THE INFLUENCE OF CONSTANT TEMPERATURE ON THE DEVELOPMENT, LONGEVITY AND REPRODUCTION OF THE TURNIP APHID, *RHOPALOSIPHUM PSEUDOBRASSICAE* DAVIS

Kazuo KAWADA

The life-history and development of the turnip aphid, ***Rhopalosiphum pseudobrassicae*** Davis, have been reported by Allen and Harrison (1941), and Essig (1947). All of their studies were carried out under considerably variable temperatures, but the effects of different constant temperatures have never been investigated. The experiments reported below were conducted to determine the influence of constant temperature on the development, longevity and reproduction of ***R. pseudobrassicae*** under closely controlled conditions.

MATERIALS AND METHODS

The viviparous, parthenogenetic turnip aphid was reared on kale leaves, ***Brassica oleracea*** L. var. ***acephala***, at ten constant temperatures between 10°—32.5°C. Each of the first instar larvae was put into a container (4.5×2.0 cm) within two hours from its birth, with a fresh leaf of kale (2.5 in width and 2.5 cm in length) for food. Food was renewed every day. The aphids were examined every day; and their reproduction period, longevity and the number of offsprings produced were recorded.

Experiments at each constant temperature were begun with four individuals and replicated five times, thus using 20 first instar larvae in all, which were obtained from colonies of the viviparous, parthenogenetic turnip aphids that had been reared continuously for more than three months on kale plants, the temperature in the rearing room being 20°—25° C, and the photoperiod 16 hours.

The aphids were reared in double-glass walled constant temperature and refrigerated cabinets, in which the temperature was controlled at ± 0.5°C of the prescribed temperature. Relative humidity of 50—70 per cent was maintained at each temperature by placing a bottle full of water in the cabinet. A fluorescent lamp (Toshiba FL-20W), operated by a time switch, gave the daily photoperiod of 16 hours; the light intensity on the surface of each container was 800—1000 lux.

RESULTS

Development

The relation between constant temperature and time required to complete

TABLE 1
The relation between development and constant temperatures

Temperature (°C)	No. of larvae full-grown	Ave. larval period in days	Coeff. of variation (%)	Ave. velocity of development	Death rate (%)
32.5	0	—	—	—	100
30	15	6.67±0.15*	8.95	0.1499	25
27.5	17	7.18±0.22	12.86	0.1393	15
25	18	7.72±0.22	12.06	0.1295	15
22.5	19	8.11±0.21	11.24	0.1233	5
20	20	10.25±0.19	8.18	0.0976	0
17.5	20	12.25±0.26	9.61	0.0816	0
15	20	15.45±0.22	6.65	0.0647	0
12.5	17	26.41±0.70	10.64	0.0379	15
10	13	37.77±0.83	7.92	0.0265	35

* Standard error.

development from birth to the production of the first offspring is shown in Table 1, and Fig. 1. As temperature increased from 10° to 30° C, the average developmental days decreased from 37.77 days at 10° to 6.67 days at 30°C. The writer was not able to determine exactly the highest limit of temperature at which development was possible. At the constant temperature of 32.5°C none of the larvae used in the experiment attained to maturity; and only a few individuals were found to survive for several days. That is, taking these facts into consideration, the writer believes that in the present experiment the limit of high temperature was somewhere about 31°C. The constant temperature of 32.5°C is injurious to the larvae of the the aphid when this temperature acts upon them continuously. In the experiments here presented, the writer was not able to carry on rearing at a constant temperature lower than 10°C. Therefore, it was so far not possible to determine the temperature at which development ceases.

If the reciprocals of the average time required for the development at each temperature are plotted against temperature, the curve of the average developmental velocity can be obtained. With the rise in temperature the velocity of development increases at first very rapidly, but its rate of increase becomes gradually smaller beyond about 22.5°C. It is apparent that, in the range of temperatures between 12.5° and 22.5°C, the relation between the developmental velocity of the aphid and temperature was very nearly linear (Fig. 1).

