Problems on the Breeding of Insects for Biological Assay of Insecticides. (XI)*

On the Growth of the Head Capsule in the Successive Instars in Larvae of the Cabbage Moth, *Barathra brassicae* L.

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The larvae of the cabbage moth were reared separately under a constant environmental condition, and the measurements were made on the width of the head capsules in the successive instars. On the basis of the result of the measurements, the growth of the head capsule in the successive instars was examined from the viewpoint of statistical theory of small sample.

INTRODUCTION

Recently, some notes on the growth of head capsule in the successive instars in larvae of the cabbage moth, *Barathra brassicae* L., were presented by Santa[8] and Hirata[5] simultaneously. Namely, Santa discussed the growth in the successive instars on the basis of the result of daily measurements on the width of head capsule of twenty individuals which were randomly taken out every day from the experimental population, while Hirata discussed the same problem on the basis of the results of measurement which was made using the exuviae of head capsules from the first to the fifth instars and the head capsule of the dead individuals of the sixth instar. As the present writer had a chance to make measurements on the widths of head capsules of successive instars of the cabbage armyworms of the second generation which were reared separately under a constant environmental condition, he wishes to discuss the growth of head capsule in the successive instars from the viewpoint of statistical theory of small sample and to compare the result obtained with those reported by the two previous authors.

MATERIAL AND METHOD

The cabbage armyworms used for the measurements were a population started from a batch of eggs of the second generation. The batch of eggs was collected early in September, 1955, at the cabbage field of the Experimental Farm, Department of Agriculture, Kyoto University, Takatsuki, Ohsaka. From the day of hatching (14th,

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September), they were reared under the constant environmental condition of temperature 25°C and 89 % relative humidity separately in a pair of petri dishes measuring 1.5 cm high × 3.0 cm in diameter on the leaves of "Komatsuna" (a horticultural variety of *Brassica campestris* L.). The width at the largest part of the head capsule of each worm was measured once a day at the prescribed time in each of the successive instars with an ocular micrometer. And the food leaves were renewed when the measurements were made.

RESULT AND DISCUSSION

Though one hundred and ten individuals hatched from a batch of eggs, about half of them, namely, fifty-five individuals completed their development to the last sixth instar. In the discussion which follows, the writer used the result of measurements on the thirty individuals which were drawn from the fifty-five individuals mentioned above by means of the table of random numbers. As has been dond in the previous papers[6,7]

Table 1. Mean width of head capsule in logarithms in each instar in the 30 larvae of the cabbage moth, *Barathra brassicae* L.; $y=1+\log$ (mm).

Worm No.	Width in logarithms for instar						Worm total	Regression on instar	
	I	II	III	IV	V	VI		$S(xy)$	$S(x'y)$
1	0.519	0.736	0.925	1.142	1.337	1.517	6.176	7.010	-0.161
2	0.526	0.723	0.925	1.313	1.325	1.519	6.149	6.977	-0.047
3	0.526	0.723	0.929	1.135	1.347	1.509	6.169	6.993	-0.151
4	0.519	0.723	0.929	1.181	1.359	1.525	6.236	7.190	-0.302
5	0.519	0.723	0.934	1.137	1.341	1.490	6.144	8.912	-0.303
6	0.526	0.723	0.934	1.142	1.302	1.514	6.141	6.885	-0.129
7	0.519	0.709	0.934	1.131	1.328	1.508	6.129	6.999	-0.162
8	0.526	0.723	0.942	1.162	1.345	1.509	6.207	7.001	-0.309
9	0.519	0.723	0.950	1.147	1.343	1.491	6.173	6.917	-0.404
10	0.519	0.743	0.917	1.142	1.372	1.532	6.225	7.177	-0.096
11	0.526	0.723	0.917	1.149	1.370	1.531	6.216	7.198	-0.072
12	0.526	0.743	0.942	1.142	1.340	1.508	6.201	6.901	-0.249
13	0.519	0.723	0.917	1.126	1.330	1.524	6.139	7.055	-0.010
14	0.519	0.736	0.934	1.162	1.313	1.520	6.184	6.964	-0.238
15	0.519	0.736	0.958	1.142	1.338	1.520	6.213	6.995	-0.279
16	0.519	0.723	0.958	1.186	1.355	1.544	6.285	7.249	-0.339
17	0.526	0.729	0.966	1.162	1.360	1.541	6.284	7.164	-0.266
18	0.519	0.723	0.934	1.181	1.351	1.529	6.237	7.181	-0.294
19	0.519	0.723	0.934	1.142	1.334	1.519	6.171	7.041	-0.171
20	0.529	0.749	0.934	1.131	1.331	1.513	6.187	6.863	-0.130
21	0.533	0.729	0.950	1.152	1.345	1.519	6.228	6.980	-0.222
22	0.526	0.729	0.934	1.142	1.352	1.538	6.221	7.137	-0.065
23	0.526	0.736	0.934	1.162	1.333	1.530	6.221	7.039	-0.173
24	0.519	0.723	0.939	1.142	1.347	1.515	6.185	7.055	-0.224
25	0.526	0.736	0.950	1.138	1.347	1.524	6.221	7.011	-0.185
26	0.519	0.736	0.958	1.131	1.379	1.534	6.257	7.177	-0.206
27	0.526	0.723	0.950	1.167	1.325	1.512	6.203	6.953	-0.326
28	0.519	0.736	0.950	1.162	1.349	1.531	6.247	7.111	-0.283
29	0.519	0.729	0.934	1.093	1.327	1.501	6.103	6.863	-0.064
30	0.519	0.723	0.950	1.149	1.374	1.530	6.245	7.207	-0.248
Total	15.671	21.857	28.162	34.411	40.299	45.597	185.997	211.205	6.108
x	-5	-3	-1	1	3	5			
x'	5	-1	-4	-4	-1	5			

in which the result of measurements obtained on the common cabbage butterfly, *Pieris rapae crucivora* Boisduval, was discussed, the figures in the left two-thirds of Table 1 are the measurements of the width (mm) in logarithms plus 1. This procedure was taken because both the formulae of Dyar[3] and of Gaines and Campbell[4] express the relation between the log-width of head capsule and the instar number, and also because, by removing the negative number in logarithmic values the computation can be made more easily. The results of daily measurement in an instar were averaged, and it was used as the representative width of that instar.

