Effects of Temperature and Photoperiod on Male Activity in *Laspeyresia pomonella* (L.) in New York

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宋裕漢 · H. 리델 : 온도와 광주기 조건이 코드링나방 수컷의 활동력에 미치는 영향

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ABSTRACT The male activity in *Laspeyresia pomonella* (L.) measured by an activity recording device in New York had two distinct peaks, the first peak at lights-off and the second one at ligts-on signal, under the defined conditions of temperature above 23°C and light:dark (LD) 16 : 8 regime. The activity initiation of the first activity was observed four to six hours prior to the onset of scotophase and seened to be entraind by lights-off cue. Under the continuous photophase (LL) the activity period freeran with a period slightly greater than 24 hours, indicating that the rhythmicity is circadian.

The activity pattern was measured in eight different temperature conditions ranging from 11.3° to 30°C under LD 16 : 8 regime. No activity was observed at 11.3°C which seems to be temperature threshold for activity. The second peak of activity at lights-on signal disappeared at the temperature below 20°C and the activity in scotophase was also suppressed at the temperature lower than 18°C. At the temperature range from 20° to 30°C, as temperature increased the second peak in the morning became larger and the activty in the scotophase was also increased. Because of the activity increase in the scotophase with rising temperature, the mean time of activity shifted towards the scotophase. The shift of the moth male activity period with the change of ambient temperature appears to be due to the suppression of activity under cool temperature (below 20°C) in scotophase.

INTRODUCTION

In moth, the activity cycles, related to mating, have been accepted to be temporally synchronous, rigidly programmed, and to serve as isolating mechanisms among species utilizing a common chemical communication system [5,6]. The activity have apparently been consideredto be endogenous, relatively invarible, and regulated by photoperiod[5].

Recent findings in an arciid[5], several noctuids[1,11,16], a saturniid[17], and numerovs tortricids[2,8,9,12,13] have revealed that rhythms of calling behavior, or male response, or both, appear to be greatly modified by fluctuations in temperature regimes: lower ambient temperatures cause the mating activity intervals to be shifted to warmer periods of the day or night. Batiste et al.[3] reported that in California during spring and early summer male codling moth, *Laspeyresia pomonella*, were most active prior to sunset, while later in the season the moths were captured in great numbers after sunset. This change was attributed to differences in early evening temperatures. Batiste[2] indicated that termination of catch appeared to be correlated with a decrease in temperature to 16° C. Presumably, this foward phase shift has adaptive significance by enabling these insects to complete their premating communication and subsequent mating before the temperature falls too low for normal activity[1].

Sueveillance of Lepidopterous insect pests in the individual orchard is basic to integrated control program. The sex attractant trap now holds great promise as a paractical means for such surveillance. However, full realization of the potfntial of surveillance for pest control will depend in part on our ability to derive accurate estimates of absolute density from trap catches. This will involve proper interpretation of the influence of interacting boitic and abiotic factors on the mating flight behavior and an increased understanding of moth behavior, especially male activity and pheromone response in relation to photoperiod and temperature, may lead to greater success in conrol programmes, due to a more effective usage of the pheromone and more complete interpretaton of results.

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This paper describes research with the male codling moth, *L. pomonella*, on the effects of photoperiod and temperature on timing and level of activity of the male moth. This research was conducted at the Department of Entomology, Cornell University, Geneva, New York, with the support of the support of the Korean Science Foundation titled "Post Doc. Training in Ecosystem Modelings for Integrated Pest Management."

MATERIALS AND METHODS

The *L. pomonella* laboratory colony originated from material collected in Geneva, New York. All insects were reared on an artificial medium modified from Shorey and Hale[15]. Temperature was maintained at 25°C with 16-hour period at around 2000 lux during the rearing.

