J. Indian Inst. Sci., Jan.–Apr. 2004, **84**, 21–29

Autecology of the endemic Crimson Rose butterfly *Pachliopta hector* (Lepidoptera : Rhopalocera : Papilionidae)

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Received on July 02, 2003; Revised on November 10, 2003.

Abstract

The study including field observations on the distribution of eggs, larvae, purpae on the larval host *Aristolochia indica* and the laboratory study on the success rate of eggs, larvae and pupae established that *Pachliopta hector* Linn., endemic to Sri Lanka and south India, is on wings throughout the year with a higher density during August/September–October/November and also during April–June. It is multivoltine with 6–7 broods yearly, with development from egg to the adult requiring 39–47 days. The species displayed single egg-laying habit, which coupled with host plant specialization of larve feeding on *A. indica* and *A. bracteolata* allowed efficient utilization of the food resource. The eggs hatched in seven days and the larvae passed through five instars. The last two instars consumed over 80% of the total food intake. Profiles of food consumption and body weight gain ran on similar lines, with increase through successive larvae. Both consumption index (CI) and growth rate (GR) declined as the larvae aged, the value of the former averaging 3.02 and the latter 0.37. The values of approximate digestibility (AD) are high: 99–87%. The values of both efficiency of conversion of ingested food (ECI) and efficiency of conversion of digested food (ECD) increased as the larvae aged, the former averaging 18.02% and the latter 22.26%. Adults of *P. hector* utilized nearly 24 floral species as nectar sources, whose sugar concentrations (12–58%) corresponded with 15–50% in psychophilic flowers. They displayed a hovering habit while harvesting nectar, and frequently contacted the essential organs with probosics and head, thus promoting cross-pollination.

Keywords: *Pachliopta hector*, *Aristolochia*, food utilization, voltinism.

1. Introduction

The Crimson Rose butterfly *Pachliopta hector* Linn. is one of the spectacular species of swallowtails, with a red body and wing span of 90–120 mm. The upper side of wings is bluish-black and fore wings carry interrupted and irregular discal and apical white bands, and hind wings bearing nearly round and marginal rows of bright crimson crescent spots. It is stated to be endemic to Sri Lanka and south India [1], but its range may extend along the east coast of Orissa, south Bihar, West Bengal and into Sikkim and parts of northeast India [2]. It is reported to assemble in thousands during winter months in plantations and forest patches, thus indicating its migratory nature [3]. It is often described as very common in the region south of Godavari river but our survey there did not reveal its preponderance. The destruction of natural vegetation and clearing of scrub jungles and foothill vegetation for raising monocultures might have resulted in the decline of its larval hosts *Aristolochia bracteolata* Lamk. and *A. indica* Linn. and consequently the decline of *P. hector* popula-

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tions. The species may occur all the year round [4], but the number of broods per year appear to be not known, and Larsen [1] suggests an investigation on voltinism pattern. Rearing of this species and releasing the same in the wild will help restocking its depleted population, and also serve as a measure of its conservation [5]. However, to be successful in this direction, one needs a complete knowledge of its autecology including life history, voltinism, seasonality and habitat conditions. Since butterflies are holometabolous with distinct developmental stages—egg, larva, pupa and adult, their reproduction depends on the combined effect of larvae- and adult-derived nutrients. Hence data on larval performance in respect of food consumption, utilization and growth, and on adult nectar hosts are necessary. This kind of information for *P. hector* and the Indian butterflies in general is woefully deficient [6]. Here, we provide the same as part of the autecological profile of *P. hector* for use in the conservation management of this endemic species.

2. Methodology

During our major study on the biology and ecology of south Indian butterflies, we noticed the Crimson Rose *Pachliopta hector* Linn. using *Aristolochia indica* Linn. and *A. bracteolata* Lamk. (Aristolochiaceae) for oviposition and subsequently as larval hosts. We selected *A. indica* for the study described here because of its relatively high density and accessibility for collection of leaf material and for the enumeration of the distribution of different life stages. We collected the eggs along with the leaf material, incubated the same in the laboratory (at round 28°C), and observed them daily for their development through various stages. We recorded the time and success rate of egg hatching, larval and pupal development and adult emergence. We supplied young leaves daily to the growing larvae, and noted the feeding behaviour of the newly hatched larvae and the successive instars, and the particulars of larvae and pupae. To have a knowledge of the population density and annual distribution, we scored thrice each month at an equal interval the numerical frequency of eggs, larvae and pupae on 20 plants of *Aristolochia indica* in the natural habitat. The same number of plants, though not the same ones, was maintained throughout the year as some tagged plants are damaged due to several unknown factors. Also we made cursorial observations on the adults on wing and breeding pairs. We measured food consumption of each larval instar and also the growth, then determined the indices of food utilization for each instar. We maintained five replications ($n = 5$ individuals) for each parameter and averaged the data. We adopted the following formulae of Waldbauer [7] for calculating the nutritional indices.

