Effects of yellow and green light stress on emergence, feeding and mating of *Anomala corpulenta* Motschulsky and *Holotrichia parallela* Motschulsky (Coleoptera: Scarabaeidae)

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Abstract: Light is one of the key environmental factors for insects to survive. Artificial light sources different from natural environmental light can cause light stress in insects. Yellow and green light stress can interfere with the diurnal rhythm of nocturnal moths and their mating, oviposition, and adult longevity. The scarabaeid beetles *Anomala corpulenta* Motschulsky and *Holotrichia parallela* Motschulsky are widely distributed, and they are very harmful underground pests. In order to clarify the effects of light stress on their behaviors, individuals of both species were exposed to yellow light (565-585 nm) and green light (525-545 nm), with different light intensity gradients of yellow light in a laboratory setting. The short-term light stress treatment of *A. corpulenta* and *H. parallela* was carried out at night. The number of beetles emerging per half an hour was recorded, and mating pairs and feeding activity in 24 h were counted. The results showed that yellow and green light stress significantly changed the rhythm and reduced the rate of beetle emergence in the two beetle species investigated. Also, the peak emergence activity was delayed and the feeding and mating activities were significantly reduced. When treated with different intensities of yellow light, it was found that the rate of emergence of *A. corpulenta* under 10 lx was close to the control groups. The rate of emergence in *H. parallela* was significantly lower than the control groups before 0:00, in the 60 lx and 110 lx treatment groups, but after 0:00, the emergence rate of *H. parallela* was significantly higher in the 60 lx and 110 lx treatment groups than other treatments. However, the emergence rhythms in the three light intensity treatment groups are basically the same as in the control groups. The feeding amount and mating beetles in the three light intensity treatment groups were significantly lower than in the control groups. There were no significant differences in the three treatments. The results show that light stress above 10 lx significantly interferes with the behavioral activities of the two beetle species, investigated. This study provides a new approach for a light control technology for nocturnal beetle pest species.

Keywords: yellow and green light, *Anomala corpulenta* Motschulsky, *Holotrichia parallela* Motschulsky, emergence rhythm, feeding, mating
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1 Introduction

With more than 30 000 known species, Scarabaeidae is one of the most species-rich groups of beetles (Coleoptera). The taxon is globally distributed and contains several important pest species[1]. The larvae (grubs) are feeding on seeds, roots, and shoots underground. Adults feed on plant leaves, flowers, buds, filaments, and clusters, thus seriously affecting crop yield and quality, and economic profit. However, these pest species usually are very difficult to be controlled[2]. During the last ten years, *Anomala corpulenta* Motschulsky and *Holotrichia parallela* (Motschulsky, 1854) had very high emergence rates in the area from the Yangtze River to the northern region of China[3-6]. The adults of these pest species have strong phototaxis, therefore, in addition to conventional chemical control, light trapping is an important measure for adult control. The commonly used light trapping devices include ultraviolet (UV) light traps, high-pressure

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mercury lamps, incandescent lamps, and searchlights. However, such light traps have very poor selectivity, and will indiscriminately kill pest species, natural enemies, and other non-target insects. Thereby, the method causes varying degrees of damage to the ecological environment[7,8]. Frick and Tallamy[7] pointed out that of the 13 789 insect species that were attracted by ultraviolet light traps, only 31 (0.22%) were biting mosquitoes. There were 6670 aquatic insects that do not harm humans, accounting for 48.8% of the contents of the traps. The relationship between the number of beneficial or harmless insects and the number of harmful insects showed that the effect of UV light traps was poor, destroyed biodiversity, and failed to achieve the intended goal[7]. In addition, UV and mixed light traps also have a great impact on plants[9]. Thus, it is particularly important to develop a new environment-friendly light prevention and control method.

The light perception of insects mainly depends on the visual pigments in the compound eyes. Most insects have two kinds of visual pigments. One pigment can detect green-yellow (G-Y) light with a wavelength of about 550 nm, and the other pigment can detect ultraviolet-blue (UV-B) light with a wavelength of less than 480 nm[10]. The compound eyes of nocturnal moths are in a light-adapted state during the daytime and in a dark-adapted state at night. Generally, the feeding, mating, and spawning activities of nocturnal moths are carried out in the dark-adapted state at night. When moths are exposed to sufficient intensities of yellow light at night, some moths will still be in the light-adapted state, which interferes with normal behavior. For example, the shielding pigment of the compound eye of *Spodoptera exigua* still covers the compound eye in the daytime (light-adapted state)[11] after such treatment. In this way, the yellow light may affect the behavior of nocturnal moths and play a role in the control of pest density. At present, yellow lamps are widely used in Japan[12], and numerous studies have been started in China[13].

The adults of many beetles and moths are nocturnal insects, and it has been shown that yellow light can interfere with the daily rhythm of moths and control their population development. The aim of the present study is to answer the question of whether yellow light also interferes with the daily rhythm of the adult beetles and reduces their feeding and reproduction activities. Herein, the effects of yellow and green light on the daily rhythm, feeding, and mating behavior of *A. corpulenta* and *H. parallela* were revealed. The expected results provide new approaches for the prevention and treatment of beetle pests. Theoretically, the applications of yellow light in insect pest control are further discussed.

2 Materials and methods

2.1 Test insects

Adult specimens of *A. corpulenta* Motschulsky and *H. parallela* (Motschulsky, 1854) were collected in the field at the Yuanyang experimental base of Henan Academy of Agricultural Sciences in the summer of 2021 (113.46°E, 35.08°N). The collected adult beetles were temporarily kept for use in glass tanks indoors and fed with fresh poplar leaves (the temperature was controlled at 25°C-28°C and the relative humidity at about 70%-75%). *H. parallela* has the habit of emerging from the ground every other day. Therefore, the beetles were kept separately and collected on odd-numbered days and on even-numbered days. During the test, the beetles from odd-numbered days were tested on odd-numbered days, and the beetles from even-numbered days were tested on even-numbered days.

