UNIVERSITY OF CATANIA
FACULTY OF AGRICULTURE
DEPARTMENT OF AGRI-FOOD AND ENVIRONMENTAL SYSTEMS MANAGEMENT

INTERNATIONAL PhD PROGRAMME IN
PLANT HEALTH TECHNOLOGIES
CYCLE XXIV 2009-2012

JENDOUBI HANENE

CURRENT STATUS OF THE SCALE INSECT FAUNA OF CITRUS IN TUNISIA AND BIOLOGICAL STUDIES ON *PARLATORIA ZIZIPHI* (LUCAS)

COORDINATOR

Prof. Carmelo Rapisarda

SUPERVISOR

Prof. Agatino Russo

CO-SUPERVISOR

Dr. Pompeo Suma

EXTERNAL SUPERVISORS

Prof. Mohamed Habib Dhouibi
Prof. Ferran Garcia Marì

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

In the name of God, Most Gracious, Most Merciful

اقْرَأْ بِاسْمِ رَبِّكَ الَّذِي خَلَقَ

Read! In the name of your Lord Who has created (all that exists).

خَلَقَ الْإِنسَانَ مِنْ عَلَقٍ

He has created man from a clot.

اقْرَأْ وَرَبُّكَ الْأَكْرَمُ

Read! And your Lord is Most Generous,

الَّذِي عَلَّمَ بِالْقَلَمِ

Who has taught (the writing) by the pen

عَلَّمَ الْإِنسَانَ مَا لَمْ يَعْلَمْ

He has taught man what he knew not.

صدق الله العظيم

God the almighty spoke the truth

Declaration

"I hereby declare that this submission is my own work except for quotation and citations which have been duly acknowledged; and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma of the university or other institute of higher learning".

Hanene Jendoubi
08.12.2011

Title Thesis

Current status of the scale insect fauna of citrus in Tunisia and biological studies on *Parlatoria ziziphi* (Lucas)

Dedication

I dedicate this thesis to my wonderful parents who have continuously told me how proud they are of me.

To the memory of my father Mustapha who sacrificed everything to bring me up with love and affection. To my warmth mother Mahbouba; without her support and encouragement before and during my study period and in my entire life, I would never have made it this far.

To my sisters and my brothers for the never ending supports that have given me and for always being there.

All my love and best wishes

ACKNOWLEDGMENTS

*It is with great pleasure that I write these letters in order to express my deep sense of gratitude to **Pr. Agatino Russo**, for giving me the opportunity to obtain my PhD degree, providing me with an adequate foundation for this thesis. He has given me numerous chances to expand my horizons and for that I am forever grateful. Great and distinct thanks to **Dr. Pompeo Suma** for his help and guidance; sincere appreciation goes to him for his encouragement and friendly approach. My gratitude to **Pr. Ferran Garcia Mari,** whom I give all my respect, for his experienced advice and scientific endless support during all my training period at the Agroforestal Mediterranean Institute, Polytechnic University of Valencia. My distinct thanks and sincere respect to **Prof. Dhouibi Mohamed Habib** for accepting me during survey period in the laboratory of entomology at the National Agronomic Institute of Tunisia. **Ms. Marehbene Jamel** director of crop protection service in Nabeul and **Ms. Bou Jemaa,** director of crop protection service in the Northwest region deserve special thanks for the continuous help and great support during all the field surveys conducted in Tunisia.*

*I acknowledge gratefully **the committee of jury** for accepting to evaluate the work and the PhD coordinator **Pr. Rapisarda C.** for all his care in managing very well the PhD programm.*

*I want to thank all my lab partners for helping me with my research. Special thanks to **Dr. La Pergola A.** and **Dr. Zappala L.** for identifying ants and parasits found during my work.*

*Finally, I would like to acknowledge the whole Department of Agri-food and Environmental Systems Management at the University of Catania for their kindness and good-natured attitude; I could not have picked a better department to attend. Special thanks to **Prs. Siscaro G., Mazzeo G., Longo S., Barbagallo S., Coccuzza G.** and the most kind **Dr. S. Bella.***

Finally, I would like to thank all the PhD students and my friends (Ahmed, Antonio, Claudia, Daniel, Khaleed, Sara, and my dear Yosra) for the merry atmosphere and all the pleasant moments we shared together; all the success.

Hanan.

Approval

scales

Scales are soft and scales are hard.

They are in the orchard and in the yard.

The soft ones are attached to their outer skin,

While the hard ones live free within.

Soft scales produce honeydew,

But hard scales find it impossible to do.

It's just as well it works that way-

Legless, the hard ones can't move away.

By Albert A. Grigarick

TABLE OF CONTENTS

ABSTRACTS

English.

The Tunisian scale insect fauna (Hemiptera: Coccoidea), is among the poorly studied fauna in the world. Actually, populations of some species have increased to pest status in many crops and the black scale *Parlatoria ziziphi* Lucas (Hemiptera: Diaspididae) is one of the most important insect pests attacking citrus crop in Tunisia. In the current study, a revision of the scale insect fauna occurring on citrus in Tunisia was done based on the results of field surveys and literature review. Moreover, effects of two temperatures (T_1=20°C; T_2=24°C) and plant substrates (green fruits of lemon and seedling plants of sour orange) on the development, fecundity and life table parameters (the intrinsic rate of increase (r_m), the mean generation time (T_0) and the net reproduction ratio (R_0)) of the black scale were assessed. From surveys conducted in the main citrus growing regions located in the northern part of Tunisia, a total of 84 samples were collected and over 200 slide-mounted specimens were identified. Twenty-one species of scale insects are occurring nowadays on citrus trees in Tunisia; three of them were detected for the first time. An inventory of all species injuring citrus crop in Tunisia and their main characteristics (pest status, change in abundance over time, and distribution) is provided. Results on laboratory studies indicated a consistent influence of the temperature more than the plant substrate on the development and reproductive capacity of *P. ziziphi*. In fact, this species was well adapted at temperatures mainly 24°C. Survival declines clearly at 20°C (37.8% at female stages); while at 24°C very low mortalities were registered. Temperature significantly affected the durations of the majority of immature and adult stages; and total female development approached globally four months at 20ºC and two months at 24ºC. Sex differentiation showed a strong male-biased sex ratio of about 2:1 at 20°C and 1:2 at 24°C. Low mean fecundities were obtained, 26±3.5 and 47.47±1.5 eggs/female at 20°C and 24°C, respectively. In addition, at each generation, *P. ziziphi* had the capacity to increase their populations by a mean of 11.0 at 20°C in an average of 161.5 days with an intrinsic rate of increase of 0.015. At 24°C, parameters become better estimated; *P. ziziphi* populations can multiply meanly 32.35 times in an average of 86 days, with an intrinsic rate of increase of 0.041. As recommendations, the situation of some species is still unclear and it is necessary to continue with prospections in order to have a clearer complete list of species associated with the citrus trees in Tunisia. For life table study, this is a first contribution to assess the biological potential of the black scale under laboratory conditions; studying more temperatures should contribute to a better understanding of the population dynamics of this pest in the field.

