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BIOLOGY AND MATING BEHAVIOR OF THE COCONUT MOTH *ATHELOCA SUBRUFELLA* (LEPIDOPTERA: PHYCITIDAE)

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ABSTRACT

The coconut moth, *Atheloca subrufella*, is responsible for most of the flower and fruit shedding in coconut cropping systems. Despite this, little is known with regard to its biology and behavior. In order to understand its biology, the duration and viability of the egg, larval, and pupal stages, number of instars, pupal weight of males and females, sex ratio, adult longevity, and fecundity were determined. In the mating behavior study, observations included mating time and duration. Duration and viability of the egg, larval, and pupal stages were 3.0 and 93.0, 14.3 and 85.0, and 11.2 d and 91.0%, respectively, totaling 28.5 d (egg-adult) with 72.0% viability. There were four instars, with head capsule means of 0.27, 0.45, 0.80, and 1.33 mm for the 1st, 2nd, 3rd, and 4th instars, respectively. The sex ratio was 0.55, and the mean pupal weight was 22.2 mg for males and 25.2 mg for females. The pre-oviposition, oviposition, and post-oviposition periods averaged 2.4, 7.5, and 5.5 d, respectively. The longevity of males and females was 17.5 and 15.2 d, with a mean fecundity of 216 eggs. With regard to mating behavior, 91.0 and 9.0% of the tested pairs mated on the first and second day of adult life, respectively. Mating always began between 1900 and 2300 h, corresponding to an interval between 45 and 285 min after dusk, with a mean mating duration of 95 min.

Key Words: Insect, Aracaceae, palms, coconut palm pest

RESUMO

A traça-do-coqueiro *Atheloca subrufella* é responsável por boa parte da queda de flores e frutos na cultura do coqueiro. Apesar disso, ainda pouco se conhece sobre sua biologia e comportamento. Para o estudo da biologia deste inseto, determinaram-se a duração e viabilidade das fases de ovo, larva e pupa, o número de ínstares, peso de pupas de machos e fêmeas, razão sexual, longevidade dos adultos e fecundidade. Para o estudo do comportamento sexual observou-se o horário e a duração do acasalamento. A duração e a viabilidade das fases de ovo, lagarta e pupa foram de 3,0 e 93,0; 14,3 e 85,0; e 11,2 dias e 91,0%, respectivamente, totalizando 28,5 dias (ovo-adulto) e 72% de viabilidade. O número de ínstares foi 4, com médias de cápsula cefálica de 0,27; 0,45; 0,80 e 1,33mm, para o 1º, 2º, 3º e 4º ínstares, respectivamente. A razão sexual foi 0,55 e o peso médio de pupas 22,2 mg para machos e 25,2 mg para fêmeas. As durações dos períodos de pré-oviposição, oviposição e pós-oviposição foram de 2,4; 7,5 e 5,5 dias, respectivamente. A longevidade de machos e fêmeas foi de 17,5 e 15,2 dias, com fecundidade média de 216 ovos. Em relação ao comportamento sexual, 91,0 e 9,0% dos casais, copularam no primeiro e segundo dia de vida, respectivamente. O início da cópula ocorreu sempre entre as 19 e 23 horas, correspondendo ao intervalo de 45 a 285 min, após o entardecer, com uma duração média da cópula de 95 min.

The coconut moth *Atheloca subrufella* (Hulst, 1887) [= *Hyalospila ptychis* (Dyar, 1919)] (Lepidoptera: Phycitidae) is one of the most important coconut pests (Ferreira et al. 2002). In Brazil, the first reports on the occurrence of this insect are dated to the beginning of the 20th century in Bahia and Pernambuco (Bondar 1940; Costa Lima 1949). It has been reported in the states of Amazonas (Sefer 1963), Sergipe, and Rio de Janeiro (Silva et al. 1968). More recently, with the expansion of coconut production in several regions of the country, its now occurs in all of the Brazilian states where coconuts are grown (Ferreira et al. 2002). The coconut moth also occurs in the south of the USA (Georgia and Florida), the north of Mexico (Habeck & Nickerson 1982; Hodges et al. 1983; Adams 2004), Cuba, and the Virgin Islands (Bondar 1940; Heinrich 1956; Kimbal 1965; Moore 2001). Palm trees in the family Arecaceae are the most important hosts, with reports mainly in the genera *Cocos*, *Attalea*, *Syagrus*, *Sabal*, and *Serenoa* (Bondar 1940; Costa Lima 1949; Kimbal 1965; Silva et al. 1968; Moura & Vilela 1998; Moore 2001; Ferreira et al. 2002).