2.2 Test equipment and lighting devices

Yellow (565-585 nm) and green (525-545 nm) LED lamps with a power of 10 W each, customized by Hebi National Photoelectric Technology Co., Ltd., were used for illumination; TES-1334a illuminance meter, manufactured by Taishi, Taiwan was used for measuring light intensity. Acrylic boxes (30 cm×20 cm×20 cm), purchased from Daizer acrylic factory store were used for keeping the insects.

2.3 Test methods

Experiment 1: Healthy male and female individuals were selected as test insects and put into acrylic transparent boxes. A layer of soil about 5 cm thick was paved at the bottom of the box, and several poplar leaves cut into rectangles were placed on the soil, which was about 200 cm^2 each.

In light treatment groups, yellow light and green light tubes were hung above the acrylic box, and light intensity was 110 lx respectively. In the control groups (CK), the box was kept in a dark room, where light intensity was 0 lx. Ten pairs of test insects were placed in each treatment. Each treatment was repeated 10 times. Before the experiment, the beetles were raised under normal conditions. The experiment was conducted from 19:00 to 7:00 the next day and observed once every half an hour. The control group was illuminated with a weak red light during night observation, and the numbers of beetle emergences and of mating pairs were recorded. At the end of the experiment, the leaves left in the feeding area were counted. During the test, the temperature was controlled at 25°C-28°C and the relative humidity was about 70%-75%.

Experiment 2: Different yellow light intensity gradients were applied. Three treatment groups were set with a light intensity of 10 lx, 60 lx, and 110 lx each (refer to Jiang Yueli *et al.*, 2020[14]). The box containing the control group was kept in the darkroom where the light intensity was measured to be 0. The experiment was done as described in "Experiment 1".

2.4 Data analysis

The data were sorted, analyzed, and visualized using Microsoft Excel®. The statistical analysis was carried out with IBM® SPSS® 19.0 software. A one-way analysis of variance (ANOVA) was carried out for different light wavelengths and light intensities, and the significance of differences was tested with Tukey's test.

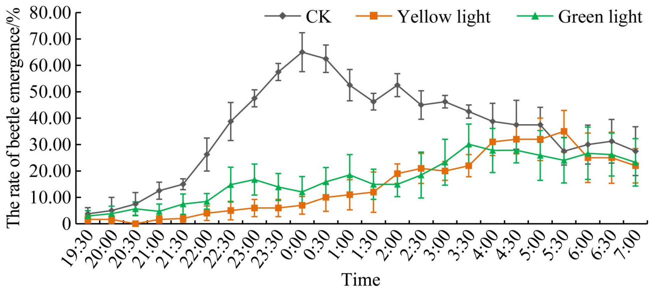
3 Results and analysis

3.1 Effects on the rate and rhythm of the emergence of two species of beetles under yellow and green light stresses

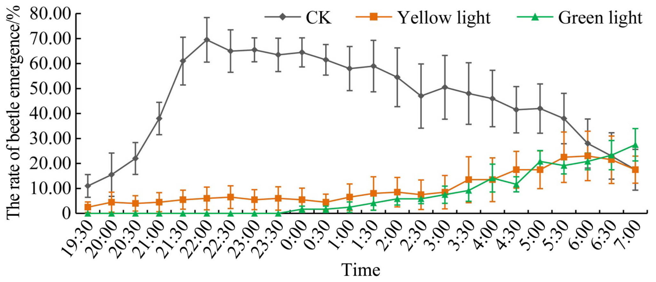
At night, the rate of *A. corpulenta* and *H. parallela* emergence decreased significantly compared with the control groups under yellow and green light stress (Figure 1). The rate of emergence in *A. corpulenta* control groups increased rapidly from 21:30 to 0:00, and at 0:00 reached a peak (65%), then decreased rapidly. Yellow light and green light groups increased slowly from 21:30 to 7:00 the next day, and the peak time of emergence was obviously delayed as in the control groups (Figure 1a).

The statistical analysis of the number of emergences in the treatment groups and in the control groups showed that there was a significant difference between the control groups and yellow light and green light treatment groups from 21:00 to 3:00 the next day ($p<0.05$), but there was no significant difference between yellow light and green light treatment groups ($p>0.05$) (Table 1).

The rate of *H. parallela* emergence increased rapidly from 21:30 to 22:00, peaked (69.5%) at 22:00, and then decreased slowly, while yellow light and green light treatment groups increased slowly from 21:30 to 7:00 the next day. The rate of emergence was basically the same as in the control groups at 6:30 the next day (Figure 1b). The statistical analysis of the number of emergences shows that its rate in the control groups was significantly different from the yellow light and green light treatment groups from 22:30 to 5:00 the next day ($p<0.05$). There was no significant difference in the rate of emergence between yellow light and green light treatment groups in all treatment periods ($p>0.05$) (Table 2).



a. *Anomala corpulenta*



b. *Holotrichia parallela*

Figure 1 Rhythms of emergence under different light treatments in *Anomala corpulenta* and *Holotrichia parallela*

Table 1 Numbers of the emergence of *Anomala corpulenta* under yellow light and green light stress in different time periods

