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Effects of different photoperiods and wavelengths of light on the life-history traits of an aphidophagous ladybird, *Coelophora saucia* (Mulsant)

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Abstract: The influence of three photoperiods, viz. short day [8 : 16 h; light : dark (L : D)], long day (16 : 8 h; L : D) and continuous light (24 : 0 h; L : D) and four wavelengths of light, viz. white (control), yellow, blue and red on pre-imaginal development and reproductive performance of a ladybird, *Coelophora* (=*Lemnia*) *saucia* (Mulsant) (Col., Coccinellidae) have been investigated under laboratory conditions. Long-day photoperiod and white light resulted in low immature stage mortality. Total larval period was longest under short-day and red-light conditions. Females kept at long-day photoperiod and under white light showed better reproductive performance than those placed under other photoperiods and wavelengths.

Key words: *Coelophora saucia*, ladybird, photoperiod, pre-imaginal development, reproductive performance, wavelength

1 Introduction

Members of family Coccinellidae, order Coleoptera, commonly known as ladybird beetles, are diurnal in habit and are able to locate their prey visually from a very short distance, but only under light conditions (Nakamuta, 1984, 1987). Most of their activities, viz. searching, foraging, mating and egg laying, are restricted by day length, and a large number of them are captured by light traps (Honek, 1977; Honek and Kocourek, 1986) indicating their sensitivity to light. Various extrinsic factors, viz. temperature, prey, photoperiods and wavelengths of light, are known to strongly affect the bioattributes of ladybirds. The study on the influence of these factors on life-history traits of predaceous ladybirds is essential for evaluation and understanding of their ecology. Influence of temperature (e.g. Omkar and Pervez, 2002, 2004; Srivastava and Omkar, 2003; Omkar and James, 2004a; Pervez and Omkar, 2004) and prey (e.g. Ceryngier et al., 1992; Omkar and Srivastava, 2003; Omkar and James, 2004b; Omkar and Mishra, 2005) on the life-history traits are the most studied aspects of coccinellid ecology. But the influence of various components of light, viz. photoperiod (Hodek et al., 1989; Mishra and Omkar, 2005), wavelength (Mondor and Warren, 2000; Omkar et al., 2005) and intensity (Hodek and Honek, 1996) on life history has not been studied well until now.

Photoperiods change in a predictable pattern throughout the year and act as principal cues signalling seasonal changes (Tauber et al., 1986) leading to synchronization in growth and reproduction of insect species with favourable periods. Timing of life-history events is also known to change in response to photoperiod (Verdier, 1976; Hewitt, 1985; Tanaka et al., 1993; Miles et al., 1998; Nakao, 1998; Ishihara, 2000; Zhou, 2001). Other than influencing insect life-history traits, photoperiods are one of the main diapause-regulating factors (Hodek and Ruzicka, 1979). They influence the relationship of diapause with oviposition (Leather et al., 1993). Many researchers have demonstrated the influence of photoperiod on several aspects, viz. oviposition (Yamaoka et al., 1976; Yamaoka and Hiaro, 1981) and larval growth (Saksena and Dashohar, 1978; Washida, 1981) of silkworm, *Bombyx mori* (L.).

Like photoperiods, the wavelengths and intensities of light also change with the time of day and habitat (Henderson, 1977; Roenneberg and Foster, 1997). Change in spectral regions (407, 530 and 655 nm) strongly affects the larvae of Sorrel dagger moth, *Acronycta rumicis* L. (Geispitz, 1957). The ability of ladybirds to identify colours is quite well established (Harmon et al., 1998; Mondor and Warren, 2000). The duration, intensity and wavelengths of light have a strong influence on their predatory abilities (e.g. Nakamuta, 1984, 1987; Quilici and Iperti, 1986; Dimetry, 1988). Exposure to different wavelengths of light influenced development, prey consumption and reproduction in ladybirds, *P. dissecta* and *Cheilomenes sexmaculata* (Fabr.) (Omkar et al., 2005).

The scarcity of literature on the influence of photoperiods and wavelengths of light on life-history traits of the ladybirds, viz. development, survival, prey consumption, reproductive performance and fitness, prompted us to undertake the present study using the aphidophagous ladybird, *Coelophora* (=*Lemnia*) *saucia* (Mulsant) as an experimental model. It is a predatory ladybird, feeding on aphid *Cervaphis rappardi indica* Basu on *Cajanus cajan* commonly found in Imphal (Shantibala et al., 1997). The ecology of *C. saucia*, however, remains largely unknown and this study would help us to understand the significance of the components of light in the life of the ladybird.

