Pakistan J. Zool., pp 1-7, 2022. **DOI**: https://dx.doi.org/10.17582/journal.pjz/20210519100508

Effects of Violet Light Radiation on Growth, Development and Reproduction of *Scopula subpunctaria* (Herrich-Schaeffer) at Different Instars

Li Qiao*, Shubao Geng, Shibao Guo, Hongmin Liu, Jian Yin and Quan Zhang

College of Agriculture, Xinyang Agriculture and Forestry University, Xinyang 464000, China

Article Information
Received 19 May 2021
Revised 05 March 2022
Accepted 31 March 2022
Available online 21 June 2022
(early access)

Authors' Contribution
Investigation: HL and SG. Conceptualization: JY. Resources: SG and QZ. Formal analysis, writing review and editing: LQ. All authors have approved the final paper for publication.

Key words
***Scopula subpunctaria* (Herrich-Schaeffer), Violet light, Development duration, Adult longevity, Reproduction**

ABSTRACT

Scopula subpunctaria (Herrich-Schaeffer) is one of the important pests in tea garden. To explore the effects of violet light on its growth, development and reproduction, the 2nd and 5th instar larvae were irradiated under light at the wavelengths of 400 and 420 nm with 6 different irradiation times (0, 60, 90, 120, 150 and 180 min). The development duration, pupation rate, abnormal pupation rate, pupal weight, adult emergence rate, male and female adult longevity, oviposition rate of *S. subpunctaria* were measured. The results showed that with the increase of treatment time, the duration of 2nd instar larvae shortened, and the difference between the two wavelength treatments was significant; while the mortality increased, the pupation rate decreased, and the pupa weight and adult emergence rate decreased. The development duration of 5 instar larvae was significantly shortened, and the pupation rate and abnormal pupation rate were significantly increased. The pupa weight of 5th instar larvae was significantly higher than that of 2nd instar larvae. Except the mortality of 2nd instar larvae increased significantly, there was no difference in adult emergence rate and average single female oviposition between the two treatments. Under violet light treatments, the longevity of male adults of *S. subpunctaria* was longer than that of female adults, with no significant difference. This paper is expected to provide a reference for in-depth study and application of light in the prevention and control of tea garden.

INTRODUCTION

Scopula subpunctaria (Herrich-Schaeffer) belongs to Lepidoptera, Geometridae, is one of the important pests in tea gardens (Qian *et al*., 2020; Geng *et al*., 2021). It has large food intake, fast reproduction speed and many generations of occurrence per year. The larvae bite the tea leaves into a C-shaped gap, resulting in incomplete leaves, bare branches and even dry death. It is the most harmful in spring and autumn, seriously affecting the yield and quality of tea (Ma *et al*., 2019). Chemical pesticides are mostly used in tea gardens, which not only increases the drug resistance of pest, but also affects the quality of tea (Lou *et al*., 2021). Therefore, it is of great significance to study new methods of pest control in tea garden.

* Corresponding author: 2017180004@xyafu.edu.cn
0030-9923/2022/0001-0001 $ 9.00/0

Light irradiation, as a new trend, has been widely used in pest monitoring, warning and control (Oh *et al*., 2011; Shimoda and Honda, 2013; Infusino *et al*., 2017). The sensitive spectra of insects are mostly concentrated in the wavelength range of 253–700 nm, different insects are sensitive to different wavelength ranges (Federico and Julio, 2010; Liu, *et al*., 2017, 2019, 2020; Qiao *et al*., 2021b), which is related to factors such as species, gender, instar larvae, etc. (Garris and Snyder, 2010). Ultraviolet light (UV, 10-400 nm), widely used in sterilization and disinfection, can also be used in biological control of insects (Infusino *et al*., 2017; Kim *et al*., 2019; Balamurugan and Kandasamy, 2021; Liu *et al*., 2021). Under UV light 320–400 nm irradiation conditions for 1 h, three-day-old *Helicoverpa armigera* adults' expressed proteins were influenced (Meng *et al*., 2010). It is reported that the sensitive spectrum of tobacco aphid cocoon bee contains ultraviolet light (Chen *et al*., 2012). Ultra violet 400 nm spectra was the most attractive for *Lasioderma serricorne* (Baliota *et al*., 2021). Among the 43 Hymenoptera insects, 28 are sensitive to 340 nm ultraviolet light (Peitsch *et al*., 1992). It is reported that ultraviolet-B (UV-B) irradiation of 2 and 5 instars larvae of *Ectropis oblqua* for 0, 30, 60, 90, 120 and 150 min has a great impact on their biological