Time	Yellow light	Green light	CK
19:30	0.33±0.29^{a}	0.59±0.29^{a}	0.75±0.48^{a}
20:00	0.33±0.29^{a}	0.76±0.40^{a}	1.00±1.00^{a}
20:30	0.00±0.00^{a}	1.14±0.37^{a}	1.50±0.87^{a}
21:00	0.33±0.29^{b}	0.94±0.39^{b}	2.50±0.65^{a}
21:30	0.40±0.24^{b}	1.49±0.54^{ab}	3.00±0.41^{a}
22:00	0.80±0.49^{b}	1.70±0.42^{b}	5.25±1.25^{a}
22:30	1.00±0.63^{b}	2.96±0.93^{b}	7.75±1.44^{a}
23:00	1.20±0.58^{b}	3.35±0.83^{b}	9.50±0.65^{a}
23:30	1.20±0.58^{b}	2.79±0.72^{b}	11.50±0.65^{a}
0:00	**1.40±0.60^{b}**	**2.41±0.82^{b}**	**13.00±1.47^{a}**
0:30	2.00±0.95^{b}	3.17±0.77^{b}	12.50±1.04^{a}
1:00	2.20±1.02^{b}	3.71±1.08^{b}	10.50±1.02^{a}
1:30	2.40±1.36^{b}	2.99±0.81^{b}	9.25±0.63^{a}
2:00	3.80±0.66^{b}	2.99±0.66^{b}	10.50±0.87^{a}
2:30	4.20±1.02^{b}	3.69±1.23^{b}	9.00±1.08^{a}
3:00	4.00±0.63^{b}	4.66±1.23^{b}	9.25±0.48^{a}
3:30	4.40±0.75^{b}	6.03±1.08^{ab}	8.50±0.50^{a}
4:00	6.20±0.92^{a}	5.55±1.18^{a}	7.75±1.38^{a}
4:30	6.40±0.98^{a}	5.57±0.67^{a}	7.50±1.85^{a}
5:00	6.40±1.44^{a}	5.18±1.33^{a}	7.50±1.32^{a}
5:30	7.00±1.41^{a}	4.81±1.21^{a}	5.50±1.04^{a}
6:00	5.00±1.67^{a}	5.34±1.40^{a}	6.00±1.47^{a}
6:30	5.00±1.73^{a}	5.24±1.15^{a}	6.25±1.65^{a}
7:00	4.40±1.17^{a}	4.65±1.27^{a}	5.50±1.85^{a}

Note: Data in the table are mean±SE, and different letters following the data in the same row indicate significant by Tukey's test ($p<0.05$). The same as below.

Table 2 Numbers of *Holotrichia parallela* emergence under yellow light and green light stress in different time periods

Time	Yellow light	Green light	CK
19:30	0.50±0.40^{a}	0.00±0^{a}	2.20±1.08^{a}
20:00	0.90±0.60^{ab}	0.00±0.00^{b}	3.10±1.10^{a}
20:30	0.80±0.59^{b}	0.00±0.00^{b}	4.40±0.81^{a}
21:00	0.90±0.48^{b}	0.00±0.00^{b}	7.60±0.82^{a}
21:30	1.10±0.48^{b}	0.00±0.00^{b}	12.20±1.21^{a}
22:00	**1.20±0.57^{b}**	**0.00±0.00^{b}**	**13.90±1.13^{a}**
22:30	1.30±0.58^{b}	0.00±0.00^{b}	13.00±1.07^{a}
23:00	1.10±0.50^{b}	0.00±0.00^{b}	13.10±0.60^{a}
23:30	1.20±0.59^{b}	0.00±0.00^{b}	12.70±0.84^{a}
0:00	1.10±0.59^{b}	0.33±0.26^{c}	12.90±0.74^{a}
0:30	0.90±0.41^{b}	0.33±0.26^{c}	12.30±0.78^{a}
1:00	1.30±0.67^{b}	0.50±0.34^{c}	11.60±1.12^{a}
1:30	1.60±0.85^{b}	0.83±0.48^{c}	11.80±1.31^{a}
2:00	1.70±0.75^{b}	1.17±0.40^{c}	10.90±1.49^{a}
2:30	1.50±0.75^{b}	1.17±0.31^{c}	9.40±1.63^{a}
3:00	1.70±0.84^{b}	1.50±0.56^{c}	10.10±1.62^{a}
3:30	2.70±1.16^{b}	1.83±0.70^{c}	9.60±1.56^{a}
4:00	2.70±1.11^{b}	2.83±0.91^{b}	9.20±1.43^{a}
4:30	3.50±0.93^{b}	2.33±0.49^{b}	8.30±1.17^{a}
5:00	3.50±0.96^{b}	4.17±0.70^{b}	8.40±1.25^{a}
5:30	4.50±1.28^{ab}	3.83±0.54^{b}	7.60±1.28^{a}
6:00	4.60±1.25^{ab}	4.17±0.54^{b}	5.60±1.24^{a}
6:30	4.30±1.20^{a}	4.67±0.95^{a}	4.60±1.18^{a}
7:00	3.50±0.69^{b}	5.50±1.06^{a}	3.50±1.04^{b}

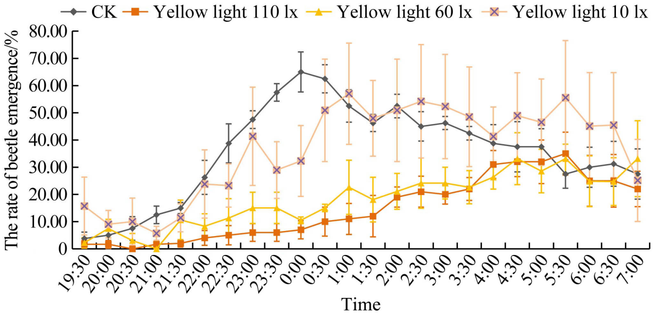
The results show that yellow light and green light stress significantly affect the rate and rhythm of emergence in *A. corpulenta* and *H. parallela*. There was no significant difference between yellow light and green light stress.

