Differences in *Anatis mali* Auct. and *Coleomegilla maculata lengi* Timberlake to Changes in the Quality and Quantity of the Larval Food (Coleoptera: Coccinellidae)

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Capacity to adjust to variable resources of food is a useful criterion for assessing the regulatory influence of predators on the population of prey. *Anatis mali* Auct. was better adapted than *Coleomegilla maculata lengi* Timberlake to tolerate a shortage of food. When the food supply was increased, survival and adult weight increased in both species — adult weight to a much greater extent in *A. mali* than in *C. maculata*, and developmental time decreased in *A. mali*, but was unchanged in *C. maculata*. *C. maculata* was better able to withstand regularly occurring periods of intermittent feeding than a shortage near the end of its development.

The conversion ratio of third-instar *A. mali* larvae and the growth rate of *C. maculata* larvae were higher when individuals were fed on *Acyrthosiphon pisum* (Harr.) than on *Rhopalosiphum maidis* (Fitch). Between the minimum food requirement and the maximum quantity eaten, the conversion ratio of *A. mali* decreased whereas that of *C. maculata* remained constant except at the highest quantities of food where the rate of intake increased and the ratio decreased. Relative food intake rate is an accurate criterion for comparing stages and species of predators that are fed on various foods.

Introduction

The relative value of a predator as a pest control agent depends mainly on its ability to change its numbers in response to changes in numbers of prey. This relationship is being determined using coccinellids as the experimental animals.

Species of predatory coccinellids vary greatly in ability to increase their numbers and so to limit the numbers of their prey. Ability to increase numbers depends in part on the rate at which food is converted into the predator's tissues. The rates of food intake and growth govern this transformation, which is expressed as the efficiency of the conversion of food into body material or simply as the conversion ratio (House 1965). As the rates of food intake and growth affect the development, survival, and weight of a predator, their determination may provide criteria for comparing the relative value of various species in control. *Anatis mali* Auct. and *Coleomegilla maculata lengi* Timberlake were compared in this respect and the results are given here. In addition, the effects of intermittent feeding that is distributed equally over the larval stages are compared for *C. maculata*, with a food shortage near the end of development.

A. mali and *C. maculata* were selected for study because they differ considerably in food specificity, in size, and in distribution. In the field, *A. mali* is more restricted in its diet than is *C. maculata*. It is the largest predatory coccinellid found in Canada and usually occurs only on conifers where it is able to survive at low prey densities. *C. maculata* is less than half the size of *A. mali*; it eats pollen as well as aphids; and it is usually found on herbaceous plants where its food is abundant (Smith 1961).

Materials and Methods

The adult coccinellids that were used to provide larvae for the experiments and these larvae were fed on dried aphids, *Acyrthosiphon pisum* (Harr.). The methods of preparing the food and of rearing predators individually in cells were described elsewhere (Smith 1960, 1965). The work was done at 21.9 ± 0.7° C.

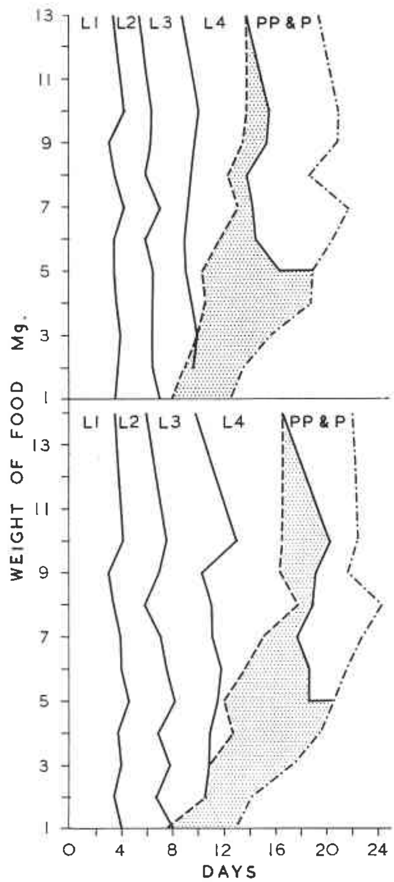

Fig. 1. Upper graph, means of duration of stages (–), of time required to eat the food supplied (---), and of length of life (-.-) for *C. maculata* reared on various quantities of *A. pisum*. Period without food stippled. Lower graph, the same relationships for *C. maculata* reared on *R. maidis*.

and about 65% R.H. A constant artificial light was used, though additional natural light came through windows.