properties (Zhang *et al*., 2016a). Ultraviolet radiation treatments (3, 6, or 9 min at 254 nm) the eggs of *Spodoptera litura*, *Corcyra cephalonica*, *Plutella xylostella* and *Helicoverpa armigera*, significantly increased the mean percentage parasitization of Trichogramma over that of the non-UV treatments (Edwin *et al*., 2016). Ultraviolet light (UV-B), which emits radiation in the range of, the *Spodoptera litura* adults were exposed to UV-B light 280–315 nm for various time periods (0, 30, 60, 90 and 120 min), the oxidative stress marker enzymes activity changed with different treatment time (Karthi *et al*., 2014). At present, there is no relevant report on the effect of short-term illumination of violet light on the biological parameters of *S. subpunctaria*.

To find out the effect of violet light on the biological characteristics of *S. subpunctaria*, its 2 and 5 instars larvae were irradiated under 400 and 420 nm lights with different irradiation times, to observe the effects of violet light on the larval development duration, pupation rate, pupal deformity rate, pupal weight, adult emergence rate, male and female adult longevity and oviposition rate. This study provides a reference for insect mutation and integrated pest control.

MATERIALS AND METHODS

Insect source and feeding method

S. subpunctaria were collected from the tea garden in Baimiao Village, Shihegang Town, Xinyang, China. The adults were fed with fresh leaves in an artificial climate box for 5 generations under normal condition at 22–26°C, relative humidity 60–70%, the photoperiod at 12h/12h light/dark, and illumination intensity at 150–200 lux. The processing is carried out indoors.

Equipment and light source

Rtop-310y artificial climate box (Zhejiang Tuopuyunnong Technology Co., Ltd., Hangzhou, China), PM6612 digital illuminance meter (Shenzhen Huayi Intelligent Measurement Technology Co., Ltd., Shenzhen, China), the insect cage (50 cm × 50 cm × 60 cm), and use cardboard to make dark box, light sources were provided at the top, left and right sides with self-made light reaction device and LED lights (Shenzhen Rongcheng Microelectronics Technology Co., Ltd., Shenzhen, China), wavelength at 400 and 420 nm, illumination intensity at 150–200 lux.

Groups and treatments

The 2nd and 5th instars of larvae after ecdysis were put into the culture dish respectively on that day, and placed 15 cm away from the light with wavelengths of 400 and 420 nm. Six radiation time treatments were set at 0, 60, 90, 120, 150 and 180 min, respectively; and were performed at 8:00 a.m. every day, 3 repetitions for each treatment, 30 larvae for each repetition. After radiation treatments, they were kept under normal condition. Adults eclosing under the same light source and the same treatment shall be fed in pairs of male and female, and observed and recorded until the adult dies. Paired feeding containers for petri dishes (diameter: 8.5 cm) and insect cover (diameter: 8.5–9 cm, high: 20–25 cm). The material is acrylic transparent round tube, and top cover 30 μm mesh white mesh.

The number of dead larvae, number of pupae, number of abnormal pupae, weighed pupa weight, number of pupae emerging into adults, life span of female adults and male adults (paired feeding), number of eggs laid by females were recorded (Qiao *et al*., 2021a).

Data processing

The data were processed using Excel and SPSS16.0 (SPSS Inc., Chicago, IL, USA). Duncan's multiple range test was used to analyze the significance among different treatments; *F* test was used to test the significance of difference between two lights.

RESULTS

Effect of irradiation on 2nd instar larvae

Under different irradiation times of 400 and 420 nm lights, the growth period of 2nd and 5th in star was lower than that of the control (Table I). With the extension of treatment time, the larval period gradually shortened, which was significantly different from that of the control. The larval growth under 420 nm illumination was lower than 400 nm, with significant difference.

The mortality under 400 and 420 nm light illumination was significantly higher than that of the control. With the extension of irradiation time, the mortality increased gradually. The 60 and 90 min illumination were significantly different from other treatments. The mortalities of 150 and 180 min illumination were higher than that of other treatments, while that of 120 min illumination was only lower than that of 150 min treatment, which was significantly different from other treatments. The pupation rate decreased with time extension, and the longer the treatment time, the more significant the difference was. Under the same treatment, the rate of abnormal pupae did not significant increase, which was significantly different from the control.

The pupa weight under two wavelengths of light was lower than that of the control, and the pupa of 180 min illumination was the lightest, significantly different from other treatments. The pupa weight under 420 nm illumination was lower than that of under 400 nm, and

showed a downward trend with the increase of treatment time, significantly different from the control, and significant difference between the two wavelength treatments. The emergence rate showed the same trend as the pupa weight, no difference between the two lights except that there was a significant difference under 120 min illumination.

