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Effects of different wavelengths of light on the life attributes of two aphidophagous ladybirds (Coleoptera: Coccinellidae)

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Abstract. The effect of different wavelengths of light, white (control; broad spectrum), blue (ca. 475 nm), yellow (ca. 570 nm) and red (ca. 650 nm), at constant intensity (195 ± 5 lux) on developmental time, reproductive and non-reproductive periods, fecundity, egg viability, prey consumption and fitness of two aphidophagous ladybirds, *Cheilomenes sexmaculata* and *Propylea dissecta* were studied. Both ladybird species consumed most aphids, developed fastest and reproduced best when kept under white light, followed by yellow, blue and red light. Fitness of both the ladybirds was highest under white and lowest under red light. There were positive correlations between prey consumption and developmental rate, and prey consumption and fecundity.

INTRODUCTION

Photoperiod, wavelegth and intensity of light, and also light reflectance properties of surfaces are known to influence the ecology of organisms (Prayitno et al., 1997; Aarseth & Schram, 1999; Phillips & Lomas, 2001; Miklosi et al., 2002). Effects of wavelength on colour perception and behavioural changes were recently studied in crustaceans (Aarseth & Schram, 1999), chicks (Prayitno et al., 1997; Miklosi et al., 2002) and cattle (Phillips & Lomas, 2001). *Drosophila melanogaster* L. exhibits low mating activity when placed in ultraviolet light (Sakai et al., 2002), and feeding by the syrphid, *Eristalis tenax* L. (Lunau & Wacht, 1997) and hawk moth, *Manduca sexta* (L.) (White et al., 1994) is inhibited in ultraviolet and blue light.

Ladybirds (Coleoptera: Coccinellidae) are diurnal in habit but a large number are captured by light traps (Honěk, 1977; Honěk & Kocourek, 1986), which indicates their sensitivity to light. The ability of ladybirds to identify colours is quite well established (Iperti & Prudent, 1986; Harmon et al., 1998; Mondor & Warren, 2000; Omkar & Mishra, 2003). The duration, intensity and wavelength of light are known to influence predation by ladybirds (Mack & Smilowitz, 1978; Miura & Nishimura, 1980; Zotov, 1983; Nakamuta, 1984, 1987; Quilici & Iperti, 1986; Dimetry, 1988). The physiological effects of photoperiod and light intensity are well studied in ladybirds in relation to induction and termination of diapause (Hodek & Růžička, 1979; Hodek & Iperti, 1983; Tauber et al., 1986; Danks, 1987; Muller, 1992). However, except for a few studies on the influence of photoperiod (Hodek, 1958) and intensity of light (Hodek & Honěk, 1996) on life attributes of a ladybird, research on the effects of light, especially different wavelengths is lacking.

We, therefore, propose to study the effects of different wavelengths of light on various life attributes, including individual fitness, of two ladybirds, *Cheilomenes sexmaculata* (F.) (*Cs*) and *Propylea dissecta* (Mulsant) (*Pd*). These two ladybirds were selected because of their abundance in local agro ecosystems. Both *Cs* and *Pd* are generalist predators and the former is well studied and has a wide prey range (Agarwala & Yasuda, 2000). Though ignored in the past, recent ecological studies (Omkar & Pervez, 2000, 2003; Omkar & Mishra, 2003; Omkar et al., 2004; Pervez, 2002; Pervez & Omkar, 2003, 2004a, b; Pervez et al., 2004) indicate that *Pd* is an effective biocontrol tool for aphid pest management. The present study may help improve the techniques used for rearing these ladybirds.

MATERIAL AND METHODS

Stock maintenance

Laboratory cultures of *Cs* and *Pd* were established from adults collected in local agricultural fields and fed an ad libitum supply of the aphid, *Aphis craccivora* Koch in Petri dishes (9.0 cm diameter × 1.5 cm height) (25 ± 2°C, 65 ± 5% R.H, 14L : 10D in white light). The aphid supply was replenished every 24 h. Eggs were collected daily and the progeny reared on an ad libitum supply of *A. craccivora* in glass beakers. The newly emerged adults produced in the laboratory were used in the experiments, which were done under the above mentioned controlled conditions of temperature and humidity.

