Longevity and Oviposition of Vedalia Beetles[1] on Artificial Diets[2]

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ABSTRACT

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Adult coccidophagous beetles, *Rodolia cardinalis* Muls. (Coleoptera: Coccinellidae), were reared on artificial diets. On lyophilized drone honey bee brood fortified with sucrose (DPS), female beetles survived longer (76.3 days) but laid fewer eggs (106.3) than control fed on living *Icerya purchasi* Maskell scales (38.6 days and 489.2, respectively). On sucrose or a chemically defined diet they also survived longer but laid only about 20 eggs. The beetles produced more eggs when *I. purchasi* was combined with DPS or other artificial diets. Beetles fed *I. purchasi* 1 day and DPS for two days oviposited 80% of the control level and beetles fed *I. purchasi* 1 day and sucrose for 2 days oviposited 120% of the control level. Controls were fed only *I. purchasi*. This technique makes it possible to breed vedalia beetles under controlled conditions with a small number of natural prey scales.

The vedalia beetles, *Rodolia cardinalis* Mulsant, have been used to control cottony cushion scales, *Icerya purchasi* Maskell, an orange tree pest in many countries. The first success was made by a small number of adult beetles imported from Australia to California (see Hagen and Franz 1973). Their virtually monophagous food habit and ability to search for their prey (Quezada and DeBach 1973) probably contributed to their success. Augmentation of vedalia as a biological control agent has been usually carried out with prey scales collected from the field (Bodenheimer 1951), but it is sometimes difficult to get a sufficient number. Laboratory studies have shown that *I. purchasi* propagated on potato or pumpkin (Takeuchi and Nishino 1972, Matsuka and Watanabe 1980) can be used, but this process is expensive and troublesome. Since vedalia is an important coccinellid, it is surprising that there has been only one reported success in rearing the beetle on an artificial diet, Smirnoff (1958), and it has never been duplicated.

Okada and his colleagues have developed a technique of using drone honey bee powder (DP) as a diet for aphidophagous coccinellids (Okada and Matsuka 1973), chrysopids (Okada et al. 1974), and other lady beetles with different food habits (Matsuka et al. 1972). After an earlier attempt to feed DP to vedalia failed, we tried again with improved rearing techniques using DP and other artificial diets.

Materials and Methods

The beetles were reared in a 9-cm petri dish at 25°C in the dark with observation and a diet change every 24 h (Matsuka and Watanabe 1980). Newly emerged adults were taken from the culture and confined either individually or in pairs then supplied with a diet- and water-saturated sponge. Live *I. purchasi* used as the control diet or as part of an experimental diet were two to three newly emerged adult scales with little wax or 3rd-instar larvae in each container. For oviposition experiments, absorbent cotton (1 by 3 cm) was supplied as a substrate for egg laying, and the male was removed several days after oviposition started (Matsuka and Watanabe 1980).

Young pupae of drone honey bees, *Apis mellifera*, were obtained from an apiary, stored at −10°C, lyophilized, and ground into drone powder (DP). Part of the experimental diet was DP fortified with sucrose, glucose, fructose or trehalose. Because sucrose fortified DP (DPS) was the most successful, it was used as the diet most of the time.

