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Original Article

Inhibition and Termination of Larval Diapause and Low-Temperature Tolerance in the Cigarette Beetle, *Lasioderma serricorne* (Coleoptera : Anobiidae)

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Abstract

Diapause larvae of the cigarette beetle, *Lasioderma serricorne* (F.) reared under a short-day (LD 12 : 12) at 25℃, were exposed to a long-day (LD 16 : 8) at the same temperature, 51 and 71 days after hatching, for the rest of their life. Since under LD 16 : 8 at this temperature they started pupating around 50 days after hatching and none started pupating when they were reared continuously under LD 12 : 12 at this temperature, it was comsidied that these larvae in diapause responded to the photoperiodic shift and started emerging 8 days following the shift. When diapause larvae were exposed to more than 6 cycles of LD 16 : 8, 20 days after the entry to the third larval instar, the shifts accelerated pupation significantly. Six days were sufficient to change the program for developmental determination. After the program was altered, 2 more days were required to pupate and 8 more days for adult development. Under LD 16 : 8, a small fraction of larvae developed at a slower rate than the majority but at a faster rate than diapause larvae reared under LD 12 : 12. The development of this fraction was also accelerated by the photoperiodic shift. This species thus responds not only to a constant photoperiod but also to a shift of photoperiod from LD 12 : 12 to LD 16 : 8. If the photoperiodic shift was made later, the effect was much smaller, indicating that the intensity of diapause increased, or otherwise, the sensitivity to photoperiodic shift decreased while diapausing. Photoperiodic shifts from LD 16 : 8 to LD 12 : 12, made at different times before and after the third larval ecdysis, demonstrated that photoperiodic sensitivity remained till the entry of the fourth instar, since more than 50% of larvae entered diapause when the shift was placed before the fourth instar. Upon the entry to the fourth instar, they lose the sensitivity to photoperiod or the ability to enter diapause. The tolerance of this species to 5℃ was weak except at the diapause stage, since the exposure of 10 days to this temperature killed all eggs, 30 days exposure killed all second instar larvae and 97.4% of the third instar. In contrast, the fourth instar larvae survived this treatment. While no pupae survived this temperature, 65% adults survived this low temperature. Although 10℃ was much milder than 5℃, the treatment of this temperature for 75 days killed about a third of the total number of non-diapause 4th instar larvae exposed. Low temperature was harmful but effective in synchronizing post-diapause emergence, since the emergence under LD 12 : 12 at 25℃ after chilling of two months at 5℃ was as fast as after the transfer to LD 16 : 8, 25℃. High humidity and the presence of cocoon helped survival at low temperature.

Key words : *Lasioderma serricorne*, Cigarette beetle, Diapause termination, Stored product pest, Photoperiodism

Introduction

Urban environment such as granaries, warehouse and household is a new habitat for some insects. Such environment can be characterized to be resource-rich, warmer and prone to disturbances to compare with natural environment (Howe, 1957 ; Tsuji, 1963 ; Naeemullah and Takeda, 1998 ; Naeemullah *et al.*, 1999, 2003). The insects colonize this kind of habitat by changing their life cycle properties to adapt and cope with such characteristics. We have demonstrated that *Lasioderma serricorne* (F.), a representative of such pests, enters diapause at full-grown larval stage under short-day conditions at intermediate temperatures

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(Higashi *et al.*, 2004). Once larvae entered diapause, they gradually resume their development if they are kept in the same conditions as they were reared till diapause stage. The time of diapause termination determines the time of reproduction in spring and therefore it has a serious consequence in the subsequent population growth. This investigation focuses on the mechanism that terminates and inhibits diapause as a fine-tuning mechanism of the life cycle. Effect of photoperiodic shift made at various stages of larval development was investigated to know the number of long-day cycles required to inverse diapause determination, and the persistence of sensitivity to photoperiod. The cold tolerance, the effects of humidity and presence of cocoon on survival, and the effect of low temperature on diapause termination were also examined, since these factors determine the survival rate of diapausing insects in the field was controlled environmental condition. The present investigation in the constant laboratory condition that could probe the insect life cycle in a controller enviromental condition.

Materials and Methods

1) Effect of shifts in photoperiod on larval diapause

The experimental animals were provided from our laboratory stock designated as the S stock, as described before (Higashi *et al.*, 2003). General characteristics in temperature and photoperiodic responses of this stock have been described in Higashi *et al.* (2003). Forty individuals were used for each experiment at 25℃. In the following experiments, they were reared individually in the glass vial. The first experiment employed a shift of photoperiod from LD 12 : 12 to LD 16 : 8, 51, 72 and 103 days after oviposition and adult emergence patterns were observed thereafter to investigate the effect of long-day to reverse diapause program, as shown in Higashi *et al.* (2003) that this stock enters diapause by the 50-th day of larval development at 25℃. Normally more than 80% of individuals pupate within 50 days under LD 16 : 8 at 25℃. The minimal days to induce pupation was investigated by observing days of pupation after the photoperiodic shift from LD 12 : 12 to LD 16 : 8.

Then the sensitive period to photoperiodic shift was investigated in the second experiment by transferring larvae from LD 16 : 9 to LD 12 : 12. Photoperiod was shifted before and after the third molt ; namely 1^{st}, 3^{rd}, 4^{th}, 5^{th}, 6^{th}, and 7^{th} days of third instar and 0 , 1^{st}, 2^{nd}, 3^{rd}, 4^{th} and 5^{th} days of 4^{th} instar.

In the third experiment, the effects of long-day exposures of 2, 4 and 6 days were investigated on the termination of diapause. The transfer was made 20 days after the third larval molt. Diapause rate was determined as percentage of larvae remaining as 4^{th} instar larvae when all long-day reared individuals completed larval development.

