Journal of Entomology

ISSN 1812-5670

Academic Journals Inc.

www.academicjournals.com

OPEN ACCESS Journal of Entomology

ISSN 1812-5670
DOI: 10.3923/je.2020.93.102

Review Article
Cotton Mealybug *Phenacoccus solenopsis* Tinsley (Hemiptera, Coccomorpha, Pseudococcidae) Associated with Various Crops and Ornamental Plants from Egypt and its Economical Threat on Egyptian Agriculture

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Abstract
Phenacoccus solenopsis Tinsley is a worldwide highly invasive agricultural and horticultural pest. It has been lately recorded as a serious pest on a wide range of host plants in Egypt. This manual presents a comprehensive assembly of information through updated literature on the *P. solenopsis* and would serve as a ready reckoner for use by students and researchers, involved in the study of the mealybug. A review would prove useful for global researchers of plant protection providing a first-hand documented one stop reference. Fascination obtained through study of publications on *P. solenopsis* made in quick succession leading to the present compilation is appreciable, as it would serve as one stop reference manual on the species. This study aims to providing revised pest threat to help more investigations in Egypt.

Key words: Cotton mealybug, *Phenacoccus solenopsis*, *P. solani*, agricultural pest, threat, manual

Citation: Suzan A. Badr, Soad I. Abdel-Razak, Fatma A. Moharum and G.H. Mohamed, 2020. Cotton mealybug *Phenacoccus solenopsis* Tinsley (Hemiptera, Coccomorpha, Pseudococcidae) associated with various crops and ornamental plants from Egypt and its economical threat on Egyptian agriculture. J. Entomol., 17: 93-102.

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

The spread of the cotton mealybug, *Phenacoccus solenopsis* Tinsley around the world is quick and fast. In the latest years many countries were recorded it on several host plants. Its common name cotton mealybug is because of the white, powdery or mealy wax secretion which covers the body of the adult female[1]. It is polyphagous pest infested the whole of the plant organs from roots to buds. It's adapted to many changes of climate, since it recorded in America north and south, Asia, from India and Pakistan reaching China, in Africa comprises Egypt[2]. It's inspired the scientists to make many researches including; phenology, taxonomy, habitat, distribution and also IPM management. Many researches achieved the thermal threshold of the pest, in an attempt to control its outbreak between many hosts all over localities.

The *P. solenopsis* was initially described Tinsley[3] from specimens infesting the roots and stems of *Boerhavia spicata* and *Kallstroemia californica* within the nests of ants, *Solenopsis geminata* in New Mexico, USA.

The adult female of *P. solenopsis* was re-described based on the type specimens from New Mexico and designated a lectotype[4]. However, the mealybug *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae) had a wide geographical distribution with its origin in Central America followed by reports of the Caribbean and Ecuador, Chile, Argentina and Brazil[5].

According to the recent information collected from revision websites[5-7]. It was reported from a wide range of hosts including field crops, vegetables, ornamentals and weeds[8]. At Britain, it was reported that, there are no precise data on the economic losses caused by *P. solani*, but it is recorded as a pest of stored potato tubers in the USA, tobacco in Zimbabwe, Festuca forage crops in Iran and a major pest of tropical foliage plants in Florida[6]. It is also recorded causing symptoms similar to damping-off to young Emilia and *Portulaca oleracea* plants in Hawaii and large colonies cause mature plants to collapse[9]. It was first recorded in Sicily in 1999, Israel 2005, Turkey 2008 and in Spain 2011[7], *Phenacoccus defectus* is an occasional pest of succulent plants[9]. It is recorded from France[7], but no details are provided.

The present study displayed a combined revision on the taxon *P. solenopsis* as well as basic aspects of its biology, ecology and economic importance with an emphasis on wide host plants range. The paper included also revision data on the biology, reproduction, survival and longevity and population growth, in attempt to approach sustainable integrated program to control it in Egypt.