Although significant damage occurs in different regions, the bioecology of *A. subrufella* is still unclear and little known. The adult is a microlepidopteran with a wingspan from 14 to 18 mm; the moth is brownish and lives protected by open coconut spathes during the day (Bondar 1940). As soon as the inflorescence opens, the moth lays its eggs on female flowers (Moura & Vilela 1998). The newly-hatched caterpillars feed on the carpels of still-tender flowers or, if the flower has already been fertilized, they penetrate the developing coconut through the lower part of the bracts (Bondar 1940; Ferreira et al. 2002). Attacked flowers are aborted and fall off; the presence of the pest can be recognized by the feces at the site and by a change in color in female flowers, which become dark brown (Bondar 1940; Moura & Vilela 1998). In young coconuts, the caterpillar feeds on the mesocarp, opening a series of galleries and causing premature shedding of fruits. Feces and small fecal pellets bound by silk strands can be visualized on the external surface of young coconuts, facilitating recognition of the pest. Attacked coconuts that do not fall off become deformed and have reduced commercial value (Bondar 1940; Ferreira et al. 2002).

Controlling *A. subrufella* is particularly difficult because of the continuous development of inflorescences in the coconut palm, which makes agrochemical spraying not viable. In addition, spraying insecticides may affect a number of beneficial and pollinating insects, such as bees (Moura & Vilela 1998); moreover, the effectiveness of insecticides is low, because the caterpillars are protected between the bracts of young coconuts.

Thus, the purpose of this work was to study in detail the biology and mating behavior of *A. subrufella*, aimed at future studies for the integrated management of this pest, with emphasis on the production of sex pheromone.

MATERIALS AND METHODS

Starting a Stock Rearing

The insects used in the experiments were collected from infested young coconuts in commercial dwarf coconut plantations in the municipal district of Touros-RN, Brazil. Infested coconuts were taken to Emparn's (Empresa de Pesquisa Agropecuária do Rio Grande do Norte) Laboratory of Entomology, where they were arranged on plastic trays containing sterilized sand for pupation. The pupae obtained were separated and sent to the Insect Biology Laboratory of Departamento de Entomologia, Fitopatologia e Zoologia Agrícola of Escola Superior de Agricultura "Luiz de Queiroz" (ESALQ), Universidade de São Paulo (USP), in Piracicaba, SP, Brazil, where a stock rearing in young coconuts was initiated to support the biology and behavioral studies. The biology experiments were carried out with laboratory-reared second-generation insects, while the behavioral studies were conducted with third-generation insects.

Adults were maintained in cages made from PVC tubes 10 cm in height × 10 cm in diameter and lined with paper towel to provide an egg-laying substrate. The ends of the tube were covered with a 12-cm diameter Petri dish to prevent the insects from escaping. Adults were fed a 10% honey solution; the food and paper towel containing eggs were replaced every two days.

Coconut Moth Biology

Upon hatching, 150 larvae were placed in clear plastic cups 7 cm height and 6 and 5 cm diameter at the base and top, respectively, to determine the duration and viability of the egg, larval, and pupal stages, pupal weight of males and females, sex ratio, longevity of males and females, and fecundity, as recommended by Parra (2001). Young coconut fruits (2.5 cm 0.5) were placed inside the cups, maintained on filter paper (same diameter as the cup), in order to absorb the excess moisture released by the fruit and to avoid or reduce contamination by saprophytic microorganisms. After ten days of larval development, each fruit was replaced with a fresh one. Pupae were later individually placed in plastic cups 3.0 cm height × 1.5 cm diameter, and arranged on a perforated metal tray and containing filter paper inside, which was moistened daily in order to maintain adequate humidity during that stage of development. Sexes were separation during the pupal stage, according to the methodology by Butt & Cantu (1962).

The number of instars was determined by daily measuring the head capsule width of 15 caterpillars with an ocular micrometer attached to a stereoscopic microscope, according to Parra & Haddad (1989).