In the fourth experiment, different developmental stages of *L. serricorne* were exposed to 5℃ for cold tolerance. Eggs were cooled (5℃) for 1, 10 or 30 days. One day old larvae were transferred to sample tube individually and reared at 25℃ under LD 16 : 8 until the third day of the second instar. They were exposed for 30 day to 5℃. Likewise, 3 days old larvae of the third instar were exposed to 5℃ for 30 days. Larvae that were reared in mass at 25℃ under LD 16 : 8 were individually transferred to a new vial and they were transferred to 20℃ under LD 16 : 8. When they span cocoon, they were transferred to 18℃ and then 5℃ and kept there for 30 days. Fourth instar larvae prepared in the same way were transferred to 25℃ when they pupated and then to 5℃ where they were kept for 30 days. Fourth instar larvae prepared in the same way were transferred to 20℃ upon eclosion from the cocoon and then to 5℃ and kept there for 30 days. Temperature was gradually lowered by 5℃ for two days at each step. Between 20 and 15℃, an acclimation step of 18℃ was employed for one day. The temperature step up took the reverse course to the step down.

In the fifth experiment, several conditions were applied, either cocoon was removed or kept intact and minimum temperature or the duration was varied. The presence or absence of humidification is the other variable. For high humidity condition, saturated NaCl solution was used. Low humidity condition was not humidified heated laboratory condition during winter months. The exposure of diapause larvae to 5 or 10℃ for designated periods began 91 days after the egg-laying until larvae were reared under LD 12 ; 12 at 25℃.

Results

Figures. 1 and **2** show the pattern of pupation after the exposure to LD 16 : 8 in larvae reared under LD12 : 12. Pupation started to occur 8 days after the exposure made 51 days after egg-laying. The long-day exposure at later stage, 72 days after egg-laying, was

equally effective to induce pupation but ca. 20% of the individuals stayed in diapause. The rise of pupation occurred more slowly than after the shift made on day 51 (**Fig 1**, closed circles). Under LD 16 : 8, a small fraction of larvae developed at a slower rate than the majority but at a faster rate than diapause larvae kept under LD 12 : 12. The development of this fraction was also accelerated by the photoperiodic shift. The result indicates that species responds not only to a constant photoperiod but also to a shift of photoperiod. When the shift was made later (**Fig 1**, triangles), the effect was much less, indicating that diapause was intensified or that the photoperiodic sensitivity was reduced. **Figure 2** shows that the transfer to LD 16 : 8 induced pupation a week or two after the transfer, that is followed by pupal eclosion 5-6 days later, while they stayed in diapause under LD 12 : 12.

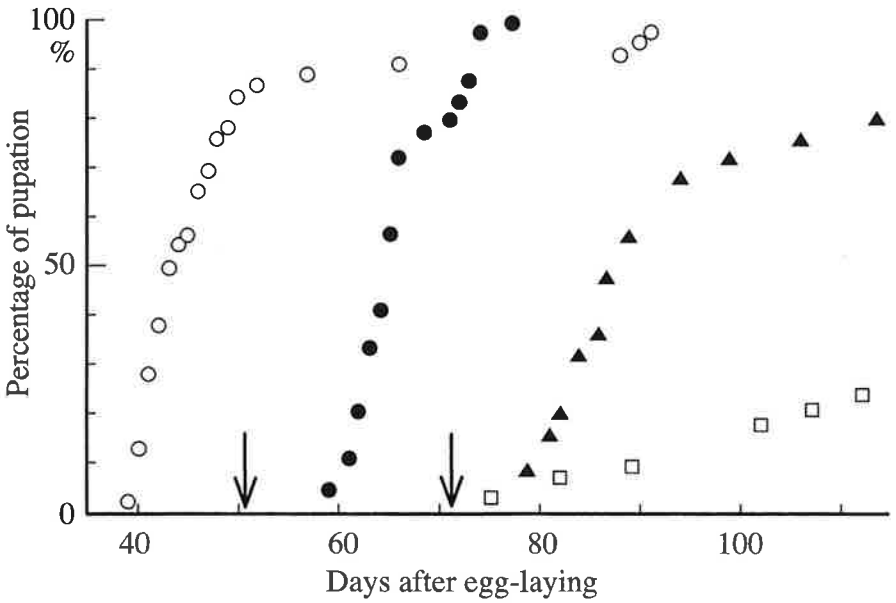

Fig. 1 Cumulative percentage of the number of pupation after transfer from LD12 : 12 to LD16 : 8. Open circles show pupation under LD16 : 8 constant; open squares under LD12 : 12 constant; closed circles transferred on the 51st day (arrow); closed triangles transferred on 72nd day (arrow).

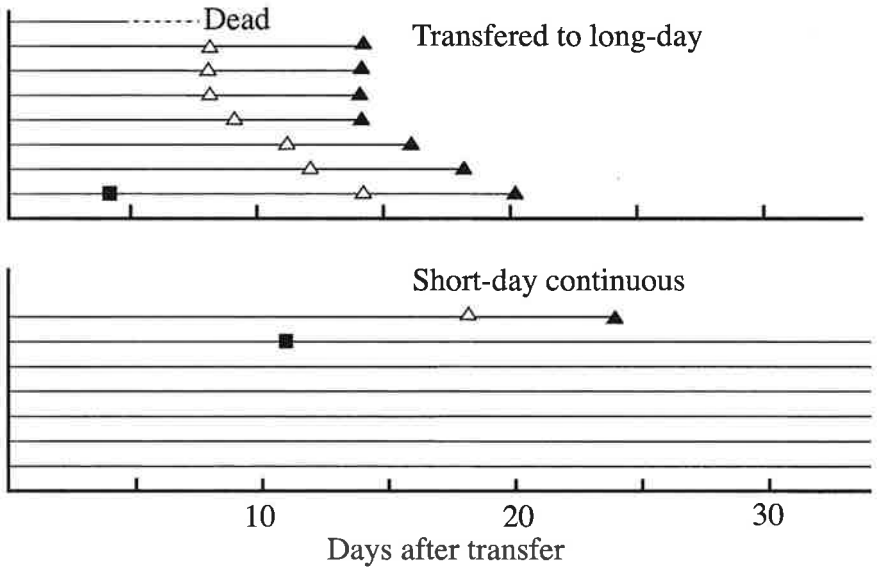

Fig. 2 Timing of metamorphic events occurring in individuals transferred to LD 12 : 12 or 16 : 8 103rd day after egg-laying. Closed spuares show larval molting, open triangles pupation and closed triangles pupal eclosion.

