First case of parthenogenesis in *Cryptolaemus montrouzieri* (Mulsant) (Coccinellidae: Scymninae) under laboratory conditions in Morocco

El Aalaoui M. [(1)], El Bouhssini M. [(2)], Bouharroud R. [(1)] et Sbaghi M. [(1)]

mohamed.elaalaoui@inra.ma

1: National Institute of Agricultural Research, Morocco.
2: International Center for Agricultural Research in the Dry Areas (ICARDA), Rabat, Morocco.

Abstract

Although *Cryptolaemus montrouzieri* (Mulsant) (Coccinellidae: Scymninae) has been widely used in biological control against a wide range of pests, no studies have been reported regarding asexual reproduction of this important predator. Our study was carried out under controlled temperature (27 °C) and photoperiod (12 H) conditions. A cohort of 250 *C. montrouzieri* 4th instar (late preimaginal stage) larvae was collected from the rearing cages and placed in Petri dishes (14.5 cm diameter) containing different developmental stages of *Dactylopius opuntiae* (Hemiptera: Dactylopiidae) as food. After the emergence of *C. montrouzieri* young adults (24 h old), they were taken individually and introduced into new Petri dishes where different developmental stages of the mealybug were maintained under the same temperature and photoperiod conditions. Twenty days after emergence, it was observed that a small portion of *C. montrouzieri* unmated females laid eggs, and 100 % of the adults that emerged from these virgin females were males. Our results show, on one hand, that several *C. montrouzieri* populations can reproduce by arrhenotokous parthenogenesis, and on the other hand, it seems that the waxy cotton produced by the scale insect females stimulates *C. montrouzieri* females to reproduce by parthenogenesis.

Keywords: Ladybird (*Cryptolaemus montrouzieri*), mealybug (*Dactylopius opuntiae*), arrhenotoky parthenogenesis.

Premier cas de parthénogenèse chez *Cryptolaemus montrouzieri* (Mulsant) (Coccinellidae : Scymninae) en conditions de laboratoire au Maroc

Résumé

Bien que *Cryptolaemus montrouzieri* (Mulsant) (Coccinellidae: Scymninae) ait été largement utilisé dans la lutte biologique contre un large éventail de ravageurs, aucune étude n'a été rapportée sur le phénomène de la reproduction asexuée de cet important prédateur. Dans notre étude qui a été réalisée dans des conditions contrôlées de température (27°C) et de photopériode (12 H), un lot de 250 larves du quatrième stade (stade préimaginal ultime) de développement de *C. montrouzieri* a été retiré des cages d'élevage et déposé dans des boîtes de pétri (14,5 cm de diamètre) renfermant différents stades de la cochenille comme nourriture. Après émergence de jeunes adultes (24 h) de la coccinelle, ils ont été pris individuellement et introduits dans de nouvelles boîtes de Pétri où différents stades de développement de *Dactylopius opuntiae* (Hemiptera: Dactylopiidae) sont maintenus dans les mêmes conditions de température et de photopériode. Vingt jours après l'émergence, il a été constaté qu'une partie des femelles non accouplées ont pondu des œufs, et que 100 % des adultes qui ont émergé de ces femelles vierges étaient des mâles. Nos résultats montrent, d'une part, qu'un certain nombre de population de *C. montrouzieri* peut se reproduire par parthénogenèse par arrhénotoky, et que d'autre part, il semble que le coton cireux produit par les femelles de la cochenille stimule les femelles de *Cryptolaemus montrouzieri* à se reproduire par parthénogenèse.

Mots clés : Coccinelle (*Cryptolaemus montrouzieri*), cochenille (*Dactylopius opuntiae*), arrhenotoky parthénogenèse.

أول حالة للتوالد العذري لدى حشرة الدعسوقة ***Cryptolaemus montrouzieri*** **(Mulsant) تحت ظروف المختبر في المغرب (Coccinellidae :Scymninae)**