Key words: Tunisia, *Citrus* spp., scale insect fauna, inventory, new records, pest status, *P. ziziphi,* temperature, plant substrate, life table, fecundity.

French.

La faune des cochenilles (Hemiptera: Coccoidea) en Tunisie est l'une des faunes les moins étudiées dans le monde. De nos jours, quelques espèces de cochenilles causent des dégâts énormes à plusieurs cultures, on cite le pou noir, *Parlatoria ziziphi* Lucas (Hemiptera: Diaspididae) qui est considéré l'un des ravageurs clés de la culture des agrumes en Tunisie. Dans le présent travail, la liste de la faune des cochenilles inféodées aux agrumes en Tunisie a été revue en se basant sur les résultats d'une prospection conduite en plein champ et une étude faite sur les précédentes publications. En outre, les effets de la température (T_1 = 20°C; T_2 = 24°C) et du substrat végétal (fruits du citronnier et plants de semis de bigaradier) sur le développement, la fécondité et les paramètres biologiques (le taux de croissance intrinsèque (r_m), le temps moyen de génération (T_0) et le ratio net de reproduction (R_0)) du pou noir ont été évalués. Suite aux enquêtes menées dans les principales régions agrumicoles au nord de la Tunisie, 84 échantillons ont été prélevés et plus que 200 spécimens montés entre lame et lamelle ont été identifiés. A présent, vingt et une espèce de cochenilles sont présents dans les différentes parcelles d'agrumes en Tunisie ; Trois d'entre elles sont mentionnées pour la première fois. Un inventaire de toutes les espèces de cochenilles et leurs principales caractéristiques (nuisibilité, changement temporel de la densité et distribution) a été défini. Les résultats obtenus sur les études biologiques menées au laboratoire sur *P. ziziphi* ont montré que la température a une influence plus effective que celle du substrat végétal sur le développement et la capacité de reproduction de cette espèce. En effet, elle a montré une bonne adaptation aux températures, en particulier 24°C. Les taux de survie montrent une baisse distincte à 20°C (37,8% au stade femelle), tandis que de très faibles taux de mortalité ont été enregistrés à 24°C. La température affecte de façon significative les durées de développement des différents stades larvaires et adultes; et le développement total de la femelle était environ quatre mois à 20 ºC, et près de deux mois à 24ºC. La différentiation sexuelle a présenté un puissant male sex ratio, environ 2:1 à 20°C et 1:2 à 24°C. La fécondité moyenne était faible, soient 26±3,5 et 47,47±1,5 œufs/femelle, respectivement à 20°C et 24°C. En outre, à chaque génération, *P. ziziphi* avait la capacité d'accroître sa population par une moyenne de 11,0 à 20°C pendant un temps moyen de 161,5 jours et avec un taux de croissance intrinsèque de 0,015. A 24°C, les paramètres deviennent mieux estimés; les populations du pou noir pouvaient se multiplier en moyenne 32,35 fois dans 86 jours, avec un taux de croissance intrinsèque de 0,041. Comme recommandations, l'état de certaines espèces de cochenilles demeure incertain et il est nécessaire de poursuivre les prospections afin d'obtenir une liste plus claire et complète sur l'ensemble des espèces associées à la culture d'agrumes en Tunisie. Pour l'étude des tables de survie de *P. ziziphi*, il s'agissait d'une première contribution à évaluer les potentialités biologiques de ce ravageur au laboratoire, et l'essai d'autres valeurs de température apportera une meilleure compréhension de la dynamique des populations de ce ravageur en plein champ.

Mots clés: Tunisie, *Citrus* spp., faune des cochenilles, inventaire, nouvelle occurrence, révision, nuisibilité, *P. ziziphi,* température, substrat végétal, table de survie, fécondité.

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Scale insects are some of the most unusual hexapod known. Their common name derives from the frequent presence of a protective covering or 'scale' or from the appearance of the insects themselves. They are very old insects those ancestors occurred in fact during the Triassic Period of the Mesozoic Era, and the primary evolutionary radiation probably occurred in the Early Cretaceous Period (Kosztarab, 1996; Gullan and Cook, 2007).

Scale insects or coccoids (Coccoidea) are sap-sucking hemipterans, sedentary, and highly specialized plant-parasitic insects. Nearly 8000 species are recognized, most of them are polyphagous and eurymerous, feeding on nearly every part of their hosts. They are most important as agricultural pests of perennial plants and can cause serious damage to nut and fruit trees, woody ornamentals, forest vegetation, greenhouse plants, and house plants (Kosztarab, 1996; Gullan and Cook, 2007).

In addition, they are successful invaders of new territories, frequently introduced and acclimatized in different parts of the world. Nowadays, the scale insects are found in all terrestrial zoogeographical regions, except the cold extremes of the Arctic and Antarctic (Pellizzari and Germain, 2010).

Main damage is usually caused by removal of plant sap, but also may be caused by plant pathogens transmission, injection of toxins and the production of large quantities of honeydew with resultant growth of sooty mold fungi that cover leaf surfaces and reduce photosynthesis. It results reduction in quality and salability of fruits, loss of plant vigor, dieback of twigs, and sometimes the death of the entire plant. The worldwide losses, including cost of control, have been estimated to reach five billion dollars yearly (Kosztarab, 1996; Silva and Mexia, 1997; Miller and Ben-Dov, 2010; Pellizzari and Germain, 2010).

In many countries in the world, there is an enormous amount of literature on scale insects including several excellent regional monographs, systematic treatises and review articles. However, the Tunisian scale insect fauna is still up to now poorly known, published records are few and scattered in taxonomic papers by authors. At present, the most complete list of scale insects occurring in Tunisia could be that catalogued in ScaleNet database. Accordingly, there are 58 species belonging to 10 families: Cerococcidae (5), Coccidae (3), Diaspididae (23), Lecanodiaspididae (1), Margarodidae (1), Micrococcidae (4), Monophlebidae (4), Ortheziidae (1), Phoenicococcidae (1), and Pseudococcidae (14). It appears to be a very poor and may be incomplete list of scale insects, compared with those recorded in neighboring countries like Morocco (148), Algeria (169), Italy (365) and France (395) (Russo and Mazzeo, 1997; Ben-Dov and Miller, 2010).

How could be explained this very poor fauna of scale insects in Tunisia? Is it a country free of coccids or because of the rarity of coccidologists and studies? Without doubt and as Gullan and Cook (2007) reported, there may be many undescribed and disguised species in morphologically complexes of cryptic scale insect in the poorly studied regions of the world as Tunisia.

Actually, populations of some species have increased to pest status in many crops in Tunisia, and some of them have been reported as economic pests. We quote the two mealybugs *Planococcus citri* (Risso) and *Planococcus ficus* (Signoret) which cause considerable damage in the vineyards of Mrissa and Takelssa districts; the San Jose Scale, *Diaspidiotus perniciosus* (Comstock), pest of deciduous fruit trees mainly pear; *Parlatoria blanchardi* (Targioni Tozzetti) and *Saissetia oleae* (Olivier) were the main pests of palms and olive trees (Jerraya, 1974, 2003; Morse *et al*., 1996; Mahfoudhi and Dhouibi, 2009).