For determination of the male moth activity periocities in various laboratory conditions newly emerged male moths were confined in an activity sound recording device. The device consisted of three main components: a) a sound produciog container with a microphone, b) a cassette tape recorder, and c) an electonic timer switch which controlled the recording intervals. One-liter icecream carton (10cm in bottom diameter, 14cm in top diameter, and 16cm in heigth) was used as the container holding tested male moths. Two windows (4×5cm) were made on the both side wall of the container and transparent cellophane was placed on the windows so that the moths in the container could be exposed on the lights. Dental cotton wicks in glass vials, two per container, were kept moist with a 5%-sucrose solution to which 0.05% ascorbic acid was added. The microphone (dynamic, 4 ohms) attached with an aluminum foil cylinder (7cm D, 10cmH) was placed inside of the container through the top lid of the container. The output jack of the microdhone was connected to the cassette tape recorder (Panasonic, model RQ-353), which was controlled the discrete intervals of recording on the tape by on electronic timer switch.

Thirty newly emerged males were caged in the sound recording container. Thə moths were held under expermental conditions for 24 hours prior to recording. The impact sound on the aluminum foil cylinder was recorded on magnetic tape every 10 minutes for 17 seconds. Activity was expressed as the number of impacts per hour per 100 moths.

Light intensity in the container was held around 1500 lux during photophase and relative humidity was not held constant but generally remained at ca. 70% throuhout all experments. Biocimatic chambers with maximum variation of ±1°C were used for the various test temperatures.

RESULTS

The daily male activity rhythm in LD 16 : 8 (Light-Dark cycle; lights-off at 21 : 00) and LL (continuous light) at 24°C over a six successive day-period is graphed in Fig. 1. Under LD 16 : 8

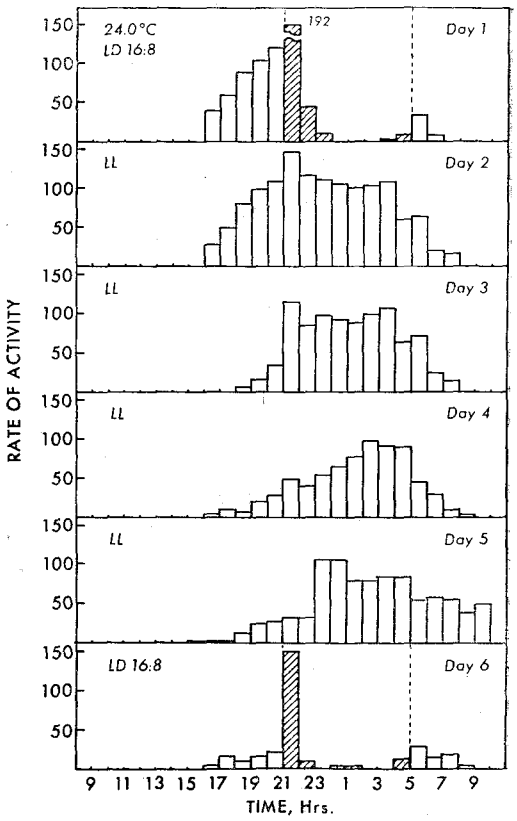

Fig. 1. The male activity rhythm in *Laspeyresia pomonella* (L.) in LD 16 : 8 on the first day, LL on the following four successive days, and LD 16 : 8 on the last day of experiments at 24°C. The time period enclosed by two vertical dotted lines on each experimental day of LD set indicates scotophase and the rates of activity in scotophase are expressed with shaded bars.

condition in the first day of the experiment, activity began mid afternoon around 16 : 00, and a high activity occurred at the onset of scotophase, followed by sudden decrease of activity in next three hours. A small but distinct peak of activity appeared after lights-on indicating a possible bimodality in the activity rhythm under LD. However, when the light-dark cycle was changed to LL on the next four days, only one big peak was shown and the mean time activity was drifted, in other words, the time period between peak activity on successive days is more than 24 hours. On the sixth day, when the condition reverted back to original LD cycle, the rhythm established very quikly to the same pattern as before with activity of light-off and light-on. This experiment in continuous light suggested that the basic activity rhythm is under circadian control. However, in a light-dark regime (LD 16 : 8) as shown in the top of the Fig. 1, two features of the rhythm appeared to be environmentally nduced: the second but smaller peak at lights-on and the increased activity following lights-off.