محمد العلاوي، مصطفى البوحسيني، رشيد بوهرود ومحمد السباغي

ملخص

على الرغم من استخدام ***Cryptolaemus montrouzieri*** **(Mulsant) (Coccinellidae: Scymninae)** على نطاق كبير في المكافحة البيولوجية ضد مجموعة واسعة من الحشرات المضرة إلا أنه الى الان لم يتم نشر أي دراسة حول امكانية التكاثر اللاجنسي عند هذا المفترس المهم. في دراستنا التي أجريت تحت ظروف مضبوطة لدرجة الحرارة (27 درجة مئوية) وللفترة الضوئية (12 ساعة)، تمت أخذ دفعة مكونة من 250 يرقة ***C. montrouzieri*** في الطور الرابع للنمو (مرحلة ما قبل التخيل النهائي) من أقفاص التكاثر ووضعها في "أطباق بتري" (دات 14.5 سم كقطر) التي تحتوي على اطوار مختلفة من الحشرة القرمزية كغذاء. بعد ظهور صغار الدعسوقة (دات عمر لا يتجاوز 24 ساعة) تم أخذها بشكل فردي وإدراجها من جديد في "أطباق بتري" أخرى التي تحتوي على اطوار مختلفة من الحشرة القرمزية ***Dactylopius opuntiae*** **(Hemiptera: Dactylopiidae)** تحت نفس الظروف من درجة الحرارة والفترة الضوئية. بعد عشرين يومًا من التتبع لوحظ أن جزءا من إناث الدعسوقة الغير المتزوجات تضع البيض وأن 100 ٪ من الدعسوقة الكاملة المنحدرة من هذه الإناث العذارى كانوا ذكور. تظهر النتائج المحصل عليها في هذه الدراسة من ناحية أن عددا معينًا من سلالة ***C. montrouzieri*** المستعملة في التجربة تمكنت من التكاثر عن طريق التوالد العذري**parthénogenèse par arrhénotoky**، ومن ناحية أخري يبدو أن القطن الشمعي الذي تنتجه إناث الحشرة القرمزية ***D. opuntiae*** يحفز الإناث المفترسة على التكاثر عن طريق التوالد العذري.

الكلمات الأساسية: الدعسوقة (***Cryptolaemus montrouzieri***)، الحشرة القرمزية (***Dactylopius opuntiae***)، التوالد العذري

Introduction

Cryptolaemus montrouzieri is one of the most common species of Coccinellidae used for biological control of mealybugs in the world. The first introduction of this ladybird for biological control dates to 1891 when Albert Koebele brought it into California for the control of *Planococcus citri* Risso (Bartlett, 1978). The predator was first introduced into Morocco in 1921 to control the citrus cochineal *Planococcus citri* (Abdelkhalek *et al*. 1998). It was recently used for the control of *Dactylopius opuntiae,* a recently introduced scale pest to the country which damaged prickly pear crop in many regions (Bouharroud *et al*. 2018; El Aalaoui *et al.* 2019). The ladybird is also known as a generalist predator of many economically important scale species (Kamala jayanthi *et al*. 2010) and ranked second only to *Rodolia cardinalis* (Mulsant) for its ability to control the population of mealybugs (Puttarudriah *et al*. 1952). Mulsant was the first one who described *C. montrouzieri* (Mulsant, 1853). Later Cockrell (Cockrell, 1929) and Korschefsky (Korschefsky, 1931) reviewed the genus *Cryptolaemus*. This genus includes two species, *C. montrouzieri* Mulsant and *C. montrouzieri* simplex Blackburn (Booth and Pope, 1986). *C. montrouzieri* adults detect and locate their prey using chemical and visual stimuli (Heidari and Copland, 1992). In contrast larval stages perceive prey only when there is actual physical contact (Heidari and Copland, 1992). The wax filamentous secretions and honeydew produced by host mealybugs such as *D. opuntiae* make *C. montrouzieri* females attractive for oviposition (Vanegas-rico *et al*. 2016). Some studies have also shown that oviposition may be suppressed by oviposition deterring pheromone associated with the waxy filaments produced by conspecific larvae (Merlin *et al*. 1996). Predation potential is higher for *C. montrouzieri* adult females than for adult males (Jayaraman *et al*. 1988). Also, *C. montrouzieri* adults consumed a high number of *D. opuntiae* adult females and crawlers compared with larval stages (El Aalaoui *et al*. 2019). Rosas-Garcia et al. (2009) reported that the adult stage of *C. montrouzieri* is more voracious than their predatory larval stages because the larval stages of the ladybug are short-lived compared to their adult stage. *C. montrouzieri* is adapted to tropical temperatures. Rearing of *C. montrouzieri* at 25–30°C resulted in optimum developmental and reproductive characteristics and life table parameters (Babu and Azam, 1988; Jalali *et al*. 1999). *C. montrouzieri* could not survive temperatures between 0 and 17°C (Babu and Azam, 1987; Hennekam *et al*. 1987). Other studies reported that the optimum temperature for survival and development of *C. montrouzieri* is between 20 and 25°C (Cooper, 1985) and 20-30°C (Babu and Azam, 1987). *C. montrouzieri* is attacked by several pests, including pathogens, predators, and parasitoids such as *Aminellus* spp. (Hymenoptera: Encyrtidae) (Puttardriah and Channabasavanna, 1953), *Homalotylus* spp. (Hymenoptera: Encyrtidae) (Niyazov, 1969) and *Cowperia indica* Kerrich (Hymenoptera: Encyrtidae) (Fry, 1987).