TAXONOMY

The mealybug *P. solenopsis* was named after the ants of the genus *Solenopsis* Tinesley, as it was first described from root of a weed associated with ants[4,10].

Synonyms and identity:

- *Phenacoccus solenopsis*[3]
- Phenacoccus cevalliae[11]
- Synonymised[7]

The names *Phenacoccus gossypiphilous* and *P. gossypiphyllous* were respectively, had been considered as nomen nodum[4]. However, the identity of *P. solenopsis* Tinsley and *P. solani* Ferris were discussed (Table 1).

Diagnosis: The mealybug has been recorded as an important plant pest, it feeds on phloem tissue, removing plant sap and causing the leaves to distort, yellow and even drop[12].

Appearance in life: In previous studies in China, the presence of two sub median longitudinal lines of pigmented spots on the dorsum of adult females, frequently has been used to identify this species[13], in immature stages male and female can be differentiated by the dark spots on body surface in late-2nd instar stage[14].

A field description of the pest was discussed in detail, identified by two dark stripes on both sides of the border in the middle of the body, which form a pair of dark longitudinal lines on the back[15], in addition to comprehensive descriptions and illustrations of adult and immature stages[4].

MORPHOLOGICAL IDENTIFICATION

The morphological differences between *Phenacoccus solenopsis* Tinsley, *P. solani* Ferris and *P. defectus* Ferris were revised in detail[4] based on the morphological variation found in the Asian material, considered-induced variants of a single

Table 1: List of vernacular names of the *mealybug Phenacoccus solenopsis* around the world

Scientific name	Country	Common name
Phenacoccus solenopsis	Worldwide	Cotton mealybug
Phenacoccus solenopsis	America	Chinese *Hibiscus* mealy bug
Phenacoccus solenopsis	Chile	Soil mealybug
Phenacoccus solenopsis	Egypt	Cotton mealybug
Phenacoccus solenopsis	India	Cotton mealybug
Phebacoccus gossypiphilous	Pakistan	Cotton mealybug

Table 2: Three conflict species differences

Diagnostic characters	*P. Solenopsis*	*P. solani*	*P. defectus*
Size	Big	Bigger	Less big
Antennae	9-segmented	8-segmented	7-, 8- or 9-segmented
Curculus	Larger	Smaller oval or round	oval, divided or usually undivided by intersegmental line
Multilocular pores	More located medially on abdominal segments 6-9. 5 loculi	More numerous located medially on abdominal segments 6-7-more than 5 loculi	Present, restricted to venter of segments 7 and 8, rarely on 6
Trilocular pores	Few on the dorsum	Associated with the anal lobe cerarii and over the dorsum	Cerarii with primarily 2 conical setae
Pigmented spots on the dorsum	Present	Without[13]	
Quinquelocular pores	Absent	Absent	Present
Translucent pores	Femur and tibia	Hind tibia only	
Gene analysis	Confirmed [2,13,17,20,21]	Confirmed [22]	Confirmed[23]
Distribution in Egypt	Present[2]	Present[18]	Not present

species. According to the morphological characters and mt COI gene sequence analysis[17], it was concluded that these individuals with phenotypic differences were likely true *P. solenopsis*. However, 2 distinct evolutionary lineages appear to exist in *P. solenopsis* and further evidence is necessary to draw reliable conclusions on the existence of *P. solenopsis* complex species. *Phenacoccus solani* Ferris (Hemiptera: Pseudococcidae) was recorded from Rosetta, a port city at the North Western Nile River Delta, lower Egypt[18]. Sequenced the transcriptomes of adult males and female, from which eight chitinase genes were identified through phylogenetic analysis[19].