2 Materials and Methods

2.1 Stock maintenance

Adults of *C. saucia* were collected from local agricultural fields and brought to the laboratory. Opposite sexes were paired and fed *ad libitum* on *M. persicae* in Petri dishes (9.0 × 1.5 cm) under controlled laboratory conditions [27 ± 2°C, 65 ± 5% relative humidity (RH); 14 : 10 h light : dark (L : D) under white light]. Prey was replenished every 24 h. Eggs were collected daily and the hatched instars reared in Petri dishes until pupation (prey and space as above). Aphid supply was increased in relation to the growth of larvae to keep pace with their energy requirements. The pupae were observed daily for emergence and the emerging adults isolated for further use in the experiments. All the experiments were conducted at abiotic conditions as mentioned here.

2.2 Experimental design

2.2.1 Effects of photoperiod

Pre-imaginal development and survival: One hundred and twenty eggs of *C. saucia* were collected from the laboratory stock and reared until adult emergence under any one of the three photoperiods, viz. 8 : 16 h (L : D) (short day), 16 : 8 h (L : D) (long day) and 24 : 0 h (L : D) (continuous light) to assess effects on pre-imaginal development. The exposure of light at different combinations was done in light chambers (40 × 40 × 40 cm) having white light (milky, broad spectrum) obtained from bulbs of 60 W (Philips brand). The walls, ceilings and floors of the light chambers were covered with white paper.

The neonates were transferred to Petri dishes (size as above). Four instars were placed per dish with *ad libitum* prey supply of aphid *M. persicae* infested on *Solanum nigrum* leaf (temperature and humidity as above). The time between moults and number of larvae surviving each moult was recorded. Pre-pupal and pupal periods along with the number of pupae formed were recorded. Missing or partially consumed bodies of immature stages were considered victims of cannibalism while intact bodies were considered cases of death due to unknown natural factors. However, in the entire study, no events of cannibalism were recorded. There were 30 replicates per photoperiod with individuals in a Petri dish constituting a replicate. The total larval period (duration from first instar to formation of prepupae), total developmental period (duration from egg laying to adult emergence), developmental rate (1/total developmental period) and per cent adult emergence (number of adults emerged/number of pre-pupae formed ×100) were also calculated for each photoperiod.

Prey consumption: For studying the effect of different photoperiods on prey consumption, 10-day-old females were starved for 24 h (to standardize the starvation level) and then provided with 200 third instars of *M. persicae* on uninfested *S. nigrum* leaf in a Petri dish in respective photoperiod chambers. After 24 h, females were removed from Petri dishes and the remaining live aphids counted. Total numbers of aphids consumed were then determined. The set-up was replicated 10 times for each photoperiod with a single female constituting a replicate.

Reproductive performance: Newly emerged adult males and females of *C. saucia* were paired in Petri dishes (prey and space as above) under white light in their respective photoperiod chambers and the pairs were observed for 30 days. Pre-oviposition period (date of emergence to day before first oviposition), fecundity, per cent egg viability (of all eggs laid), oviposition at peak, day of peak and reproductive rate (fecundity/oviposition days) were calculated for each photoperiod. The experiment was replicated 10 times under each photoperiod; a pair per Petri dish constituted a replicate.

2.2.2 Effects of wavelength of light

Pre-imaginal development and survival: The experimental design was similar to that of photoperiod except that the four arenas used for different wavelengths had white (broad spectrum, control), yellow (approximately 570 nm), blue (approximately 475 nm), and red coloured light (approximately 650 nm). The bulbs used were of different wattage so as to ensure similar light intensity; blue and red coloured bulbs of 100 W, yellow coloured bulb of 11 W and white of 60 W. The light intensity and photoperiod in all these experiments was approximately 190–200 lx and 24 : 0 h (L : D) respectively. The walls, ceilings and floors of light chambers were covered with glossy paper of the same colour as that of light bulbs, thus enhancing the effect of light and also providing a completely coloured arena. Abiotic conditions (temperature and humidity) were same as in stock; observations and recordings were taken as in the above experiment under varying photoperiods.

Prey consumption: Experimental design and recordings were made at the four different wavelengths following the methodology used in the photoperiod section.

Reproductive performance: Newly emerged adults of *C. biplagiata* were paired and reared in Petri dishes (size and prey as above) in the respective wavelength chambers under 24 : 0 h (L : D) photoperiod. The experiment was replicated 10 times with a pair per Petri dish forming a replicate under each wavelength. All the observations and recordings were taken as in photoperiod section.