3.2 Effect of different intensities of yellow light stress on the emergence rate and rhythm of *H. parallela* and *A. corpulenta*

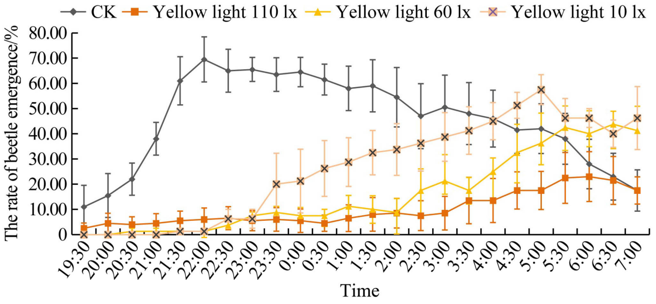
The results of Experiment 1 showed that yellow light and green light stress had the same effect on the rhythm of the emergence of the two beetle species investigated. Therefore, For the yellow light, the effects of different light intensities on the rhythm of emergence, feeding, and mating were evaluated. As can be seen in Figure 2, the rhythm of emergence is basically consistent with the values at 110 lx, when yellow light intensity is 60 lx (Figure 2a). There was no significant difference in the number of emergences (Table 3). The rate of emergence decreased significantly in comparison with the control groups. The emergence rate of the treatment with light intensity of 10 lx was similar to that of controls, but significantly higher than that of 60 lx and 110 lx treatments. However, the similar dynamic of emergence was observed between the treatments with light intensity of 60 lx and 110 lx, which significantly delayed the controls. The statistical analysis showed that the number of emergences decreased significantly compared with the control groups from 21:00 to 2:00 the next day ($p<0.05$), when light intensity was 60 lx or 110 lx, but there was no significant difference between 60 lx and 110 lx ($p>0.05$). Most of the values had no significant difference between 10 lx and the control groups ($p>0.05$). The numbers of emergences were significantly higher than at 60 lx or 110 lx in most time periods (Table 3).

The rhythm of *H. parallela* emergence was basically the same under yellow light 10 lx, 60 lx, and 110 lx stress, rising slowly from 21:30 to 7:00 the next day, and reaching the peak value after 5:00 the next day. The rate of *H. parallela* emergence decreased significantly under all lighting conditions compared with control groups, and the peak was significantly delayed (Figure 2b).

Compared with the control, the number of *H. parallela* emergences decreased significantly from 22:30 to 5:00 the next day at 110 lx, (p<0.05). It also decreased significantly between 22:30 and 3:30 the next day at 60 lx (p<0.05). At 10 lx, it decreased significantly from 22:00 to 1:30 the next day (p<0.05). There was no significant difference at 10 lx or at 60 lx compare with 110 lx before 0:30 (p>0.05), and the numbers of *H. parallela* emergences increased significantly in most of the following periods at 10 lx (Table 4).



a. *Anomala corpulenta*



b. *Holotrichia parallela*

Figure 2 Rhythms of the emergence of *Anomala corpulenta* and *Holotrichia parallela* under yellow light treatments of different intensities

Table 3 Numbers of *Anomala corpulenta* emergence under yellow light stress of different intensities in different time periods

Time	Yellow light 110 lx	Yellow light 60 lx	Yellow light 10 lx	CK
19:30	0.33±0.29^{a}	0.44±0.44^{a}	3.14±2.46^{a}	0.75±0.48^{a}
20:00	0.33±0.29^{a}	1.81±1.17^{a}	1.49±0.79^{a}	1.00±1.00^{a}
20:30	0.00±0.00^{a}	0.61±0.61^{a}	2.00±2.00^{a}	1.50±0.87^{a}
21:00	0.33±0.29^{b}	0.00±0.00^{b}	1.14±0.59^{b}	2.50±0.65^{a}
21:30	0.40±0.24^{b}	2.12±1.69^{ab}	2.29±1.19^{ab}	3.00±0.41^{a}
22:00	0.80±0.49^{b}	1.66±1.06^{a}	4.76±2.90^{a}	5.25±1.25^{a}
22:30	1.00±0.63^{b}	2.26±1.64^{b}	4.65±1.84^{a}	7.75±1.44^{a}
23:00	1.20±0.58^{b}	3.01±1.33^{b}	8.27±4.17^{a}	9.50±0.65^{a}
23:30	1.20±0.58^{bc}	3.01±1.32^{b}	5.80±2.40^{bd}	11.50±0.65^{a}
0:00	**1.40±0.60^{d}**	**2.10±0.28^{cd}**	**6.46±3.00^{bc}**	**13.00±1.47^{a}**
0:30	2.00±0.95^{b}	3.01±0.32^{b}	10.18±4.35^{a}	12.50±1.04^{a}
1:00	2.20±1.02^{b}	4.53±2.30^{ab}	11.40±4.30^{a}	10.50±1.02^{a}
1:30	2.40±1.36^{b}	3.62±1.90^{ba}	9.59±3.21^{a}	9.25±0.63^{a}
2:00	3.80±0.66^{b}	4.22±1.53^{bc}	10.18±4.35^{ac}	10.50±0.87^{a}
2:30	4.20±1.02^{a}	4.83±2.14^{a}	10.85±4.82^{a}	9.00±1.08^{a}
3:00	4.00±0.63^{bc}	4.83±1.34^{ab}	10.47±4.43^{a}	9.25±0.48^{ac}
3:30	4.40±0.75^{a}	4.53±1.41^{a}	9.70±4.23^{a}	8.50±0.50^{a}
4:00	6.20±0.92^{a}	5.27±1.02^{a}	8.26±2.49^{a}	7.75±1.38^{a}
4:30	6.40±0.98^{a}	6.63±2.2^{a}	9.78±3.66^{a}	7.50±1.85^{a}
5:00	6.40±1.44^{a}	5.72±1.85^{a}	9.31±3.67^{a}	7.50±1.32^{a}
5:30	7.00±1.41^{a}	6.63±1.24^{a}	11.12±4.84^{a}	5.50±1.04^{a}
6:00	5.00±1.67^{a}	4.97±2.16^{a}	9.02±4.54^{a}	6.00±1.47^{a}
6:30	5.00±1.73^{a}	4.95±2.03^{a}	9.1±4.45^{a}	6.25±1.65^{a}
7:00	4.40±1.17^{a}	6.63±3.22^{a}	5.03±3.48^{a}	5.50±1.85^{a}