Figure 3 shows a surtch in developmental fate by the transfer from LD 16 : 8 to LD12 : 12 at different times after the third larval molt. The result showed that the transfer to LD 12 : 12 was effective to induce diapause until 1-3 days before the molt but the transfer thereafter could not keep them from pupating. Diapause program was more solidly committed and enforced if the transfer was made in later time.

Figure 4 shows the result of experiment that examined the effect of long day treatment on diapause-destined larvae 20 days after the third larval molt for diapause termination. Pupation seemed to be accelerated by the treatment of 6 days but the treatment of 2-4 days failed to reverse the

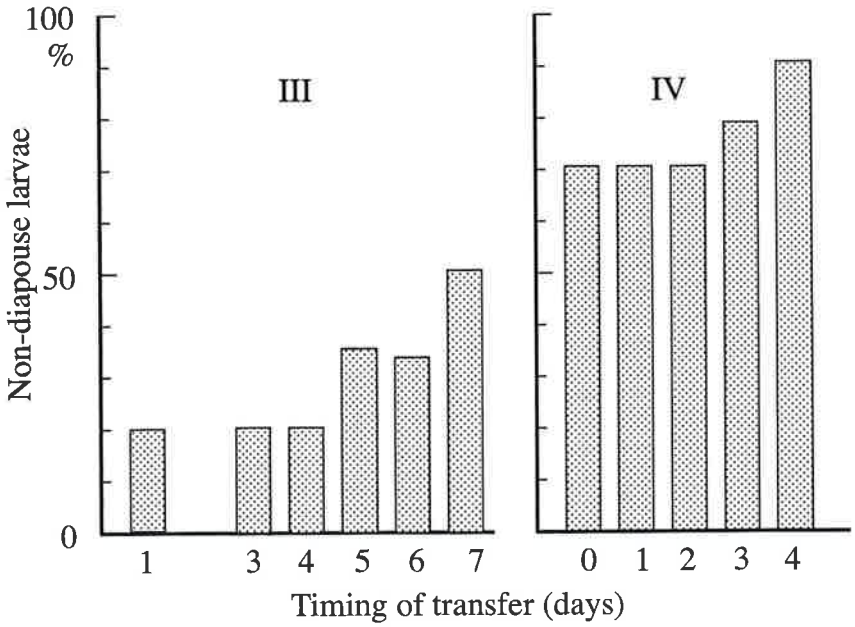

Fig. 3 Percentage pupation without diapause after transferred from LD 16 : 8 to LD12 : 12. Numbers indicate age in days after molting to 3rd (Ⅲ) or 4th (Ⅳ) instar.

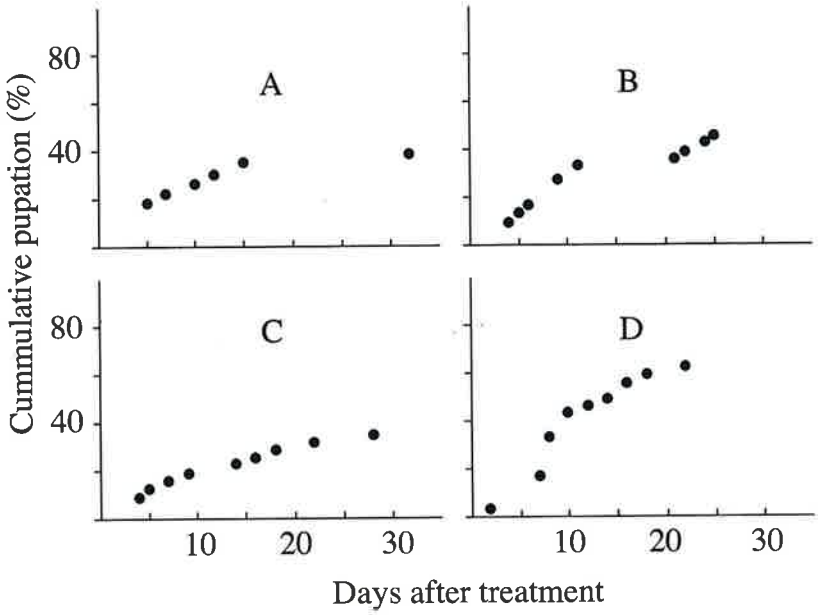

Fig. 4 Effects of periods of long-day exposure on diapause termination in *L. serricorne*. Dots show cumulative percentage of pupation. The insects were exposed to LD 16 : 8 on the 20th day after the third larval molting. A, LD12:12 continued without long-day exposure; B, two days exposure to LD 16:8; C, 4 days exposure; D. 6 days exposure.

determination made by the preceding photoperiodic condition.

The effect of low temperature exposure in different conditions and at different developmental times is given in **Tables 1** and **2**. The exposure of eggs to 5℃ for one day killed about 10% of individuals but the exposure for 10 days or longer killed all. Second and third instar larvae reared under LD 16:8 were also not much cold-hardy. However, only 3.6% were killed by 30 days exposure of 4th instar larvae. Pupae were not cold-hardy but adults endured of cold more than other stages but 4th instar larvae. The presence of cocoon and humidification improved survival.

When diapause larvae were exposed to 5℃ for two months, 91 days after the egg-laying, the pupation was very synchronous when they were returned to 25℃ and 50% of individuals pupated within 10 days after the transfer to 25℃ even under LD 12 : 12 (**Fig.5**).

Table 1. Mortality at each developmental stage after exposed to 5℃.

Developmental stage	Period of exposure (days)	Mortality (%)	N
Egg	1	10.5	76
	10	100	78
	30	100	90
2nd larval instar	30	100	40
3rd instar	30	97.4	39
4th instar	30	3.6	28
pupa	30	100	40
Adult	30	35.0	40

All but 4th instar larvae were kept in humid condition. N, the number of samples.