The larvae were inspected twice daily during development. The results were analysed by means of the F test and the differences at the 1% level were considered significant. Means and standard errors are given herein. Other methods are described where applicable.

Effects of Food on Development, Survival, and Adult Weight

Coleomegilla maculata

Previously unfed first-instar larvae of *C. maculata* were divided into two groups each of at least 15 larvae. Each larva in the first group was fed 1.0 mg. of *A. pisum* and each larva in the second group was fed 1.0 mg. of *Rhopalosiphum maidis* (Fitch). This was repeated with both foods, using 2.0, 3.0 mg. and so forth until satiation. The time required to eat the food supplied, and the longevity of each individual, the extent of development, and the number surviving to the adult stage were recorded. On emergence the unfed adults were weighed, killed by exposure to −15° C., dried over calcium sulfate in a desiccator, and weighed again.

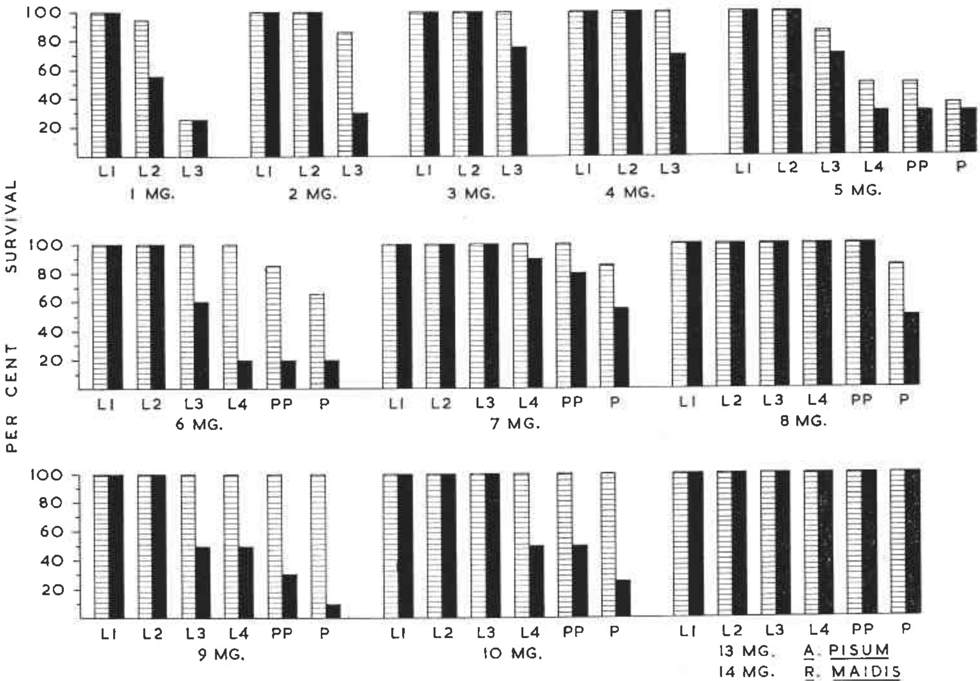

Fig. 2. Percentage surviving to the end of the stage indicated of *C. maculata* larvae reared on various quantities of *A. pisum* (crosshatched) and *R. maidis* (solid).

The relationships between the weight of food supplied and the time required to eat the food, the longevity, and the extent of development are shown in Fig. 1. The relationship between weight of food supplied and survival is shown in Fig. 2. About 5.0 mg. of either *A. pisum* or *R. maidis* was required to produce an adult.

Adults that were reared on 5.0 mg. of *A. pisum* had the lowest dry weights and were smaller than those that were reared on greater quantities of food. Dry weight and size increased as the quantity of food was increased up to about 10.0 mg. Additional food ingested contributed nothing to the weight of the adult (Fig. 3). The results for adults reared on *R. maidis* were similar but, because of higher mortality, insufficient data were obtained to make a detailed comparison.

