EFFECT OF VISIBLE LIGHT ON THE BEHAVIOR OF STORED-PRODUCT INSECTS

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ABSTRACT: Insects that infest stored products respond like many other species to visible light wavelengths ranging from 350 to 770 mm. Responses other than phototactic responses are reflected in many types of rhythmic behavior. In *Anagasta kuehniella, Cadra cautella,* and *Plodia interpunctella* visible light influences the development and emergence of adults, the reproductive behavior, and the development of reproductive organs. Adult emergence can be entrained to specific times of the day, and light-dark cycle can be used to regulate oviposition, mating, and the "calling" and the release of pheromone by the females. Also, light, mediated probably through the neuroendocrine system, influences spermatogenesis in male *P. interpunctella* and *A. kuehniella.* The many responses of insects to light provide opportunities for investigation of the physiological mechanisms that can be exploited to alter or manipulate behavior of stored-product insects. Such an investigation would supplement existing physiological, chemical, or biological data and could pinpoint ways to develop or improve control methods.

INTRODUCTION: Studies concerning how light affects insect behavior and development fall mainly into 2 categories. The first includes determinations of physiological mechanisms involved with light perception, and the second, the reactions or behavior of the insects to light. In the latter case, the responses of the insects may be immediate as when insects are attracted or repelled by light, or the response may be delayed and reflected in some form of behavior or development after the light stimulus is removed. Examples of these responses and influences of light on insect development and behavior are numerous and well documented in the literature. Time will not allow an extensive review of this subject; and as we are concerned primarily with stored-product insects, I will limit my remarks to a few specific examples of the effects of light on the behavior or development of some stored-product insects. These include the effects of: (1) light visible to the human eye (390-770 mm), (2) light used alone and not in combination with other factors such as temperature, humidity, or diet, and (3) light when it is continuous or alternated with dark periods.

RESPONSE TO MONOCHROMATIC LIGHT: Insects infesting stored products do not differ radically from other insects in their spectral responses, and for many species of insects spectral responses are generally similar. For example the spectral responses of species studied by electrophysiological methods and in light tests show that all are sensitive to wavelengths ranging from 340 to 650 mm [1,2,3,4] (Table 1). Moreover, the responses of the moths *Plodia interpunctella*, *Tineola bisselliella*, and *Sitotroga cerealella*, to wavelengths ranging from 350 to 550 mm support the observations made of other lepidopteran species [5,6].

TABLE 1. Spectral responses of some stored-product insects.

Species	Stage of insect	Region of spectrum with maximum response (nm)
Lepidoptera:		
Plodia interpunctella	Adult	340-365 [1][a/]
Sitotroga cerealella	Adult	475-550 [4]
Tineola bisselliella	Adult	500-550 [4]
Coleoptera:		
Sitophilus oryzae	Adult	365-550 [1]
Lasioderma serricorne	Adult	525-575 [4]
Tribolium confusum	Adult	520-540 [4]
Trogoderma granarium	Larva	600-650 [3]
Tenebrio molitor	Adult	520-540 [2]

[a/] Reference

Spectral responses of insects have previously been exploited in the numerous light traps, repellent lights, and electrified grids that have been designed to either capture, repel, or kill insects. However, pest control by such methods has been limited because the methods are generally selective for flying adults, in the physiological state that leads them to the traps or grids.

BEHAVIOR AND PHYSIOLOGICAL EFFECTS INFLUENCE BY GENERAL ILLUMINATION: The most extensively studied effects of light on insects probably have to do with photoperiodism and insect development [5,7,8], but, only a few stored-product insects have been included. For example, the effects of photoperiodism on diapause have been described for *Plodia interpunctella* and *Ephestia elutella* [9,10], and for *Anthrenus verbasci*, and *Attagenus megatoma* [11,12]. Light (critical day length) is the most important of the various factors shown to affect diapause but, it is not the only factor, and in many cases the effect of light interacts with the effects of moisture, diet, and temperature. However, few stored-product pests undergo diapause.