TAXONOMIC NOTES

According to the conflict about the related species *P. solenopsis* Tinsley, *P. solani* Ferris and *P. defectus* Ferris, the problem was revised with suggestion that, these three species might be environmentally induced variants of a single species. A few details are given of the biology of *P. solenopsis* on cotton in Pakistan[4]. In China, a sample from Guangxi province, on the basis of the distribution of multilocular disc pores, a discussion about the occasional absence of pigmented spots, took place, emphasizing that they are 2 separate species, *P. solenopsis* and similar species; *P. solani* Ferris[13]. The Food and Environment Research Agency in the UK published PRA (Pest Risk Analysis) of the three species *P. solenopsis* Tinsley, *P. solani* Ferris and *P. defectus* Ferris, as different species[9]. The presence of morphological variations among specimens of *P. solenopsis* in different regions of India often led to misidentification of the mealybug species (Table 2)[24].

It was declared that *P. solenopsis* appears a separate species, identifiable on the basis of both biological and morphological macro and micro-scopic characters[9]. However, just as stated in Egypt on the basis of DNA analysis[2]. Description and illustration of the adult female, immature

Fig. 1(a-b): Appearance in life of (a) Cotton mealybug and (b) *Phenacoccus solenopsis*
Source: (a) Beshr *et al.*[16]
Source: (b) USB Digital Microscope 800X screen

stages and the adult male based on materials from India and Pakistan in Fig. 1 and 2. Confirmed that *P. solenopsis* do not have the pores on their venter[4,25] .

BIOLOGY AND ECOLOGY

Females of this parthenogenic species are capable of producing eggs with a mean range of 150-600 eggs[26]. Therefore, it was concluded that high rainfall reduced the

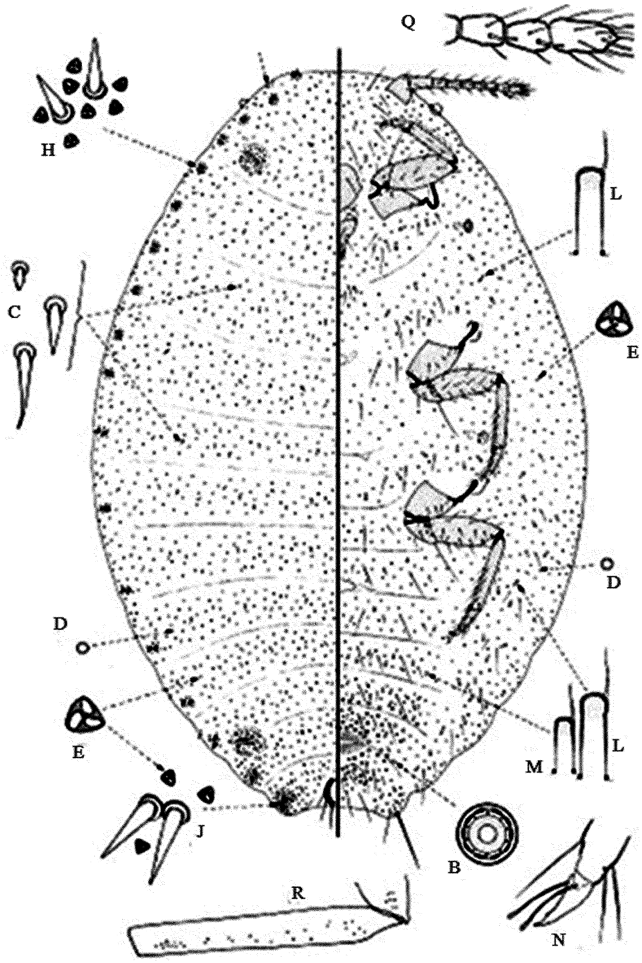

Fig. 2: Description of adult female
Source: Venila *et al.*[47]

population and they found that different phenophases of cotton, as well as biotic and abiotic factors, had direct correlation with the life history of *P. solenopsis*[27]. It was figured out that increasing temperature and decreasing relative humidity had profound effect on the longevity of the females, whereas, longevity of males was less affected [28]. Ability of the *P. solenopsis* to develop with parameters relative to the appearance of symptoms on the cotton crop was discussed in India[29,30]. A discussion about the male role in reproduction took place in China[31]. Gene validation was studied under various biotic and abiotic conditions in India[32].