Table 2. Mortality of full grown larvae reared under LD16:8 or 12:12 (*) at 25℃ after the exposure to low temperatures, 5 or 10℃, for a variable period

Temperature (℃)	Period	Humidity	Cocoon	Mprtality (%)	N
5	60	hi	present	69	32
5*	60	hi	present	53	32
5	30	hi	present	21	34
5	30	hi	removed	32	38
5	30	lo	removed	81	37
10	75	lo	present	31	13
10	61	lo	present	0	22

The low temperature exposures began 91st days after egg-laying. N, the number of samples. High humidity condition is made by saturated salt solutions, while low humidity means an unhumidified condition.

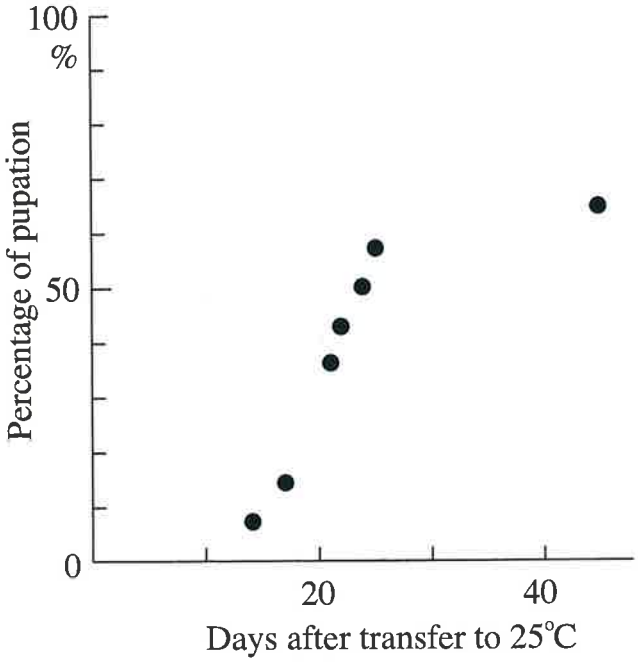

Fig. 5 Cumulative % pupation after the exposure to 5℃ for two months. Diapause larvae were transferred to 25℃ under LD 12 : 12 after the cold exposure.

Discussion

Developmental responses of *L. serricorne* to various environmental conditions are complicated and unique (Higashi *et al.*, 2005). Diapause of *L. serricorne* that occurs at 4th larval instar was terminated by long-days and low temperature though the former seems more effective than the latter. This stage is by nature tolerant to low temperature since about 50% non-diapause larvae at this stage survived this temperature of two months. Diapause at this stage is thus the adaptation to overwinter. The adult stage is also somewhat more tolerant than the other stages but 4th instar larva. However, it is not certain whether adults can overwinter indoors, since Howe (1957) has reported that adults cannot survive 4℃ for more than 6 days, though our strain survived 5℃ for 30 days. There may be a strain difference. The sensitive stage to photoperiod may include all larval stage before diapause stage but the number of short day cycles required for diapause induction should be more than the period of fourth larval instar. On the other hand, the long-day exposure of 6 days or longer terminated or blocked diapause effectively. A variety of control channels for development as well as a long period of diapause that is sporadically terminated makes the life cycle patterns more variable. Photoperiodic response has most frequently been analyzed at constant photoperiods but a most elaborate set of responses to photoperiod has been demonstrated in the regulation of prepupal diapause in the tailed zygaenid moth, *Elcysma westwoodii* (Gomi and Takeda, 1991) that includes the response to changing photoperiods. *L. serricorne* also has such an adaptation, though less dramatical.

The drugstore beetle *Stegobium paniceum* that belongs to the same Anobiidae as *L. serricorne* also shows an extension of the fourth larval instar at 20℃ (Momoi and Sadamori, 1982). *S. paniceum* is more toleranat to low temperature than *L. serricorne*. The former has been found in bird nests of temperate areas (Kiritani, 1959; Yoshida, 1978), whereas *L. serricorne* has seldom been observed outdoors. Momoi, S. has failed to detect photoperiodic response in *S. paniceum* (unpublished data). Both *L. serricorne* and *S. paniceum* have colonized Japan in warehouse habitats in the same way from tropical forest environment relatively recently. Comparison of life cycle traits of these beetles may provide interesting clues to the evolutionary process of colonization of the new environment in these species. The life cycles of these beetles may depend on various physiological, developmental and ecological constraints such as history of colonization, the stability of the new habitat, the presence of the competitors, the periodicity of stress conditions, physiological limit of low temperature tolerance and degree of migration. Clarifications of these factors in relation to life cycle traits are desperately needed for the implementation of effective urban pest management.

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We thank Ms Reiko Tomita for excellent artworks for illustration. We dedicate this article to late Ms A.Yasuhara who encouraged us constantly.

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長日と低温によるタバコシバンムシ幼虫休眠の終結と休眠誘導の阻害

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25℃短日（LD12：12）で個体飼育したタバコシバンムシの幼虫を色々な時期（産卵後 51 日目，71 日目および 103 日目）に長日（LD16：8）に移し，休眠期間の調節と休眠覚醒機構を検討した．いずれの時期でも，長日処理で休眠間発育が促進され，処理後約 10 日で羽化した．51 日目で長日に移した場合と比べ，71 日目に移した場合では蛹化がゆっくり起こった．このことは，休眠時間とともに，休眠が深化するか，短日に対する感受性が低くなるためと考えられる．長日で一部発育遅延がみられたが，短日 51 日目から長日に移し変えた場合には，これが見られなかった．このことは，一定の光周期だけではなく，光周期の変化にも本種は反応している可能性を示す．長日 6 日目でかなりの個体が羽化したことから，休眠覚醒には 6 日間の処理で十分であることが判った．次に 4 齢脱皮を挟んでその前後を 25℃長日で飼育したものを，短日へ移しかえたところ，短日に対する感受性は幼虫の 4 齢に達するまで持続することが判った．日本の冬で遭遇する低温 5℃に 10 日間暴露すると，全ての卵が死亡し，蛹，2 齢及び 3 齢幼虫では 30 日間の暴露で，それぞれ 100 %，100 % および 97.4 % の死亡率となったから，この発育ステージでは本種の低温に対する耐性は低いと結論された．しかし，4 齢幼虫は低温耐性が高く，成虫では 65 % がこの処理（5℃，30 日間）に耐えた．4 齢幼虫では，餌の存在と高湿度で低温条件での生存率が高くなった．5℃に比べ 10℃は厳しい条件ではないが，低温 75 日間処理すると 3 分の 1 は死亡した．2 ヶ月 5℃で処理すると，休眠が早期終結する効果を示した．