The water content of the unfed adult was not affected by the larval food. It was about 82% for individuals reared on both species of aphids (live weights 12.6 ± 0.4 and 8.5 ± 0.4 mg. respectively on *A. pisum* and *R. maidis* and respective dry weights 2.2 ± 0.05 and 1.5 ± 0.05 mg.).

Anatis mali

First-instar larvae of *A. mali*, from the same egg masses, were divided into three groups each of at least eight individuals. The first group was fed 5.0 mg. of *A. pisum*, the second 15.0 mg., and the third 30.0 mg. Two additional groups each of 35 larvae were fed an excess of *A. pisum* and *R. maidis*, respectively. All larvae were supplied with drinking water. The quantities of food eaten during development from the second ecdysis to emergence and from the first instar to adult emergence were determined for each larvae in these groups. Adults were weighed after emergence and after drying, as with *C. maculata*. The total time

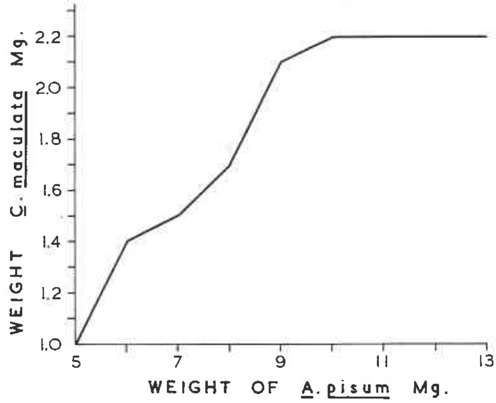

Fig. 3. Mean dry weights of *C. maculata* adults reared as larvae on various quantities of *A. pisum*.

of development and number that reached the adult stage were recorded for all groups.

The *A. mali* larvae fed 5.0 mg. of *A. pisum* died in the fourth instar after about ten days. The development, survival, and adult dry weight of the group reared on 15.0 mg. were respectively: 24.7 ± 0.1 days, 30%, and 4.6 ± 0.3 mg. The data for the group reared on 30.0 mg. were: 19.2 ± 0.1 days, 90%, and 6.7 ± 0.4 mg. respectively.

Larvae supplied with an excess of food ate about 45 mg. of either *A. pisum* or *R. maidis* in the period from the second ecdysis to emergence of the adult and about 55 mg. in the period from the first instar to emergence of the adult. No significant difference in the duration of development from egg to adult (20.9 ± 0.3 days), the survival (85%), and the dry weight of the adult (12.8 ± 0.3) was attributable to food quality. Adult water content was about 73% on both foods.

Effects of Food on Intake, Growth, and Conversion Ratio

Coleomegilla maculata

Indices of relative food intake, relative growth, and food conversion were calculated from a number of measurements described by Gordon (1959): the initial body weight, W1; the final body weight, W2; the amount of food ingested, F; and the time of development, T. From these were calculated: the average body weight, W = ½(W1 + W2); the weight increase, w = W2 − W1; the index of relative food intake, F/TW; the index of relative growth, w/TW; and the index of food conversion, w/F.

The indices were calculated for 50 individuals of *C. maculata* reared from the first-instar larva to the adult stage on an excess of *A. pisum*, for 16 similarly reared on an excess of *R. maidis*, for at least four individuals reared to the adult stage on each of 5.0, 6.0 mg., and so forth, to 13.0 mg. of *A. pisum*, and for 22 males and 28 females reared on an excess of *A. pisum*. Internal genitalia were examined to determine adult sex. The weights of both the predators and the aphids were in milligrams and were in dry weights. The initial dry weight of the first-instar larva was estimated using the water content of the litter mates of the experimental larvae.