There are 5 stages (egg, 1st, 2nd and 3rd in stars nymph and adult) in the life cycle of female, while in the male there are six stages (egg, 1st and 2nd instars nymph, pre-pupa, pupa and adult). The egg stage is short, the nymph stage of the female last 15-20 days and the total life span of the female is about 47-59 days, while in the male the nymphal and pupal stage together last about 17-22 days and the total life span of the male is about 20-26 days. Egg ranging from 200-862 (average 458 eggs)[14]. On the other hand the females of this bisexual species are capable of producing 150-600 pale-yellow eggs in a white, waxy ovisac[10].

Longevity of *P. solenopsis* was discussed on three different host plants under controlled environmental conditions[33], in addition the biology of the cotton mealybug on tobacco plant was studied[34]. It was concluded that indoxacarb resistance in *P. solenopsis* was autosomal, incompletely dominant, polygenic and metabolism based[35].

In Egypt, *P. solenopsis* was recorded on three vegetable crops and one field crop. On which also population density studies were made at Fayoum Governorate[36]. Ecological studies were conducted on the Eggplant at Sharkia Governorat[37], the pest were registered on four economical crops for the first time also at sharkia Governorate[38] , then, biological studies were performed under laboratory conditions[39]. The biology of the mealybug was discussed

based on the thermal requirements values, the average life cycle duration from January-December, 2016 was 61.78 days and the number of annual generations was 7.143 when, the average annual temperature was 23.29°C[40]. Also, studying the population dynamic of *P. solenopsis* Tinsley on cotton plants and its susceptibility to some insecticides, in relation to the exposure method[41]. The pest was recorded on soybean, *Glycine max* L. plants (var. Giza 111) in late August at Farm of Sakha Agricultural Research Station, Kafr El-Sheikh[42]. The population fluctuation of *P. solenopsis* was carried out on tomato at Ismailia and Kafr El- Sheikh Governorates[43]. Seasonal fluctuation of *P. solenopsis* on mulberry trees at Giza Governorate was performed[44].

HOST RANGE

There are reported 55 host plant in 18 families[4]. However, documented 154 host plant species 20 of them are economically important field crop, 64 weeds 45 ornamental plants and 25 shrubs and trees, belonging to a total of 53 plant families. The host plants also divided into 4 categories: Incidental, Low, Medium and High[45,10]. Most of these belong to the families Malvaceae, Solanaceae, Asteraceae, Euphorbiaceae, Amaranthaceae and Cucurbitaceae[46]. Weeds aid the faster spread and increased severity across cotton fields[47]. In Nigeria *P. solenopsis* was confirmed as a pest[48]. A discussion on the outbreak of the mealybug on a wide range of host plants in China took place[49]. A study on the effect of photosynthetic performance of tomato after infestation was performed[50]. The infestation problem of the melybug on tobacco host plant (*Nicotiana tabacum*) effect on eggs and crawlers in comparison with cotton was discussed[51]. New distribution were documented with a discussion progress, in the biological control, in Southeast Asia and West Africa[52]. The *P. solenopsis* recorded in Italy and France as an important pest alien to Europe[53]. In a complete study revising the host plants of the mealy bug, in which a list of host plant species were given in alphabetical order, percentage of infestation and ranking of intensity, surveyed the host plant range and the over wintering of the pest in agroecological conditions. However, a definition to the criteria of true 'host plants', which resulted that the presence of the insect on the following host plant species (jangli kikir *Acacia leucophloea,* phulai *A. modesta*, *Albizzia lebbek*, (Mimosaceae), mango *Mangifera indica* (Anacardiaceae), symbol *Salmalia malabarica* (Bombacaceae), shisham *Dalbargia sisso* (Fabaceae), date palm *Phoenix dactylifera* (Palmae)) were a temporary lodge for the mealybug, but these plants did not fall in the criteria of true 'host plants'[51]. All about the biology of *P. solenopsi*, which include its use of diverse host plants, reproductive capacity and mode, adaptation to temperature, response to food shortage and insecticidal resistance was summerized[54]. Extensive field survey had performed on the pest and its natural enemies[55].