On citrus crop, many species of scales have long been listed in literature as major pests at various times and in various parts of the country; but they are not generally considered to be the most serious pests. The 1st list of scale insects occurring on citrus trees in Tunisia was published by Pagliano (1938), who mentioned 17 species, and then Millet (1959) who listed the most economic scale species on citrus in the same region. Since then, there have been a very few studies on scale insects on citrus, some of them are quite old. In 2008, studies and field surveys have started again in Cap Bon region in order to identify the species of scale insects feeding on citrus and assess their incidence. A list of 11 species with a new record was reported in the work of Jendoubi *et al*. (2008). As well, it revealed that *Pl. citri*, *Parlatoria pergandii* Comstock and primarily *Parlatoria ziziphi* (Lucas) constitute a real threat to this important crop; they were the most abundant species, spreading in all Cap Bon area. Additionally, the lack of well records documenting the current distribution and biology of main species in Tunisia makes the control difficult and inefficient (Jendoubi *et al*., 2008).

Therefore, this current investigation was imperative to achieve the results of the 1st survey, to improve our knowledge on the biodiversity of scale insects associated with the citrus trees in Tunisia, and eventually to detect additional invasive species of Coccoidea; obviously with the ultimate aim to design an appropriate control strategy. For that, we decided to enlarge the study area in all the northern part, inspecting especially the not yet suspected localities in the Cap Bon region (northeast) and the new planting citrus groves in the northwest.

Here, we present the results of a wide field-survey on scale insect injuring citrus trees in Tunisia, relating these data to those previously reported in literature review in order to give a most complete list of scale species occurring on citrus. Moreover, laboratory experiments on *P. ziziphi* were conducted to study the effect of temperature and plant substrate on the development, survival and reproduction potential of this pest.

The present work has the following objectives:

- Recognition and morphologic identification of species of scale insects collected during the survey;
- Assessment of the incidence and the distribution of species in the northern citrus area;
- Checklist and update of the scale insect fauna of citrus in Tunisia; the origin, regional distribution, abundance and potential harmfulness for each species are discussed;
- Macro-morphological description of the different development stages of *P. ziziphi*
- Life table study of *P. ziziphi* at two temperatures 20°C and 24°C; using two plant substrates fruits of lemon and seedling plants of sour orange.

The manuscript is composed of 4 main sections: after a general introduction, the first section which is a brief literature review on scale insects of citrus; the second section, materials and methods in which we give a description of experimental protocols used for each objective, then the third section, results and the fourth is the discussion. Finally, we input the conclusion and the references cited.

CHAPTER 1. LITERATURE REVIEW

I. Importance of citrus crop

I.1. Historic

The citrus fruit (*Citrus* spp.), because of its attractiveness, good taste and nutritive value, has gained popularity with peoples all over the globe. Citrus is originated from Southeast Asia, since at least 4000 Before Christ, and it has been introduced into many arid or humid, subtropical to tropical regions around the world. The major commercial citrus species that are currently being grown include sweet orange, *C. sinensis*; mandarin, *C. reticulate*; grapefruit or pomelo, *C. paradise*; lemon, *C. limon* and lime, *C. aurantifolia* (Webber, 1967; Mendrec *et al*., 1998).

I.2. Production

According to CLAM (2006), in 2004 there were 140 citrus producing countries. However, most production is concentrated in certain areas; 70% of the world total citrus production is grown in the Northern Hemisphere, in particular in countries around the Mediterranean and the United States; although Brazil is one of the largest citrus producers (Table. 1).

World production of citrus fruit has experienced continuous growth in the last decades of the XX century. Current annual worldwide citrus production is estimated at over 105 million tons, with more than half of this being oranges. In the Mediterranean countries, citrus fruits are produced mainly for fresh fruit consumption. Spain is the leading producing country in the area. USA and Brazil are the leading producing countries of processed citrus fruits. In United States most of the production is consumed domestically (CLAM, 2006; Spreen, 2010)

Table 1. First ten citrus fruits producers in 2007 (Spreen, 2010)

Country	**Production(tons)**
Brazil	20,68
China	19,61
United States	10,01
Mexico	6,85
India	6,28
Spain	5,70
Iran	3,73
Italy	3,57
Nigeria	3,32
Turkey	3,10

I.3. Exports-Imports

Citrus fruits are the first fruit crop in international trade in terms of value. There are two clearly differentiated markets in the citrus sector: fresh citrus fruits market, with a predominance of oranges, and processed citrus products market, mainly orange juice (Mau and Martin Kessing, 2007).

According to FAO, exports of fresh citrus fruits represent roughly 10% of total citrus fruit production. The bulk of exports of fresh citrus fruits is situated in the Northern Hemisphere, accounting for around 62% of world fresh citrus fruit exports in 2003. The Mediterranean region plays a prominent role as fresh citrus exporter, providing nearly 60% of global fresh citrus fruits exports. Major destinations of Mediterranean exports of fresh citrus fruits are the European Union countries. In the case of United States, primary destinations of fresh citrus fruits exports are Japan, Canada and Southeast Asian countries (Fig. 1) (CLAM, 2006; Mau and Martin Kessing, 2007).

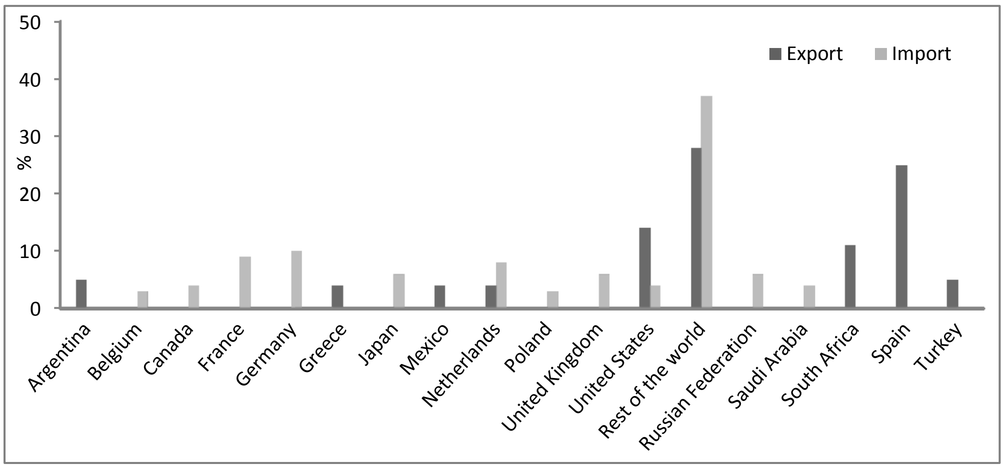

Figure 1. Geographical distribution of fresh citrus exports and imports (Spreen, 2010)

Orange juice

One third of total citrus fruit production approximately is accounted for citrus fruits processing. More than 80% of it is orange processing, mostly for orange juice production. The major feature of the world market for orange juice is the geographical concentration of production in two countries. The State of Florida in USA and the State of Sao Paulo in Brazil makes up roughly 85% of the world market of orange juice: Brazil exports 99% of its production while 90% of Florida's production is consumed domestically and only 10% is exported. The European Union is the largest importer of orange juice, accounting for over 80% of world orange juice imports. Most of imports by the EU and Japan come from Brazil. In North America, the United States and Canada consume mainly orange juice from Florida (CLAM, 2006; Spreen, 2010).