A chemical diet (CD) was of the following composition: 30% L-amino acids (in the same proportion as in natural drone pupae, Niijima et al. 1977); 4% minerals and ca. 0.1% vitamins (as in the diet of aphids, *Myzus persicae*, in Dadd and Mittler [1966]) fortified with carotene and tocopherol; 20.9% lipids (based on an analysis of *I. purchasi* lipids [unpublished data]) and 45% sugars. The composition in grams of a 100-g diet was as follows: arginine 1.2, histidine 0.3, isoleucine 1.2, leucine 2.4, lysine 2.0, methionine 0.5, phenylalanine 0.8, threonine 0.8, tryptophane 0.3, valine 2.0, alanine 2.4, aspartic acid 3.6, cysteine 0.3, glycine 1.4, glutamic acid 5.0, proline 3.4, serine 1.2, tyrosine 1.2, sucrose 43.0, trehalose 2.0, cholesterol 6.0, stearic acid 2.0, oleic acid 3.0, linoleic acid 4.0, myristic acid 2.4, palmitic acid 3.5, K_3PO_4 2.27, $MgCl_2 \cdot 6H_2O$ 1.71, and in (mg): $FePO_4 \cdot 4H_2O$ 4.4, $MnSO_4$ 1.3, $CuSO_4 \cdot 5H_2O$ 1.3, $ZnSO_4 \cdot 7H_2O$ 1.3; thiamine 1.2, riboflavine 1.5, pyridoxine 7.1, Ca-pantothenate 4.2, choline chloride 19.2, inositol 60.6, biotin 0.001, folic acid 3.3, vitamin B_{12} 0.001, nicotinic acid 2.9, β-carotene 1.0 and DL-tocopherol 1.0. A small amount of ethanol solution containing the lipid materials was dissolved in warm water (ca. 2%) and added to water-soluble components. After the mixture was thoroughly stirred, frozen, and dried in a vacuum, it was combined with a small amount of warm water and lyophilized again, then ground into powder at 5°C. All diets were kept in a desiccator over silica gel.

Results and Discussion

Longevity

The longevity of 20 groups of 20 adults each was examined for each of 20 different diets. Individual beetles were separately confined immediately after emergence and before copulation. Figure 1 represents the

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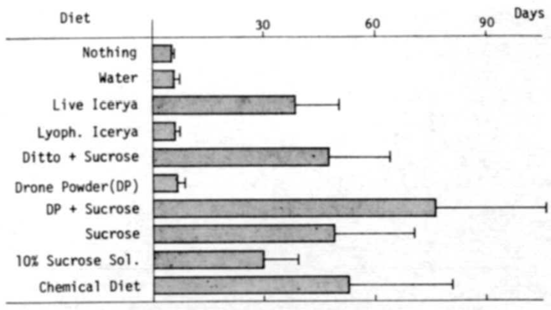

FIG. 1.—Average longevity (+SD) of nonpaired female vedalia adults on various diets.

longevity of the nonpaired females which was 20 to 30% longer than that of males in this experiment. A paired female usually died earlier than a male, possibly because of a loss of strength due to oviposition (Bodenheimer 1951).

On a diet of pulverized (after lyophilization) *I. purchasi* and water, eight females died within 8 days (6.0 ± 1.2 on the average). There was a similar longevity with a DP diet, a water diet, or an absence of food. Frozen scales, dewaxed, or dried scales did not sustain beetles (not shown in the figure). Since the nutritional value of frozen or lyophilized *I. purchasi* should not have deteriorated, the diet's failure is probably due to the physical differences between it and live *I. purchasi* such as shape, hardness, or a lack of moisture. Sucrose added to a diet provided longer longevity than a diet of living *I. purchasi* (38.6 ± 11.9 days). The maximum time (76.3 ± 29.8 days) was obtained with the combination of DP and sucrose (1:1, DPS). A powdery diet fortified with sucrose and put with a water-saturated sponge in a petri dish absorbed moisture and became rather sticky within hours. The order of a hygroscopicity (fructose > sucrose > glucose) parallelled the longevity (not shown in the figure) with the diet fortified with each sugar.

Our CD with its 45% sugars and 20% lipids also sustained vedalia very well. They survived an average of only 10 days with another chemically defined diet (Niijima et al. 1977) containing 32.5% sucrose, no lipids except cholesterol, and 60% amino acids. However, the latter diet was good for the survival of an aphidophagous beetle, *Harmonia axyridis*. A survey to clarify the cause of the differences between the two diets is in progress.