Experimental design

Pre-adult development

Twenty-five eggs of both the ladybirds (*Cs* and *Pd*) were collected from the stock cultures and reared to adult emergence in each of four arenas; illuminated with either blue (*ca.* 475 nm), yellow (*ca.* 570 nm), red (*ca* 650 nm) or white light (broad spectrum, control), to assess the effects of different wavelengths of light on their development. The three colours other than the control were selected because they make up a broad portion of the light spectrum. The exposure to light of different colours was done in light chambers (40 × 40 × 40 cm) using blue and red coloured bulbs of 100 W, yellow coloured bulbs of 11 W and white (milky, broad spectrum) bulbs of 60 W (brand Phillips). The purpose of using bulbs of different wattage was to ensure similar light intensity. The light intensity in all these experiments was approximately 190–200 lux. The intensities were measured using a Eurisem EP628 digital luxmeter. The walls, ceilings and floors of the light chambers were covered with glossy paper of the same colour as the light bulb, thus enhancing the effect and also providing a completely coloured arena.

The neonates were transferred to muslin covered glass beakers (6.5 × 9.5 cm); five individuals to a beaker (to reduce overcrowding) (5 replicates per arena), fed an ad libitum supply of *A. craccivora* and reared till adult emergence. The supply of aphids was changed and observations made every 24 h. The supply of aphids was increased as the larvae developed. The period from egg to adult emergence (total development period) was recorded for each arena, with the development of the immature stages recorded twice a day (n = 5).

Reproduction

Newly emerged adults from the above experiment were paired, kept in Petri dishes and fed on *A. craccivora* to assess the effects of the different wavelengths of light on their reproductive performance. The experiment was replicated five times, with individuals in one Petri dish constituting a replicate.

Pre-oviposition, oviposition and post-oviposition periods, daily oviposition, fecundity and percentage egg viability (of all eggs laid) were recorded in each light regime.

Prey consumption

To understand the effects of different wavelengths of light on life attributes, the prey consumption of 10-day-old female *Cs* and *Pd* was recorded under different wavelength conditions.

For this purpose, adult females starved for twenty-four hours were each provided with 200 individuals of *A. craccivora* in a Petri dish (9.0 × 1.5 cm) and placed in a particular light arena for 24 h. Gravid aphid females were not included in the experiment in order to avoid error in observation through their multiplication. Thereafter, the females were removed from the Petri dishes, the remaining live aphids were counted and the number of aphids consumed determined. This was replicated five times for each wavelength, with a single female constituting a replicate.

Fitness

Individual fitness measures should take into account different aspects of growth, development and reproduction, since life attributes respond differently to changes in the environment. A useful way of summarizing the above data sets is to combine measures of life attributes (viz. developmental period, fecundity, survival) in a value that acts as a fitness indicator. This may help make changes that occur in overall performance under different wavelengths more obvious. Following Sadeghi & Gilbert (1999, 2000), individual fitness (r) was calculated as a performance measure (McGraw & Caswell, 1996) by integrating development time (D), survival (m = 1 for each surviving female) and total fecundity of each surviving female (V) via the equation:

$$r = [\mathrm{Ln}(m.V)]/D,$$

where Ln = natural logarithms.

Individual fitness of each of the five reproducing females for each arena was calculated.

Statistical analysis

The data were subjected to One-way ANOVA using statistical software MINITAB. Differences in activity were calculated using post hoc Tukey's honest significance test at 5% levels. Prey consumption was also correlated with fecundity and developmental rate.

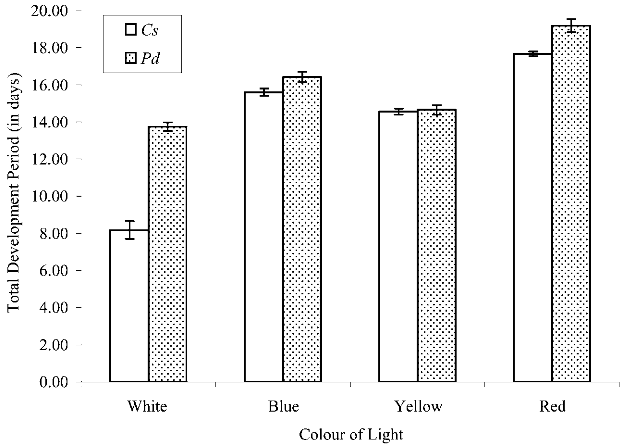

Fig. 1. Total developmental period of *Cheilomenes sexmaculata* (*Cs*) and *Propylea dissecta* (*Pd*) reared under different colours of light. Values are Mean ± S.E.