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原　著

餌の有無がタバコシバンムシ成虫の移動と日周活動に及ぼす影響

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Effect of Food in the Movement of the Adult Cigarette Beetle, *Lasioderma serricorne* (Fabricius), and Their Daily Activity. Hideakira Tsuji. KSK Institute for Environmental Biology, F-409, 2-1 Nishino-Rikyu-cho, Yamashina-ku, Kyoto 607-8345, Japan

Abstract

Laboratory arena experiments were carried out to investigate the movement of adult cigarette beetles to new food and their daily activity from May through September in 2005. Almost all the beetles moved out of the release cup with no food, and moved to the capture cups with new food. Almost all the beetles stayed in the release cup with new food for several days, then they gradually moved to the capture cups with new food. The beetles tended to gather in the capture cups on the darker side of the arena than in those on the lighter side in early to mid May. The number of active adults increased around 8p.m. in the arena, and they walked and flew in the nighttime. Some beetles swarmed on food and others walked on the wall and ceiling of the arena. The number of active adult beetles decreased after 6a.m., and they tended to stay in the shelter in the daytime.

Key words：Cigarette beetle, *Lasioderma serricorne*, Movement to new food, Daily activity.

2005 年5～8月，タバコシバンムシ成虫が大型および中型のアリーナ中央の放飼カップから新しい餌の入った捕獲カップに移動する状況を調べた．放飼カップは餌がある場合とない場合とを設定し，いずれもベニヤ板製のシェルターを入れた．その結果，放飼カップに餌がある場合，成虫は放飼カップに留まる傾向が強く，放飼カップ中に餌が無かったり，餌の品質が低下した場合，成虫は新しい餌を求めて捕獲カップへ移動した．なお，成虫は5月上旬には暗い北側の捕獲カップに多く移動する傾向が認められた．2005 年9月，タバコシバンムシ成虫を小型のアリーナに放飼し，2時間ごとにシェルターから出ている成虫の分布を調べた．その結果，シェルター外で活動する成虫は 18 時ごろから増加し，夜間に歩行や飛翔する個体が認められた．また，シェルター外で活動する成虫は6時ごろから減少し，昼間はシェルター内に潜伏していた．なお，シェルター外に出た成虫は餌に集まる場合と壁や天井で活動する場合があった．

はじめに

タバコシバンムシは乾燥食品の害虫として重要であり，人家や工場施設において広範囲の食品に侵入して繁殖する（How, 1957；Mallis, 1997）．高山ら（1992）は食物源のない工場の屋内のライトトラップに多数の本種成虫が捕獲されたので，あらためてその屋内と屋外にフェロモントラップを設置したところ，屋内より多くの成虫が屋外で捕獲されたことから，成虫が 1.5 km 離れた飼料工場から飛来していることを示唆した．川上・中野（1996, 1997）は，本種成虫がフェロモントラップおよびベイトトラップにより人間の住居内および住居に近い屋外の両方で捕獲されたことから，成虫が住居と屋外との間で移動していることを示唆した．また，本種はわずかな餌でも発生することから，発生源の特定が容易でなく（川上・中野，1996），気づかぬうちに食品への侵入が起こっていることが多い．したがって，被害防止のためには，成虫の潜伏と移動，産卵，幼虫の侵入などに関する習性行動をさらによく知ることが是非必要である．著者はその一環として，餌の有無の条件が成虫の移動と日周活動に及ぼす影響を室内試験で観察し，若干の知見を得たのでここに報告する．

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材料と方法

1）成虫の移動

試験Ⅰ～Ⅳは 2005 年 5 ～ 7 月に京都市内の集合住宅 4 階南面の室内で行った．その間，室内は冷暖房を行わなかった．中型（**図1A**，底面辺 26×16 cm，上部口辺 28×17 cm，深さ 19 cm）および大型（**図1B**，底面辺 31×17 cm，上部口辺 34×20 cm，深さ 21 cm）のプラスチック容器をアリーナとし，成虫と新しい餌（7 g）の入った放飼カップ（**図2**，口径 9 cm，底面径 8 cm，深さ 5 cm のプラスチックカップ）あるいは成虫の入った餌なしの放飼カップを中央に置き，両短辺には新しい餌（3 g）の入った捕獲カップ（口径 3 cm，底面径 2.9 cm，深さ 5 cm，市販 35 mm フィルムケース）を置いた．放飼カップには，ベニヤ板製のシェルター（**図2**，5 × 3 cm，厚さ 3 mm のベニヤ板 2 枚を切り口 8 × 8 mm の角材をはさんで接着したもの）を垂直に置き，通常は成虫がその中に潜伏していた．アリーナにはナイロンゴースの網をかけ，その上から付属のプラスチック格子で蓋をした．餌は市販の小麦粉（薄力粉）9 と日本薬局方乾燥酵母（エビオス，東京田辺株式会社）1 の重量比で混合したものを用いた．

試験Ⅰ：5 月 8 日，放飼カップ内の全ての成虫とシェルターを除去し，餌の中で幼虫と蛹が生育している放飼カップに古い餌の表層を覆うように新しい餌を 7 g 追加し，新しいシェルターを入れて中型アリーナの中央に置いた（**図1A**）．なお，捕獲カップはアリーナの北側と南側に各 2 個配置した．5 日後（5 月 13 日，この間の室温は 22 ～ 25℃．室温表示は以下同様）に新たに出現した成虫の分布を調べた．この時は成虫を除去せず，7 日後（5 月 15 日，室温 21 ～ 24℃）に成虫を全て除去した．12 日後（5 月 20 日，室温 21 ～ 23℃）に新成虫の分布を調べ，直後に成虫を全て除去した．18 日後（5 月 26 日，室温 22 ～ 26 ℃）と，23 日後（5 月 31 日，室温22～26℃）に同じ操作を繰り返した．5月8日から46日後（6 月 23 日，室温 24 ～ 30℃）に次世代成虫の分布を調べた．