Oviposition with Artificial Diets

The absence of successful reports of substituting the prey scale with an artificial diet is perhaps due to the fact that the prey specificity of vedalia is very high and monophagous on *I. purchasi* scales (Quezada and DeBach 1973). We investigated oviposition by vedalia on artificial diets because we found that viscous material with sugar sustained vedalia's survival. Three powdery diets were used (Table 1). However, each diet prolonged the preoviposition period and reduced the number of eggs laid (see also Fig. 2 and 3). Sucrose-fortified DP (DPS) was the best artificial diet, producing more than one-fifth of the number of eggs of the control. Hatching rate was an average of 32.3%, decreasing to 0 after 10 days of oviposition, but 70.8% of the control eggs hatched. With sucrose or CD, not more than 50 eggs were deposited. Eggs hatched normally from a sucrose diet but not at all from a CD diet.

Newly emerged vedalia females have undeveloped ovarioles and well-developed fat bodies. *I. purchasi* feeding caused a rapid rate of ovarian development within 3 days, without decoloration of the fat bodies. When artificial diets were given, this rate was slightly retarded, whereas the contents of the fat bodies seemed to be consumed in supplying vitellogenin for egg production. Since sucrose did not provide any nitrogenous nutrients, the reserved materials must have corresponded to the ca. 20 eggs they oviposited. Vedalias given only water as a diet were unable to use these materials, because they died soon without oviposition.

Combination of Artificial Diets and I. purchasi for Oviposition

Vedalia survived and even oviposited on some artificial diets. DP especially seemed to be a positive nutrient source for egg production, though inferior to the natural prey. We next tried to augment egg production by combining *I. purchasi* feeding and the artificial diets, using 8 to 10 females for each experimental group.

With *I. purchasi* given for the first day from emergence, and DPS thereafter, the preovipositional period was shortened and the total number of eggs laid increased (Fig. 2). When fed *I. purchasi* for 3 days, vedalia started to oviposit almost at the same time as the control group but at a 2/3 rate at 20 days, then the rate fell further behind the control. These vedalia deposited twice as many eggs as the vedalia fed only DPS. The longer *I. purchasi* were fed, the more eggs they deposited. Judging from around day 30 in Fig. 2, feeding of *I. purchasi* for a day, at least during the first several days, was equivalent to 30 eggs produced later. This correlation, however, was dependent on DPS as a basic diet. Similar combinations of *I. purchasi* and sucrose or CD did not bring about as good a result. Thus, the superiority of DPS to other artificial diets was confirmed.

When fed sucrose or CD, vedalia stopped oviposition about 15 days from emergence after deposition of ca. 20 eggs (Fig. 3). The effect on the oviposition of feeding *I. purchasi* was examined after beetles fed on DPS, sucrose, or CD for the first 15 days of adult life. As illustrated in Fig. 3, the effect of feeding *I. purchasi* was the same for each of the three diets: 210 to 240 eggs were produced during 10 days of observation after a lag of 2 to 3 days. The time was shorter until the resumption or sharp increase in egg laying, and the rate of oviposition was higher than in the control (Fig. 2; also shown at top of Fig. 3). The ingestion of an artificial diet seemed to hasten ovarian development.

The resumption of egg laying is important when vedalia beetles are released into the field as a biological

Table 1.—Oviposition by *R. cardinalis* on four kinds of diet

Determination	*I. purchasi*	DPS	CD	Sucrose
No. of females tested	10	22	14	53
Longevity (days)	37.6 ± 9.1	25.9 ± 8.2[a]	22.6 ± 8.3[a]	24.0 ± 5.7[a]
Preovipositional period (days)	3.7 ± 1.1	8.5 ± 4.2	7.3 ± 1.8	6.8 ± 2.7
No. of oviposition (days)	30.4 ± 6.8	13.0 ± 4.5	5.9 ± 1.9	5.2 ± 2.6
No. of eggs; maximum	908	179	43	50
Mean	489.2 ± 234.6	106.3 ± 43.0	22.3 ± 10.5	22.6 ± 15.2
Per day	16.1 ± 6.1	8.2 ± 2.6	3.8 ± 2.3	4.3 ± 1.7

[a]These figures were obtained from different groups of individuals. $\bar{x}$ ± SD.