Parthenogenesis is defined as the production of embryos and eggs from a gamete female without any intervention of gamete male (Mittwoch, 1978). When the offspring of virgin females are exclusively males is called arrhenotokous parthenogenesis (Bonato *et al*. 2006). When virgin females produce an equal ratio rate of both sex, parthenogenesis is called deuterotokous (Portier, 1949), and when only females are produced, is it called thelytokous (Grasse, 1949; Lynch, 1984). Parthenogenesis in Coccinellidae was not recorded until recently (Gokhman and Kuznetsova, 2018) and thelytokous parthenogenesis was apparently found lately in a species of *Nephus voeltzkowi* (Magro *et al*. 2019). Parthenogenesis is relatively rare in Lepidoptera order

(Suomalainen, 1962; Lynch, 1984), as only 20 species belonging to various families of Lepidoptera (Gelechiidae, Bombycidae, Gracillariidae, Liparidae, Lasiocampidae, Nepticulidae, Saturnidae, Sphingidae, Sesiidae) are reported to reproduce by parthenogenesis (Megido *et al*. 2012). All members of Hymenoptera order (sawflies, bees, ants, and wasps) can reproduce by parthenogenesis and the commonest type among them is arrhenotoky, which is combined with haplodiploidy (Gokhman, 2009; Normark, 2003, 2014). For Coleoptera order, Thelytokous parthenogenesis is much more common than arrhenotoky (Normark and Kirkendall, 2009; Gokhman and Kuznetsova, 2018).

Even though *C. montrouzieri* has been extensively adopted as a biological control agent for a wide range of pests, its mode of reproduction by parthenogenesis has not been reported so far. The purpose of this study was to test whether this predator can reproduce by parthenogenesis and if the waxy layer of *D. opuntiae* stimulates *C. montrouzieri* oviposition.

Materials and Methods

Experimental procedure.

The experiment was conducted on different developmental stages of *D. opuntiae* under the following controlled conditions: 27°C and 12 hours of photophase. The individuals used in this study are from the continuous rearing of this predator at the entomology laboratory at Khemis Zemamra experimental station, INRA, Morocco (32°37'48" N, 8°42'0" W) in the Sidi Bennour region (120 km north-west of Marrakech), since the beginning of 2018. 250 *C. montrouzieri* at four instar larvae stage (ultimate preimaginal stage) were removed from the rearing cages and then isolated separately in Petri dishes (14.5 cm in diameter) containing different developmental stages of *D. opuntiae*. After their fledging, young adults were then introduced individually into new Petri dishes containing different developmental stages of the mealybug. After 20 days of emergence, some unmated females laid eggs. It was suspected that the waxy cottony matter produced by the mealybugs stimulates the ladybird females to reproduce by parthenogenesis. A mixed diet that included all *D. opuntiae* development stages was offered ad libitum until the females die and the number of eggs produced by each female was counted daily. When these eggs reached stage L4, a new diet was placed and emerging adults sexed under a binocular loupe (Motic) using the methods of Gordon (1985).

In addition, two groups of ten adult males and ten adult females (less than 4 days old) from the same insect cultures were placed into each of two Petri dishes (14.5 cm in diameter) with an excess of *D. opuntiae* females for 48 h to allow copulation. Then each pair (male and female) was placed in an individual Petri dish (14.5 cm in diameter) (Gordon, 1985). The diet was offered ad libitum and the observations on number of eggs laid by each female were recorded daily until the death of adult female beetles. All the experiments were repeated four times.

***Confirmation of the role of mealybug waxy cottony in stimulation of oviposition of the predator* (*C.montrouzieri*).** To confirm the role of waxy cottony matter in the stimulation of *C. montrouzieri* females oviposition, 100 young unmated *C. montrouzieri* females (> 24 h old) were kept individually in Petri dishes (9.5 cm in diameter), and provided daily with *D. opuntiae* females with waxy cottony matter or *D. opuntiae* females without waxy cottony matter (females were individually removed from cladodes and dewaxed by rolling their wax onto a pin). The number of eggs laid by each female was recorded daily until the death of the adult beetle. The experiment was repeated three times.

Statistical analysis

Data on the number of eggs laid by virgin and fertilized females were subjected to statistical analysis One-way ANOVAs using Tukey's test ($p \leq 0.05$) with the software package SPSS ver. 18.0 (Carver and Nash, 2011).