The effect of light on development and behavior is another matter. Adult moths, particularly, are influenced by manipulating light and dark conditions, and the effect of light on periodic behavior or rhythmic activities of *Anagasta kuehniella* [13,14] and *Cadra cautella* [15] has been studied extensively. As a result, we know that patterns of adult emergence can be induced by light and dark periods and that the times of emergence can be accurately predicted. *Plodia interpunctella*, another of the stored-product moths, shows similar rhythmic behavior, in short, adult emergence follows one of two patterns. With alternating light and dark, the moths emerge in approximately 24-hr cycles and in continuous light or dark, moths emerge in a random asynchronous pattern (Figure 1) (Lum, unpublished information). In the latter case, moths will emerge as they develop; thus emergence of a population will be continuous. However, in alternating light and dark, emergence is forced into a pattern in which moths emerge only during a few hours of a 24-hr cycle. Indeed with 12-hr light and 12-hr dark, emergence is confined for the most part to the latter half of the light period and very few adults emerging in the dark period.

Underlying physiological mechanisms (still to be understood) are responsible for the circadian rhythms that control the time of moth emergence. Furthermore, the onset of the first emergence is determined by the time of change from light to dark. For example, in pupae that were reared in continuous light, a single dark period of 10 hr initiated the first emergence approximately 24 hr after the light to dark change (Figure 2).

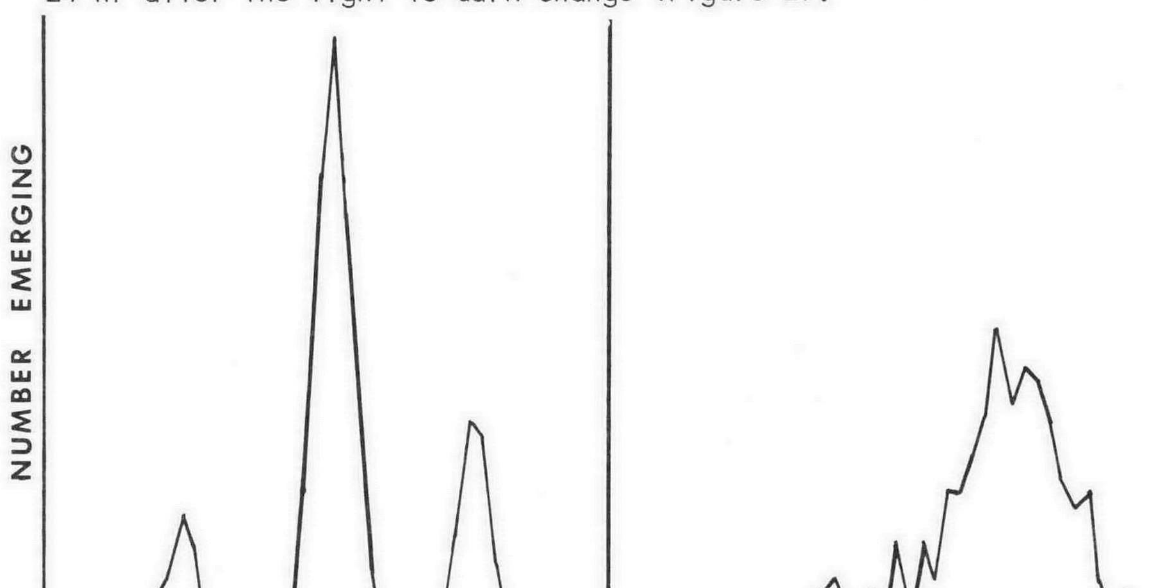

FIGURE 1. Emergence patterns of *Plodia interpunctella*.