Effect of irradiation on 5th instar larvae

There is no difference among the 5th instar larvae and the control under 400 nm illumination at different irradiation times (Table II), under 420 nm light, there were significant different compared with the control. 420 nm light shortened the larval stage, there was significant difference between the two wavelengths at irradiation times of 90, 120 and 180 min. With the extension of irradiation time, the mortality of each treatment did not change significantly, but the difference with the control was significant. The mortality under 420 nm light was higher than that under 400 nm light, and the pupation rate under 400 nm light showed a downward trend, which was significantly different from the control. The pupation rate of 420 nm irradiation was higher at 180 min, which was consistent with the control, the performance trend was the same as that of 400 nm light.

Table I. Effects of light on the growth and development of 2nd instar larvae.

Light wavelength	Treatment time (min)	Larval (d) period	Mortality rate %	Pupation rate %	Abnormal rate %	Pupal weight (mg)	Emergence rate (%)
400 nm	0	11.73 ± 0.72^{a}	2.55 ± 1.13^{d}	93.00 ± 0^{a}	5.84 ± 0.16^{b}	119.83 ± 1.17^{a}	91.58 ± 2.81^{a}
	60	10.79 ± 0.33^{abA}	35.00 ± 1.73^{cA}	65.33 ± 1.45^{bA}	15.68 ± 0.80^{aA}	105.54 ± 4.33^{bA}	73.55 ± 3.18^{bA}
	90	10.14 ± 0.67^{abA}	33.13 ± 2.03^{cA}	67.33 ± 1.12^{bA}	16.77 ± 0.78^{aA}	98.5 ± 3.18^{bA}	70.45 ± 4.33^{bA}
	120	10.41 ± 0.63^{abA}	42.25 ± 1.45^{bA}	57.67 ± 2.03^{cB}	15.94 ± 0.93^{aA}	93.59 ± 2.78^{bA}	64.95 ± 4.04^{bB}
	150	9.95 ± 0.10^{abA}	50.17 ± 2.60^{aA}	49.67 ± 2.05^{dB}	17.59 ± 1.00^{aA}	92.64 ± 4.06^{bA}	64.14 ± 3.77^{bA}
	180	8.78 ± 0.55^{bA}	53.22 ± 0.88^{aA}	47.00 ± 1.73^{dB}	19.07 ± 0.90^{aA}	79.37 ± 2.60^{cA}	63.63 ± 5.49^{bA}
420 nm	0	11.73 ± 0.72^{a}	2.55 ± 1.13^{d}	93.00 ± 0^{a}	5.84 ± 0.16^{b}	119.83 ± 1.17^{a}	91.58 ± 2.81^{a}
	60	7.52 ± 0.13^{bB}	20.33 ± 1.45^{cB}	67.00 ± 1.15^{bA}	14.90 ± 0.89^{aA}	81.85 ± 2.11^{bB}	71.58 ± 2.64^{bA}
	90	6.97 ± 0.09^{bB}	22.33 ± 1.45^{cB}	67.33 ± 1.12^{bA}	15.89 ± 1.01^{aA}	72.98 ± 0.77^{cB}	72.04 ± 1.70^{bA}
	120	7.08 ± 0.14^{bB}	30.00 ± 1.53^{bB}	68.00 ± 1.15^{bA}	15.03 ± 1.30^{aA}	73.94 ± 0.83^{cB}	73.88 ± 2.83^{bA}
	150	7.92 ± 0.20^{bB}	37.67 ± 1.20^{aB}	65.00 ± 1.53^{bA}	17.76 ± 0.57^{aA}	73.72 ± 1.94^{cB}	65.40 ± 1.51^{bA}
	180	6.93 ± 0.22^{bB}	39.67 ± 1.45^{aB}	58.33 ± 2.91^{cA}	17.22 ± 1.15^{aA}	71.35 ± 2.29^{cB}	64.39 ± 1.59^{bA}

Notes: Different letters in the same column indicated the significance of the difference at the level of 0.05; lowercase letters a, b, c and d indicated the significance of the difference under the same wavelength and different treatment time; capital letters A and B indicated the significance of differences between different wavelength; the same letter indicated no significant difference. The values in the table are mean ± standard error.

Table II. Effects of light on the growth and development of 5th instar larvae.