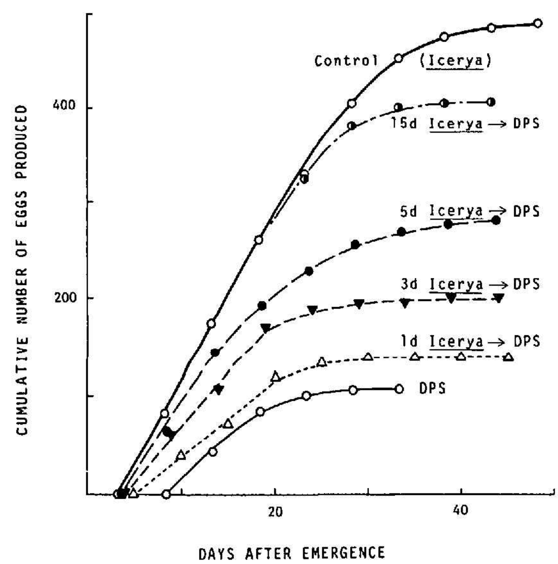

FIG. 2.—Oviposition by *R. cardinalis* on DPS after feeding live *I. purchasi* for different duration.

control agent after having been kept for a while. Such resumption by *I. purchasi*-fed beetles was also observed after 20 or 30 days of feeding on sucrose. In these cases, however, many beetles died before they were fed *I. purchasi*. Maintenance and an increase in oviposition of beetles with a more appropriate diet are points to be considered further.

Effect of Interval Feeding of I. purchasi on Oviposition

Results obtained from feeding *I. purchasi* every 3, 5, or 10 days in combination with DPS, sucrose, or CD are illustrated in Fig. 4. Feeding *I. purchasi* every 5 or 10 days combined with any of the artificial diets yielded poor results in oviposition. In contrast, feeding *I. purchasi* 1 day followed by 2 days with DPS produced plenty of eggs. A better result might be obtained if *I. purchasi* is supplied for the first 3 days and every 3 days thereafter. This would be a more economical use of the natural prey.

The effect was remarkable of feeding sucrose fortified with *I. purchasi* every 3 days. Although the rate was slightly lower than that of continuous *I. purchasi* feeding (control), oviposition lasted very long and produced 617 eggs, 26% more than the control. The persistence of the

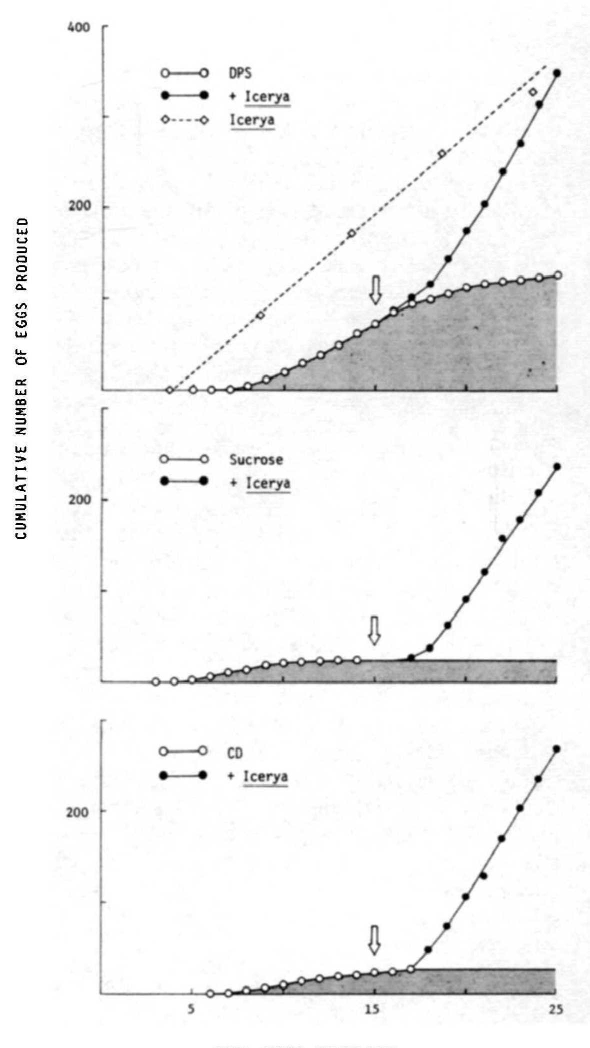

FIG. 3.—Oviposition by *R. cardinalis* on DPS, sucrose, or CD, and oviposition restoration by feeding live *I. purchasi* 15 days after emergence.