$$\text{CI (Consumption index)} = \frac{\text{Wt of food consumed}}{\text{Wt of instar} \times \text{number of feeding days}}$$

$$\text{GR (Growth rate)} = \frac{\text{Wt gain of instar}}{\text{Mean wt of instar} \times \text{Number of feeding days}}$$

$$\text{AD (Approximate digestibility)} = \frac{\text{Wt of food consumer} - \text{Wt of faeces}}{\text{Wt of food consumed}} \times 100$$

$$\text{ECD (Efficiency of conversion of digested food)} = \frac{\text{Wt gain of instar}}{\text{Wt of food consumed} - \text{Wt of faeces}} \times 100$$

$$\text{ECI (Efficiency of conversion of ingested food)} = \frac{\text{Wt gain of instar}}{\text{Wt of food consumed}} \times 100.$$

We found the adults of *P. hector* seeking floral nectar avidly in their habitat. We recorded the nectar host plants, their flowering periods and corolla tube length. We measured nectar volume and sugar concentration selecting five flowers per plant species and averaged the readings. We used graduated pipettes for measuring nectar volume and refractometer for finding nectar sugar concentration. On three fine weather days during the peak blooming of plants in their natural habitats, we recorded the flower visiting activity pattern of adults by continuously scoring the flowers (on a selected branch each time) visited each hour during 0600–1800 h. Using a stopwatch we also recorded the foraging speed in terms of number of flowers visited per unit time and the time spent at a flower during nectar harvesting. We followed the intrafloral behaviour from close quarters. We examined the various body parts of the captured adult butterfly using a light microscope for pollen placement on the body, and ultimately the pollination potential.

3. Results

3.1. *Life history stages*

The adults of *P. hector* breed throughout the year. They lay eggs singly mostly during 0800–1200 h of the day on the lower surfaces of young leaves of *A. indica* and *A. bracteolata*. Six to eight eggs are laid in a sequence, preferably on different leaves. The eggs are round, with longitudinal ridges extending from base to apex. They are orange red in colour and 2.4–2.6 mm (2.6 ± 0.03 mm) in diameter. The eggs hatch in about 7 days and the larva has five instars.

Instar I lasts 2–3 days and has a length of 5.0–5.8 (5.5 ± 0.12) mm. Its body is reddish brown in colour and rectangular in shape. It has several spines in orange red colour. Instar II lasts 3–4 days and grows to 7.0–7.4 (7.2 ± 0.06) mm length. The middle segmental spines of the body become orange. Spines also begin to appear on other segments of the body. Instar III lasts 3–4 days and grows to 10–11 (10.5 ± 0.02) mm length and 2–3 (2.4 ± 0.12) mm width. Spines show a length in the range of 1.5–1.8 (1.6 ± 0.11) mm. A pair of red stripes is present on the ventral side of the body between the last thoracic and first abdominal segment. All spines of the body turn to dark orange. Instar IV lasts 4–5 days. It grows to 20–21 (20.6 ± 0.14) mm length and 2.5–3.0 (2.8 ± 0.11) mm width. Spines are 1.8–2.2 (2.0 ± 0.12) mm long. The other characters are the same as in the third instar. Instar V lasts 6–7 days. It grows to 30–33 (31.5 ± 0.07) mm length and 3.7–4.2 (3.8 ± 0.12) mm width. Spines are 2.5–3.0 (2.7 ± 0.06) mm long. There is no change in other characters. At the end of this instar the larva thickens itself by shortening and enters the pupal stage. It is then 25–37 (26.2 ± 0.14) mm long. It attaches to the substratum with the help of head and tail. This stage lasts 1 or 2 days. The pupal stage lasts 13–15 days and grows to a length of 25.0–26.5 (25.6 ± 0.04) mm and to a width of 10.0–12.0 (11.4 ± 0.04) mm at the broadest region. It is flattened dorsoventrally. Two lateral projections appear in the thoracic region and also segmentation in the abdominal region. The duration between oviposition and adult emergence is 39 to 47 days.