Table 4 Numbers of *Holotrichia parallela* emergences under yellow light stress at different intensities in different time periods

Time	Yellow light 110 lx	Yellow light 60 lx	Yellow light 10 lx	CK
19:30	0.50±0.40^{a}	0.00±0.00^{a}	0.00±0.00^{a}	2.20±1.08^{a}
20:00	0.90±0.60^{ab}	0.00±0.00^{b}	0.00±0.00^{b}	3.10±1.10^{a}
20:30	0.80±0.59^{b}	0.25±0.25^{b}	0.00±0.00^{b}	4.40±0.81^{a}
21:00	0.90±0.48^{b}	0.25±0.25^{b}	0.00±0.00^{b}	7.60±0.82^{a}
21:30	1.10±0.48^{b}	0.25±0.25^{b}	0.25±0.25^{b}	12.20±1.21^{a}
22:00	**1.20±0.57^{b}**	**0.25±0.25^{b}**	**0.25±0.25^{b}**	**13.90±1.13^{a}**
22:30	1.30±0.58^{b}	0.75±0.48^{b}	1.25±0.75^{b}	13.00±1.07^{a}
23:00	1.10±0.50^{b}	1.50±0.29^{b}	1.25±0.75^{b}	13.10±0.60^{a}
23:30	1.20±0.59^{b}	1.75±0.48^{b}	4.00±2.45^{b}	12.70±0.84^{a}
0:00	1.10±0.59^{b}	1.50±0.65^{b}	4.25±2.53^{b}	12.90±0.74^{a}
0:30	0.90±0.41^{c}	1.50±0.50^{c}	5.25±2.21^{b}	12.30±0.78^{a}
1:00	1.30±0.67^{c}	2.25±0.85^{bc}	5.75±1.93^{b}	11.60±1.12^{a}
1:30	1.60±0.85^{c}	2.00±1.08^{bc}	6.50±1.76^{b}	11.80±1.31^{a}
2:00	1.70±0.75^{c}	1.75±1.11^{bc}	6.75±2.06^{ab}	10.90±1.49^{a}
2:30	1.50±0.75^{c}	3.50±1.71^{bc}	7.25±2.21^{ab}	9.40±1.63^{a}
3:00	1.70±0.84^{c}	4.25±2.10^{bc}	7.75±1.93^{ab}	10.10±1.62^{a}
3:30	2.70±1.16^{c}	3.50±1.04^{bc}	8.25±1.89^{ab}	9.60±1.56^{a}
4:00	2.70±1.11^{b}	5.00±1.08^{ab}	9.00±1.47^{a}	9.20±1.43^{a}
4:30	3.50±0.93^{b}	6.50±2.25^{ab}	10.25±1.03^{a}	8.30±1.17^{a}
5:00	3.50±0.96^{b}	7.25±2.39^{ab}	11.50±1.19^{a}	8.40±1.25^{a}
5:30	4.50±1.28^{bc}	8.50±1.71^{ac}	9.25±1.55^{a}	7.60±1.28^{ab}
6:00	4.60±1.25^{bc}	8.00±1.83^{ac}	9.25±0.75^{a}	5.60±1.24^{ab}
6:30	4.30±1.20^{b}	8.75±1.03^{ac}	8.00±1.08^{bc}	4.60±1.18^{bc}
7:00	3.50±0.69^{b}	8.25±1.93^{a}	9.25±2.50^{a}	3.50±1.04^{b}

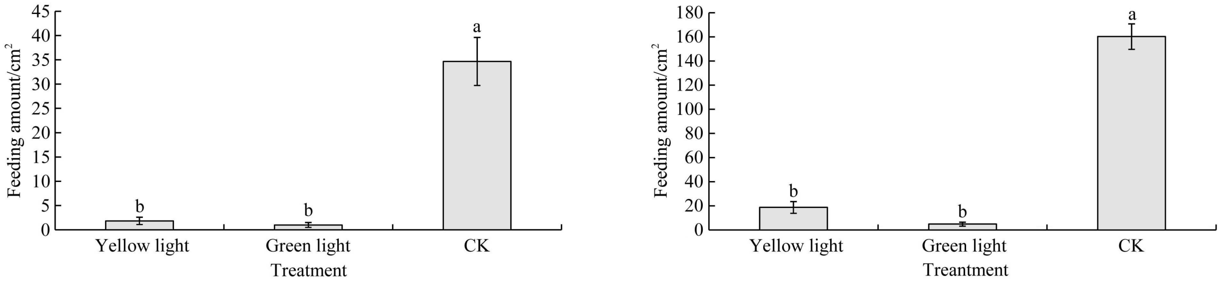
These results indicate that light intensity has a certain impact on the rhythm of the emergence of the two beetle species investigated. The greater the light intensity, the greater the impact on the rate and rhythm of emergence.