The water content of 59 first-instar larvae of *C. maculata* was 74% (live weight 0.2 ± 0.00 and dry weight 0.04 ± 0.00). The index of relative growth for *C. maculata* was significantly higher for individuals reared on *A. pisum* than those reared on *R. maidis*, i.e. 0.09 ± 0.00 versus 0.08 ± 0.00 mg. per day

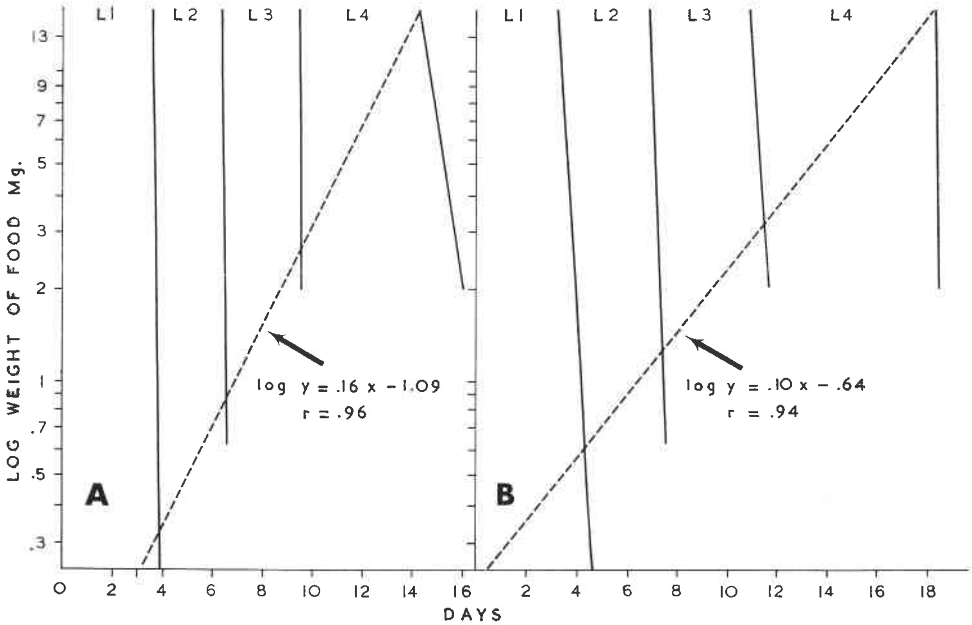

Fig. 4. A, lines (—) equidistant from means for the duration of stages of *C. maculata* reared on various quantities of *A. pisum* showing points of intersection with the line for the time required to eat the food supplied (---). B, the same relationships for *R. maidis*.

respectively. However, the indices of relative food intake and of food conversion were the same on both aphid species, i.e. 0.45 ± 0.01 mg. per day and 0.20 ± 0.00 mg. per milligram of food respectively.

The indices did not vary when 5.0 to 10.0 mg. of *A. pisum* was fed, but when more than 10.0 mg. was fed, the food intake was significantly higher at 0.60 ± 0.03 mg. per day, the food conversion was lower at 0.17 ± 0.01 mg. per milligram of food and the growth rate was unchanged. Sex had no effect on the indices.

The food capacity, i.e. maximum food intake of the larval instars of *C. maculata*, is small and difficult to measure directly. The food conversion was therefore calculated for the larval instars using estimated values of the food capacity and observed weight gains for the four larval instars fed on *A. pisum* and *R. maidis*. The food capacities of the first- and second-instar larvae were extrapolated and those of the third- and fourth-instars were interpolated from the graphed relationships between the logarithm of food quantity and the time taken to eat the food supplied and also the duration of stages (Fig. 4). In these calculations the live weights of predators and aphids were used. The live weights of aphids were calculated assuming 80% water content.

The calculated values of the food conversion for the various instars of *C. maculata* reared on *A. pisum* and *R. maidis* (in parenthesis) were: first instar, 0.3 (0.2); second instar, 0.4 (0.4); third instar, 0.4 (0.3); and fourth instar, 0.2 (0.1).