In 27°C condition, LD 16 : 8 regime was shifted back and forth several hours during a six successive day-period. On the first day of the experiment, the activity pattern was almost the same as prevous experiment at 24°C as shown in Fig. 2. On day 2, the scotophase was delayed by three hours, and activity increased following lights-off and lights-on, however, the initiation of the first peak activty remained the same hour (16 : 00) as previous day. On day 3 the normal activity pattern established itself similar to day 1 witq activity initation four hours prior to onset of scotophase. Advancing the scotophase by four hours on day 4 caused again an overresponse in activity following lights-off and

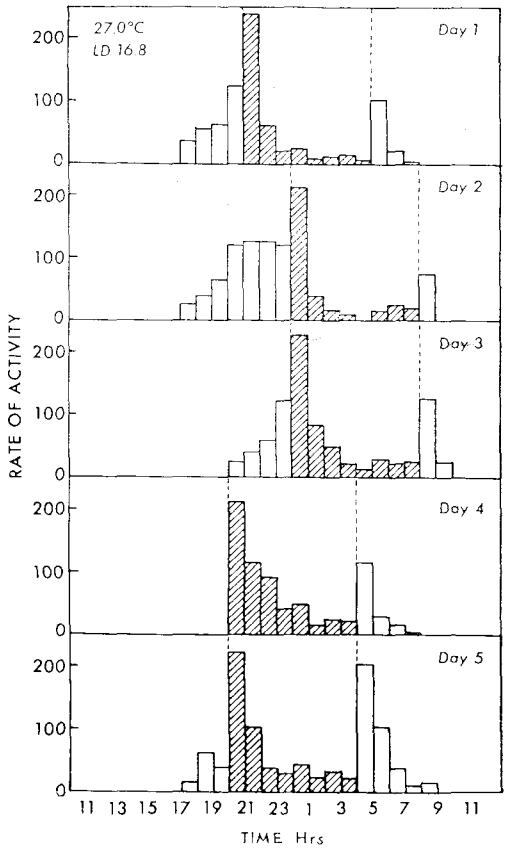

Fig. 2. Effects of shifting scotophase on the activity rhythm in the male moth under LD 16 : 8 regime at 27°C. The scotophase was delayed for three hour on day 2 and advanced for four hours on day 4. Scotophase is enclosed by two vertiacl dotted lines.

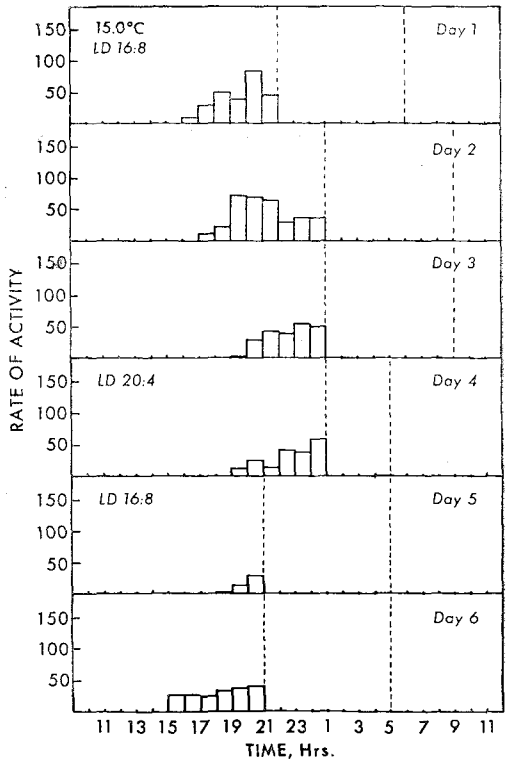

Fig. 3. Effects of shiftingoscotophase on the activity rhythm in the male moth under LD 16 : 8 at 15°C. The scotophase was delayed for three hours on day 2 and advanced for four hours on the 5 again. The two vertical dotted lines denote the scotophase period.