3.3 Effect of different light treatments on the feeding activity of *H. parallela* and *A. corpulenta*

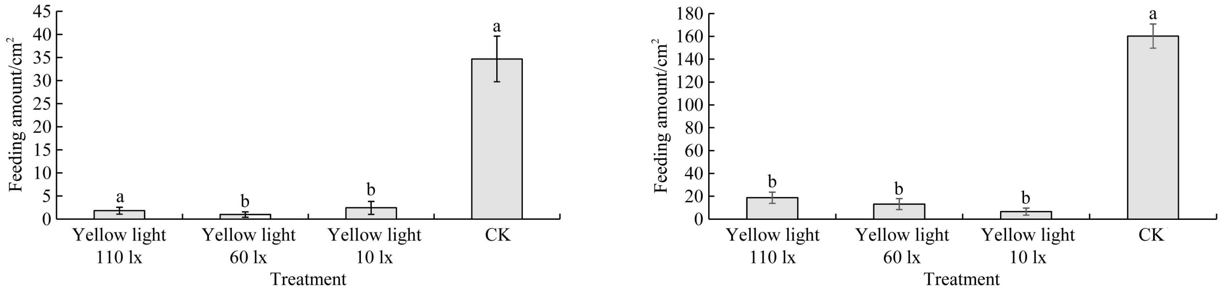
The amount of food taken up by (1.83 cm^2 and 1 cm^2) *A. corpulenta* and *H. parallela* decreased significantly in comparison with the control groups (34.67 cm^2) under the stress of yellow or green light, (Figure 3a: df=2, F=43.762, p=0; Figure 3b: df=2, F=59.484, p=0). There was no significant difference between yellow light and green light treatment groups. Under the stress of different light intensities of yellow light, the feeding amount of the treatment groups of *A. corpulenta* and *H. Parallela* was significantly reduced compared with the control groups (Figure 3c: df=3, F=26.437, p=0; Figure 3d: df=3, F=53.150, p=0). There was no significant difference between the treatments at different light intensities.

3.4 Effect of light stress on mating in *H. parallela* and *A. corpulenta*

Compared with the control groups, the mating activity was also significantly reduced in yellow light and green light treatment groups. Mating pairs of *A. corpulenta* between 2.67 and 0 mating pairs were observed in the control groups, giving a mean of 0.17 mating pairs (df=2, F=19.750, p=0). There was no significant difference between treatment groups. No mating pair was observed in the treatment groups. The difference between the control groups and the treatments was statistically significant (df=2, F=9.473, p=0), and there was no significant difference between the yellow and green light treatment groups (Table 5). It was found that there was no significant difference in the mating of the two beetle species investigated at 10 lx, 60 lx, and 110 lx yellow light stress, but there were significant differences in comparison to the control groups (df=3, F=0.981, p=0.001; df=3, F=0.980, p=0).



a. *Anomala corpulenta* under yellow light and green light stress b. *Holotrichia parallela* under yellow light and green light stress



c. *Anomala corpulenta* under yellow light stress at different light intensities d. *Holotrichia parallela* under yellow light stress at different light intensities

Figure 3 Feeding amounts for *Anomala corpulenta* and *Holotrichia parallela* under different light treatments

Table 5 Mating pairs observed in *Anomala corpulenta* and *Holotrichia parallela* under yellow and green light stresses

Treatments	Pairs of mating beetles/24 h	
	Anomala corpulenta	*Holotrichia parallela*
Yellow light	0.00 ± 0.00^{b}	0.00 ± 0.00^{b}
Green light	0.17 ± 0.17^{b}	0.00 ± 0.00^{b}
CK	2.67 ± 0.56^{a}	1.73 ± 0.32^{a}

Note: Data in the table are Mean±*SE*, and different letters following the data in the same column indicate significant by Tukey's test ($p<0.05$). The same as below.

Table 6 Difference analysis of mating pairs in *Anomala corpulenta* and *Holotrichia parallela* under yellow light stress of different light intensities

Treatments	Pairs of mating beetles/24 h	
	Anomala corpulenta	*Holotrichia parallela*
Yellow light 110 lx	0.00 ± 0.00^{b}	0.00 ± 0.00^{b}
Yellow light 60 lx	0.00 ± 0.00^{b}	0.00 ± 0.00^{b}
Yellow light 10 lx	0.33 ± 0.33^{b}	0.17 ± 0.17^{b}
CK	2.67 ± 0.56^{a}	1.73 ± 0.32^{a}

4 Discussion

Light is one of the important environmental factors for insect survival. Light sources different from natural environmental light can cause light stress for insects.

More and more studies have shown that nocturnal artificial light can affect the behavior of insects, such as their flight, orientation, diffusion, migration, communication, predation, mate recognition, spawning, eclosion, molting, visual response, and various other rhythmic activities[12,15-19]. The compound eyes of nocturnal moths can maintain the "light-adapted state" during the day under yellow and green light stress at night. This interferes with their daily rhythm, and affects the foraging, mating, and ovipositing behavior, reducing adult longevity and the ability to reproduce. Consequently, artificial light stress can be used to control the development of pest populations[20-27].

This study shows that the emergence rate and rhythm of *A. corpulenta* and *H. parallela* are affected significantly by conditions of artificial yellow and green light stress. Simultaneously, the feeding and mating behavior are significantly reduced. These observations did not reveal significant differences between yellow and green light, which is consistent with similar research on moths[28-30]. These results indicate that yellow and green light can interfere with the daily rhythm, reducing foraging and mating in *A. corpulenta* and *H. parallela* as in most nocturnal moths.