Light wavelength	Treatment time (min)	Larval (d) period	Mortality rate %	Pupation rate %	Abnormal rate %	Pupal weight (mg)	Emergence rate (%)
400 nm	0	4.93 ± 0.35^{a}	3.33 ± 1.67^{b}	96.67 ± 1.67^{a}	8.40 ± 0.50^{b}	126.78 ± 4.92^{a}	89.95 ± 2.31^{a}
	60	3.89 ± 0.10^{aA}	15.33 ± 1.76^{aA}	85.00 ± 2.89^{bA}	28.75 ± 0.70^{aA}	115.75 ± 3.83^{abA}	87.76 ± 3.47^{aA}
	90	4.36 ± 0.36^{aA}	12.67 ± 1.45^{aB}	88.00 ± 2.31^{bA}	29.28 ± 1.09^{aA}	104.28 ± 6.93^{bA}	77.91 ± 5.77^{abA}
	120	4.05 ± 0.11^{aA}	13.33 ± 2.03^{aB}	87.00 ± 1.73^{bA}	30.13 ± 0.78^{aA}	98.78 ± 5.20^{bB}	77.23 ± 4.05^{abA}
	150	3.87 ± 0.48^{aA}	17.67 ± 1.45^{aA}	83.00 ± 2.72^{bA}	30.18 ± 0.86^{aA}	96.38 ± 4.91^{bA}	73.64 ± 2.96^{abA}
	180	4.70 ± 0.41^{aA}	16.67 ± 1.67^{aA}	84.00 ± 1.15^{bB}	32.18 ± 1.05^{aA}	94.19 ± 3.47^{bA}	67.93 ± 2.63^{bA}
420 nm	0	4.93 ± 0.35^{a}	3.33 ± 1.67^{b}	96.67 ± 1.67^{a}	8.40 ± 0.50^{d}	126.78 ± 4.92^{a}	89.95 ± 2.31^{a}
	60	2.32 ± 0.15^{bcA}	16.00 ± 1.00^{aA}	86.67 ± 1.67^{bA}	17.99 ± 1.27^{cB}	97.17 ± 2.36^{bB}	84.82 ± 1.14^{abA}
	90	1.95 ± 0.41^{bcB}	16.33 ± 0.88^{aA}	85.00 ± 2.89^{bA}	21.91 ± 0.95^{bB}	99.32 ± 2.06^{bB}	79.03 ± 4.13^{bcA}
	120	2.02 ± 0.19^{bcB}	17.33 ± 1.45^{aA}	81.67 ± 1.67^{bB}	27.92 ± 1.05^{aA}	100.59 ± 4.30^{bA}	77.43 ± 1.70^{bcA}
	150	2.73 ± 0.12^{bA}	17.67 ± 1.45^{aA}	81.67 ± 4.41^{bA}	27.59 ± 1.53^{aA}	89.01 ± 2.08^{bB}	74.88 ± 3.19^{bcA}
	180	1.55 ± 0.16^{cB}	18.00 ± 1.15^{aA}	90.00 ± 0^{abA}	31.67 ± 1.33^{aA}	90.12 ± 1.63^{bB}	68.57 ± 1.05^{cA}

For superscripts and other statistical details see Table I.

The rate of abnormal pupae of two lights irradiation was significantly higher than that of the control. The pupa weight decreased with the increase of time, which was significantly different from the control, and there was significant difference between the two lights irradiation. The pupa weight decreased gradually with the extension of irradiation time. The emergence rate at 180 min irradiation was the lowest. From the treatment of 5th instar larvae, with the increase of instar, its stress resistance gradually increased and its adaptability to adverse environment increased, which laid a foundation for population reproduction.

Effect of irradiation on adult longevity

Illumination of 2nd instar larvae had a certain effect on the longevity of adults. When the irradiation at 150 and 180 min, the difference between the female longevity and the control was significant. The longevity of males showed the same trend as that of females. Under 420 nm light irradiation, there was significant difference among 120–180 min irradiation and the control, the longevity was significantly shortened. The longevity of males in each treatment was higher than that of females, and there was no difference between the two lights (Table III). Illumination of 5nd instar larvae under 400 nm, there was no significant difference on the longevity of females at each irradiation time, but was a significant difference compared with the control. The two wavelengths showed the same trend, with the extension of irradiation time, the longevity of female and male adults decreased.

Effects of illumination on female oviposition

The 2nd and 5th instar larvae under two lights showed that the oviposition per female decreased with the extension of time (Table IV). The two lights irradiation showed that the oviposition per female under 420 nm light was lower than that under 400 nm light. For the 5th instar larvae, there were significant differences among the control and treatments. The maximum oviposition of a single female showed a same trend as that of oviposition per female, with a gradual downward trend. The oviposition per female under 400 nm light was higher than that under 420 nm light.