試験Ⅱ：試験Ⅰにおいて 5 月 8 日に除去した成虫を大型アリーナの中央に置いた餌なしの放飼カップ内にシェルターと共に入れた（**図1B**）．なお，捕獲カップはアリーナの北側と南側に各 3 個配置した．9 日後（5 月 17 日，室温 21 ～ 24℃）に成虫の分布を調べた．また，試験Ⅰにおいて 5 月 15 日に除去した成虫を用いて同様の操作を繰り返し，1 日後（5 月 16 日，室温 21 ～ 24℃）に成虫の分布を調べた．

試験Ⅲ：成虫が餌表面に出現した 2 日以内の成虫を 6 月 24 日に 2 分割し，一方を餌なしの放飼カップに入れ，他方を新しい餌（7 g）のある放飼カップに入れ，それぞれを大型アリーナの中央に置いた（**図1B**）．前者は 1 日後（6 月 25 日，室温 26 ～ 30℃），後者は 6 日後（6 月 30 日，室温 29 ～ 31℃）までの成虫分布を調べた．なお，捕獲カップはアリーナの北側と南側に各 3 個配置した．

試験Ⅳ：試験Ⅲと同様に，成虫を 6 月 26 日に 2 分割し，一方を餌なしの放飼カップに入れ，他方を新しい餌のある放飼カップに入れ，それぞれを大型アリーナの中央に置いた（**図1B**）．前者は 1 日後（6 月 27 日，室温 26 ～ 30℃），後者は 1 日後と 5 日後（7 月 1 日，室温 26 ～ 31℃）に成虫の分布を調べた．なお，捕獲カップはアリーナの北側と南側に各 3 個配置した．

2）成虫の日周活動

試験ⅤとⅥ：試験は 2005 年 9 月 13 ～ 15 日（室温 28 ～ 30℃）に前記と同じ室内で行った，小型プラスチック容器（**図3**，底面辺 15×8 cm，上部口辺 16×9 cm，深さ 10 cm）をアリーナとして，その底面の片方の長辺中央にベニヤ板製のシェルター（**図2**と同じもの）を水

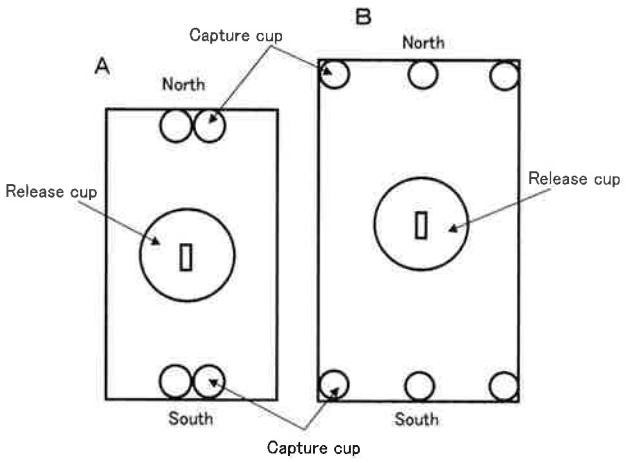

Fig. 1 Cup arrangements in A and B arenas for the movement tests of adults

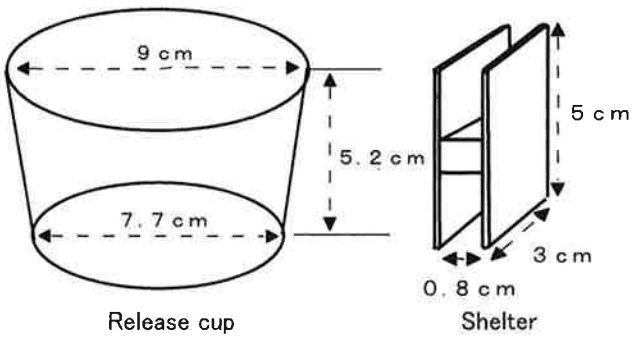

Fig. 2 Release cup and plywood shelter for the movement tests of adults

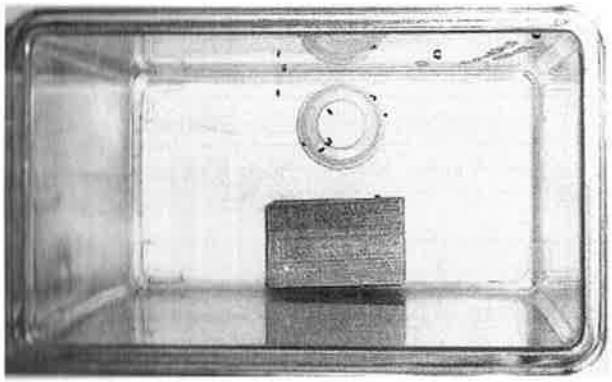

Fig. 3 Arrangements of the shelter and food (flour) tray in the small arena for daily activity tests of adults

中に設置した．餌は餌器として用いた外径 33 mm，高さ 6 mm の円盤形プラスチック台（市販 35 mm フィルムケースの蓋を逆さにしたもの）の中心にある内径 18 mm 深さ 2 mm の凹みに入れ，シェルターの反対側に置いた（**図3**）．アリーナは試験毎に2個用意し，試験Vでは9月 13 日 16 時にシェルター内に成虫それぞれ 24 個体と 26 個体を放飼し，9月 16 日0時まで2時間ごとにシェルター外に出ている成虫の分布を調べた．また，試験Ⅵでは9月 14 日 12 時に，それぞれ 43 個体と 33 個体を放飼し，9月 16 日0時まで2時間ごとに同様に調べた．なお，アリーナにはナイロンゴースの網をかけ，その上から付属のプラスチック格子の蓋をした．