International trade in orange juice takes place in the form of frozen concentrated orange juice, in order to reduce the volume used, so that storage and transportation costs are lower (Mau and Martin Kessing, 2007).

I.4. Citrus production in Tunisia

Tunisia has a long tradition in producing wide varieties of citrus fruit. As in the whole Mediterranean basin, cultivation of citrus goes back to Roman-Era. It appears to have been introduced into the country by Arabs and Portugueses during the fifteenth century. The real development of the citrus industry started in the beginning of the last century. At that time large orchards were created by French occupants. Nowadays, two distinct sectors coexist in Tunisia. One modern, where the production is geared for export and the second, traditional, where the production is oriented to local market and processing. Modern sector is composed of large farms of 50-100 ha and the latter is composed mostly of small farms with an average area less than 6 ha (GIF, 2010).

Citrus production in Tunisia, although widely distributed geographically, is located primarily in the northeast regions (Fig. 2). Nabeul produces 74% of national production; the remaining regions produce 26%. The orange is the most cultivated citrus fruit in Tunisia, followed by the Clementine and lemons. Maltaise ½ sanguine oranges make up about 50% of orange production with 5500 ha under production and 84% planted in Nabeul. It is considered the first citrus species oriented to foreign markets having a high potential for export (100%). European Union markets mainly France and the Middle East are by far the main destination of Moroccan export. Citrus cultivation represents an important source of employment for thousands of families. As over 50% of the production volume is exported, it is thus an important source of hard currency (GIF, 2006).

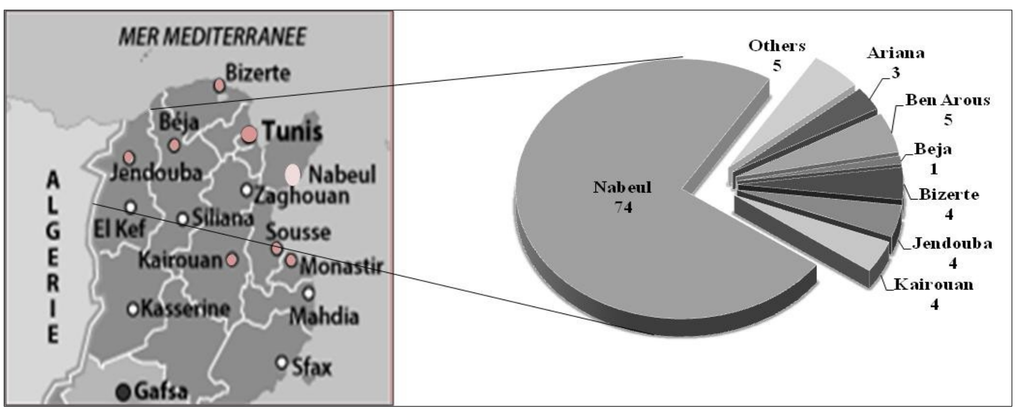

Figure 2. Citrus distribution (%) in different regions of Tunisia (GIF, 2010)

The current harvest of citrus in the Nabeul region will reach an estimated 258,000 tons, an increase of 13% on the same period last year. The increase in production concerns tangerines in particular, which increase from their previous level of 18,700 tons to 30,000, lemons (from 22,000 to 30,000 tons), and Thomson oranges (from 23,000 to 30,000 tones). Nabeul is known as Tunisia's citrus capital, and is home to 85% of the country production (GIF, 2010).

II. Coccoid pests of citrus

The coccoids have been serious pests of citrus crops for over one hundred years. The families Margarodidae, Pseudococcidae, Coccidae and Diaspididae include the largest number of species injuring to citrus (Gullan and Cook, 2007).

The taxonomic, biology, management and economic importance literatures on scale insects are extensive and many publications are available. Here, we provide a brief description of the main features of species belonging to these four families.

II.1. Classification

Scale insects are more diverse in terms of major evolutionary lineages (families), species richness, genetic systems and morphology. Until fairly recently, there is some discusses about their rank in the classification system. They were thought to belong to the Order Homoptera, but now they are considered by many to be members of the Order Hemiptera, belonging to a distinct suborder called the Sternorrhyncha. As well, there is currently considerable debate among scale workers about the appropriate level of classification of the scale insects; the question is whether they should be a superfamily (Coccoidea) or a suborder (Coccinea). For example, some authors as Kosztarab (1996) used the group as order, divided in two Superfamilies, Orthezioidea and Coccoidea.

Additionally, evolutionary relationships of scale insects are still controversial. The neococcoids (advanced group) form a monophyletic group supported by both morphological and genetic data. In contrast, the monophyly of the archaeococcoids (primitive group) is uncertain and the higher level ranks within it have been controversial. In fact, there are many unresolved questions in scale insect phylogeny relating to relationships within and among families, and monophyly of major groups at family level and above. Most species diversity of Coccoidea occurs within the neococcoid families Coccidae, Diaspididae and Pseudococcidae, and resolving the relationships of their constituent species and genera will provide more predictive classifications of these economically important families. Lately, a phylogenetic study based on the morphology of adult male neococcoids is in progress. The latter, together with the ongoing molecular studies, should culminate in a new family-level classification of all neococcoids in the near future (Gullan and Cook, 2007).

For the purpose of this work, we follow the most recent classification reported in scalenet database (Table. 2). The group will be the superfamily of Coccoidea which comprises up to 32 families, with 8000 species (Gullan and Cook, 2007; Ben-Dov, 2010).

Table 2. Classification of the superfamily Coccoidea (Ben-Dov, 2010)

Class: Insecta
Sub-class: Pterygot
Super order: Hemipteroida
Order: Hemiptera
Sub-order: Sternorrhyncha
Super family: Coccoidea

Family Name	
Aclerdidae	Kukaspididae
Albicoccidae	Kuwaniidae
Arnoldidae	Labiococcidae
Asterolecaniidae	Lebanococcidae
Beesoniidae	Lecanodiaspididae
Burmacoccidae	Lithuanicoccidae
Calipappidae	Marchalinidae
Carayonemidae	Margarodidae
Cerococcidae	Matsucoccidae
Coccidae	Micrococcidae
Coelostomidiidae	Monophlebidae
Conchaspididae	Ortheziidae
Dactylopiidae	Pennygullaniidae
Diaspididae	Phenacoleachiidae
Electrococcidae	Phoenicococcidae
Eriococcidae	Pityococcidae
Grimaldiellidae	Pseudococcidae
Grohnidae	Putoidae
Halimococcidae	Serafinidae
Hammanococcidae	Steingeliidae
Inkaidae	Stictococcidae
Kermesidae	Stigmacoccidae
Kerriidae	Weitschatidae
	Xylococcidae

II.2. Morphology

The Coccoidea are known as Sternorrhyncha, belonging to the order Hemiptera. They are distinguished from other groups of Sternorrhyncha by the possession of a single claw at the apex of each tarsus; all other insects possess double claws in this position (Dhouibi, 2002).