The adult compound eyes of most insects detect a wide range of light intensities. However, the light intensity will affect a variety of insect behaviors to a certain extent. For example, strong or continuous light can inhibit mating behavior and sex pheromone synthesis in moths[28-30]. 50 lx white light irradiation can inhibit courtship behavior, sex pheromone synthesis, and mating behavior in female moths of the species *Helicoverpa armigera*. Low light irradiation of 0.5 lx can promote the courtship behavior of females and it promotes rapid mating in *H. armigera*[31]. The intensity of yellow light had different effects on fecundity, pre-fecundity, and adult longevity in *Spodoptera exigua*[14]. In addition, the transformation of the compound eye state of *Spodoptera frugiperda* was very sensitive to yellow light irradiation, and weak changes had a significant impact on the light or dark-adapted state of *S. meadowi*[27].

In this study, no significant differences were found between the effects of yellow and green light stresses on the beetle species *A. corpulenta* and *H. parallela*. Therefore, the investigation of different light intensities was done using yellow light, only. The results show that there was no significant difference in the rate, and rhythm of the emergence of *A. corpulenta*, as well as in the feeding amount and in the number of mating pairs observed under 60 lx or 110 lx of yellow light. When yellow light intensity was 10 lx, the rate of the emergence of *A. corpulenta* was similar to the control groups. There was no significant difference between the treatment groups at yellow light intensities of 60 lx and 110 lx in the rhythm of the emergence of *A. corpulenta*, the feeding amount, or the number of mating pairs. When light intensity was 10 lx, 60 lx, or 110 lx, the rhythm of the emergence of *H. parallela* was basically the same. This value increased slightly after 0:00 in 10 lx treatment groups. There was no significant difference in the feeding amount or in the number of mating pairs between the three groups of different illumination intensities. These results show that light stress significantly interferes with the rate and rhythm of emergence, feeding, and mating in *A. corpulenta* and *H. parallela*, when yellow light intensity reaches 10 lx. This conclusion is consistent with the observations of Jiang et al.[32] on *Spodoptera exigua*.

Up to now, the control effect of yellow light on nocturnal moths has been studied and applied[12,13]. The control effect of yellow light on nocturnal beetle pest species has so far not been reported. Our results improve the knowledge of insect visual ecology. In this study, the behavioral responses of *A. corpulenta* and *H. parallela* to the yellow and green lights were described, which provide a new approach to uncovering the influences of light stress on the diurnal rhythm of insects in the future researches. In practice, the results will not only provide new possibilities for green prevention and control of nocturnal beetle pest species, but they also provide a theoretical basis for the expansion of the use of yellow light in the control of nocturnal moths and other insect pest species in China.

Through short-term stress of yellow or green light, this study preliminarily clarified the interference effect on the behavior of the beetle pest species *A. corpulenta* and *H. parallela*. However, effects on their behavior, physiological and molecular response under long-term yellow or green light stress need to be studied on a deeper level. In addition, to establish the use of yellow or green light stress to control nocturnal beetle pests, more researches on beetle pests, especially field experiments are needed to provide a better theoretical basis for the development and application of light control equipment.

5 Conclusions

This study showed that the emergence rate and rhythm of *A. corpulenta* and *H. parallela* are affected significantly by conditions of artificial yellow and green light stress. Also, the peak emergence activity was delayed and the feeding and mating activities were significantly reduced. When tested with different light intensities of yellow light, it was found that the rate of emergence of *A. corpulenta* was close to the control groups under 10 lx. The rate of emergence was significantly lower than the control groups in *H. parallela* before 0:00, in the 60 lx and 110 lx treatment groups, but after 0:00, the emergence rate of *H. parallela* was significantly higher in the 60 lx and 110 lx treatment groups than other treatments. However, the emergence rhythms are basically the same as in the control groups under three light intensity treatment groups. The feeding amount and mating beetles in the three light intensity treatment groups were significantly lower than in the control groups. There were no significant differences in the three treatments. The results show that light stress significantly interferes with the behavioral activities in the two beetle species when it reaches more than 10 lx. The expected results provide new approaches for the prevention and treatment of beetle pests.

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[References]

[1] Wu J X. Agricultural Entomology, Beijing: China Agriculture Press, 2002; pp.49–51. (in Chinese)

[2] Yuan F. Agricultural Entomology. 3rd ed. China Agriculture Press, Beijing, 2001; pp.157–158. (in Chinese)

[3] Miao C S, Miao X J, Wang Y J, Jin S P. Studies on the scarab species by lure into of black light lamp and their dynamics in Hebei Province. Journal of Hebei Agricultural Sciences, 2007; 11(1): 41–45. (in Chinese)

[4] Zhang L L, Wu J X, Lu J J. Scarabs species trapped by black light and population dynamics of dominant species in Yangling, Shanxi Province. Journal of Environmental Entomology, 2012; 34(3): 395–399.

[5] Chen Q, Fan Z Y, Liu D, Hou Y H, Zhuo X N, Li S M. Scarabspecies trapped by black light and population dynamics of dominant speciesin Luohe City, Henan Province. Journal of Henan Agricultural Sciences, 2014; 43(12): 102–105. (in Chinese)

[6] Zhao R H, Dong J M, Lu J J, Liu J L, Yang X R, Liu Z B. Investigation on the species composition dominant speciesan dsexratio of scarabs in Xinfu District of Xinzhou City. China Plant Protection, 2014; 34(8): 41–44. (in Chinese)

[7] Frick T B, Tallamy D W. Density and diversity of non-target insects killed by suburban electronic insect traps. Entomologica News, 1996; 102: 77–82.

[8] Zhang G X, Zheng G, Li X J, Bu J. Discussion of using frequency trembler grid lamps from angle of protecting biodiversity. Entomological Knowledge, 2004; 6: 532–535. (in Chinese).