Effects of insect instar on larval growth and development under the same light

Under 400 nm light irradiation, the mortality of 2nd instar larvae was significantly higher than that of 5th instar larvae, and the mortality of 2nd instar larvae increased gradually with the extension of treatment time (Tables I and II). Under 420 nm light irradiation, the mortality trend of the two instars was consistent with that of 400 nm light, showing that the mortality caused by violet light irradiation was related to the instar. The lower the instar, the weaker the resistance, thus the higher the mortality, and vice versa.

The pupation rate of the control was higher and there was no difference with the two instars (Tables I and II). The pupation rate of 2nd instar larvae was significantly lower than that of 5th instar larvae under light irradiation, indicating that the pupation rate is greatly affected by the instar under the same light irradiation. The rate of abnormal pupae of 5th instar larvae was significantly higher than that of 2nd instar larvae, indicating that light had a great impact on the quality of pupation in the 5th instar larvae group, resulting in an increase in the rate of abnormal pupae.

Table III. Effects of light on the longevity of 2nd and 5th instar larvae.

Light wavelength	Treatment time (min)	2nd instar		5th instar	
		Female	Male	Female	Male
400 nm	0	8.00±1.15^{a}	9.00±1.15^{a}	8.47±0.79^{a}	9.33±0.88^{a}
	60	5.98±0.54^{abA}	7.85±0.20^{abA}	6.33±0.88^{bA}	7.67±0.88^{abA}
	90	6.08±0.33^{abA}	6.30±0.35^{bA}	6.03±0.26^{bA}	8.90±0.10^{abA}
	120	5.67±0.33^{abA}	5.80±0.42^{bA}	5.70±0.17^{bA}	6.76±0.39^{bA}
	150	4.55±0.58^{bA}	5.33±0.88^{bA}	4.80±0.25^{bA}	6.38±0.36^{bA}
	180	4.02±0.77^{bA}	5.67±0.33^{bA}	4.70±0.57^{bA}	6.50±0.36^{bA}
420 nm	0	8.00±1.15^{a}	9.00±1.15^{a}	8.47±0.79^{a}	9.33±0.88^{a}
	60	5.82±0.45^{abA}	7.94±0.24^{abA}	5.37±0.35^{bA}	7.37±0.58^{abA}
	90	5.68±0.27^{abA}	7.09±0.27^{abA}	5.42±0.52^{bA}	7.87±0.47^{abA}
	120	5.44±0.45^{abA}	6.19±0.31^{bA}	5.06±0.53^{bA}	7.07±0.64^{abA}
	150	5.05±0.40^{bA}	5.57±0.30^{bA}	4.85±0.31^{bA}	6.72±0.64^{abA}
	180	4.26±0.58^{bA}	5.69±0.32^{bA}	4.33±0.43^{bA}	6.11±0.59^{bA}

For superscripts and other statistical details see Table I.

Table IV. Effects of irradiation of larvae with different wavelengths on the oviposition of adults.

Light wavelength	Treatment time (min)	2nd instar		5th instar	
		Oviposition per female	Maximum oviposition per female	Oviposition per female	Maximum oviposition per female
400 nm	0	422.37±3.02^{a}	775	427.13±8.69^{a}	564
	60	195.26±4.62^{bA}	672	163.26±6.69^{bA}	526
	90	144.35±6.66^{cA}	622	161.18±3.48^{bA}	506
	120	145.27±5.69^{cA}	439	131.35±5.81^{cA}	359
	150	123.56±5.86^{cdA}	365	122.62±5.33^{cA}	327
	180	107.33±4.36^{dA}	295	102.37±6.94^{dA}	210
420 nm	0	422.37±16.02^{a}	775	427.13±8.69^{a}	564
	60	181.00±4.36^{bB}	556	168.67±2.40^{bA}	502
	90	147.33±4.81^{cA}	513	163.00±4.16^{bA}	475
	120	125.00±5.77^{cdB}	479	134.67±6.77^{cA}	362
	150	102.00±1.15^{dB}	305	109.33±2.96^{dB}	303
	180	102.33±1.76^{dA}	271	105.00±3.21^{dA}	376

For superscripts and other statistical details see Table I.

Under 400 nm light irradiation, the emergence rate of the 5th instar was significantly higher than that of the 2nd instar, with no significant difference compared with control. Under 420 nm light treatment, the difference between the 2nd instar and the 5th instar were significant under 60 and 150 min irradiation, and the emergence rate of the 5th instar larva was higher than that of the 2nd instar larva.