II.2.1. Adult females

These are variable in shape but normally are ovoid, elongate or circular. The main body regions often are indistinct and fused. The dorsum is usually convex, with the venter which can be flat, concave, or rarely slightly convex (Dhouibi, 2002).

The body size of scales varies from 0.5 to 35 mm. The antennae are absent or 1- to 16-segmented. In the Diaspididae, the antennae are reduced to un-segmented stubs, while in some Margarodidae, the segments rarely number up to 16. The eyes are simple, and normally reduced to two small pigmented areas. In some Pseudococcidae, the eyes are normally on sclerotized bulging eyestalks. The mouthparts include the clypeolabral shield and the un-segmented to 4-segmented conical labium with four piercing-sucking stylets; labial characters were found to be useful in higher classification (Kosztarab and Kozar, 1988; Williams and Watson, 1988; Dhouibi, 2002; Ben-Dov and Miller, 2010).

The legs in scale insects vary from well-developed and 5 –segmented to entirely lacking (e.g. Diaspididae). At base of the claw are two setose or spatulate claw digitules, of adhesive function. The claw often has a small denticle on its inner or plantar surface. The trochanter is normally triangular with 2 or more sensory pores on each surface; a number of small translucent pores often occur on the hind coxa, on the femur of some Eriococcidae, and on all or any of the coxa, femur or tibia of some Pseudococcidae. Morphological characters of leg segments, and also the arrangement, size and number of setae and spines, are often useful in separating species (Kosztarab and Kozar, 1988; Williams and Watson, 1988; Dhouibi, 2002; Ben-Dov and Miller, 2010).

The four large thoracic spiracles are present in all families, but the small abdominal spiracles are only found in Margarodidae and Ortheziidae. Normally, a number of discoidal pores are associated with each thoracic spiracle, and such pores often form rows or bands from the spiracle to the margin of the body, where some thick spiracular setae are situated in some families (Kosztarab and Kozar, 1988; Williams and Watson, 1988; Dhouibi, 2002; Ben-Dov and Miller, 2010).

The body margin and derm surface normally bear setae of various sizes and shapes. Wax-producing discoidal derm pores are different types; these types and their arrangements often are characteristic of certain higher taxa. Most dermal ducts are tubular and of various shapes and sizes, and are useful characters in the classification of coccoids (Kosztarab and Kozar, 1988; Williams and Watson, 1988; Dhouibi, 2002; Ben-Dov and Miller, 2010).

The abdominal segmentation is not always distinct. There are only 8 segments in the Diaspididae and 10 in the Pseudococcidae (McKenzie, 1967). In the Diaspididae the terminal segments from the 4th or 5th to the 8th are fused into a pygidium, which contains specific lobes and plates on its posterior margin. The anal opening normally is located on the last abdominal segment. In most of the families the anal opening is surrounded by a sclerotized anal ring which bears setae and wax pores. In the family Margarodidae the anal ring is small and lacks setae or pores. The anal opening normally is covered by two anal plates in the Coccidae, an anal cleft is present. The vulva is located on the ventral side of the abdomen between the borders of the 8th and 9th segment in Pseudococcidae. Its presence identifies mature females. In the Diaspididae, it is located between the 7th and 8th segments and usually is surrounded anteriorly and laterally by 4 or 5 groups of perivulvar pores. The abdomen usually terminates in two protruding anal lobes, e.g. Pseudococcidae, which bear setae. The longest seta is distinguished as the anal–lobe seta (Kosztarab and Kozar, 1988; Williams and Watson, 1988; Dhouibi, 2002; Ben-Dov and Miller, 2010).

The female body and her eggs are usually protected by a felt-like ovisac, by wax powder and loose wax threads (e.g. Pseudococcidae), or by a secreted test or shield (e.g. Diaspididae). Primitive scales carry their eggs attached to the end of their abdomen, in a tube-like ovisac made of wax plates (Kosztarab and Kozar, 1988; Williams and Watson, 1988; Dhouibi, 2002; Ben-Dov and Miller, 2010).

II.2.2. Immature stages

Immature instars have not been studied intensively until recently. This stage normally is recognized by its elongate elliptical or ovoid shape; small size, 0.3 to 1mm length in most; well developed 5-segmented legs, with 1 claw; and usually long 5- or 6-segmented setaceous antennae, which may possess several fleshy setae. Their derm normally bears 2 single-faceted eyes, 4 thoracic spiracles, a large clypeolabral shield, and a labium with a crumena and 4 stylets; various disc pores, tubular ducts, and setae; an anal ring which has a band or row of translucent pores, and 6 setae. The anal lobes usually are well-developed, protruding, and have long, anal-lobe setae (Kosztarab and Kozar, 1988; Williams and Watson, 1988; Dhouibi, 2002; Ben-Dov and Miller, 2010).

II.2.3. Adult males

The three main body regions are usually distinct. The head is often sclerotized and is well separated from the thorax with a "neck" region (e.g. Coccidae, Pseudococcidae), or is fused to the thorax (e.g. Diaspididae). The antennae are thread-like and are 9-10 segmented, with many setae. The eyes are of several different types depending on the family. A pair of multifaceted compound eyes is common in some Margarodidae; 5 to 7 pairs of simple eyes, also a pair of ocelli are found in Putoidea; 2 to 5 pairs of simple eyes with 1 pair of lateral ocelli are present in many Coccidae; and only 2 pairs of simple eyes (1 pair located dorsally and 1 pair ventrally on the head) are common in most Coccidae, Eriococcidae and Diaspididae, except that ocelli are also present in nearly all Aspidiotini. The mouth is non-functional; its opening is usually surrounded by a small ventral plate (Kosztarab and Kozar, 1988; Williams and Watson, 1988; Dhouibi, 2002; Ben-Dov and Miller, 2010).

The thorax is variable, usually partially sclerotized with well-defined sclerites and ridges separating it into pro-, meso-and metathorax. The mesothorax normally has the main sclerites (prescutum, scutum, and scutellum), well differentiated. When present, only 1 pair of wings develops; these usually are long and slender or are short. The wings are thin, membranous, and normally transparent; usually with only 2 obvious veins. The second wing pair is reduced to hamulohalteres, each bearing apically one or more hooked setae. The legs are long and slender, with many setae and 1-or 2-segmented tarsus and a single claw. The trochanter and femur are rarely fused. Four thoracic spiracles are present (Kosztarab and Kozar, 1988; Williams and Watson, 1988; Dhouibi, 2002; Ben-Dov and Miller, 2010).