RESULTS

Pre-adult development

The total development period of *Cs* ($F_{3,16}$ = 221.72; P < 0.001) and *Pd* ($F_{3,16}$ = 72.10; P < 0.001) varied significantly among the arenas (Fig. 1). The fastest development of both ladybirds was in the white (control) followed by yellow, blue and red arenas.

Reproduction

In *Cs,* the pre-oviposition ($F_{3,16}$ = 36.98; P < 0.001), oviposition ($F_{3,16}$ = 143.66; P < 0.001) and post-oviposition ($F_{3,16}$ = 6.31; P < 0.05) periods differed significantly with change in wavelength of light (Table 1). Fecundity ($F_{3,16}$ = 67.51; P < 0.001) and percentage viability of eggs ($F_{3,16}$ = 18.31; P < 0.001) also varied significantly under different wavelengths. The overall reproductive performance in terms of egg output was best under white followed by yellow, red and blue light, the differences between blue and red light being statistically insignificant. The progeny output (percentage egg viability) under red light was however, significantly lower.

In *Pd,* the pre-oviposition ($F_{3,16}$ = 43.49; P < 0.001) and oviposition ($F_{3,16}$ = 64.50; P < 0.001) periods also differed significantly under different wavelengths of light (Table 1). However, the post-oviposition period did not differ significantly ($F_{3,16}$ = 2.89; P < 0.1; Table-1). Both fecundity ($F_{3,16}$ = 244.45; P < 0.001) and percentage egg viability ($F_{3,16}$ = 42.95; P < 0.001) varied significantly among the different arenas (Table 1). *Pd* did best in white followed by yellow, blue and red arenas.

Both the ladybirds reproduced erratically when kept in blue and red arenas, which is different from their usual oviposition pattern where eggs are laid daily.

Prey consumption

In *Cs*, the adult females consumed significantly different numbers of prey when kept under different wavelengths of light ($F_{3,16}$ = 292.44; P < 0.001) (Table 1). Maximum consumption occurred under white followed by yellow, blue and red light. There is significant positive

TABLE 1. Reproductive attributes and prey consumption of *Cheilomenes sexmaculata* (*Cs*) and *Propylea dissecta* (*Pd*) when kept under different colours of light.

Colour of light	Pre-oviposition period (days)		Oviposition period (days)		Post-oviposition period (days)		Fecundity (no. of eggs)		Egg viability (%)		Prey consumption (no. of aphids)	
	Cs	*Pd*	*Cs*	*Pd*	*Cs*	*Pd*	*Cs*	*Pd*	*Cs*	*Pd*	*Cs*	*Pd*
White (control)	3.20± 0.52a	2.80± 0.26a	67.20± 0.61d	49.60± 0.94d	11.80± 0.82d	2.80± 0.57a	1042.00± 28.89c	902.40± 9.59d	94.36± 1.75b	96.38± 0.54c	56.00± 1.22d	60.12± 4.15d
Blue	7.20± 0.26b	7.40± 0.36c	37.20± 1.29c	33.00± 1.28b	5.00± 1.36b	7.60± 1.39a	438.80± 23.63a	470.00± 16.67b	92.24± 0.58b	83.23± 1.06b	32.20± 0.97b	45.00± 1.06b
Yellow	7.40± 0.36b	3.80± 0.26b	34.00± 1.64b	43.80± 1.03c	7.60± 1.61c	6.20± 0.41a	858.40± 5.19b	611.40± 15.11c	99.02± 0.12c	93.44± 0.73c	42.40± 0.75c	51.24± 2.34c
Red	12.80± 0.61c	12.80± 0.82d	22.00± 0.63a	23.60± 0.73a	1.40± 0.99a	9.40± 1.73a	450.04± 35.68a	213.20± 8.82a	72.34± 3.43a	69.27± 2.24a	20.40± 0.81a	33.00± 1.36a
F-value	36.98*	43.49*	143.66*	64.50*	6.31**	2.89***	67.51*	244.45*	18.31*	42.95*	292.44*	53.56*

Values are Mean ± SE. Means followed by the same letter are not significantly different. *, **and *** denote F-values at $P < 0.001$, $P < 0.05$ and $P < 0.1$, respectively (Tukey's test range = 4.05; df = 3, 16).

correlation between number of prey consumed and development rate (r = 0.86), and prey consumed and fecundity (r = 0.88).