Anatis mali

The indices of relative food intake, relative growth, and food conversion were calculated for *A. mali* reared from the first-instar larva to the adult stage on eight species of aphids: *A. pisum*, *Dactynotus* sp., *Erisoma ulmi* L., *Hoplochaitphorus quercicola* Monell, *Macrosiphum rosae* (L.), *Myzus cerasi* (F.), *Procphilus* sp., and *R. maidis*. At least three individuals were reared on each aphid. The indices were also calculated for the third-instar larva, the fourth-instar larva, and the period from the second ecdysis to the adult in eight individuals of *A. mali* reared on an excess of *A. pisum* and 11 reared on an excess of *R. maidis*. The initial dry weight of the first-instar larva was estimated from the water content of litter mates of the experimental larvae.

The water content of 32 first-instar larvae of *A. mali* was 78% (live weight 0.7 ± 0.05 mg. and dry weight 0.2 ± 0.01 mg.). The means and ranges of the indices of relative food intake, relative growth, and food conversion for *A. mali* reared on the eight species of aphids were respectively: 0.47 (0.39–0.53) mg. per day, 0.09 (0.08–0.10) mg. per day, and 0.20 (0.19–0.25) mg. per milligram of food.

No significant differences attributable to food quality were found in the indices of food intake and growth of stages of *A. mali* larvae that were fed on *A. pisum* and *R. maidis*, but the means for the third-instar larva were much higher than those for the fourth-instar and the means for the period from the second ecdysis to the adult were close to those for the fourth-instar larva. The respective means for food intake in milligrams per day were: 1.17 ± 0.05, 0.37 ± 0.01, and 0.45 ± 0.01. The respective means for growth in milligrams per day were: 0.38 ± 0.02, 0.09 ± 0.00, and 0.11 ± 0.00.

The food conversion of the third-instar larva was significantly higher when fed on *A. pisum* (0.39 ± 0.02 mg. per milligram of food) than when fed on *R. maidis* (0.29 ± 0.02 mg. per milligram of food), but no significant differences attributable to food quality were found for the fourth-instar (0.24 ± 0.01 mg. per milligram of food) or the period from the second ecdysis to the adult (0.25 ± 0.00 mg. per milligram of food).

Effects of Intermittent Feeding on *Coleomegilla maculata*

First-instar larvae of *C. maculata* from the same egg masses were divided into two equal groups of eight larvae. The first group was given a continuous excess of *A. pisum*. The second group received an excess of food and no food alternately for two-day periods. Drinking water was always present.

The duration of development of all stages except the first instar was significantly longer for the intermittently fed group than for the group on continuous feeding. That first-instar larvae were unaffected probably can be explained by a carry-over of nutrient from the egg. The percentage differences for the other instars and pupa and for the total development from first instar to adult were: second instar, 46% longer; third instar, 40%; fourth instar, 46% pupa, 30%; and first instar to adult, 36%. The eight-day duration of the fourth instar of the intermittently fed group is longer than that of *C. maculata* reared on 5.0 mg. of *A. pisum* (Fig. 1). Such a period was probably maximum for continuous development to the adult stage. The effect of intermittent feeding on alternate two-day periods was about equivalent to the provision of a suboptimal amount (5.0 mg.) of *A. pisum* at one time.

Survival to the adult stage of the intermittently fed group was significantly less (62%) than that of the group that was fed continuously (100%). The percentage survival for the intermittently fed group was equivalent to that obtained when about 6.0 mg. of *A. pisum* was fed at one time (Fig. 2).

The mean dry weights of adults of the intermittently fed and continuously fed groups were 2.0 ± 0.10 and 1.9 ± 0.20 mg.

Discussion

Within the limits from the minimum food requirements to the maximum quantity eaten, *A. mali* was more flexible than *C. maculata* in its ability to adjust developmental time and adult weight. However, *C. maculata*, and no doubt *A. mali*, can increase developmental time in response to a food shortage that is equally distributed over the feeding stages. For *C. maculata* the maximum increase in time taken to develop from egg to adult compatible with survival is probably about 36%. *A. mali* differs from *C. maculata* mainly in its ability to adjust the adult weight to the available food supply. When food was scarce a greater percentage of food was converted into body weight in *A. mali* than when food was abundant. *C. maculata* apparently cannot do this, under similar conditions.