The abdomen is 9-segmented and terminates in a well –developed bivalve penial sheath. Disc pores are present or absent. Their presence is characteristic of primitive members of Coccoidea (Kosztarab and Kozar, 1988; Williams and Watson, 1988; Dhouibi, 2002; Ben-Dov and Miller, 2010).

Some species, especially in Diaspididae, males are dimorphic. In such cases, the winged forms are usually abundant in the first generation, while wingless forms are predominant in the second generation of the same species. The mealybug, *Polystomophora ostiaplurima* (Kiritchenko), was found trimorphic by Vinis and Kozar (1981) (cited in Kosztarab and Kozar, 1988) but this condition, the presence of macropterous, brachypterous and apterous forms in the same species, is probably not uncommon in other taxa.

II.3. Biology and life history

For such a large group of insects, it is no surprise that their life histories are quite variable. Males have their own specially derived form of a complete metamorphosis. They usually have four immature stages, two pupalike instars called prepupa and pupa that develop in a waxy enclosure produced initially by the second instars. Their activities are restricted to feeding (only at the first two instars) and mating. Females usually have two or three developmental stages to reach maturity (Fig. 3) (Dhouibi, 2002; Ben-Dov and Miller, 2010).

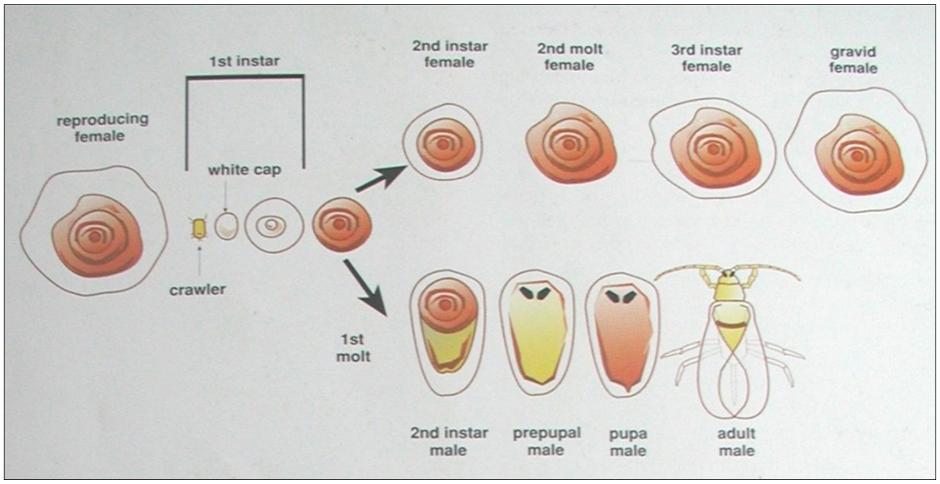

Figure 3. Life cycle of red California scale (Forster *et al*., 1999)

Reproduction is usually sexual but parthenogenesis occurs in some species; hermaphrodity has been recorded in Margarodidae species, at least 5 species of *Icerya* are hermaphroditic. Others species as soft scales have both sexual and parthenogenetic reproductions. Scales have the greatest diversity of sperm structure and sex determining chromosome systems. Ovipary, ovovivipary and vivipary occur; the eggs lack a peduncle and are laid under the protective scale cover or in a waxy ovisac produced by the female (Kosztarab and Kozar, 1988; Kosztarab, 1996; Ben-Dov, 2007).

Most species of scale insects have from one generation, two or three per year and up to eight generations indoors for *Phenococcus gossypii* Townsend and Cockerell, while some Margarodidae require more than one year for development. The overwintering stage varies between species. *Lepidosaphes ulmi* (Linnaeus) remains in the egg stage. *D. perniciosus* passes the winter as a first instar. *Parthenolecanium corni* Bouché and *Quadraspidiotus ostreaeformis* (Curtis) survive the winter as second instars while *Epidiaspis leperii* Signoret, overwinters as an adult female (Kosztarab, 1996; Ben-Dov and Miller, 2010).

II.4. Ecology and dispersal

Abiotic conditions. Nutrients in the soil or in the plant may play a role in the rate of scale infestation. The population build-up of *Pseudococcus comstocki* (Kuwana) and *Fiorinia Externa* Ferris was directly related to the amount of nitrogen fertilizer in apple orchards. Both temperatures and humidity limit the range and abundance of scale insects. Many species are adversely affected by high humidity which favours the development of parasitic fungi. On the other hand, extensive summer heat and drought could be the main cause of mortality among the unprotected crawlers of some armoured scales (Williams and Granara De Willink, 1992; Kosztarab, 1996; Miller and Davidson, 2005; Ben-Dov and Miller, 2010).

Biotic conditions. Scale insects maintain various types of relationships with both plants and other animals. Miller and Kosztarab (1979) have been summarized the host-scale interactions with emphasis on North American conditions. Coccoids occur on nearly all parts of the host, but most Coccinea live on the above-ground parts of plants, and many species are specific to certain parts of plants. Some species infest roots only, e.g. *Chortinaspis subterraneus* (Lindinger), *Rhizoecus spp*.; while *P. pergandii*, infests all the above-ground parts of trees and shrubs (Williams and Granara De Willink, 1992; Kosztarab, 1996; Miller and Davidson, 2005; Ben-Dov and Miller, 2010).

Micro-habitats. Many scale insects show preference for tight protected areas, such as crack and crevices of bark, leaf axils, root crowns, or nodes of grass stems. Mealybugs often seek out tunnels bored by insect larvae in the roots or stems (Kosztarab, 1996).

Host-specificity. The Coccoid infesting citrus crop vary in their degree of polyphagy and host preference. Most of the important pest species are polyphagous (e.g. *Pl. citri*). Others are oligophagous and feed on plant belonging to one family or one genus as *P. ziziphi*. There are very few monophagous species; e.g., *Xylococcus filiferus* Lôw, which is known only from linden (Kosztarab, 1996; Miller and Davidson, 2005; Ben-Dov and Miller, 2010).

Scale insects and ants. Mealybugs and soft scales benefit most from ant associations, both directly and indirectly. The ants by removing the honeydew produced by these insects, they eliminate the growth of sooty mould, a fungus that could destroy the scale insects. They protect the coccoids from their natural enemies. Further protection is provided by ants when they keep the scales in their underground galleries during winter, construct tents over mealybug and soft scale colonies to protect them from summer heat and sunlight, and transport the scales to new plants when host conditions become unsuitable. Ants in turn benefit from this mutuality association by being provided with honeydew for a constant food supply (Rosen, 1990; Kosztarab, 1996; Ben-Dov and Hodgson, 1997).