2.3 Statistical analysis

A common value of fitness, viz. individual fitness (r), was calculated as a performance measure following McGraw and Caswell (1996).

$$r = \frac{\ln(m \cdot v)}{D}$$

where ln is the natural logarithm, D the developmental time, $m = 1$ for each surviving female, and v the total fecundity.

The data of the four larval, pre-pupal and pupal durations, total larval period, total developmental period, developmental rate, per cent adult emergence, pre-oviposition period, daily oviposition, per cent egg viability, oviposition at peak, day of peak, reproductive rate and individual fitness per treatment (photoperiods or wavelengths of light) were subjected to one-way ANOVA using statistical software MINITAB (2003) for overall comparisons. Comparisons in individual activity were calculated using *post hoc* Tukey's honestly significantly different test at 5% levels. Prey consumption was also correlated with fecundity and developmental rate using data of each replicate.

3 Results

3.1 Effects of photoperiod

3.1.1 Pre-imaginal development and survival

The results reveal a significant effect of photoperiod on the total larval period, total developmental period, developmental rate and per cent adult emergence of *C. saucia*. The mean durations of different immature stages, viz. first instar, second instar, third instar and fourth instar, pre-pupae, and pupae showed significant differences at all the three photoperiods. The pupal period however showed insignificant differences among individual mean values. The development was fastest with the highest adult emergence under long-day conditions (table 1a).

3.1.2 Prey consumption

The adult females consumed significantly different numbers of aphids when kept under different photoperiods. Maximum prey consumption was recorded under long-day followed by continuous light and short-day conditions. Number of prey consumed showed positive correlation with both developmental rate ($r = 0.546$; $P < 0.05$) and fecundity ($r = 0.583$; $P < 0.001$).

3.1.3 Reproductive performance

Different photoperiods significantly affected pre-oviposition period, fecundity, per cent egg viability, peak oviposition, day of peak and reproductive rate of *C. saucia*. The measures were highest under long-day photoperiod except pre-oviposition period and day of peak (table 2a).

3.1.4 Fitness

The mean values of fitness of *C. saucia* kept under different photoperiods were significantly different from one another. Those reared under long-day (16 : 8 ; L : D) showed maximum fitness followed by continuous light (24 : 0 h; L : D) and short-day (8 : 16 h; L : D) conditions.

3.2 Effects of wavelength of light

3.2.1 Pre-imaginal development and survival

Significant effect of different wavelengths of light was found on total larval period, total developmental period, developmental rate and per cent adult emergence of *C. saucia*. The durations of first, second, third and fourth instars showed significant differences at all the four wavelengths. This was however not the case in pre-pupae and pupae. Fastest development and highest adult emergence were recorded under white light followed by yellow, blue and red lights (table 1b).

3.2.2 Prey consumption

Females consumed significantly varying number of aphids when kept under different wavelengths of light. Maximum consumption was observed in white light followed by yellow, blue and red lights. There is positive correlation between prey consumed and developmental rate ($r = 0.343$; $P < 0.05$) and prey consumed and fecundity ($r = 0.695$; $P < 0.001$).

3.2.3 Reproductive performance

The pre-oviposition period, fecundity, per cent egg viability, peak oviposition, day of peak and reproductive rate differed significantly with the wavelengths of light. The reproductive performance was best under white light and worst under red light (table 2b).

3.2.4 Fitness

The mean fitness was significantly different at varying wavelengths of light. Maximum fitness was recorded under white light followed by yellow, blue and red.

4 Discussion

The results revealed that both photoperiods and wavelengths of light had a significant influence on development of immatures, survival, reproductive performance and prey consumption of adults of *C. saucia*. Among the three photoperiods tested, long-day exposure positively affected various life-history traits of the ladybird. The pre-imaginal development, immature survival and reproductive performance were best under long-day while they were poor under short-day conditions. *Megalurothrips sjostedti* (Tryborn) and a northern population of *Locusta migratoria* L. are known to have reduced pre-oviposition period and egg production on exposure to short photoperiods (TANAKA et al., 1993; EKESI et al., 1999). Moreover, the larvae of noctuid, *Agrotis occulta* L. develops more rapidly under long-day conditions (DANILEVSKII, 1965).

Sensitivity to photoperiods is never extended to the whole life stages and sensitive and responsive stages mostly differ with species (DE WILDE, 1962). However, this was not found in our study, as all stages showed overall significant differences in developmental time indicating sensitivity to the different photoperiods.