結果および考察

1）成虫の移動

試験Ⅰ：試験Ⅰの結果を**表1**に示した．5～ 18 日後の5月 13 ～ 26 日の間の調査では，放飼カップから捕獲カップへ移動した成虫（いずれも繭を出てから5～6日齢）は認められず，昼間はシェルターに付着している個体が多かった．また，23 日後の6月 31 日には一部の成虫が捕獲カップへ移動したが，放飼カップに留まる個体が多かった．したがって，放飼カップに新しい餌が追加された場合，成虫は放飼カップに留まり，産卵などの行動を行うと考えられる．なお，その場合にも成虫は新しい餌の上に常に滞在するのではなく，シェルター下部の暗い部分に潜伏する個体が多いことが判明した．一方，6月 23 日には次世代成虫のほとんどが捕獲カップへ移動した．これは5月8日に放飼カップに追加した新しい餌の品質が排泄物などによる汚染で低下したため，成虫の移動が引き起こされたと考えられる．

試験Ⅱ：試験Ⅱの結果を**表2**に示した．9日後の5月 17 日および1日後の5月 16 日の調査とも，すべての成虫が捕獲カップへ移動した．なお，いずれも成虫は明るい南側より暗い北側の捕獲カップに多く移動する傾向が認められ，この傾向は試験Ⅰの6月 23 日の結果でも認められた．したがって，放飼カップに新しい餌がない場合，成虫は新しい餌を求めて積極的に移動すると考えられる．

試験Ⅲ：試験Ⅲの結果を**表3**に示した．餌なしの放飼

Table 1 Numbers of adults in release and capture cups in test Ⅰ

With food in release cup	Dates	In release cup			In capture cups	
			Shelter part			
		On food	Upper	Lower	Southern	Northern
After 5 days	May 13	14	2	20	0	0
After 12 days	May 20	0	0	16	0	0
After 18 days	May 26	4	0	16	0	0
After 23 days	May 31	2	0	6	2	0
After 46 days	June 23	2	0	0	1	15

Table 2 Numbers of adults in release and capture cups in test Ⅱ

No food in release cup	Dates	In release cup		In capture cups					
		Bottom	Shelter	Southern			Northern		
				East	Center	West	East	Center	West
after 9 days	May 17	0	0	1	1	6	16	13	8
after 1 day	May 16	0	0	1	0	3	1	2	15

Table 3　Numbers of adults in release and capture cups in test Ⅲ

With or No food in release cup	Dates	In release cup			In capture cups					
		Bottom	Shelter part		Southern			Northern		
			Upper	Lower	East	Center	West	East	Center	West
No：After 1 day	June 25	0	0	0	2	1	3	7	2	8
With：After 2 days	June 26	2	0	15	0	0	0	0	0	0
With：After 3 days	June 27	1	0	12	0	2	0	1	1	0
With：After 4 days	June 28	3	0	0	2	4	1	4	2	0
With：After 5 days	June 29	3	0	0	1	0	0	4	2	5
With：After 6 days	June 30	3	0	0	3	0	1	5	2	2

Table 4　Numbers of adults in release and capture cups in test Ⅳ

With or No food in release cup	Dates	In release cup			In capture cups					
		Bottom	Shelter part		Southern			Northern		
			Upper	Lower	East	Center	West	East	Center	West
No：After 1 day	July 27	4	0	4	15	15	10	18	11	11
With：After 1 day	July 27	31	5	20	6	2	3	2	1	3
With：After 5 days	July 1	36	0	0	8	7	5	5	3	4

カップに成虫を入れた場合，1日後の6月25日にはすべての個体が捕獲カップに移動し，成虫は明るい南側より暗い北側の捕獲カップに多く移動する傾向が認められた．一方，餌ありの放飼カップに成虫を入れた場合，2日後では捕獲カップに移動する個体はなかったが，3日後からは移動がみられ，4～6日後の6月28～30日では7～8割の個体が捕獲カップに移動した．

試験Ⅳ：試験Ⅳの結果を**表4**に示した．餌なしの放飼カップに成虫を入れた場合，1日後にはほとんどの成虫が捕獲カップに移動した．なお，この試験では北側と南側の捕獲カップにほぼ同数の個体が移動した．一方，餌ありの放飼カップに成虫を入れた場合，成虫は放飼カップに留まる傾向が強かった．なお，この試験では放飼した成虫が多かったためか，1日後に捕獲カップに移動する個体もみられた．

以上，試験Ⅰ～Ⅳの結果から，摂食や産卵に利用可能な新しい餌がある場合，成虫はその付近に留まる傾向が強く，餌がなかったり，餌の品質が低下した場合，成虫は新しい餌を求めて積極的に移動することが示された．なお，試験Ⅰ～Ⅲでは明るい南側の捕獲カップよりは暗い北側の捕獲カップへ移動する個体が多かったが，試験Ⅳでは北側と南側の捕獲カップにほぼ同数の個体が移動した．この原因は不明であるが，成虫の移動方向に気温が影響している可能性が考えられ，今後の検討が必要である．

2）成虫の日周活動

試験ⅤとⅥ：試験の結果を**図4**と**図5**に示した．シェルター外に出て活動する成虫は18時ごろから増加し，夜間は歩行や飛翔する個体が認められた．シェルター外に出て活動する成虫は6時ごろから減少し，昼間はシェルター内に潜伏していた．一部の成虫は昼間でもシェルターの外で認められたが，その成虫は餌器に付着して静止する個体が多く，そこをシェルター代わりにしていると考えられた．

以上の結果は，自然条件下で本種の成虫が昼間は隠れ場所に潜伏し，日没近くから前夜半にかけて活発に活動することを示唆している．Reed *et al.*（1934）は倉庫内において成虫の活動が盛んになる日没前後に吸引ライトトラップを用いて成虫を捕獲し，良好な防除結果を得たことを報告している．Back（1939）は成虫が午後遅くに飛翔して頭髪や衣服内に侵入するため不快や食物汚染の原因になることに言及している．

なお，試験ⅤとⅥの結果から，シェルター外に出た成虫は，餌上や餌器に集まる場合と，壁や天井で活発に活動している場合があった．これらは，餌上で摂食や産卵を行う個体と，餌以外の場所で交尾や分散行動を行う個体が存在するためと考えられる．