- **Dispersal**

Many important pest species of Coccoidea have been spread by man through the movement of cuttings, nursery stock and produce, to the extent that they are now virtually cosmopolitan. Consequently, natural dispersal mechanisms have been a largely neglected topic for research. But many studies have all shown that dispersal by wind currents is a common feature among Coccoidea. In fact experimental results demonstrated the importance of wind in the dispersal of crawlers of principally armoured scales, *Aonidiella aurantii* (Maskell) and *Aulacaspis tegalensis* (Gresthead), some Monophlebidae as *Icerya seychellarum* (Westwood) and soft scales as *Ceroplastes floridensis* Comstock and *Coccus hesperidum* (Linnaeus). Ants often purposefully move honeydew producing specimens to new host plants or an overwintering shelter (Rosen, 1990; Ben-Dov and Hodgson, 1997).

Scale insect populations disperse mainly through the motile first instar or crawler stage. Crawlers generally are on the underside of branches and leaves and on the side of the trunk that provides maximum protection from direct sunlight, wind, and rain. The adult females and nymphal stages of species that retain their vagility throughout their entire life as the Pseudococcidae may also move limited distances. The males are able to disperse as winged adults. With some species like *Dactylopius austrinus* De Lotto, female crawlers develop long waxy threads which aid dispersal (Moran *et al*., 1982; Kosztarab, 1996; Miller and Davidson, 2005; Ben-Dov and Miller, 2010).

III. Pest status of citrus scale insects
III.1. Economic importance and damages
III.1.1. Economic importance

The injury severity of scale insects is related to several features; they are obligatory plant parasites and cosmopolitan pests which are found in all terrestrial zoogeographical regions except Antarctica. Most of them are eurymerous, feeding on various parts of the host plant as Pseudococcids species, while a smaller number are stenomerous, restricted to only one plant organ as feeding site. In addition, their success in invading new territories has made them a constant threat in many parts of the world. Notable examples are diaspidids, classical invading pests; being sessile and rather cryptic; they have often invaded new area with the imported plant material. Also, in local areas, many species can build up damaging population levels under favorable conditions such as the more active groups of scale insects, the mealybugs (Kosztarab and Raymond, 1997; Rose, 1997; Silva and Mexia, 1999; Ben-Dov and Miller, 2010).

However, a substantial number of scale species have been proven to be especially troublesome to the plants cultivated. In some cases, the monetary loss caused by some species has devasted the agricultural economy of several nations. The economic loss worldwide attributed to all scale insects, including the cost of control, has been estimated to be 5 billion US$ annually and probably a quarter of that loss was due to species of Coccidae (Kosztarab and Raymond, 1997). This expense can be reduced by the prevention of infestation and appropriate pest management practices.

III.1.2. Damages

Scale insects are generally regarded as being extremely polyphagous pests. They are most important as agricultural pest of perennial plants and can cause serious damage to nut and fruit trees, woody ornamentals, forest vegetation, greenhouse plants, and house plants (Kosztarab, 1996; Ben-Dov and Miller, 2010).

Damages caused by scale insects to host plants include both direct and indirect components. The direct components occur as a result of feeding activities. In fact, the main injury caused by scale insects is the ingestion of plant sap, resulting in the loss of plant vigor, poor growth, dieback of twigs and branches, leaf drop, and sometimes the death of the plant. While penetrating the plant tissues with their piercing stylet for feeding, they also inject saliva, which appears to be toxic to the plant. The saliva often produces chlorotic yellow or red discoloration on leaves and fruits, deformation of shoots and branches (Fig. 4) (Kosztarab, 1996; Silva and Mexia, 1997).

Scale insects also cause indirect damages to plants by excreting honeydew that becomes a growth medium for sooty mold fungi, producing a black coating on leaf surfaces. The coating interferes with photosynthesis and may cause poor growth, leaf drop, less sugar in fruits, and unsightly appearance of ornamentals plants. Scale insects, by injuring the plant surface with their feeding stylets, open wounds for the entry of plant pathogens, they also may transmit pathogens and plant virus diseases. About 18 species of mealybugs have been reported as vectors of plant viruses but no mealybug is reported to transmit pathogens on citrus trees (Cabaleiro and Segura, 1997; Kosztarab and Raymond, 1997; Petersen and Charles, 1997; Vranic, 1997).


Figure 4. Scale insects infesting citrus twigs (*Icerya purchasi* Maskell) and fruits (armored scale)

Although most species of scale insect are potentially damaging, a few may be beneficial to man. Thus, some species may be found to be useful as biocontrol agents of weed species as mealybugs, whilst others have been found to produce useful products as sources of dyes (cochineal scales, gall-like scales, giant scale, and lac scale), of candle wax (soft scales), of the manna of the Israelites (mealybugs). Thus, *Ericerus pela* (Chavannes) has been used for more than 1000 years to produce “china wax”. The wax produced by *Ceroplastes ceriferus* (Fabricius) has been similarly important in India. In addition, soft scales produce large quantities of honeydew, which can form an important part of the diet of many ants, wasps, flies and others animals (Kosztarab, 1996).

III.2. Control

III.2.1. Monitoring and prevention

The frequently method used as a guide for forecasting the cycle of pests and making control decisions include sexual pheromonal trapping, sampling and the thermal integrals or temperature sums. For example, the thermal integral for *L. beckii* is 1083 degree days from 1st January with a zero of development at 7.6 °C. Agrometeorological models, based on climate data, have been realized also to estimate the length and starting times of parasites phenological phases. In Italy (Sicily), a new network of 95 GSM meteorological stations and a specific mathematical model for *A. aurantii* are used for the integrated pest management program of citrus orchards (Kosztarab, 1996; Pasotti *et al*., 2006).

Prevention of scale insect infestation is an important and continuous task for plant growers. This may include planting of resistant varieties, use of certified pest free nursery stock for propagation; prevent the introduction of pest species to new areas which are provided by quarantine regulation. It is particularly important to localize foci early in cracks and cavities in the bark of the trunk and main branches, as well as in fruits which remained on the tree after harvest (Kosztarab, 1996).

III.2.2. Cultural and mechanical controls

Cultural practices are important in infestation prevention and control. They provide optimal conditions for plant growth with proper cultivation practices. Pruning will aid in opening up the canopy to maximize spray penetration and coverage. Additionally, considerations should be given to the native and ornamental vegetation surrounding crop systems. These plants frequently serve as reservoirs for reinfestation of orchards. Thorough cleaning of equipment and harvest materials will help prevent the spread of mealybug from an infested grove to others (Kosztarab and Kozar, 1988; Kosztarab, 1996; Kerns *et al*., 2004)

Mechanical control may include scraping encrusted scales from tree trunks and large branches with a wire brush. The scraping should be removed, by placing sheet at the base of the tree, and destroyed if eggs or crawlers are present. Tying sticky tangle foot bands to tree trunks will kill many scale crawlers and other insects (Kosztarab and Kozar, 1988; Kosztarab, 1996).

III.2.3. Chemical control

Chemical control should be applied only when it is justified by economic level of scale infestation. Most scale insect species can be best controlled at the time of first instars emergence, the most fragile and easily controlled stage due to the absence of the protective wax cover (Kosztarab and Kozar, 1988; Kosztarab, 1996).