Shelford called this part where the velocity of development makes a straight line the medial range of temperature. By the method of least squares from the data of experiments in the medial temperature range, an equation,

$$y = 0.0081\,x - 0.0616$$

was calculated. This equation represented very well the temperature-velocity relation, and the theoretical threshold of development proved to be 7.60°C.

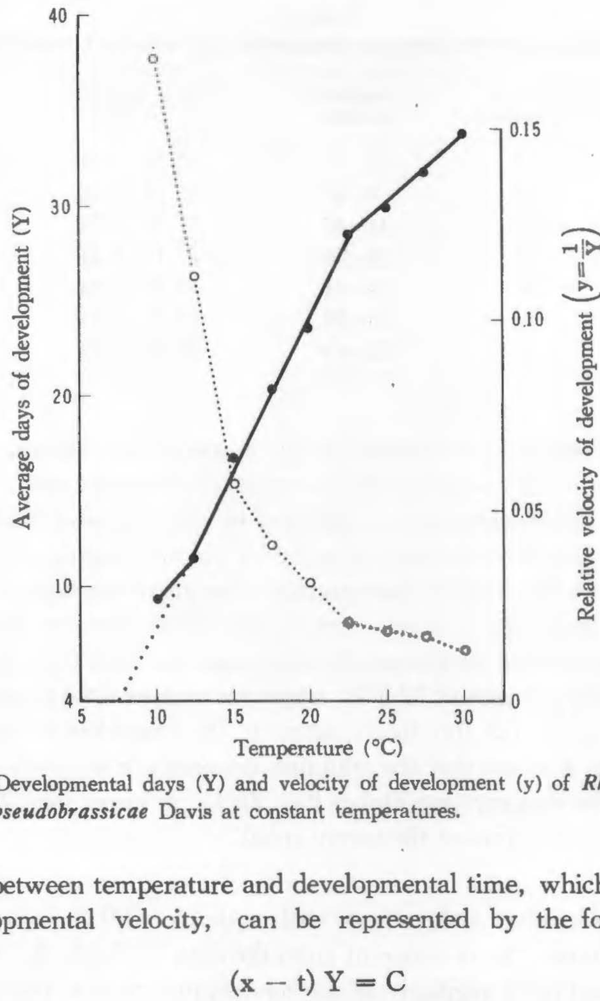

Fig. 1. Developmental days (Y) and velocity of development (y) of ***Rhopalosiphum pseudobrassicae*** Davis at constant temperatures.

The relation between temperature and developmental time, which is the reciprocal of the developmental velocity, can be represented by the formula,

$$(x - t)\,Y = C$$

where, Y is developmental time, C the so-called thermal constant, and t corresponds to the theoretical threshold of development, 7.60°C. The values of x and Y were substituted in the equation and the numerical value of C was determined. It was found to be 123.59. In terms of heat units, therefore, it may be said that 123.59 day-degrees on an average was required as the effective accumulated temperature for complete development of the species at constant temperatures between 12.5°—22.5°C. The value of t, 7.60°C, represents the developmental zero. This value must be regarded as purely theoretical, however, since validity for such extrapolation is dubious in the absence of experimental verification. The calculated curve conforms nearly to the empirical values within the medial temperature range. The greatest variation was 2.24 days at 15°C.

Death rate

The object of experiments herein reported was primarily to investigate the

TABLE 2
The relation between average longevity and constant temperatures

Temperature (°C)	No. of individuals	Longevity in days	Ave. longevity in days	Coeff. of variation (%)
30	15	12—17	14.13±0.36*	9.91
27.5	17	8—29	17.53±1.14	26.72
25	18	14—28	21.33±0.54	10.83
22.5	19	12—36	27.11±1.48	23.74
20	20	15—44	25.35±1.82	32.16
17.5	20	20—50	33.65±1.73	23.05
15	20	23—49	35.50±1.68	21.00

* Standard error.

velocity of development. The number of larvae reared was limited, so that it was impossible to obtain very acculate data in regard to the death rate. But the writer believes that the results obtained are sufficient to show general tendency of death rates in the turnip aphid larva under a variety of constant temperatures. The death rate obtained under the constant temperature experiment are shown in Table 1. It shows that the death rate is 0 per cent in the range between 15°—20°C, but increases according as the experimental temperature deviates from the above range, until it reaches 100 per cent at 32.5°C. At a low temperature of 10°C, the death rate was 35 per cent, but this figure seems to be somewhat too large. Judging from these results it seems that the optimum temperature lies somewhere between 15°—22.5°C. The temperatures higher than 25°C, or lower than 12.5°C seem to be unfavorable for the larva of the turnip aphid.