Longevity and fecundity determinations were made on each of 25 pairs in PVC cages, as previously described. Food was replaced daily, and the number of eggs and mortality of males and females were recorded. Rearing was conducted in an air-conditioned room at a temperature of 25 ± 1°C, relative humidity of 70 ± 10%, and 14h photophase.

The χ^2 test was used to determine the possible occurrence of protogyny, considering a daily sex ratio of 0.5 as the expected values. Regression analysis was used to determine a mathematical model that would best explain the daily emergence rhythm of males and females.

Mating Behavior of Coconut Moth

Preliminary visual observation studies with *A. subrufella* pairs demonstrated that mating in this species always occurred after dusk. Therefore, 5 groups of 9 pairs in their first day of life were formed, in clear plastic cups 13.0 cm in height and 8.5 6.0 cm in diameter at the base and top, respectively, inverted on a Petri dish 9.0 cm in diameter × 0.8 cm in height, containing filter paper moistened with distilled water at the base. These pairs were arranged in a greenhouse under natural light, temperature of 25 ± 3°C, and relative humidity of 70 ± 10%. Visual observations were made every 10 min, from the beginning of dusk until the mating activities ceased; the age, time at the start and end of copulation, duration, and a description for the courtship and copulation activity were recorded. Observations were made with a hand flashlight (Maglite® with a red filter). The light source was maintained at a ca. 60 cm from the arena so as to prevent possible interference with insect behavior. This experiment was conducted until the fifth day of life of those adults, and only pairs that performed at least one copulation during that period were considered for the analysis.

The sunset time for Piracicaba-SP was obtained from Observatório Nacional in Rio de Janeiro-RJ, Brasil, and occurred on average at 1830 h in March 2004 during the bioassays (Moreira 2004).

Results

Biology

The means (± SEM) for duration of the egg, caterpillar, and pupal stages was 3.0 ± 0.01; 14.3 ± 0.09, and 11.2 ± 0.09 d, and viability was 93.0 ± 0.04; 85.0 ± 0.30, and 91.0 ± 0.29%, respectively. The complete cycle (egg-adult) lasted 28.5 ± 0.96 d and total viability was 72.0 ± 0.34%.

Four instars were determined for *A. subrufella*, with mean head capsule width of larvae of 0.27, 0.45, 0.80, and 1.33 mm, for the 1st, 2nd, 3rd, and 4th instars, respectively. The mean pupal weight was 22.2 ± 5.0 mg for males and 25.2 ± 4.1 mg for females. The sex ratio was 0.55 and the longevity of males and females was 17.5 ± 1.19 and 15.2 ± 0.95 d, respectively.

The durations of the pre-oviposition, oviposition, and post-oviposition periods were 2.4 ± 0.20, 7.5 ± 0.68, and 5.5 ± 0.84 d, respectively. In average terms, the oviposition rate was 29 eggs per d, and fecundity was 216.4 ± 20.86 eggs per female. Egg-laying decreased through the oviposition period, but oviposition until the 14th day was observed for some females (Fig. 1).

Females emerged in higher numbers than males during the first two d of emergence, indicating that this species presents the protogyny phenomenon (Fig. 2). Significant values were determined by the χ^2 test for the first two d (higher number of emerged females) and for the last two d (higher number of emerged males). There were no significant differences for the third and fourth d.

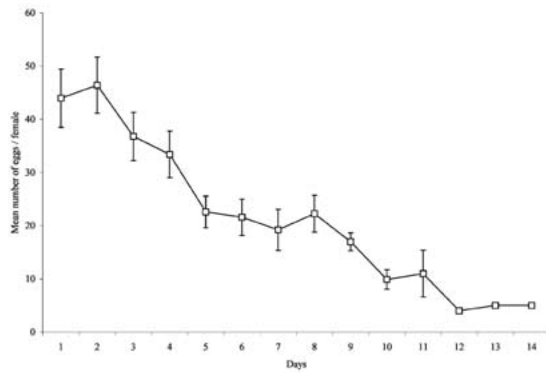

Figure. 1. Daily oviposition of *A. subrufella* reared during the larval stage on young coconut fruits. Temp.: 25 ± 1°C; RH: 70 ± 10%, photophase: 14h. Bars indicate the standard error of the mean (SEM).