The ability of *C. maculata* to withstand regularly occurring periods of intermittent feeding better than a shortage near the end of its growth may be related to the proportion of food eaten by the fourth-instar larva. It is greater in *C. maculata*, at 81%, than in *A. mali*, at 65%. Its value in a number of other species according to the data of various authors is: *Adalia decempunctata* (L.), 54% (Dixon 1959); *Aphidecta obliterata* L., 51% (Smith 1958); *Hippodamia quinquesignata* (Kirby) and *Paranaemia vittigera* (Mannerheim), 71% (Kaddou 1960). Species that can tolerate a food shortage in the fourth instar may be better able to survive at low prey density than those that cannot.

When food was unlimited no important differences existed between the overall indices of relative food intake of *A. mali* and *C. maculata* that could be attributed to food quality. About 0.5 mg. per milligram of predator is a low estimate for the larvae of both species as the pupal period is included in the calculation. As interspecific variation in the value of the index was small, differences in growth, development, and survival were probably caused by nutritional factors. The index of relative food intake is a more accurate criterion for comparing stages and species than "predatory value" as defined by Evans (1962), i.e. total food eaten divided by the duration of development, because it makes allowance for differences in size. Evans (1962) showed with *Phonoctoncus nigrofasciatus* Stål. (Hemiptera: Reduviidae) that the predatory value is a variable index that must be used with care in comparing instars.

The indices of relative growth of *A. mali* and *C. maculata* decreased with increases in size and age but there was no important interspecific differences in the overall rate, which had a value of about 0.09 mg. per day in the period from the first-instar larva to the adult stage. Food quality significantly affected the rate in *C. maculata*, but had negligible effect on *A. mali*. The growth rate of *C. maculata* was not affected by food quantity over a relatively wide range. Although males and females of *C. maculata* grew at the same rates, it remains to be shown that this would apply to *A. mali*.

The food conversion of *A. mali* and *C. maculata* was generally greater in the earlier than in the later larval instars. The overall value for both species was about 20%. This is lower than the 51% reported for *Stalia major* Costa (Heteroptera: Nabidae) (Fewkes 1960), the 33–63% for *P. nigrofasciatus* (Evans 1962), and the 27% for the spider, *Linyphia triangularis* Clerck (Turnbull 1962). It is also lower than the calculated efficiency of *A. decempunctata*, based on Dixon's data (1959). In this species it was about 68% under the following conditions: food intake, 77 third-instar aphids, *Microlophium evansi* Theob.; dry weight of adult, 2.1 mg.; dry weight of aphid, 0.04 mg.; and water content of aphid, 80%.

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Dissimilarity of Heptachlor-resistance in Life-stages of the Turnip Maggot, *Hylemya floralis* (Fall.) (Diptera: Anthomycidae)[1]

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Abstract

Laboratory tests of heptachlor-resistance in larvae and adults from treated and untreated farm populations of *Hylemya floralis* (Fall.) showed that only larvae were developing resistance. Therefore it is suggested that all life-stages of insect pests should be tested to determine which stage soonest reflects the highest level of resistance. This stage could be used to detect levels of resistance in the field and to permit alteration of control programs, to prevent development of complete resistance and the consequent loss of crop.

Third-instar larvae from the farm where all cruciferous crops had been treated with heptachlor annually, from 1952 to 1961, were resistant to 80 times greater concentrations of heptachlor than those from the untreated farm. From 1962 to 1964 the level of resistance remained constant in third-instar larvae from the untreated farm but it decreased fivefold in those from the treated farm. This decreased resistance is attributed to dilution of the population by non-resistant *H. floralis* from adjoining crops untreated during this period.

The turnip maggot, *Hylemya floralis* (Fall.), which has a single generation each year, is a serious pest of crucifers throughout the Nearctic regions of the world. In Saskatchewan it can still be controlled with heptachlor or dieldrin. The closely related multiple generation species *Hylemya brassicae* (Bouché), also a pest of crucifers, which is distributed generally in Canada and northern United States but not in Saskatchewan, has become resistant to heptachlor and to

[1]Contribution No. 231, Canada Department of Agriculture, Research Station, Saskatoon, Saskatchewan.