Longevity

The average number of days from birth to death of 20 larvae was determined at each temperature. As is apparent from the data in Table 2, the duration of longevity decreased fairly regularly as the temperature became higher up to 30°C. Beyond this temperature, however, almost all larvae died before reaching maturity. The minimum duration of longevity was found to be 8 days at 27.5°C, and the maximum 50 days at 17.5°C. (Table 2). The relation between accumulated mortality and temperature is shown in Fig. 2. It is evident, that, as the temperature increased, the longevity decreased. The average number of days of survival at the time when 50 per cent mortality occurred was 14, 21, 24 and 36 days at the temperature of 30°, 25°, 20° and 15°C., respectively.

Reproduction

Table 3 shows the average number of youngs produced during a life-time by a female at each constant temperature. Considerable variation in the number of offsprings was observed at each temperature, but the difference between the number at 25°, 22.5°, 20°, 17.5° and 15°C was not large. Significantly less youngs were produced at 27.5° and 30°C than at any other temperatures. The constant tempera-

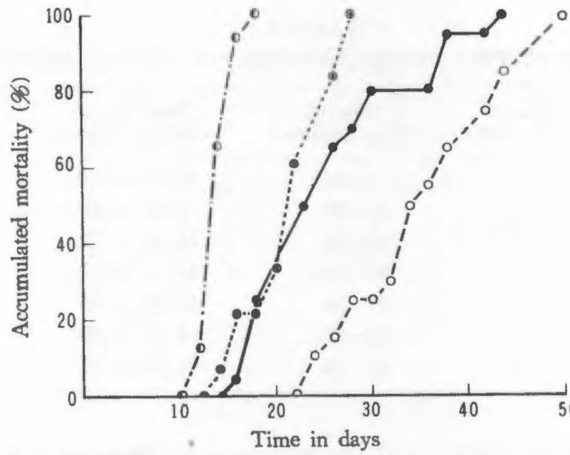

Fig. 2. Accumulated mortality of ***Rhopalosiphum pseudobrassicae*** Davis at constant temperatures. ◐ 30°C, ◉ 25°C, ● 20°C, ○ 15°C.

ture of 30°C seemed to be nearly the uppermost limit for continuous reproduction. This result can be traced back to the unfavourable influence of high temperature on embryogenesis, or the shorter reproductive period on account of the earlier death of mothers at this temperature, or to a combination of these two factors.

DISCUSSION

It is generally recognized that the relation of the speed of development of insects to temperature does not conform to a true straight line, but a sigmoid curve throughout the whole range of temperature at which the development is possible. (Uvarov, 1931; Davidson, 1944; Andrewartha, 1961). In the case of the turnip aphid, the above stated relations were also observed. The temperature-velocity curve obtained is very nearly a straight line at the temperatures approximately between 12.5°—22.5°C as is apparent from Fig. 1, but it does not seem to fit the experimental data accurately when the rearing temperature is beyond the medial range, that is, the observed value of y is somewhat smaller at high temperature and larger at low temperature than the theoretical value, forming a sigmoid curve in the relation to the whole range of temperature. As is already mentioned, in the medial tempeature range, the temperature - velocity relation of the turnip aphid was represented by the equation

$$y = 0.0081x - 0.0616$$

and the theoretical threshold of development by 7.60°C. But it is easily recognized from the following facts that the value of 7.60°C is the theoretical one and not the temperature at which development actually ceases, being fairly higher than the latter. In the vicinity of Kurashiki the turnip aphid is usually found in the field, during winter (December, January and February, where the mean daily tempera-