In Egypt, it was recorded on tomato[56]. New record on 18 host plants belonging to 11 families at Dakahlia Governorate were carried out by Moharum *et al.*[57]. In Giza Governorate the cotton mealybug recorded on quinoa plants at seed formation stage[58], Okra plant recorded infesting with *P. solenopsis*, in addition to three other vegetable plants as economic crops[38]. Ecological studies were conducted on the pest at Sharkia Governorate[37]. The impact of weather factors on the population density of *P. solenopsis* and its natural enemy were studied[59]. A study was made on the mealybug, added 29 new host plants, they were listed in alphabetical order of families[8]. In Alexandria Governorate, it recorded on two ornamental plants[60]. Other study submitted 20 host plants from 12 families, 8 of them new to Egypt[16], in addition to cotton plant[41]. The annual generations with thermal development of the *P. solenopsis* was carried out[40].

ADAPTATION, DIFFUSION AND DISTRIBUTION

The introduction of *P. solani* through quarantine interceptions were recorded[9]. All the mealybug species accidentally introduced to the USA were listed[23]. The potential distribution of the pest demonstrated that potential distribution was limited by cold in high latitudes and altitudes and dryness in northern Africa, in Australian land and parts of the Middle East[61]. Egypt was involved in the distribution map of the mealybug[5]. *Aenasius arizonensis*, the parasitoid of *Phenacoccus solenopsis* is recorded in Iraq[62]. Study focused on the biology of *P. solenopsis* (Tinsley) under various biotic and abiotic conditions[32]. In Ethiopia, it was recorded *P. solenopsis* on Sesame (*Sesamum indicum*) during a survey for mealybug infestation[63].

BIOLOGICAL CONTROL

As the mealybug was initially discovered in the nests of ant *Solenopsis geminata* Tinsley, 1898a[3]. However, this behavior was proved[46,64]. The impact of the predator *Cryptolaemus montrouzieri* and *Chrysoperla carnea* on the mealy bug *Phenacoccus solenopsis* under laboratories conditions was discussed[65]. In China, the positive interaction of the ant *Solenopsis invicta* (Hymenoptera: Formicidae), in protecting the mealybug through the role of the leaf roller *Sylepta derogate* was studied[66]. Also, in China, a study made

to proposed counter measures for the integrated management of *P. solenops*[67]. It has been reported to be capable of surviving temperatures ranging from 0-45°C, throughout the year[68].

In India, it was surveyed the presence of *Aenasius bambawalei* Hayat (Chalcidodea: Encyrtidae) and *Promuscidea unfasciativentris* Girault (Chalcidoidea: Aphelinidae) as parasitoid[55]. In addition, a laboratory experiments study was conducted on *Aenasius bambawalei* as a solitary endoparasitoid[69]. In a study assessed the impact of primary and secondary parasitoids on the population of the *Solenopsis* mealybug, it was resulted that one primary parasitoid, *Aenasius bambawalei* Hayat and four hyperparasitoids were recovered, *Myiocnema comperei* Hayat (Encyrtidae) and *Allotropa phenacocca* (Platygasteridae)[70]. The parasitoids of *Phenacoccus solenopsis* from Guangdong and Hainan provinces were reported[71]. Also, reported *Aenasius* sp. on the mealybugs[68]. In Israel, it was recognized 14 species of natural enemies in association with *P. solenopsis*, the most commons were: *Aenasius arizonensis* (Girault) (Hym. Encyrtidae), *Cheilomenes propinqua* (Mulsant), *Hyperaspis vinciguerrae* (Capra), *H. polita* Weise, *Exochomus nigripennis* (Erichson), *Parascymnus varius* Kirsch and *Scymnus flagellisiphonatus* (Fursch) (Col., Coccinellidae)[72].