A perusal of many previous papers indicates that the relation between the instar number and the growth of head capsule in the successive instars in the larvae of insects, especially of moths and butterflies, may be expressed either by Dyar's simple equation or by the quadratic equation proposed by Gaines and Campbell in almost all cases. In the case of larvae of the cabbage moth, already Santa reported that Dyar's formula was most suited to his result of measurements, while Hirata found that Gaines and Campbell's formula was more suited to his data than Dyar's formula. As the writer has pointed out in the introduction, Santa's figures are the average results of daily measurements on the twenty individuals which were randomly taken out every day from the experimental population, and also Hirata's figures are the results of measurements of the exuviae of head capsules from the first to the fifth instar larvae and of the head capsule of dead individuals of the sixth instars. Therefore, their figures of measurement in each instar do not always represent the growth of the head width of the same individual. Accordingly, the writer wishes to consider here, from the viewpoint of the statistical theory of small sample, the growth on the basis of the results of successive measurements taken from the individuals which were reared separately.

For this purpose, it is best to test whether the quadratic term of Gaines and Campbell's formula is significant by means of the method of analysis of variance which was used by Bliss and Beard[2] in the discussion of the results obtained on the milkweed bug, *Oncopeltus fasciatus* Dall. If the quadratic term of Gaines and Campbell's formula is not significant, we may expect that the simple Dyar's equation is applicable to that data, but if it is significant, Gaines and Capmbell's quadratic equation should be applied to that data.

For the purpose of computation, first a parabola was fitted by the orthogonal coefficient x and x' to the results for each larva, and $S(xy)$ and $S(x'y)$ which are leading to the linear and quadratic terms for the trend and curvature in a parabola was obtained as shown in the right one-fifth of Table 1. In addition, as shown in the eight column of Table 1, the average width of head capsule in each instar was totaled for each larva. And the thirty figures in each column were summed up as shown in the last line. The result of analysis of variance using these figures is shown in Table 2. The mean square for the quadratic term is significant as seen in the figure of the third row of Table 2. $F=64.65 > F^{1}_{58}(0.01)$. It is, therefore, concluded that Gaines and

Table 2. Analysis of variance of the mean log-widths of head capsule ($\times 10^3$) in successive instars of larvae of the cabbage moth, *Barathra brassicae* L.

Row	Term	Degrees of freedom	Sum of squares	Mean square	F
1	Among larva totals	29	9799	338	1.48
	Regression on instar				
2	Linnear trend	1	21241691	21241691	* *
3	Simple curvature	1	14805	14805	64.65**
4	Scatter	2	3693	1847	8.07**
	Interaction of larvae by				
5	Linear trend	29	5348	184	0.80
6	Simple curvature	29	3374	116	0.51
7	Scatter (error)	58	13295	229	1.00

F significant at * $P<0.05$, ** $P<0.01$.

Campbell's formula should be applied to the present data. This result exactly agrees with Hirata's conclusion. Santa stated in his paper that no formulae but Dyar's one seemed to be applicable to his data. However, the present writer has been led to conclude, judging from the result of computation carried out by applying to his data the method of analysis of variance which has been described by Bliss[1], that Gaines and Campbell's formula fits to his measurements much better than Dyar's one. The quadratic equation computed based on the figures of Table 1 is

$$y = 0.29520 + 0.22684\,X - 0.00368\,X^2,$$

where, X denotes the instar number. And the relation between these two variables is shown in Fig. 1.

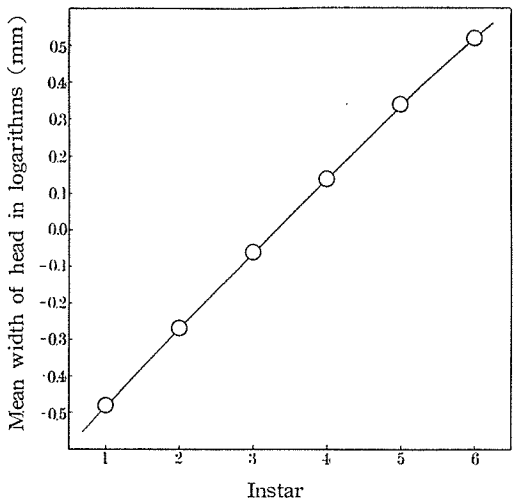

Fig. 1. Relation between mean log-width of head capsule and instar number of larvae of the cabbage moth, *Barathra brassicae* L.

SUMMARY

Starting on the day of hatching, larvae of the cabbage moth were reared separately with leaves of "Komatsuna" under the constant environmental condition of temperature 25°C and 89% relative humidity, and measurement of the width at the largest part of the head capsule of each worm was made daily in successive larval stages. As the result of analysis carried out from the viewpoint of statistical theory of small sample, it was shown that the relation between the log-width of head capsule $y = 1 + \mathrm{Log}\ (\mathrm{mm})$ and the instar number X is expressed by Gaines and Campbell's formula, and it fits much better to the present data than Dyar's formula. The quadratic equation computed based on the figures of Table 1 is

$$y = 0.29520 + 0.22684\,X - 0.00368\,X^2.$$

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