Another behavior that is influenced by light was examined in studies of *Anagasta kuehniella* [16], the "calling behavior" of females before mating. With 12-hr light-dark cycles, females showed a peak period of calling at the beginning of each light period, and when females from such cycles were transferred to continuous dark,

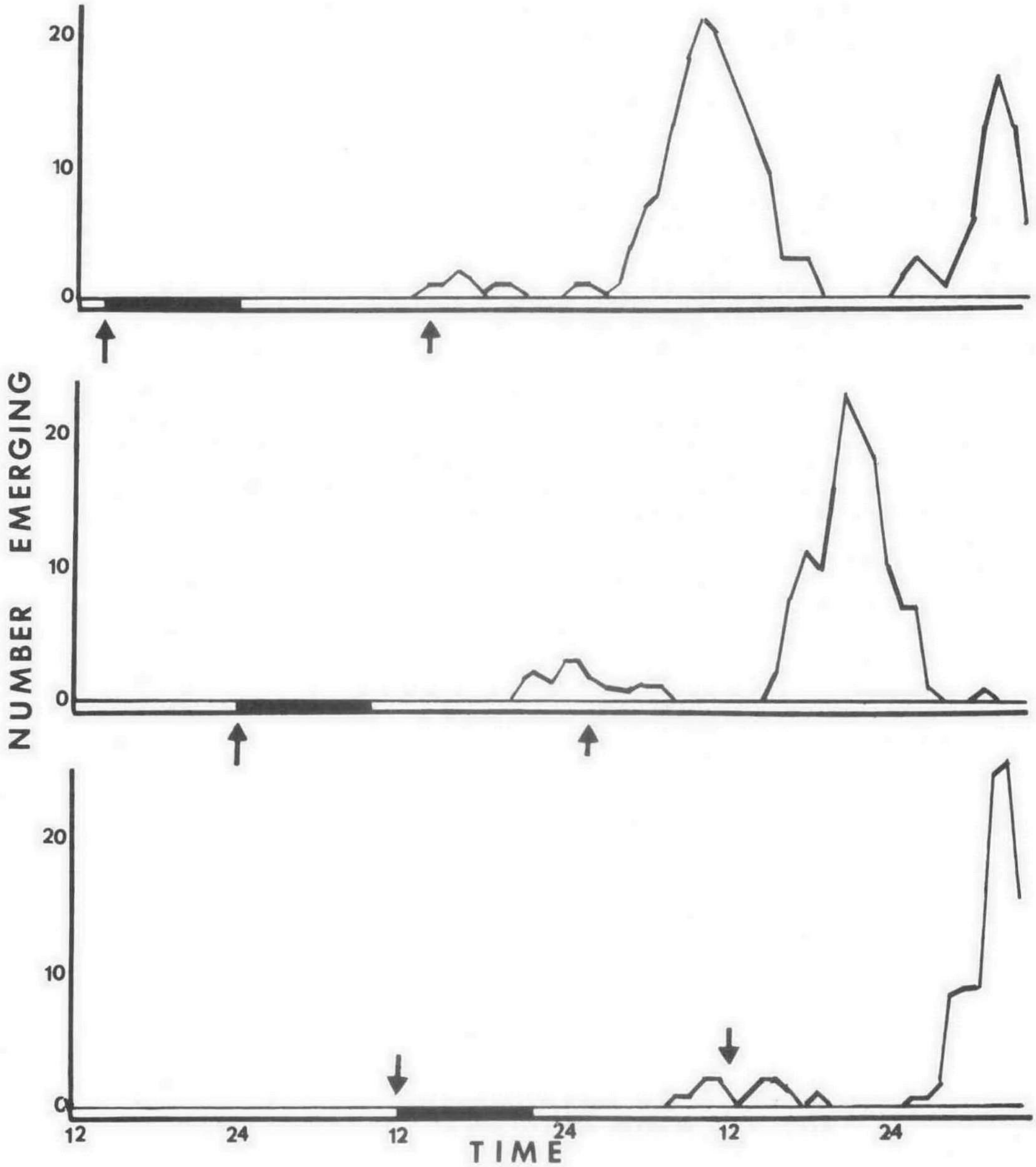

FIGURE 2. Synchronization of emergence in *Plodia interpunctella* by single dark period. Arrows indicate emergence approximately 24 hr after onset of dark period.

calling continued to follow that pattern. Thus calling is entrained by light-dark cycles; but when the timing of the cycle was shifted by 12 hr, females were able to readjust to the change within the second or third occurrence (Figure 3). The male moths show identical responses to light and dark periods in regard to the sex pheromone. Light, therefore, influences the behavior of both sexes of *Anagasta kuehniella*.