lights-on. The time of the first peak initiation (20: 00 on previous day) merged by abrupt activity at the onset of scotphase. On day 5, the activity rhythm was again in synchrony with the LD cycle. Both the increased activity at the onset of scotophase and photophase in this experiment seemed to be disectly effected by the light-dark and dark-light changes. However, time of activity initiation of the first peak was not immediately adjusted by the shift of scotophase.

In a similar experiment at 15°C, the second peak with the lights-on signal disappeared as shown in Fig. 3. Also in contrast to the high temperature experiment, the scotophase seemed to be suppress activity rather than induced it, and the first peak activity initiated approximatly two hours earlier. It was not clear whether the initiation time of the first activity was due to the to the lights-on or lights-off cue in the high temperature experiment at 27°C (Fig. 2). However, in low temperature (15°C) experiments on day 4, 5, and 6 in Fig. 3, it seems to be clear that the lights-off cue on previous day controls the first activity peak initiation.

These two experiments at 27°C(Fig. 2) and 15°C (Fig. 3) pointed out that the activity rhythm appeared to be temperature sensitive. Therefore, the aim of the following experiments were to determine, in detail, how the activity rhythm is affected by temperature. The activity was measured in eight different temperature conditions ranging from 11.3° to 30°C. The light-dark cycle LD 16 : 8 was the same in all experiments and the results are shown in Fig. 4. The figure shows that there was no activity at 11.3°C which can be the temperature