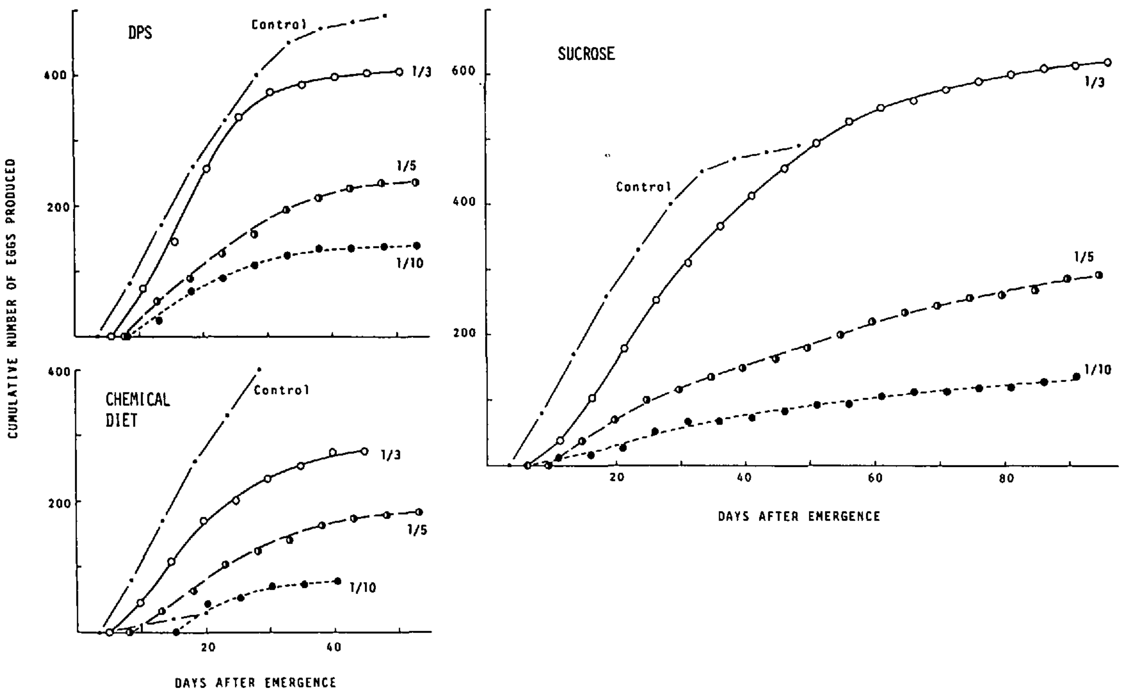

FIG. 4.—Effects of interval feeding of live *I. purchasi* on oviposition by *R. cardinalis* in combination with DPS, sucrose, or CD. 1/3, 1/5, and 1/10 indicate feeding *I. purchasi* every 3, 5, and 10 days, respectively.

constant rate of oviposition of 80 to 90 days was a characteristic of feeding sucrose combined with *I. purchasi*.

A diet of sucrose-fortified DP for vedalia beetles resulted in the first successful case in which their longevity and oviposition were maintained under controlled conditions in laboratory. The beetles survived a long time on only sucrose but produced few eggs. Thus, DPS was confirmed to provide fairly good nourishment to vedalia beetles as well as to other predaceous coccinellids as previously shown (Matsuka et al. 1972, Okada and Matsuka 1973, Niijima 1979). The improvement of physical conditions (particularly moisture content and viscosity as shown here) would probably improve a diet's effectiveness. The insufficiency of artificial diets was alleviated when they were partly combined with natural prey. These results offer good clues for further investigation concerning (1) the production of a biological control agent using a small amount of natural prey and (2) the nutritional requirements for survival and egg maturation of the coccidophagous beetle, vedalia.

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