In *Cadra cautella* oviposition is strongly influenced by environmental lighting [15]. When these moths are subjected to light-dark cycles, marked bimodal diurnal rhythms are seen at dusk and dawn (Figure 4), and most oviposition occurs at dusk. When

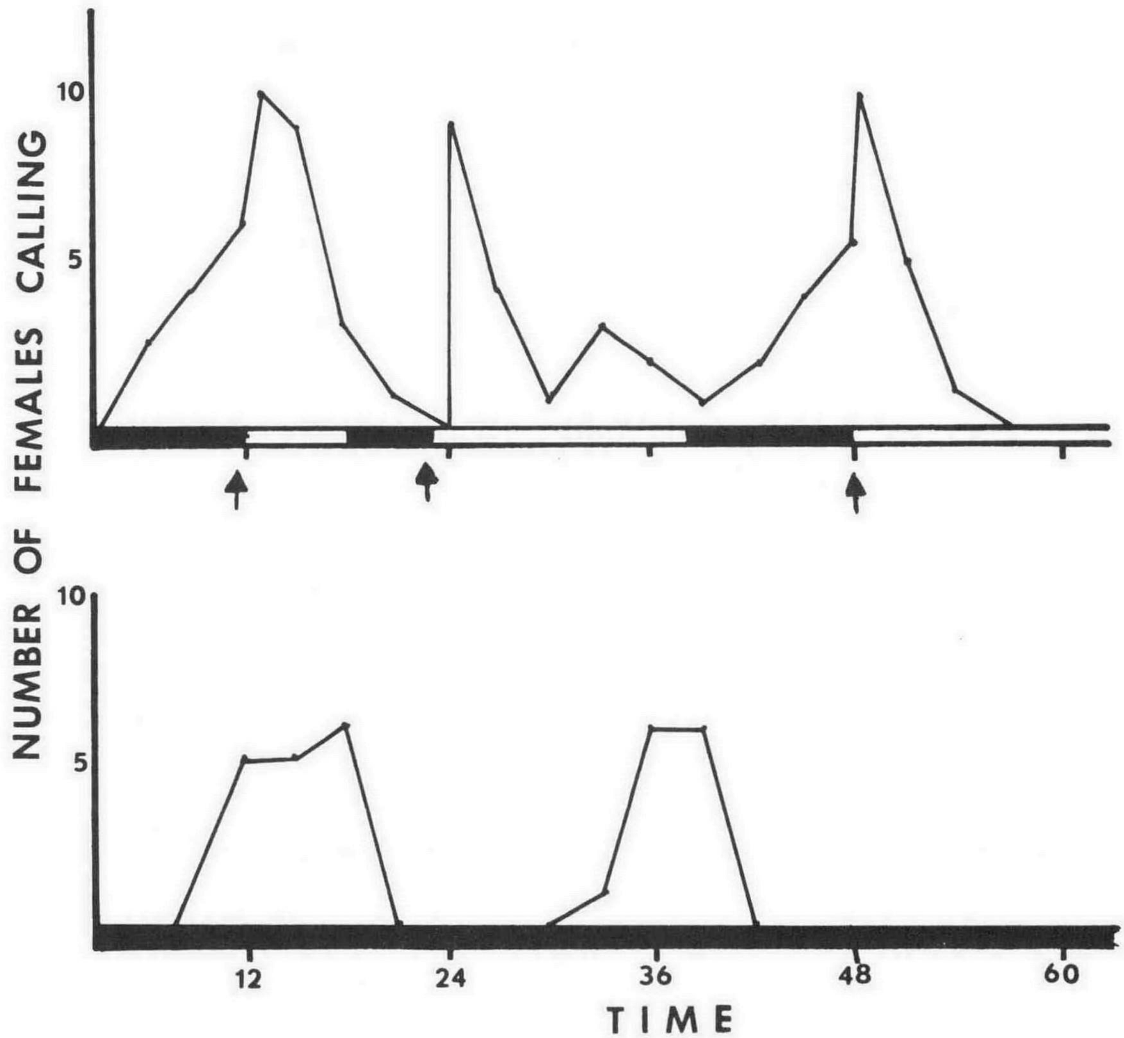

FIGURE 3. Influence of light on calling in *Anagasta kuehniella* (from Traynier, [16]).

light intensity is decreased to the point that there is not sufficient contrast between light and dark, the rhythms of oviposition disappear. However, increased intensity has an inhibitory effect on oviposition when moths have been held in continuous dark or light (Figure 5).