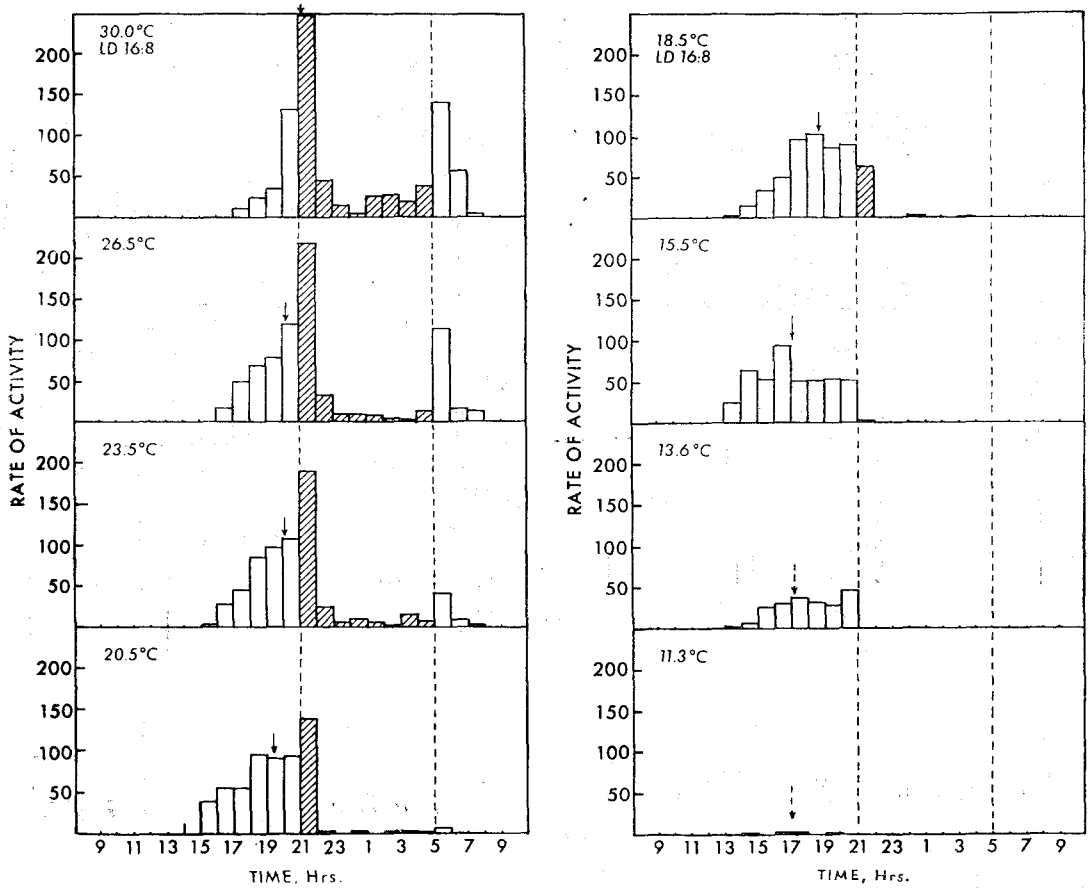

Fig. 4. Effect of ambient temperature on the activity rhythm in the male moth. Arrows represent the mean time of activity and shaded bars denote the rate of activity in scotophase. Between two vertical dotted lines indicates the scotophase perion.

threshold for activity. As temperature increased the activity before the lights-off signal increased and the activity in the scotophase started to appear aroune 18°C. The secone peak after lights-on signal started to appear at 23.5°C. At the range of temperature from 20° to 30°C, as temperature increased the second peak in the morning became larger, the activity in the scotophase increased, and the over responce at the lights-off signal also became larger and larger, Because activity increases in the scotophase with rising temperature, lhe mean time of activity, indicated by small arrows in Fig. 4, also shifted towards the scotophase.

Fig. 5 clearly shows that increasing temperature delays the first activity peak. The relationship between temperature and mean time of the first activity peak appears to be linear and is highly correlated. However, there is no indication that temperature causes a similar shift in the second peak following lights-on. This suggests the second peak is not circadian but environmentally induced.

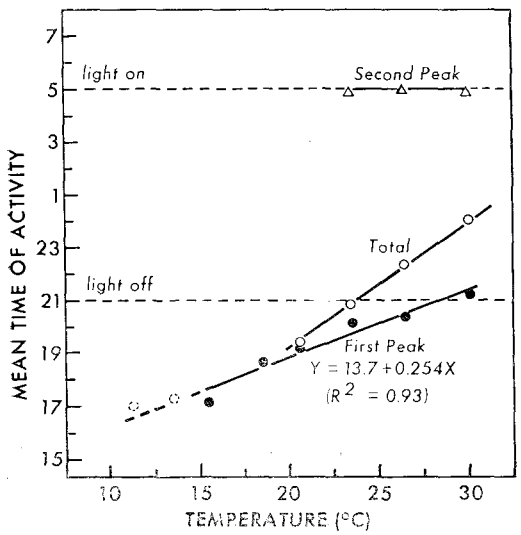

Fig. 5. Effect of ambient temperature on the mean time of the moth activity.

DISCUSSION

One of the most intersting physiological ruythms encountered is that of pheromone release and male flight activity in Lepidoptera[1]. It is generally accepted that female calling and male activity in Lepidoptera show some sort of of rhythmic periocity[5] and the activity rhythms are modified by various environmental factors especially by ambieut temderatu[14].

The work presented here provides the evidence that the male activity in the codling moth is generally under circadian control. In the absense of periodical exogenous stimuli, the activity rhythm runs free with a period greater than 24 hours in LL, however, there were two distinct peaks of activity in LD 16 : 8 regime in relatively warm temperature (above 23°C), one at the lights-off and the other at lights-on signal.