Relatively high oviposition rate and high fecundity were obtained in *C. septempunctata* under long-day conditions (HODEK et al., 1989). In addition, continuous light has a negative affect on physiological function of the ladybird, *P. dissecta*, leading to poor development, survival and reproductive performance (MISHRA and OMKAR, 2005).

Table 1. *(a) Pre-imaginal development of* C. saucia *at different photoperiods. (b) Pre-imaginal development of* C. saucia *at different wavelengths of light*

	Duration of immature stages (in days)								Developmental rate (per day)	Adult emergence (%)
	Ist	IInd	IIIrd	IVth	Pre-pupae	Pupae	TLP	TDP		
(a) Photo-periods										
8 : 16 h (L : D)	2.00 ± 0.01 c	2.02 ± 0.54 b	1.91 ± 0.38 c	2.15 ± 0.51 b	0.93 ± 0.22 b	2.56 ± 0.19 a	8.09 ± 1.27 c	11.59 ± 2.05 b	0.08 ± 0.02 a	83.89 ± 20.17 b
16 : 8 h (L : D)	1.08 ± 0.04 a	1.01 ± 0.12 a	1.33 ± 0.32 a	1.47 ± 0.30 a	0.76 ± 0.16 a	2.97 ± 0.59 a	4.89 ± 0.53 a	8.64 ± 1.09 a	0.11 ± 0.01 c	99.17 ± 4.56 ab
24 : 0 h (L : D)	1.72 ± 0.13 b	1.23 ± 0.28a	1.65 ± 0.34 b	1.66 ± 0.44 a	0.82 ± 0.17 ab	2.48 ± 0.83 a	6.27 ± 0.78 b	9.58 ± 1.43 a	0.10 ± 0.01 b	90.00 ± 17.29 a
F-value	969.63***	65.38***	20.65***	20.18***	6.00***	3.32	91.15***	25.93***	19.82***	7.33***
(b) Wave-lengths										
White	1.70 ± 0.30 a	1.08 ± 0.18 a	1.35 ± 0.29 a	1.39 ± 0.35 a	0.83 ± 0.15 a	2.97 ± 0.52 a	5.53 ± 0.42 a	9.33 ± 0.80 a	0.10 ± 0.00 c	100 ± 0.00 b
Yellow	1.95 ± 0.10 b	1.43 ± 0.26 b	1.48 ± 0.31 a	1.66 ± 0.47 b	0.81 ± 0.22 a	3.30 ± 0.84 a	6.52 ± 0.79 b	10.64 ± 1.40 b	0.09 ± 0.02 b	100 ± 0.00 b
Blue	1.99 ± 0.32 b	1.93 ± 0.20 c	1.82 ± 0.26 b	1.88 ± 0.42 b	0.85 ± 0.25 a	3.20 ± 0.75 a	7.62 ± 0.69 c	11.65 ± 1.72 c	0.08 ± 0.01 ab	99 ± 4.56 b
Red	2.74 ± 0.19 c	1.77 ± 0.37 c	1.52 ± 0.44 a	2.24 ± 0.48 c	0.81 ± 0.25 a	3.24 ± 1.06 a	8.29 ± 0.56 d	12.35 ± 1.09 c	0.08 ± 0.01 a	90 ± 23.71 a
F-value	98.52***	60.88***	10.46***	20.28***	0.18	0.94	110.44***	7.95***	18.66***	4.89**

Values are mean ± SD. TLP and TDP stand for total larval period and total developmental period, respectively.
*, ** and *** indicate significance of F-value at $P > 0.05$, $P < 0.05$ and $P < 0.001$, respectively.
For (a) Photo-periods: d.f. = 2, 87; Tukey's critical value = 3.37.
For (b) Wave-lengths: d.f. = 3, 116; Tukey's critical value = 3.69.
Mean values followed by the same letter are not statistically significant.