In *Pd*, the differences in number of prey consumed by adult females under white, yellow, blue and red wavelengths of light were statistically significant ($F_{3,16} = 53.56$; $P < 0.001$). The highest number of prey was consumed when kept under white followed by yellow, blue and red light. This species also shows positive correlation between prey consumption and fecundity (r = 0.86), and prey consumption and development rate (r = 0.73).

Fitness

The mean fitnesses of *Cs* kept under white, yellow, blue and red light are 0.859 ± 0.105, 0.462 ± 0.011, 0.389 ± 0.018 and 0.344 ± 0.018, and significantly different from one another ($F_{3,16} = 94.21$; $P < 0.001$). Similarly the maximum fitness for *Pd* was recorded under white light (0.495 ± 0.020) and the minimum under red light (0.279 ± 0.016). The fitness of the beetles kept under yellow and blue light are 0.438 ± 0.023 and 0.375 ± 0.010, respectively. The mean fitness measures under different wavelengths of light are statistically significant ($F_{3,16} = 106.74$; $P < 0.001$).

DISCUSSION

The results reveal that the different wavelengths of light used had a significant influence on development, reproduction, and prey consumption. Both the ladybird species performed best when kept under white, followed by yellow, blue and red light. The better performance under white light is most probably a result of its similarity to sunlight.

The poorer performance observed under coloured light could either be a result of (1) certain physiological modifications, and/or (2) reduced prey consumption due to reduced visual capabilities of the beetle under these conditions. Although there is no support in the literature for the first suggestion, our study supports the second. Prey consumption was significantly reduced under coloured light. This could account for the difference in development time and reproduction under the coloured compared to white light.

The strong positive correlation of fecundity and developmental rate with prey consumption under the different wavelengths of light probably indicates that the decreased performance of both the ladybirds under coloured light may be ascribed to a reduction in prey consumption. The positive relation between prey consumption and life attributes is well established (Ferran & Larroque, 1977; Mills, 1982; Hodek & Honěk, 1996; Dixon, 2000). A decrease in the number of prey consumed probably leads to a lowered metabolic rate resulting in the decrease in life processes. Reduced prey consumption probably results from the lower ability of ladybirds to locate prey, which along with predation is known to be influenced by the duration, intensity and wavelength of light (Quilici & Iperti, 1986; Dimetry, 1988). The reduction in prey consumption under blue light observed in the study contradicts the active predation under blue-green light (480–522 nm) recorded for larvae of *Adalia bipunctata* (L.) (Dimetry, 1988).

Ladybirds mainly attack and consume aphids that contrast with their background (Harmon et al., 1998). This may be the reason for the reduced predation by *P. dissecta* under blue and red light; the dark colour and low contrast of *A. craccivora,* would make it less visible in blue and red light compared to white and yellow light.

Our results indicate that the colour of an arena affects prey location by ladybeetles probably by hindering or modifying searching efficiency, which could account for the low consumption. The role of visual cues thus needs to be properly addressed.

Unlike the effect of light intensity on the hatching of eggs of *Bombyx mori* (L.) (Sakamoto et al., 2003) and *Bemisia argentifolii* Bellows & Perring (Blackmer et al., 2002), that of coloured light on life processes is, less well explored and, a unique aspect of this study.

The ladybird, *Myrrha octodecimguttata* (L.), responds photonegatively to short and long wavelengths of light after desiccation when in diapause (Pulliainen, 1963, 1964). The results of the present study indicate that ladybirds do best when reared under white light and that there is a need for further studies on the affect of different aspects of light on life attributes and the physiological mechanisms.

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