Results and discussion

The results obtained (Table 1; Fig 1) showed that the descent of virgin *C. montrouzieri* females is exclusively made up of males and therefore confirm that *C. montrouzieri* can reproduce by arrhenotoky (Bonato *et al*. 2006). The results also showed that none of *C. montrouzieri* females that fed on *D. opuntiae* females without waxy cottony were reproduced by parthenogenesis. Specific mechanisms of determination of sex under arrhenotoky parthenogenesis vary among different insect orders. These mechanisms include genomic imprinting and complementary sex determination (CSD) (Heimpel and de Boer, 2008; Blackmon *et al*. 2017). Under complementary sex determination, several loci (De Boer *et al*. 2007) or a particular multiallelic locus (Van Wilgenburg *et al*. 2006) are engaged in sex determination.

Table 1. Descent of virgin females of *C. montrouzieri* reared on different developmental stages of *D. opuntiae* under laboratory conditions at 27 °C

Number of females tested	Number of virgin females	Fecundity (eggs per female)	% of males in descendants	% of females in descendants	% of emerged adults	% of sterility in adults
105	5	82.9±19.8	60	0	60	70

Fig 1. Egg production by *C. montrouzieri* virgin female (arrow) feeded daily with *D. opuntiae* females with cottony wax matter.

A small portion (1.8 %) of the 300 predator females tested were able to reproduce by arrhenotoky parthenogenesis when fed on *D. opuntiae* females with waxy cottony (Table 2). This observation suggests that the waxy cottony matter produced by *D. opuntiae* females seems to stimulate *C. montrouzieri* females to reproduce by parthenogenesis.

Table 2. The role of *D. opuntiae* waxy cottony matter in *C. montrouzieri* asexual reproduction under laboratory conditions at 27 °C

Number of female predators tested	Number of females provided daily with *D. opuntiae* females with waxy cottony reproduced by parthenogenesis (Mean ± SE)	Number of females provided daily with *D. opuntiae* females without waxy cottony reproduced by parthenogenesis
300 (100 x 3)	5.3±1.5	0.0

Many other Coleoptera were reported to reproduce by parthenogenesis. For example, *Micromalthus debilis* (LeConte, 1878) (Micromalthidae) in general reproduces by thelytokous parthenogenesis, but it also has a rare arrhenotokous phase that obviously represents an evolutionary dead-end (Pollock and Normark, 2002). Also, arrhenotoky parthenogenesis was detected in two other groups of beetles belonging to subfamily Scolytinae (Curculionidae): *Hypothenemus eruditus* (Westwood, 1836), and *tribe Xyleborini* (Eichhoff, 1874) (Jordal *et al*. 2000). Parthenogenetic populations were reported also in Hydrophilidae family, for example, *Helophorus orientalis* (Motschulsky, 1860) in North American (Angus, 1970). In addition, both triploid and

diploid parthenogenesis were reported in European *Anacaena lutescens* (Stephens, 1829) females, and particular chromosomes of these diploid females significantly vary from those of bisexual ones (Shaarawi and Angus, 1990). Furthermore, the majority of North American populations of *Cis fuscipes* (Mellie, 1848) (Ciidae) and *Aeolus mellillus* (Say, 1836) (Elateridae) are apparently parthenogenetic (Jewett, 1940; Lawrence, 1967).

The average number of eggs laid per *C. montrouzieri* virgin female (82.9±19.8) is significantly lower than the average number of eggs laid under the same conditions with fertilized females (193.2±34.4 eggs) (F= 104249.260, df= 1, P< 0.05). Persad and Khan (2002) reported that under laboratory conditions (27±3°C and 58±3% RH), the average longevity and total fecundity of *C. montrouzieri* were respectively 98.1±1.6 days and 118.7±1.8 eggs on *Maconellicoccus hirsutus.* Özgökçe *et al*. (2006) reported that under laboratory conditions (25±1°C and 45±5% RH), the average longevity of *C. montrouzieri* was 120.8±17.4 days, the female fecundity (average number of eggs per female) was 805.0±92.1 and daily oviposition per female was 7.0±0.6 on *P. citri*. This difference can be attributed to a larger proportion of eggs not viable in virgin females, but nothing is mentioned in the literature about the role of mating on egg viability for *C. montrouzieri*. The results also show that the percentage of sterility in the descent of these virgin females (*C. montrouzieri*) was high (70 %). This mode of reproduction by arrhenotoky parthenogenesis should be part of any reflection on the development of strategies to control mealybugs and other sale pests using *C. montrouzieri*.

Conclusion

We have reported here the first case of arrhenotoky parthenogenesis in the ladybird *Cryptolaemus montrouzieri* and the role of the *D. opuntiae* waxy cotton matter in stimulating oviposition of the predator (*C.montrouzieri*). Generally, parthenogenesis is considered to develop spontaneously as a result of mutation within the sexual population or as a consequence of hybridization and/or polyploidy (Simon *et al*. 2003; Kearney, 2005; Lundmark, 2006).Thus, further studies are required to determine the mechanisms and circumstances underlying parthenogenesis in *C. montrouzieri*.

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