Table I
Food consumption and utilization efficiencies of *P. hector* larvae fed with *A. indica* leaves

Instar number	Wt of food ingested (mg)	Wt of faeces (mg)	Wt gain by larva (mg)	GR	CI	AD (%)	ECD (%)	ECI (%)
I	47.5 ± 0.12	0.30 ± 0.02	2.5 ± 0.06	0.45	8.60	99	18.8	5.2
II	93.5 ± 0.19	4.21 ± 0.08	19.7 ± 0.12	0.45	2.20	94	21.9	20.9
III	1426.3 ± 1.20	122.80 ± 0.20	71.0 ± 0.14	0.39	1.96	92	15.4	14.9
IV	2189.7 ± 4.20	189.50 ± 0.23	453.1 ± 0.41	0.35	1.69	91	22.6	20.6
V	4320.6 ± 12.40	540.10 ± 0.41	1232.0 ± 1.10	0.20	0.73	87	32.5	28.5

GR = Growth rate; CI = Consumption index; AD = Approximate digestibility; ECI = Efficiency of conversion of ingested food; ECD = Efficiency of conversion of digested food.

3.2. *Consumption and utilization of food, and growth of larvae*

The newly hatched-out larvae fed on the empty egg shells from which they emerged, and later commenced to feed on the leaves supplied. They did not engage in continuous feeding. The first two instars fed each 2 to 4 times taking 20–35 min, while the other, each fed 4 to 7 times taking 40–58 min during a 4-h observation period from 1000–14000 h. Instars I and II fed slowly and the other instars fed rapidly. Table I gives the data on the weight of food ingested, the weight of frass, the weight gain by the larvae and the performance indices of food consumption and utilization. Food consumption increased gradually from instar I to V. The weight of frass is minimum with instar I and it progressively increased with each instar. The weight gain in the larvae showed a progressive increase from instar I to V. On the contrary, the values of relative growth (GR), consumption index (CI) and approximate digestibility (AD) showed a descending trend from instar I to V. Values of efficiency of conversion of digested food (ECD) and efficiency of conversion of ingested food (ECI) showed an increase from instar I to II, a steep decrease in instar III and again a steep increase in instar IV and V.

3.3. *Distribution and success rate of development of life stages*

Table II gives the results of the searches made of the life stages of egg, larvae, purpae on 20 plants of *A. indica* in the field. The three stages occurred on the host plant over the entire year with higher frequency during April–May and, September–December for eggs, during April–July and, August–September for larvae, and during September–October for pupae. In the laboratory, there was a high success rate of development of all stages in all the months of the year. Hatching success varied between 80 and 100%, larval survival and pupal development between 90 and 100% and adult emergence rate between 95 and 100% (Table III).

Table II
Distribution of different life stages of *P. hector* on *A. indica* (Total of 20 plants)

Life stages	Month											
	J	F	M	A	M	J	J	A	S	O	N	D
# Eggs	12	16	14	22	24	18	16	15	20	24	18	21
# Larvae	2	3	2	4	6	4	2	5	4	2	2	3
# Pupae	1	1	0	2	1	2	1	2	3	4	1	0

Table III
Success rate of development of eggs, larvae and pupae of *P. hector* in the laboratory

Life stage	Month											
	J	F	M	A	M	J	J	A	S	O	N	D
# Eggs incubated	10	15	10	15	15	15	20	20	20	20	15	10
# Larvae hatched	8	14	10	14	14	14	20	19	20	20	14	10
# Pupae formed	8	14	9	14	13	14	19	18	19	19	14	9
# Adults emerged	8	14	9	14	12	14	19	18	18	19	14	9

3.4. *Particulars of nectar host plants and butterfly foraging*

Adult of *P. hector* utilized 24 species for harvesting nectar, and one or the other species of these plants was in flower at any time of the year (Table IV). The length of corolla of these species ranged between 2 and 39 ($\overline{X}$ = 12.0) mm while that of proboscis approximated an average of 27 mm. The butterfly visited 12–32 ($\overline{X}$ = 21.6) flowers in a minute, and spent 1.2–4.5 ($\overline{X}$ = 2.6) seconds sucking nectar at a flower across the studied plant species. Nectar volumes ranged between 0.20 and 2.25 μl, and sugar concentration from 12 to 58% (Table V). Five of the nine species examined had nectars rich in sucrose and the other four had glucose dominant nectar. Flower-visiting activity generally varied from hour to hour, and though the time of peak activity varied for different floral species, it fell mostly between 0600 and 1000 h, but in the case of *Clerodendrum infortunatum* the peak activity was at