The reproductive response of *Plodia interpunctella* [17,18] to light is similar to that of *Cadra cautella*, that is, it is strongly influenced or affected by visible light or the combination of light and dark cycles. In addition, recent studies have shown that visible light influences the reproductive development of male moths [19]. Male *P. interpunctella* reared in continuous light did not develop sufficient eupyrene sperm during the first 48 hr of adult life. Also *A. kuehniella* reared in light-dark cycles, show a daily cycle of sperm release from the testes but there is no apparent cycle in moths kept in continuous light, and

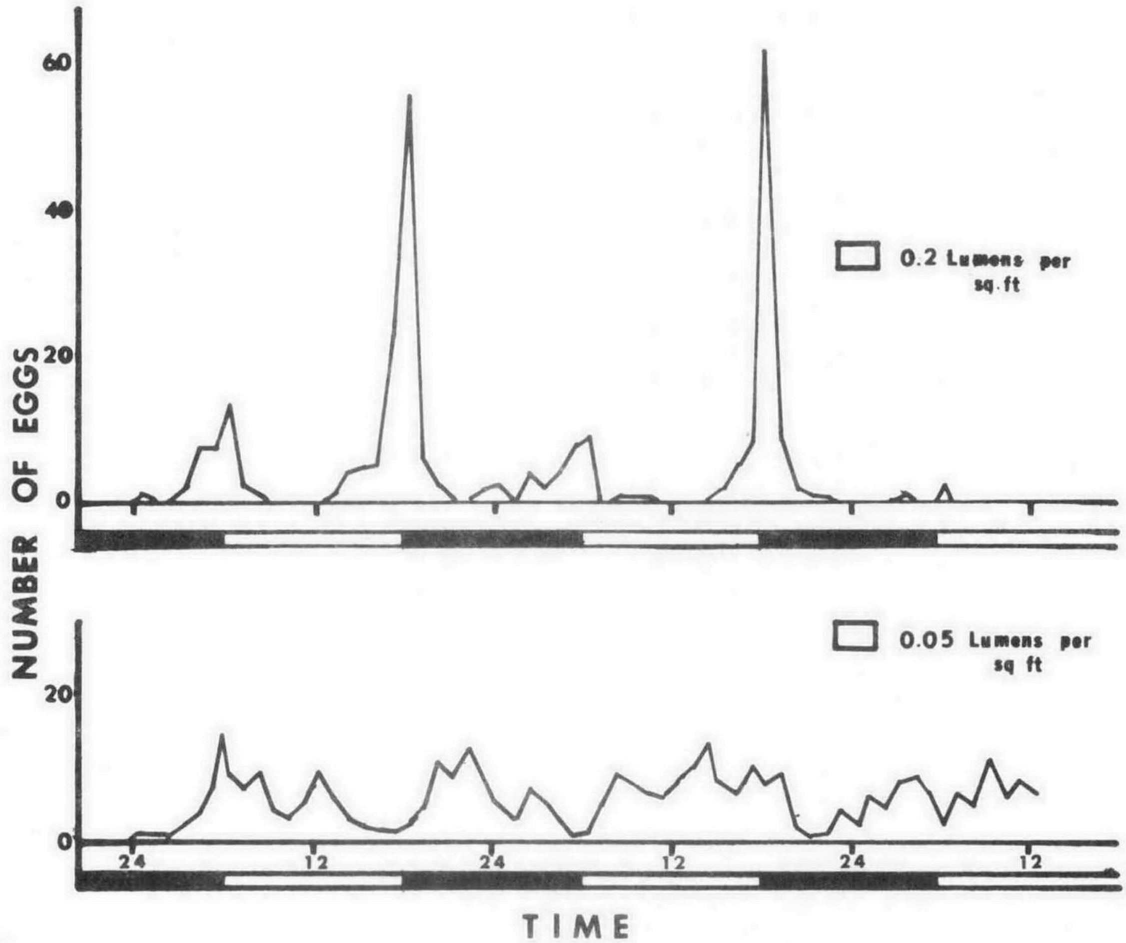

FIGURE 4. Mean hourly oviposition of *Cadra cautella* (from Steele, [15]).