TABLE 3
The relation between average fecundity and constant temperatures

Temperature (°C)	No. of individuals	No. of young produced	Ave. no. of young produced	Coeff. of Variation (%)
30	21	5—23	13.05±0.67*	23.67
27.5	25	10—60	29.00±2.47	42.57
25	20	24—98	51.35±1.22	10.67
22.5	27	29—106	61.70±3.67	20.92
20	20	31—94	49·30±3.04	27.57
17.5	20	33—120	64.80±5.26	46.29
15	20	22—98	61.00±4.40	32.25

* Standard error.

ture is 5.9°, 3.3°, and 3.8°C, and the minimum temperature 1.3°, −1.1°, and −0.9°C, respectively), and its development is continuous though very slow. The lethal temperature for the species in the outdoor must be considerablly below the temperature at which development ceases.

Though in summer there are many cruciferous plants (cabbage, kale, and turnip, etc.) in the field, the turnip aphid disappears there. This seems to be chiefly due to the atmospheric circumstance that the air temperature in the season is not favorable to the metabolic activity of the larvae. Really, at a high temperature of 32.5°C, no larvae could attain to full-growth in the rearing experiments. This fact indicates that the warmest period of the summer is the most unfavorable for the turnip aphid.

The results of observations on the death rate which was obtained at the constant temperature have already been stated. It shows that the death rate was 0 per cent from 15°C up to 20°C and then continued to increase until it reached 100 per cent at 32.5°C. Judging from the death rate, it seems that the optimum temperature lies somewhere between 15°−22.5°C. Temperature higher than 25°C seems to be unfavorable to the nymph of the turnip aphid. On the other hand, at the low temperatures of 10° and 12.5°C, the death rates were 35 and 15 per cent, but these values, especially the former seem to be somewhat too large. Various factors are thought to be responsible for this high mortality. The writer considers that the most important one of them must have been the low temperature. At the temperature of 32.5°C, the full development could not be expected but the partial development could be observed. Takaoka (1960) reported that the duration of survival of the green peach aphid, ***Myzus persicae*** Sulzer, decreased with the temperature rising from 15° to 25°C; also that the number of offsprings produced at 25°C was smaller than that at the lower temperatures of 20° and 15°C. Barlow (1961) observed that the duration of survival of the potato aphid, ***Macrosiphum euphorbiae*** Thomas, decreased with the temperature rising from 5° to 30°C, and the number of larvae produced at 25°C was less than half the number at the lowest temperature of 5°C. Noda (1951), and Tanaka (1957) found that longevity of the apple-grain aphid, ***Rhopalosiphum prunifoliae*** Fitch, decreased from 25.°C with rising temperature, becoming minimal at 30°C. The results of the present experiment also indicates a similar tendency, namely that the longevity decreases with the temperature rising from 15° to 30°C, and the number of off-springs produced decreases markedly at 30°C than in the optimum temperature range of 15° to 25°C. This response to temperature, together with shorter longevity and smaller fecundity at higher temperature, may partly explain the often reported disapperance of this aphid in the field during summer.

It is difficult to determine how many generations of the turnip aphid there are in a year. As has been already pointed out, the behavior of this species in the hot summer time has not yet been fully traced. Therefore, it is not yet possible to determine the number of generations in a year. However, if we ignore, for the moment, the number of generations in the summer time in which the behavior of the turnip aphid is not clear, there may be as many generations as ten or more during a year.

SUMMARY

The results of the experiments conducted on the relations of temperature to the development, longevity, and reproduction of the turnip aphid, ***Rhopalosiphum pseudobrassicae*** Davis, are summarized as follows:

1) The relation between temperature and velocity of development was linear between 12.5° and 22.5°C. and represented by the equation

$$y = 0.0081x - 0.0616$$

2) The theoretical threshold of development was 7.6°C, and the effective accumulated temperature necessary for the complete development was 123.59 day-degrees on an average.

3) The longevity decreased with rising temperature, the minimum longevity being 8 days at 27.5°C, and the maximum 50 days at 17.5°C. At 32.5°C, all aphids died before maturity.

4) The average number of youngs produced per female decreased with rising temperature. The maximum number of youngs produced were 120 at 17.5°C, and the minimum only 5 at 30°C.

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