The regression analysis factor for the emergence rhythm of males factor was significant ($y^{0.5} = -4.55 + 4.92x - 0.59x^2$; $R^2 = 0.86$; $F = 10.02$; $P = 0.01$; $df = 2$), where the coefficients were different from zero by Student's "*t*" test ($P \leq 0.05$). The emergence rhythm of females was significant ($y = -36.99 + 262.05/x - 214.64x^2$; $R^2 = 0.97$; $F = 20.99$; $P = 0.01$; $df = 2$), indicating that the equations fit the data well.

Mating Behavior

From 45 *A. subrufella* pairs observed, 29 mated (64.4%). Of these mating pairs, 91.0 and 9.0% copulated on the first and second days of life, respectively.

The beginning of copulation always occurred between 1900 and 2300 h, corresponding to the interval from 45 to 285 min after dusk. The mating frequency from 2100 to 2200 h was statistically different from 1900 to 2000, but it was not different from 2000 to 2100 h, and from 2200 to 2300 h (Fig. 3). The mean copulation duration was 95 min (43-149 min).

Discussion

There have been few reports on the biology of *A. subrufella*. Data presented in this paper suggest high biotic potential, although in the field climatic factors and the action of natural enemies must contribute to reducing this potential. According to Bondar (1940), the life cycle of this moth is approximately 25 to 30 d, while Moura & Vilela (1998) mentioned 40 d; these authors did not present durations for the different stages. In the present work, the life cycle lasted 28.5 d, on average, for a temperature of 25°C. The females normally begin laying eggs about 2 d after mating, laying a higher number of eggs in the very

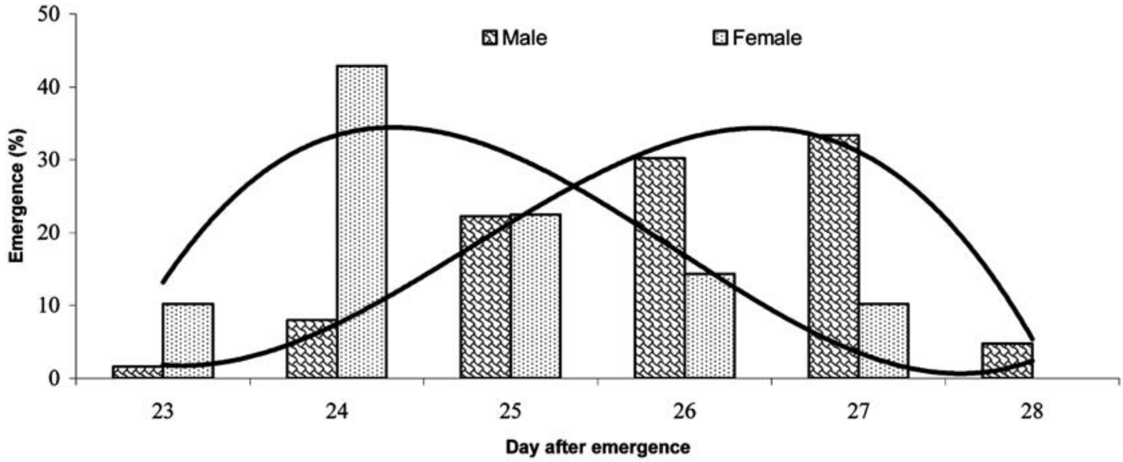

Figure. 2. Emergence of *A. subrufella* females and males. The solid and dashed lines indicate the emergence trend for males and females, respectively. Temp.: 25 ± 1°C; RH: 70 ± 10%, photophase: 14h.

first days. Even though the females have a longevity of about 2 weeks, the oviposition period is short, around 7 d, with a mean fecundity of 216 eggs per female. The post-oviposition period was 5.5 d. Eggs were laid individually, initially showing a pale-yellow color, becoming slightly reddish later, and acquiring a dark hue on the last day of embryonic development. The caterpillar stage lasted 2 weeks on average, and caterpillars may reach 15 mm in length. The pupal stage lasted 11