Table 2. *(a) Reproductive attributes and prey consumption of* C. saucia *in relation to different photoperiods. (b) Reproductive attributes and prey consumption of* C. saucia *in relation to different wavelengths of light*

	Pre-oviposition period (in days)	Fecundity (no. of eggs)	Egg viability (%)	Oviposition at peak (no. of eggs)	Day of peak	Reproductive rate	Fitness	Prey consumption
(a) Photo-periods								
8 : 16 h (L : D)	7.50 ± 0.70 b	310.80 ± 67.68 a	92.41 ± 3.46 a	38.50 ± 5.60 a	18.70 ± 5.27 b	10.36 ± 2.25 a	0.53 ± 0.07 a	122.90 ± 4.46 a
16 : 8 h (L : D)	6.50 ± 0.52 a	784.60 ± 91.73 c	97.06 ± 1.06 c	51.30 ± 6.03 b	8.00 ± 2.16 a	26.15 ± 3.05 c	0.78 ± 0.09 c	147.50 ± 21.00 b
24 : 0 h (L : D)	7.20 ± 0.78 ab	477.70 ± 35.82 b	93.13 ± 4.05 b	40.00 ± 9.35 a	12.70 ± 8.38 ab	15.92 ± 1.19 b	0.65 ± 0.11 b	139.90 ± 9.42 b
F-values	5.64***	121.35***	6.38***	9.45***	8.40***	121.34***	17.14***	8.66***
(b) Wave-lengths								
White	5.30 ± 0.48 a	1044.1 ± 51.2 d	95.19 ± 4.27 a	50.30 ± 2.21 c	13.40 ± 2.63 a	3.17 ± 0.14 b	0.73 ± 0.06 c	166.80 ± 7.63 b
Yellow	6.50 ± 0.52 b	681.1 ± 52.8 c	91.5 ± 4.34 a	42.90 ± 5.70 b	14.20 ± 5.16 ab	3.17 ± 0.14 b	0.58 ± 0.08 b	158.90 ± 20.29 b
Blue	8.40 ± 0.51 c	365.9 ± 44.0 b	79.18 ± 5.65 b	27.80 ± 3.76 a	19.10 ± 6.26 b	2.40 ± 0.76 a	0.51 ± 0.08 ab	145.70 ± 8.33 ab
Red	9.30 ± 0.48 d	229.9 ± 50.3 a	80.51 ± 6.93 b	27.40 ± 6.80 a	22.00 ± 3.05 b	2.68 ± 0.23 a	0.45 ± 0.04 a	134.10 ± 10.10 a
F-values	129.59***	532.38***	21.70***	52.91***	8.13***	8.51***	28.46***	12.99***

Values are Mean ± SD.
***Indicate F-values to be significant at $P < 0.001$.
For (a) Photo-periods: d.f. = 2, 27; Tukey's critical value = 3.51.
For (b) Wave-lengths: d.f. = 3, 36; Tukey's critical value = 3.81.
Mean values followed by the same letter are not statistically significant.

Exposure of ladybird, *C. saucia* to different wavelengths of light also influenced the developmental rate, survival and reproductive performance. The performance of the ladybird was best under white light followed by yellow, blue and red light. Similar effects and order of wavelengths were earlier reported in ladybird *P. dissecta* and *C. sexmaculata* (Omkar et al., 2005).

The poor prey consumption under short day and red light probably negatively affected the developmental and reproductive performance of the ladybird. A positive relationship between prey consumption and life attributes was well established (Mills, 1982; Hodek and Honek, 1996; Ferran and Larroque, 1997). The increased prey consumption under long day may be ascribed to hyperactivity and high metabolic rate, also possibly resulting in high fecundity and higher reproductive rate under long-day conditions. As oviposition is an energy-driving process, maximum prey consumption possibly helps sustain the energy requirements of the ladybird.

The colour of aphid and its contrast with that of background facilitates predation by a ladybird (Harmon et al., 1998) indicating prominent colour perception mechanism in ladybirds. Beetles are known to perceive different photoperiods and wavelengths of light through their compound eyes, which act as photoreceptors for circadian entrainment. Compound eyes are known to perceive photoperiodic signals in several other species (Numata et al., 1997; Nakamura and Hodkova, 1998; Morita and Numata, 1999).

Some pigments, viz. rhodopsin, consisting of a chromophore, retinal (a vitamin A metabolite), coupled with a protein, opsin associated with the retina of the compound eyes and the retinuala of the ocelli are responsible for vision in insects (Pollock and Benzer, 1998). Different opsin molecules offer wavelength sensitivities and many different opsins have been identified in a single species (Briscoe, 1998).

Thus, the present study reveals that both the photoperiods and wavelengths of light influence the life-history traits of *C. saucia*. Long-day and white light have positive effect on the ladybird, leading to faster development, higher survival of immature stages and enhanced reproductive performance. This study could possibly help in forming the foundation for developing further understanding of physiological trends in ladybirds under coloured arenas, and in different seasons particularly in *C. saucia*.

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