the quantity of sperm is lower [20]. Thus although no direct proof is presently available, light probably interacts with the endocrine system responsible for the development of the testes.

Finally, the effect of light on the normal physiological processes in the male moth indirectly influence the reproductive behavior of the females. For example, females mated with males that are deficient in sperm will lack the necessary stimuli for oviposition. Instead, they continue calling or mating until they do obtain sufficient sperm. Also, the levels of pheromone in the female are greatly influenced by insemination during mating [21]. Although no direct effects of light on the reproductive system of the female have been reported, light could be used to supplement present methods of sterilizing insects.

CONCLUSION: The foregoing are only a few selected examples to illustrate how visible light affects the behavior and development of some stored-product insects. What should be stressed here is not that one can observe and record various behavioral responses of insects to visible light but that there are physiological responses

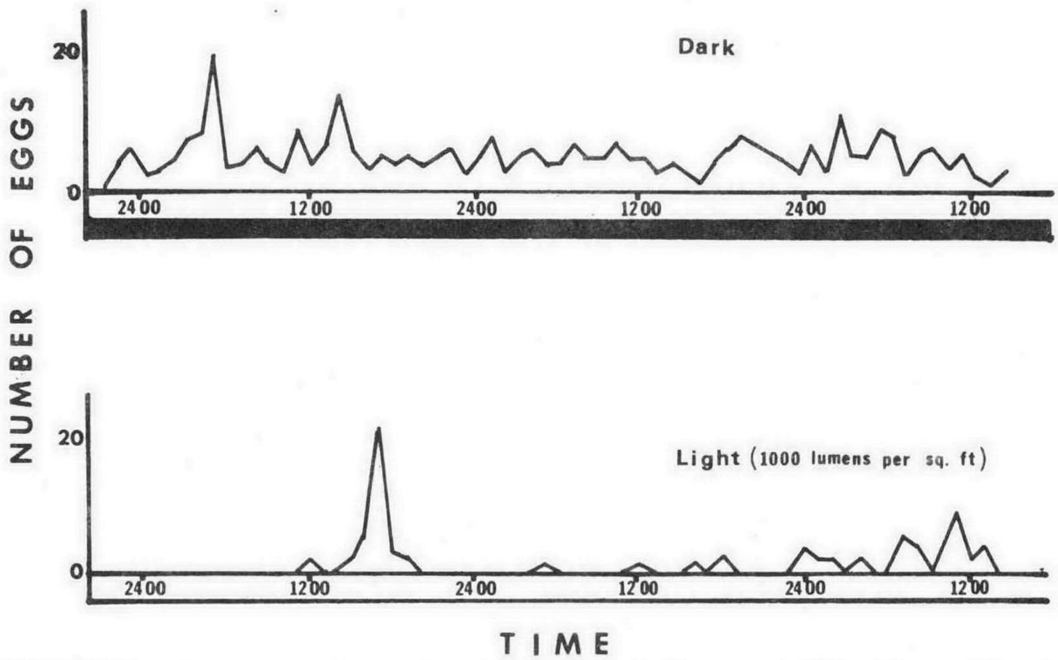

FIGURE 5. Mean hourly oviposition of *Cadra cautella* (from Steele, [15]).

or mechanisms that are easily controlled or influenced by light and by light-dark cycles. We can now use visible light to understand and alter insect behavior but we need to discover the physiological mechanisms that are affected by light (and by other environmental factors). Then we can integrate this information with other chemical or biological data to develop methods of altering or controlling insect behavior so as to render pest insects amenable to practical or acceptable control methods.

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