In Egypt, under laboratory conditions, it was carried out a biological study on *Dicrodiplosis manihoti* Harris (Diptera: Cecidomyiidae), the common predator of the mealy bug, *Phenacoccus solenopsis* Tinsley (Homoptera: Pseudococcidae)[73]. A study determine the effects of different temperatures (10, 15, 20, 25, 30, 35 and 40°C), pH values (2, 4, 6, 7, 8, 10 and 12) and incubation periods (1, 3, 5, 7, 9, 11, 13 and 15 days) on *Beauveria bassiana* mycelial growth rates as a biological control agent[74]. In a study it was recorded the primary parasitoid, *Aenasius arizonensis* (Girault) (*Aenasius bambawalei* Hayat) as a solitary, endoparasitoid of *Phenacoccus solenopsis* emerged from its adult stage[75]. Therefore, a study on the natural enemies, the results indicated three species of predators, they are *Hyperaspis vinciguerrae* Capra (Coleoptera:Coccinellidae), *Dicrodiplosis manihoti* Harris (Diptera: Cecidomyiidae), *Scymnus syriacus* Mars. (Coleoptera: Coccinellidae) and two different primary parasitoids associated with the mealybug, *Acerophagus gutierreziae* Timberlake (Hymenoptera: Encyrtidae) and *Chartocerus dactylopii* (Ashmead) (Hymenoptera: Signiphoridae)[44]. The effect of common natural enemies on the population fluctuation of *P. solenopsis* on tomato was studied at Ismailia and Kafr El- Sheikh Governorates[43]. Studied on the feeding potential of the predator *Chrysoperla carnea* (Stephens) in a semi field experiments was carried out at Giza and Qalyubia Governorates[76].

Aenasius bambawalei Hayat, *Anagyrus kamali* Mani, *Cryptolaemus montrouzieri* (Mulsant), *Chrysoperla carnea* (Stephens), *Verticillium lecanii* (Zimmermann) and *Beauveria bassiana* (Vuillemin) are the effective biological control agents in managing the infestation of the pest[5].

CHEMICAL CONTROL

The resistance of chlorpyrifos and Acetamiprid was emphasized[77,78]. It was demonstrated that the mealybug *Phenacoccus solenopsis* suppresses the induced defenses in tomato plant[79]. However, considering *Aenasius* sp. the most effective natural enemies[68]. Eight toxic materials belonging to different chemical group was displaying[41]. In India conducting an article review with IPM Programs suggestions[80]. A management studies was conducted in India on the mealybug[81].

In Egypt, 8 toxic materials belonging to different chemical group were displayed and investigated[41]. Chemical study on potato crops in Alexandria in order to limit the pest's spread was conducted[82]. In addition to that, evaluation of the influence of different chemical and non-chemical treatments against nymphs and adult females of *Phenacoccus solenopsis* on cotton leaves under laboratory conditions in El-Mattana Agricultural Research Station, Luxor Governorate took place[83].

CONCLUSION

The purpose of this study is to serve as a database for researchers and scholars, to enable them to combat this pest worldwide. With the latest changes in climate in addition to the studies available in this database, it is going to be easy to anticipate the spread of this insect and mitigate its current and future effects in Egypt. The combination of studies through computer programs will help in launching an early warning system which can fight the pest effectively.

SIGNIFICANCE STATEMENT

This study discovers the history and controversy surrounding the pest, its main assumption and risks. That can be beneficial for both scientists and farmers. This study will help the researcher to uncover the critical areas of *P. solenopsis* that many researchers were not able to explore. Consequently, a new theory may be devised to limit the serious effects of pest and to reveal invasion history and patterns of dispersal. The aim is to predict simulated programed interaction that in addition to climactic changes could enable the sustainability of Integrated Control Programs in Egypt.

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