[9] Beggs C J, Wellmann E, Grisebach H. Photocontrol of flavonoid biosynthesis. In: Kendrick RE, Kronenberg G H M (eds). Photomor phogenesis in plants, Martinus Nijhoff Publishers, Dordrecht Boston Lancaster, 1986; pp.467–499.

[10] Land M F, Nilsson D E. Animaleyes. Oxford University Press, Oxford, 2002; 271p.

[11] Gao W Z. The relation between transitional speed and the time of light adaptation of noctuid copound eyes. Acta Entomologica Sinica, 1989; 32(3): 306–310.

[12] Shimoda M, Honda K I. Insect reactions to light and its applications to pest management. Applied Entomology and Zoology, 2013; 48(4): 413–421.

[13] Jiang Y L, Zhang J Z, Yuan S X, Li T, Gong Z J, Miao J, et al. Progress in research and application of yellow light for pest control at home and abroad. Plant Protection, 2018; 44(3): 6–10.

[14] Jiang Y L, Guo P, Li T, Li G P, Wang X Q, Wu Y Q. Effects of yellow and green light on the reproduction and adult longevity of fall armyworm *Spodoptera frugiperda* (Lepidoptera: Noctuidae). Journal of Plant Protection, 2020; 47(4): 902–903.

[15] Longcore T, Rich C. Ecological light pollution. Frontiers in Ecology and the Environment, 2004; 2: 191–198.

[16] Rich C, Longcore T. Ecological consequences of artificial night lighting: OAI, 2006.

[17] Liu Q H, Wu Y Q, Zhao M F. Photo-induced visual response of western flower thrips attracted and repulsed by their phobotaxis spectrum light. Int J Agric & Biol Eng, 2022; 15(2): 48–57.

[18] Liu Q H, Zhao M Q, Miao J, Fu G C, Wu Y Q. Influences of yellow and green lights on the visual response of western flower thrips and field verification. Int J Agric & Biol Eng, 2022; 15(4): 49–56.

[19] Liu Q H, Jiang Y L, Miao J, Gong Z J, Li T, Duan Y, et al. Photoreceptive reaction spectrum effect and phototactic activity intensity of locusts' visual display characteristics stimulated by spectral light. Int J Agric & Biol Eng, 2021; 14(2): 19–25.

[20] Yabu T. Control of insect pests by using illuminator of ultra high luminance light emitting diode (LED). Effect of the illumination on the flight and mating behavior of *Helicoverpa armigera*. Plant Protection Science, 1999; 53: 209–211. (in Japanese)

[21] Yase J, Nagaoka O, Futai K, Izumida T, Kosaka S. Control of cabbage webworm, *Hellula undalis* Fabricius (Lepidoptera: Pyralidae) using yellow fluorescent lamps. Applied Entomology and Zoology, 2004; 46: 29–37.

[22] Yamada M. Insect control lighting for reduced and insecticide-free agriculture. Matsushita Denko Giho, 2006; 54(1): 30–35. (in Japanese with English summary)

[23] Hirama J, Seki K, Hosodani N, Matsui Y. Development of a physical control device for insect pests using a yellow LED light source: results of behavioral observations of the Noctuidae family. Shokubutsu Kojo Gakkaishi, 2007; 19: 34–40.

[24] Duan Y, Wu Y Q, Jiang Y L, Wu R H, Zhao M Q. Effects of LED (light

emitting diode) illuminationon light adaptation and mating of Helicover paarmigera. Acta Ecologica Sinica, 2009; 29(9): 4727-4731.

[25] Yoon J B, Nomura M, Ishikura S. Analysis of the flight activity of the cotton bollworm *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae) under yellow LED lighting. Applied Entomology and Zoology, 2012; 56: 103–110.

[26] Firebaugh A, Haynes K J. Experimental tests of light-pollution impacts on nocturnal insect courtship and dispersal. Oecologia, 2016; 182: 1203–1211.

[27] Jiang Y L, Wu Y Q, Li T, Miao J, Gong Z J, Duan Y, et al.. Light and dark adaptation of adult compound eyes of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) and their transformation rate to light-adapted state under yellow light. *Acta* Entomologica Sinica, 2021; 64(9): 1120–1126.

[28] Webster R P, Conner W E. Effects of temperature, photoperiod, and light intensity on the calling rhythm in Arctiid moths. Entomologia Experimentalis et Applicata, 1986; 40(3): 239–245.

[29] Raina A K, Davis J C, Stadelbacher E A. Sex-pheromone production and calling in *Helicoverpa zea* (Lepidoptera, Noctuidae): effect of temperature and light. Eenvironmental Entomology, 1991; 20(5): 1451–1456.

[30] Kawazu K, Adati T, Tatsuki S. The effect of photoregime on the calling behavior of the rice leaf folder moth, *Cnaphalocrocis medinalis* (Lepidoptera: Crambidae). Japan Agricultural Research Quarterly: JARQ, 2011; 45(2): 197–202.

[31] Yan S, Li H T, Zhu W L, Zhu J L, Zhang Q W, Liu X X. Effects of light intensity on the sexual behavior of the cotton bollworm, Helicoverpa armigera (Lepidoptera: Noctuidae). Acta Entomologica Sinica, 2014; 57(9): 1045–1050.

[32] Jiang Y L, Guo P, Hao C Q, Li T, Miao J, Gong Z J, et al. Interference effect study on reproductive behavior and adult longevity of *Spodoptera exigua* (Lepidoptera: Noctuidae) on different yellow light intensity. Journal of Environmental Entomology, 2020; 42(5): 1225–1229.