Similar activity rhythms were reported in several field experiments. Borden[4] observed that the moth activity as measured by catches in bait traps were high in the period immediately before or immediately after sunset and were bimodal when nights were very warm. Riedl (Unpubl.) also found the second peak of male catches on a timing pheromone trap in the early morning when the temperature was above 20°C. Batiste[2] used a timing sex-pheromone trap for thə moth and concluded that the flights of the male moth were initiated well before sunset and peak occurred around the sunset. Parrott and Collins[10] also observed two periods of normal male flight occurring during the morning and evening twilight. The results obtained in this study were corresponded well to these previous observations.

The two abrupt peaks after lights-off and lights-on signal in this laboratory experiment may be due to sudden LD or DL transition. However, they were also temperature sensitive and this phenomenone disappeared when temperature was cool down to 20°C. This result appear to indicate that the expression of circadian rhythm as the rate of activity may depend on environmental conditions such as ambient temperature. Cool temperature (below 20°C) suppress the expression of both the first activity in the scotophase and the second peak at the lights-on signal.

Our experiments also indicated that the initiation time of the first activity was slightly shifted toward the scotophase with rising temperature. The initation time seems to be controlled by lights-off cue rather than lights-on cue. However, as shown in

Fig. 4, the mean time activity of the first peak was shifted mainly because of the suppression of activity in scotophase at cool temperature. Cool temperature condition cut off the activity tail in scotophase and this causes the mean time activity shift toward day time. Castrovillo and Carde[7] also observed similar activity suppression of the male moths in scotophase at 16°C in their laboratory experiments.

Three different mechanisms have been suggested for shifting moth activity by temperature: 1) the shift determined by the temperature exposed in pupal stage (ex. *Antheraea pernyi*, 17), 2) by direct adjusting effect for maximizing copulation (ex. *Holomelina immaculata*, 5, 6), and 3) by temporary shifting in responce to temperature (ex. *Trichoplusia ni* and *Pseudoplusia includens*, 1). In this study, it is evident that the male modifies its activity periodicity in responece to daily temperature rather than possessing a fixed internal program during adult development. which is the first model as reported by Truman(1973), and the shift is not temporary adjustment, the third model, but persists as long as temperature condition is not changed. Our results partially fit the second model, the shift by direct adjustment to ambient temperature, however, the adjustment was expressed by suppression of activity in cool temperature in scotophase.

Our data can also be useful for understanding the relationship between the rate of actidity of the moth and ambient temperature. The detailed study of the relationship would provide appropriate models for estimating field population density from pheromone trap catch data.

摘 要

광주기 16 : 8(명기 : 암기) 온도 23°C 이상 30°C 이하의 실험실 조건에서 코드링나방(*Laspeyresia pomonella*) 수컷의 활동리듬을 활동력 측정장치로 조사한 바, 소등시에 한번(제 1 활동기)과 점등시에 한번(제 2 활동기)의 두번의 활동최성기를 나타내었다. 제 1 활동기는 소등 5~6시간 전에 시작되었으며 소등신호에 의해 활동시작시간이 결정되는 것으로 나타났다. 또한 계속조명조건에서는 활동주기가 24시간보다 약간 길어지는 경향이었으며 이는 곤충의 일주활동성의 특징에 부합되는 것으로 나타났다.

광주기 16 : 8 하에서 11.3°C부터 30°C까지 8단계의 온도조건을 두어 숫나방의 활동리듬을 조사한 결과 11.3°C에서는 전혀 활동하지 못하였다. 또한 20°C 이하의 온도에서는 제 2 활동기가 나타나지 않았으며 18°C 이하에서는 제 1 활동기 중 암기에서의 활동이 완전히 억제되었다. 온도범위 20°C~30°C 하에서는 온도가 상승함에 따라 제 2 활동기와 제 1 활동기 중 암기에서의 활동성이 증대되었다. 이러한 온도상승에 따른 제 1 활동기의 암기에서의 활동력 증대로 인하여 활동 평균시간이 암기쪽으로 이동하였다.

코드링나방의 온도에 따른 평균 활동시간의 변동은 상기한 저온에서의 암기에 활동력 감퇴에 의해 나타나는 것으로 추정된다.

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