Table IV
Nectar sources of *P. hector*

Name of plant species	Flowering period
Adathoda zeylonica	January–March
Albizzia lebbeck	March–June
Anacardium occidentale	December–March
Antigonon leptopus	Year long
Bougainvillea spectabilis	Year long
Caesalpinia pulcherrima	Year long
Capparis spinosa	December–February
Carissa carandus	Year long (April–July)
Catharanthus roseus	Year long
Citheroxylum subserratum	April–June
Clerodendrum infortunatum	February–April
Duranta repens	June–December
Hibiscus rosasinensis	Year long
Hyptis suaveolens	September–January
Jasminum angustifolium	June–August
Lantana camara	Year long
Muntingia calabura	Year long
Nerium odorum	Year long
Premna latifolia	March–August
Sida acuta	August–December
S. cordifolia	August–December
Stachytarpheta indica	June–September
Wrightia tinctoria	April–June
Zizyphus oenoplia	August–December and March–June

Table V
Nectar characteristics of the floral hosts and foraging speed of *P. hector*

Plant species	Nectar					Foraging speed	
	Mean vol. (ml)		Mean conc. (%)		Sugars*	Mean number of flowers visited/ min (n = 5 observations)	Mean time spent per flower (seconds) (n = 5 observations)
	10.00 h	17.00 h	10.00 h	17.00 h			
Albizzia lebbeck	0.40	0.70	19.00	17.00	Gsf	28	4.5
Anacardium occidentale	0.60	1.30	31.00	26.00	Gsf	16	3.1
Antigonon leptopus	0.02	0.40	58.00	54.00	Gsf	32	1.2
Caesalpinia pulcherrima	0.68	1.22	29.00	18.00	gSf	28	2.0
Citheroxylum subserratum	0.08	0.20	24.00	18.00	gSf	12	3.2
Clerodendrum infortunatum	0.99	2.25	12.00	20.00	gSf	19	1.3
Jasminum angustifolium	0.50	0.61	28.00	16.00	gSf	20	3.0
Sida cordifolia		Traces of nectar			Gsf	20	2.2
Stachytarpheta indica	0.90	1.00	27.00	28.00	gSf	16	4.2

*G = Glucose; S = Sucrose; F = Fructose. Capital letter indicates dominance.

1600 and 1700 h (Table VI). While sucking nectar, the butterfly hovered in front of the flower, and in the process the type of body part on which pollen got deposited was dependent on the floral architecture of the species. Among the 20 floral hosts examined for the purpose, pollen was deposited on: proboscis 16, head and legs each 3, and wings 1 species. Likewise, the frequency of contacts of these body parts with the stigma varied.

4. Discussion

Regular field observations of adult butterflies over the year, distribution of eggs, larvae and pupae on the larval host *A. indica*, and the laboratory study of the development success of eggs, larvae and pupae and adult emergence established that *Pachliopta hector* occurs

Table VI
Diurnal activity pattern of *P. hector* on different floral species
(Visits per hour are given as percentage of total foraging visits per day)

Plant species	Time of day (h)											
	6–7	7–8	8–9	9–10	10–11	11–12	12–13	13–14	14–15	15–16	16–17	17–18
Albizzia lebbeck	0	30–35	10–15	0	1–5	0	1–5	5–10	10–15	10–15	15–20	1–5
Anacardium occidentale	10–15	20–25	0	0	10–15	10–15	10–15	1–5	10–15	1–5	0	0
Caesalpinia pulcherrima	5–10	10–15	0	25–30	15–20	0	5–10	0	10–15	5–10	1–5	0
Clerodendrum infortunatum	0	1–5	5–10	1–5	1–5	0	15–20	10–15	1–5	5–10	35–40	15–20
Jasminum angustifolium	0	5–10	1–5	75	0	1–5	0	0	0	0	0	0
Stachytarpheta indica	40–45	35–40	5–10	5–10	1–5	0	0	0	0	0	0	0
Wrightia tinctoria	45–50	30–35	0	5–10	5–10	0	0	5–10	0	0	0	0

throughout the year but with higher density during August/September–October/November and during April–June. As adult butterflies normally live for brief periods of 7–12 days [8], *P. hector* must be breeding without diapause to have adults occurring over the entire year. Observations of eggs, larvae and pupae on the larval host over the entire year, and the laboratory study of egg hatching, larval and pupal development and adult emergence attest to the uninterrupted breeding of mature adults of *P. hector* in the wild. In the laboratory at around 28°C, development from egg stage to the emergence of adult required 39–47 days and this relatively short life cycle is characteristic of the tropical butterfly species [8, 9]. Short life cycle permits *P. hector* to become multivoltine with about 6–7 broods in a year.