Under 400 nm light irradiation, the longevity of male adults in the 5th instar larva group was higher than that in the 2nd instar larva group at 120–180 min irradiation, with no significant difference, with the same trend of control and 60 min irradiation. At 90 min irradiation, the difference was significant, the longevity of male adults in the 5th instar larva group was significantly longer than that in the 2nd instar larva group. Under 420 nm light, there was no difference in the overall trend, indicating that different time irradiation of violet light shortens the longevity of adults for 2nd instar larvae, but has relatively little effect on 5nd instar larvae.

Under the treatment of two different wavelengths of light, the oviposition rate of adults in the 2nd instar larva group was higher than that in the 5th instar larva group under the treatment time of 60–120 min, and the oviposition rate of adults in the 5th instar larva group was higher than that in the 2nd instar larva group under the treatment time of 150–180 min, with significant difference (Fig. 1). Overall, the oviposition rate decreased with the extension of irradiation time.

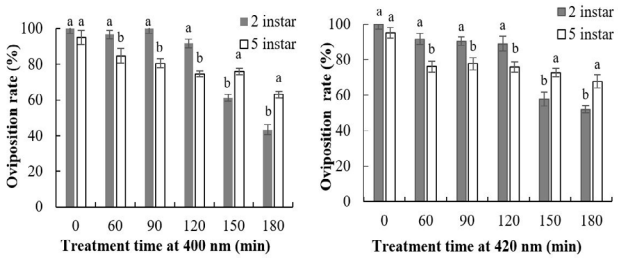

Fig. 1. Effects of different wavelengths and different treatment time on the oviposition rate.
Different letters indicate the significant difference at the level of 0.05 at the same treatment time on 2 and 5 instars. The values are Mean ± SEM.

DISCUSSION

This study showed that, with the increase of irradiation time, the insect mortality increased gradually, and the pupation rate, abnormal pupation rate, pupa weight, adult emergence rate, male and female adult longevity and oviposition rate all showed a downward trend. The results were consistent with the changing trend of *Ectropis grisescens* Warren larvae irradiated by UV-B (Zhang *et al*., 2016a), and were consistent with Fang's (2015) study in *Grapholitha molesta* treated with 395 nm light. However, it is not consistent with the research by exposing the black soldier fly adults with UV-LED resulting in enhancement of its indoor reproduction (Oonincx *et al*., 2016), and may due to different insects respond to different lights. In addition, the adult emergence rate after violet light

treatment decreased significantly, which was consistent with Liu *et al*. (2021) on the emergence rate of *Drosophila melanogaster* treated with lights.

Different instar larvae have different effects on different treatments, and suitable instars can be selected for control, which is consistent with the research results of different instar larvae of *Drosophila melanogaster* under UV light treatments (Ghadireh and Mohammad, 2009). The results of this study showed that the longevity of adults decreased with increasing treatment time which was consistent with the conclusion that UV radiation can promote aging and decrease longevity in invertebrates (Shen and Tower, 2019). The increase of wavelength, the longevity of males of 2nd instar larvae was higher than that of females, which was consistent with the conclusion between reproductive yield and longevity in male nutrients, toxic semen and life history theory in the hypothesis that the longevity of males was higher than that of females (Zhang *et al*., 2016b).

In this study, the behavior and biological parameters of male and female *S. subpunctaria* changed with irradiation of different wavelengths and irradiation time. Different instars had a great influence on the pupation rate under the irradiation of same wavelength, irradiation in pre-pupation stage can significantly affect the quality of pupation, resulting in an increase in the rate of abnormal pupation, while irradiation at 2nd instar larvae may cause it had a certain degree of adaptability, the specific reason needs to be further studied. In addition, the impact on the treatment of successive generations of adults needs to be further studied.

CONCLUSION

The irradiation of lights at 400 and 420 nm had an impact on the growth of *S. subctaria*, with its larval development duration, pupation rate, abnormal pupation rate, pupal weight, adult emergence rate reduced, the longevity of male and female adults reduced, the life cycle shortened and the number of next generation larvae reduced, so as to achieve the purpose of prevention and control. This paper aims to provide a reference for the research and application of light trapping and killing technology in the field of green control of tea pests.

ACKNOWLEDGEMENTS

This study was supported by Key Research and Development and Promotion Projects (Scientific and Technological Breakthrough) of Henan Province (Project name: Based on the combined control technology of light and biocontrol bacteria for lepidopteran pests in tea garden; No.: 222102110109); National Key R&D Program of China (No.: 2017YFD0200907), and Creation and Application of Attractant on *Scopula subpunctaria* Herrich-Schaeffer (No.: 20200017).

Statement of conflict of interests

The authors have declared no conflict of interest.

