig. 7. Growth dynamics of the laboratory population of *N. reunioni* (10 beetles initially) and establishment of stable age distribution in it (b) under optimum conditions (1 -eggs, 2 - larvae, 3 -prepupa and pupa, 4 -adults).

DISCUSSION

We showed that *N. reunioni* is slightly susceptible to air humidity and can develop within the wide range of temperatures. Ecological plasticity of the predator gives reasons for hope that its acclimatization is possible under variety of conditions in the whole distribution area of citrus mealybugs. The data obtained enable to optimize the mass rearing of *N. reunioni* for release. For this purpose, growth rate of laboratory population is of great importance. With temperature increasing over 25 °C the reproduction coefficient of *N. reunioni* begins decreasing (fig. 4b). However, as the temperature increases the generation development time becomes shorter. To choose temperature for the maximum production of biological material both aspects should be kept in mind. Let us use the approximate method of calculation of generation development duration (**Pianka**, 1978), according to which it is estimated by the total duration at preimaginal development (d_0) and half the maximum adult longevity ($d_i max$), i.e. by the equation :

$$T = d_0 + \frac{d_i \max}{2} \quad (6).$$

The value of d_0 is determined by the equation from Table 1 in depending on temperature, d_i max is estimated by equation (2). The calculations made due to formula (6) show, that the duration of *N. reunioni* generation depending on temperature will be determined by the curve given in Fig. 8a.

In order to calculate the rate of predator population growth at different temperatures, let us introduce the value W, which shows an increase in population number per day. It is evident, that this value is connected with the duration of generation and the reproduction coefficient by a simple relation :

$$W^T = R_0 \quad (7)$$

Using logarithm to equation (7) we obtain :

$$T \ln W = \ln R_0,$$

$$\ln W = \frac{\ln R_0}{T} \quad (8)$$

It should be noted that ln W corresponds to r indexing the specific rate of population growth (**Pianka**, 1978). From equation (8) the formula, determining W is derived, exactly :

$$W = \exp \frac{\ln R_0}{T} \quad (9)$$

As the dependence of R_0 and T on temperature is approximated by equations (3) and (6), respectively, formula (9) determines the relation between W and temperature (fig. 8a). Calculations made from formula (9) show that the maximum rate of *N. reunioni* population development can be reached at 29 °C. Thus, to get the greatest amount of *N. reunioni* within the shortest time possible it is necessary to rear it at 29 °C, and for the purpose of getting the most viable progeny, rearing should be carried out at 24 - 25 °C. The temperature selection should be made in accordance with specific aims.

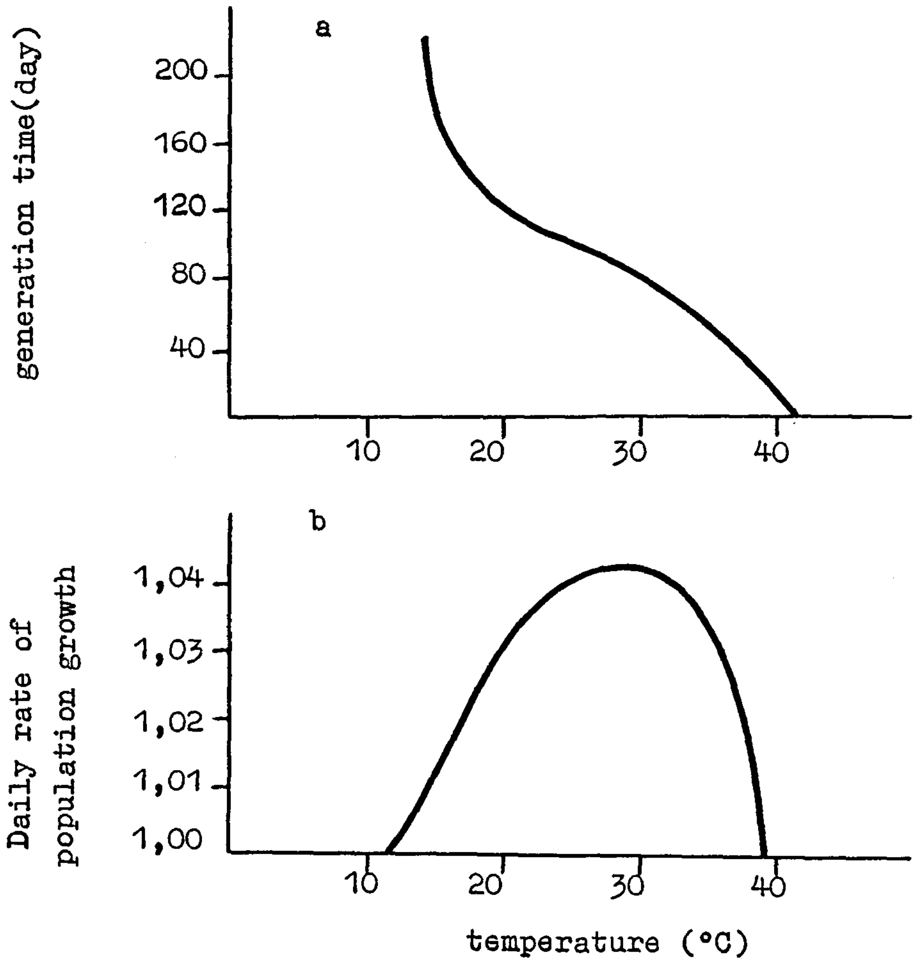

Fig. 8. Dependence of the generation longevity (a) and population growth rate (b) on temperature (air humidity - 55 ± 5 %).

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RÉSUMÉ

Biologie du prédateur de pseudococcines importé :
Scymnus (Nephus) reunioni [*Col. : Coccinellidae*]

La biologie de *Nephus reunioni* introduit de l'Ile de la Réunion a été étudiée. La température optimale pour le développement de l'insecte entomophage est 24-25 °C. Dans ce cas la survie des stades préimaginaux est la plus forte, comme la durée de vie des adultes et la capacité de reproduction. Le taux de croissance de la population était calculé au moyen de la formule suivante :

$$W = \exp. \frac{\ln R_0}{T}$$

où R_0 est le coefficient de reproduction et T la durée de développement d'une génération. W représente la croissance quotidienne de la population prédatrice elle est maximum à 29 °C. *N. reunioni* est capable de se développer dans une très large échelle d'humidité relative. Celle de 55 ± 5 % est optimale pour le développement de la population. Du fait de sa plasticité écologique, *N. reunioni* peut être employé dans la lutte biologique menée contre les Pseudococcines sur une aire beaucoup plus vaste qu'avec *Cryptolaemus montrouzieri*, introduit primitivement.

MOTS CLÉS : *Scymnus (Nephus) reunioni*, Pseudococcides, biologie, prédateur, longévité.

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