Pachliopta hector has the habit of laying eggs singly as is the case with most papilionid butterfly species [10]. It uses the herbaceous *A. indica* and *A. bracteolata* in the biotope of the study area for oviposition and subsequent larval feeding. The single egg-laying habit confers an advantage in that it averts the likelihood of larval saturation by resource exhaustion, and enables effective utilization of isolated plants [11]. The different life stages of *P. hector* occurred only on *A. indica* and *A. bracteolata* and there was nearly 100% survival of larvae on these host plant leaves in the laboratory. This kind of host plant specialization called monophagy allows efficient utilization of the resource [12].

As the body weight across the instars increased, there was increased food consumption and the two variables showed a linear relationship giving $y = 1.47$; $\bar{X} = 190.31$ in the straight line equation as per Legender's principle, and the coefficient of correlation ($r = 0.77$) is significant at 1% level. Food consumption in the last two instars was over 80% of all instars and such accelerated food consumption helps building up reserve energy for utilization in the nonfeeding pupal period [7, 13]. The values of CI declined as the age of the larva advanced, the first instar recording the highest value of 8.6. The average of 3.02 is well accommodated within the range of 0.27–6.90 ($\bar{X} = 2.03$) reported for forb-chewing Lepidoptera [14]. Also the values of the last two instars (1.7; 0.7) compared well with those of the penultimate (1.04–3.31) and final instars (0.92–2.27) of swallowtail butterfly species [15]. Since the values of CI and ECI at any instar stage are inversely related, the corresponding high CI (8.6) at instar I may be the result of related low ECI (5.2%) compared to the values at other successive instars (14.9–28.5%) [14]. The values of GR also decreased with the advancing age of the larvae but the first two instars recorded similar values. The tendency of higher rate (0.35) at penultimate than at final instar (6.20%) agrees with the finding of Scriber and Feeny [16] on swallowtail butterfly species.

The AD values gradually declined through successive instars from 99% at instar I to 87% at instar V (Table I). There are relatively higher than the ones reported for Lepidoptera in general (19–81%) [17] and for *Pericallia ricini* (28.7–84.6%) [18], but are comparable with those of *Euploea core* (82.8–98.0%) [19] and agree with the prediction of Slansky and Scriber [14] that foliage chewers often attain high AD values. Such high AD values may also result if the food item is rich in nitrogen (and water) [17]. The ECD values increased progressively as the larvae aged. The very low ECD at instar III compared to those at the preceding and succeeding instars could be the result of high-energy expenditure on metabolism due to some unidentified stress [20]. The pattern of ECI values across the instars followed closely the trend of ECD. The values (5.2–28.5%) are quite comparable with those reported for swallowtail butterfly species (6.7–41.5%) [16]. The ECI does not follow the pattern of AD thereby deviating from Waldbauer's [7] observation of ECI following the declining pattern in AD across the instars. But it fits into the observation of Slansky and Scriber [14] that ECI may increase, decrease or show little changes with the age of the larvae.

The suitability of habitat depends on the availability of larval and adult resource [21], and the larvae- and adult-derived nutrients have a combined effect on reproductive output [22]. Both oviposition (and larval) nectar plants are available throughout the year to sustain the immature and adult stages of *P. hector*. Nectar provides energy and amino acids for butterfly nutrition [23], and its intake may increase butterfly longevity and egg production [24, 25]. Although butterfly nectars are generally dilute [26], *Pachliopta hector* harvests nectar from a variety of flowers having varying sugar concentrations and this range in sugar concentration is comparable to that of 15–50% in the psychophilic flowers [27]. When *P. hector* probed the flowers for nectar, pollen got deposited mostly on the proboscis and head, and at the same time (if flowers are homogamous) or during the subsequent probing of another conspecific flower the pollen got transferred to the stigma resulting in successful pollination. Examination of the stigmas of such taxa as *Jasminum angustifolium*, *Anacardium occidentale*, *Catharanthus roseus* after *P. hector's* visitation confirmed pollen transfer. Deposition of pollen on proboscis and head is an important requirement of butterfly pollination [27]. While probing the flowers and sucking nectar, *P. hector* simply hovered in front of the flowers. This mode of foraging increases the rate of intake of carbohydrate energy in the form of nectar [28]. Such hovering high-energy flower foragers may fly long distances seeking nectar resources and promote cross-pollination with the attended genetic diversity in the nectar resource plants.

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