REFERENCES

Balamurugan, R. and Kandasamy, P., 2021. Effectiveness of portable solar-powered light-emitting diode insect trap: Experimental investigation in a groundnut field. *J. Asia-Pac. Ent.*, **24**: 1024-1032. https://doi.org/10.1016/j.aspen.2021.09.013

Baliota, G.V., Athanassiou, C.G. and Cohnstaedt, L.W., 2021. Response of phosphine-resistant and susceptible *Lasioderma serricorne* adults to different light spectra. *J. stored Prod. Res.*, **92**: 101808. https://doi.org/10.1016/j.jspr.2021.101808

Chen, Z., Kuang, R.P., Zhou, J.X. and Liu, X., 2012. Phototactic behavior in *Aphidius gifuensis* (Hymenopera: Braconidae). *Biocontrol. Sci. Technol.*, **22**: 271-279. https://doi.org/10.1080/09583157.2012.655261

Edwin, E.S., Vasantha-Srinivasan, P., Ponsankar, A., Thanigaivel, A., Selin-Rani, S., Mankin, R.W., Senthil-Nathan, S., Kalaivani, K., Murali-Baskaran, R.K., Duraipandiyan, V. and Al-Dhabi, N.A., 2016. Effects of temperature and nonionizing ultraviolet radiation treatments of eggs of five host insects on production of *Trichogramma chilonis* Ishii (Hymenoptera: Trichogrammatidae) for biological control applications. *J. Asia-Pac. Ent.*, **19**: 1139-1144. https://doi.org/10.1016/j.aspen.2016.09.011

Fang, C., 2015. *Effect of different lights on main biological parameters and protective enzymes of Grapholita molesta* (*Lepidoptera: Tortricidae*). Northwest A and F University, Yangling, China.

Federico, C. and Julio, C.R., 2010. Behavioral responses of larvae and adults of *Estigmene acrea* (Lepidoptera: Arctiidae) to light of different wavelengths. *Fl. Entomol,* **93**: 505-509. https://doi.org/10.1653/024.093.0405

Garris, H.W. and Snyder, J.A., 2010. Sex-specific attraction of moth species to ultraviolet light traps. *Southeast. Nat.*, **9**: 427-434. https://doi.org/10.1656/058.009.0302

Geng, S.B., Hou, H.L., Wang, G.J., June C.L., Yin, J. and Qiao, L., 2021. Temperature dependent ovi position model of *Scopula subpunctaria* (Lepidoptera: Geometridae). *J. Asia-Pac. Entomol.*, **24**: 948-953. https://doi.org/10.1016/j.aspen.2021.08.004

Ghadireh, M. and Mohammad, T., 2009. A study of the effect of ultraviolet light (UVC) in short intervals on 3rd instar larvae of *Drosophila melanogaster*. *J.*

Sci. (Kharazmi Univ.), **9**: 613-624.

Infusino, M., Brehm, G., Marco, C.D. and Scalercio, S., 2017. Assessing the efficiency of UV LEDs as light sources for sampling the diversity of macro-moths (Lepidoptera). *Eur. J. Ent.*, **114**: 25-33. https://doi.org/10.14411/eje.2017.004

Karthi, S., Sankari, R. and Shivakumar, M.S., 2014. Ultraviolet-B light induced oxidative stress: Effects on antioxidant response of Spodoptera litura. *J. Photochem. Photobiol., B*, **135**: 1-6. https://doi.org/10.1016/j.jphotobiol.2014.04.008

Kim, K.N., Huang, Q.Y. and Lei, C.L., 2019. Advances in insect phototaxis and application to pest management: A review. *Pest Manage. Sci.*, **75**: 5536. https://doi.org/10.1002/ps.5536

Liu, Q.H., Hou, X.H. and Zhou, Q., 2017. Influence of locusts visual reaction effect stimulated by orange light on response effect. *J. Biobased Mater. Bioener.*, **11**: 264-270. https://doi.org/10.1166/jbmb.2017.1678

Liu, Q.H., Jiang, Y.L., Miao, J., Gong, Z.J., Li, T., Duan Y. and Wu, Y.Q., 2019. Regulation of visual sensitivity responses in locusts stimulated by different spectral lights. *Pakistan J. Zool.*, **51**: 2245-2255. https://doi.org/10.17582/journal.pjz/2019.51.6.2245.2255

Liu, Q.H., Jiang, Y.L., Li, T., Miao, J., Gong, Z.J., Duan, Y. and Wu, Y.Q., 2020. Changes in the visual response and thoracic temperature of *Locusta migratoria manilensis* stimulated by LED spectral light. *Pakistan J. Zool.*, **52**: 355-362. https://doi.org/10.17582/journal.pjz/2020.52.1.355.362