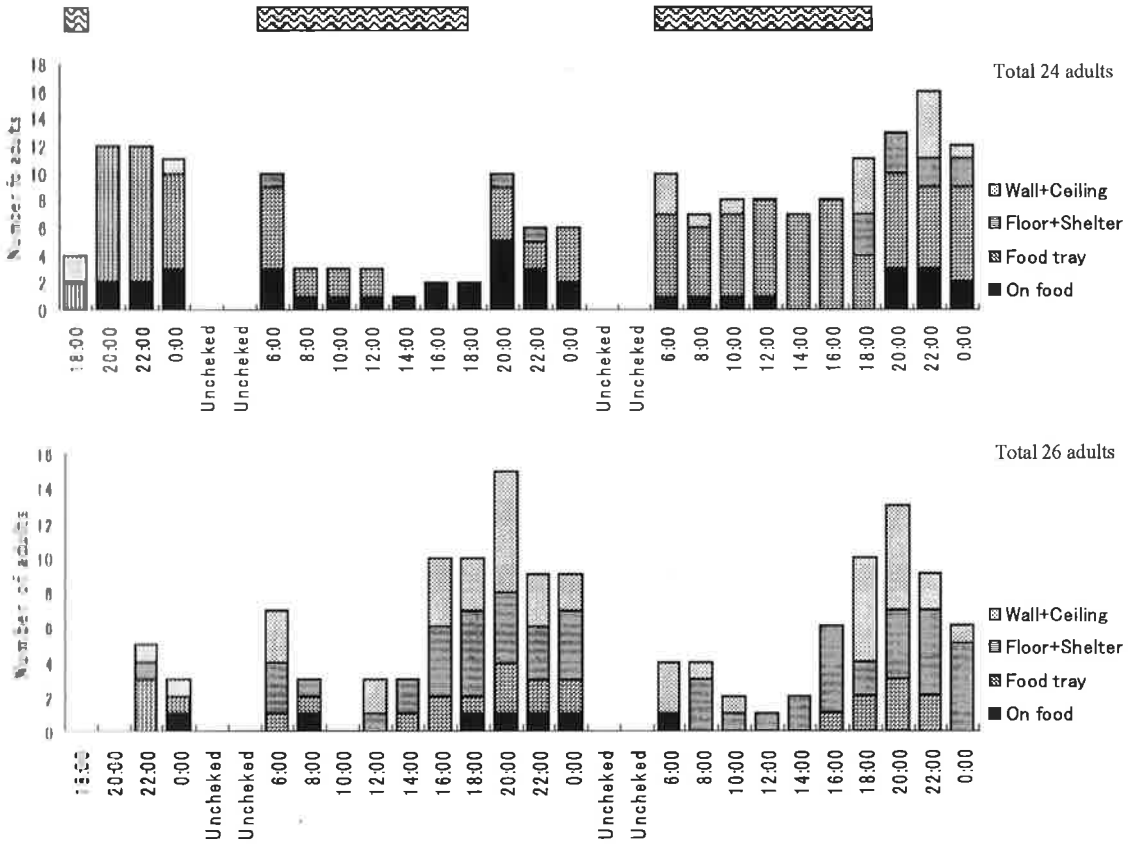

Fig. 4 Number of active adults outside the shelter in test V
Date : September 13～16, 2005 Top bars indicate lighter period of time

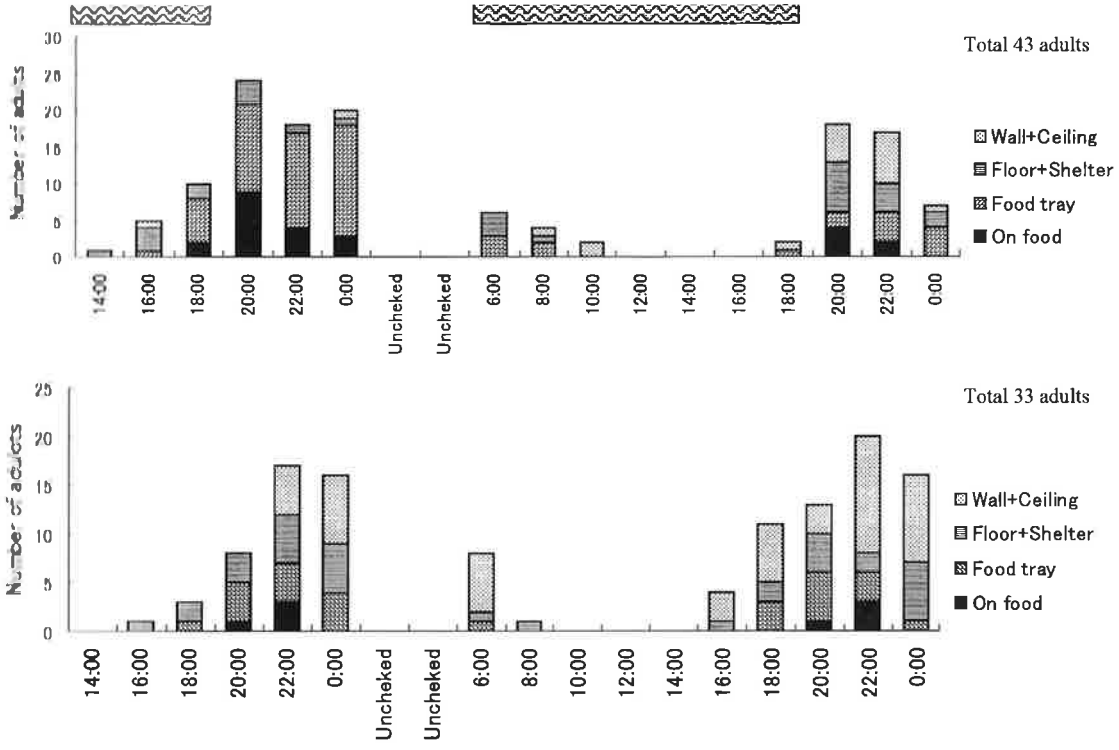

Fig. 5 Number of active adults outside the shelter in test VI
Date : September 14～16, 2005 Top bars indicate lighter period of time

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