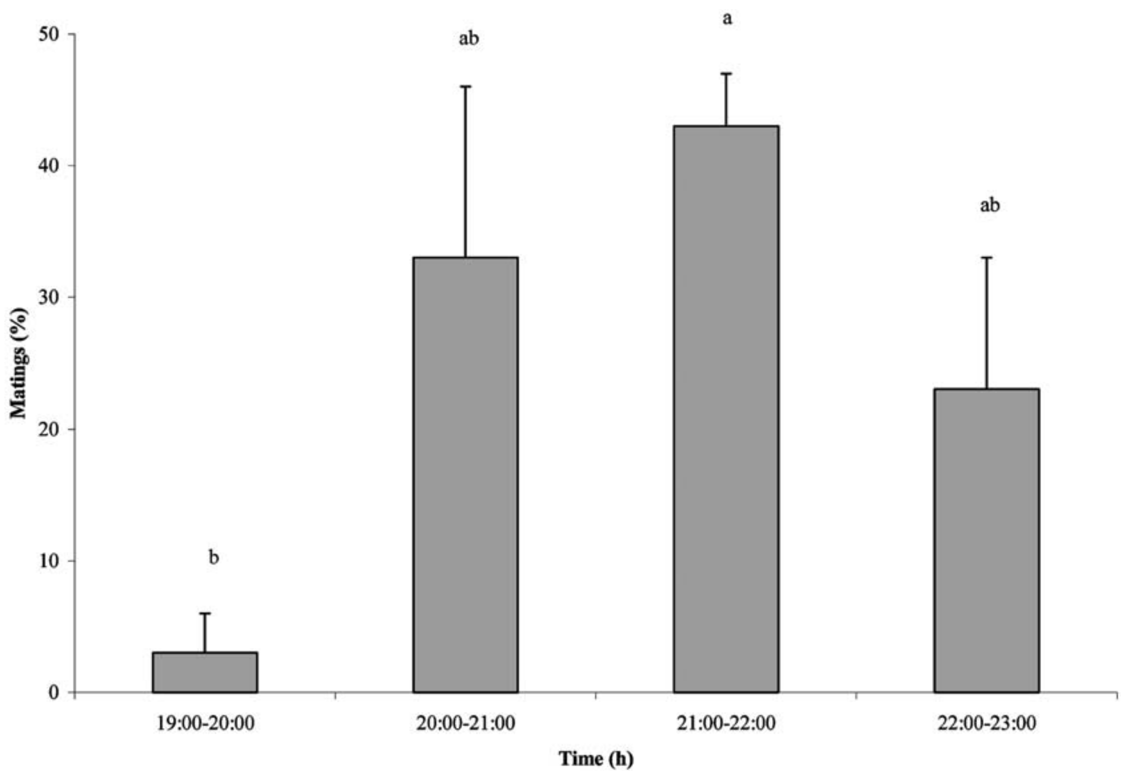

Figure. 3. Mating time of *A. subrufella*. Means followed by the same letter are not statistically different by Tukey test at the 5% probability level. Sunset time for Piracicaba-SP, Brazil, at 1830 h (March 2004).

d, differing from findings by Bondar (1940), who found a duration from 6 to 8 d. These differences may be associated with abiotic factors, not mentioned by Bondar (1940).

The emergence rhythm of *A. subrufella* adults indicates that females begin emerging before males (protogyny). The percentage of emerged females was significantly higher than that of males in the first two d (Fig. 2). The biological reason for this emergence pattern is still little understood in insects (Thornhill & Alcock 1983), but it has been demonstrated in other lepidopteran species and could represent an evolutionary strategy to promote mating between individuals from distinct populations (Uematsu & Morikawa 1997).

Mating always started during the scotophase, and were mainly concentrated in a period of two to four h after dusk. After the beginning of dusk, females and males became very agitated, especially the latter. With time, the females remained almost motionless, possibly in a "calling" position, even though no exposure of any exogenous gland or abdomen movements could be observed. A male near a female showed frenetic antennal and wing movements, walking in a semi-circular fashion around the female's body. Once the female was receptive, the male assumed a (contrary position) in relation to her, at a 180° angle, then walked backwards, with light wing and abdomen movements until copulation was achieved; this could last 1 h and 30 min on average ($P \leq 0.05$). If for some reason the female rejected the male's lunge before copulation was accomplished, the male restarted the whole procedure. In general, more than 90% of females mated on the first day of life.

More than 12 annual generations with high biotic potential may develop, because, in addition to laying more than 200 eggs, the insect shows high viability in all developmental stages. Development of an artificial diet for *A. subrufella*, which is available for other insects in the same family (Singh 1983), would facilitate the development of future management strategies for this pest.

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