Liu, Q.H., Jiang, Y.L., Zhao, M.Q., Miao, J., Gong, Z.J., Li, T., Duan, Y. and Wu, Y.Q., 2021. Study on the visual response of *Frankliniella occidentalis* to ultra violet-visible spectroscopy with different wavelength ranges. *J. Biobased Mater. Bioener.*, **15**: 497–503. https://doi.org/10.1166/jbmb.2021.2082

Lou, S., Zhang, B.R. and Zhang, D.H., 2021. Foresight from the hometown of green tea in China: Tea farmers' adoption of pro-green control technology for tea plant pests. *J. Cleaner Prod.*, **320**: 128817. https://doi.org/10.1016/j.jclepro.2021.128817

Ma, T., Shi, X.H., Lin, N., Wang, Z.B., Xiao, Q., Sun, Z.H. and Wen, X.J., 2019. Temporal pattern of adult emergence and sexual behavior of *Scopula subpunctaria* (Lepidoptera: Geometridae). *Phytoparasitica*, **47**: 17-29. https://doi.org/10.1007/s12600-019-00713-6

Meng, J.Y., Zhang, C.Y. and Lei, C.L., 2010. A proteomic analysis of *Helicoverpa armigera* adults after exposure to UV light irradiation. *J. Insect Physiol.*, **56**: 405-411. https://doi.org/10.1016/j.jinsphys.2009.11.015

Oh, M.S., Lee, C.H., Lee, S.G. and Lee, H.S., 2011. Evaluation of high power light emitting diodes (HPLEDs) as potential attractants for adult *Spodoptera exigua* (Hübner) (Lepidoptera: Noctuidae). *J. Korean Soc. appl. biol. Chem.*, **54**: 416-422. https://doi.org/10.3839/jksabc.2011.065

Oonincx, D.G.A.B., Volk, N., Diehl, J.J.E., van Loon, J.J.A. and Belušič, G., 2016. Photoreceptor spectral sensitivity of the compound eyes of black soldier fly (*Hermetia illucens*) informing the design of LED-based illumination to enhance indoor reproduction. *J. Insect Physiol.*, **95**: 133-139. https://doi.org/10.1016/j.jinsphys.2016.10.006

Peitsch, D., Fietz, A., Hertel, H., de Souza, J., Ventura, D.F. and Menzel, R., 1992. The spectral input system of Hymenopteran insects and their receptor-based colour vision. *J. comp. Physiol., A*, **170**: 23-40. https://doi.org/10.1007/BF00190398

Qian, J.L., Luo, Z.X., Li, J.L., Cai, X.M., Bian, L., Xiu, C.L., Li, Z.Q., Chen, Z.M. and Zhang, L.W., 2020. Identification of cytochrome P450, odorant-binding protein, and chemosensory protein genes involved in Type II sex pheromone biosynthesis and transportation in the tea pest, *Scopula subpunctaria*. *Pestic. Biochem. Physiol.*, **169**: 104650. https://doi.org/10.1016/j.pestbp.2020.104650

Qiao, L., Guo, S.B., Jin, Y.L., Wang, C.S., Yin, J. and Geng, S.B., 2021a. Effect of different light-emitting diode (LED) lights on the behavior and habits of *Scopulasub punctaria* Herrichet Schaeffer. *J. Biobased Mater. Bioener.*, **15**: 203-209. https://doi.org/10.1166/jbmb.2021.2029

Qiao, L., Zhang, Q., Geng, S.B., Zhang, F.M., Chen, J.H. and Guo, S.B., 2021b. Effect of LED illumination on the biological habits of the adults of *Ectropis grisescens*. *Pakistan J. Zool.*, **54**: 71-76. https://doi.org/10.17582/journal.pjz/20200601040657

Shen, J. and Tower, J., 2019. Effects of light on aging and longevity. *Ageing Res. Rev.*, **53**: 100913. https://doi.org/10.1016/j.arr.2019.100913

Shimoda, M. and Honda, K., 2013. Insect reactions to light and its applications to pest management. *Appl. Ent. Zool.*, **48**: 413–421. https://doi.org/10.1007/s13355-013-0219-x

Zhang, H., Li, H.L., Wang, D.F., Li, L.D., Wang, Q.S., Zeng, M.S. and Wu, G.Y., 2016a. Effect of UV-B on growth of *Ectropis oblqua* larvae. *Fujian J. agric. Sci.*, **31**: 487-490.

Zhang, S.Y., Li, D., Zeng, J.P., Wu, X.F. and Liu, X.P., 2016b. Effect of male mating history on female reproductive fitness in moths: A meta-analysis. *Chin. J. Ecol.*, **35**: 551-558.