For coccoids feeding on roots, systemic pesticeds may be applied in granular form as a drench. Scale insects that live on leaves, or in leaf sheaths of grasses, are controlled with systemic sprays. On woody plants, dormant oil sprays may be applied against over wintering life stages during early spring, while systemic or contact insecticides are used during the crawler stage. Scale insects were also controlled successfully with summer oil sprays like Volk-Ete in California and Algeria. As bioassays, it is shown recently that a full-strength mixture of limonene 1%, a citrus extract, provided a good control of mealybugs and scales varying between 69% and 100% of control (Hollingsworth, 2005).

III.2.4. Ant control

The management of ants that tend honeydew-secreting Coccoidea pests is a key component of integrated pest management citrus orchards and biological control programs, in order to optimize the effectiveness of natural enemies (Tollerup *et al*., 2004).

Itioka and Inoue (1996) demonstrated that ladybird beetles (Coccinellidae) and green lacewings (Chrysopidae) reduced the population of mealybug, *Pseudococcus cryptus* Hempel, on Satsuma orange by 94% when the ant (*Lasius niger*) was controlled. The percentage parasitism by *Aphytis melinus* DeBach on *A. aurantii* in the ant-free control treatment averaged 24.9% than the 2.4–11.5% parasitism found in the presence of three ant species (Martinez-Ferrer *et al*., 2003).

The argentine ant *Linepithema humile* (Mayr) is regarded as a nuisance or a pest in the Mediterranean Basin that it has invaded. (Franco *et al*., 2004) showed that in the absence of this ant, the populations of the citrus mealybug were effectively reduced by their respective natural enemies.

Current strategies to control ants in orchards generally include the application of the short residual organophosphate insecticides chlorpyrifos applied as granules or a liquid spray on the soil surface. Repeated applications with chlorpyrifos or diazinon on skirt-pruned citrus trees gave reasonably good results. However, Low-toxicity ant baits are more effective than the broad-spectrum insecticides. Ant baits are target-specific, the risk to non target organisms and risk of environmental contamination are also minimized. This method includes sticky bands strapped or taped around the tree trunk, or placing insecticide-treated bands around them (Grafton-Cardwell *et al*., 1996; Jahn and Beardsley, 1998; Rust *et al*., 2000; Jahn *et al*., 2003).

III.2.5. Biological control

An important component of Integrated Pest Management is the biological control. It has been successfully practiced on citrus groves in the Mediterranean region. The potential natural enemies for the biological control of most scales, and mealybugs appeared to be very promising in many cases. For example, the exotic natural enemies *Aphytis melinus* DeBach, and *Cryptolaemus montrouzieri Mulsant* and *Leptomastix dactylopii* Howard can efficiently biocontrol *A. aurantii* and *Pl. citri* respectively and they are currently used by several citrus growers in the Mediterranean countries such as France, Italy and Morocco. Also, many scale species have a diverse complex of natural enemies including hundreds of native species of parasites and predators. The largest numbers of parasitoid are chalcidoid wasps, most of which belong to the Encyrtidae, Aphelinidae and Eulophidae families. The best known predators reported in the literature are Coleoptera (Coccinellidae), Lepidoptera, Diptera and Acari (Driesche and Bellows, 1996; Morse *et al*., 1996; Miller and Davidson, 2005).

The management of natural enemies in the Mediterranean Basin can be divided in two major categories: augmentation and conservation. The augmentation involves the direct manipulation of parasitoids and predators, either by mass production and periodic releases or by planned genetic improvement. Effective conservation of established natural enemies involves manipulation of the environment (Driesche and Bellows, 1996; Morse *et al*., 1996).

III.3. Major species pests in Mediterranean Basin

III.3.1. Recognition of main pest citrus families

Diaspididae are generally considered to be the most speciose family and the most economically important and destructive groups of pests in agricultural and horticultural crops, followed by the Coccidae and then the Pseudococcidae. Species occur in all zoogeographic regions and they have been collected on a diverse array of host plants. Based on an analysis of the host data presented in Borchsenius' catalog (1966), armored scales injury about 180 families of host plants and nearly 1,400 host genera. Besides, Soft scales and mealybugs occur on a wide diversity of host plants from woody perennials to herbaceous and in all zoogeographical regions of the world. Based on an analysis of the host information in the mealybug catalogue by Ben-Dov (1994), Mealybugs occur on about 250 families of host plants (Ben-Dov, 2010).

- **Pseudococcidae**

The presence of honeydew and sooty fungus is one way to detect infestations of these insects. Adult females are often characterized by a white, mealy or powdery secretion that covers the body. This makes them appear like small spots of cotton on the plant particularly when the female is laying eggs (Fig. 5). Many of them produce marginal filaments of wax that may be wedge-shaped or spine-like, but others lack marginal filaments entirely. An ovisac is produced which encloses the eggs in the last part of the body (Williams and Granara De Willink, 1992; Dhouibi, 2002).

Figure 5. Young instars and females of *Pl. citri*

Diaspididae

Diaspididae were reported as first family by Brues and Melander (1932) (cited in Ben-Dov, 2010). Armored scales are the smallest scale insects (1- 3mm). Armored scales are fairly easy to recognize because of the many adaptations that occurred. The body of the insect is protected by an armor that isn't attached to the body; it can be seen by lifting off this hardened wax cover; wax covering contains exuviae of 1 or 2 immature instars incorporated and usually visible; occurring on nearly any part of plant, rare on roots and rootlets; some species become buried under plant epidermis. The exposed body is usually yellow or orange, but may have a pink or red color to it (Fig. 6). Scale cover varies from circular to elongate or oyster shell-shaped. Male and female covers may differ in size and shape for the same species, the female cover is generally the largest (Dhouibi, 2002; Miller and Davidson, 2005).

Coccidae

This family is so diverse morphologically that there are exceptions to most diagnostic characters. The appearance of soft scales in the field is highly variable depending on the group but can be distinguished by their larger size (2-6mm); round or oval body outline, and convex or hemispherical profile. The body is bare or covered with a clear glassy-type wax that adheres to the insect's body (Fig. 7). If one turns the adult soft scale over, legs, antennae and thread-like mouthparts are readily visible under the microscope. Infested plants are often sticky with honeydew excreted by the insect (Williams and Watson, 1988; Ben-Dov, 1993; Hodgson, 1994).

Figure 6. Females of *L. beckii* (Diaspididae)

Figure 7. Colonies of *C. hesperidum* (Coccidae)

III.3.2. List of main species

Scientists have listed at least 900 species of scale insects in the Palearctic region. 21 species are recorded as the major scale pests on citrus, knowing to occur in the Mediterranean area (Table. 3). The armored and mealybugs scales constitute the predominant citrus-infesting scale fauna in the Mediterranean regions, representing 47% and 35% of major species respectively. According to historical accounts, various species such as the California red scale, the purple scale, the Florida red scale and others have caused major loses to citrus in the past and nowadays (Franco *et al*., 2004; Ben-Dov and Miller, 2010).

Table 3. Major scale pests of citrus in the Mediterranean regions (Rose, 1997; Franco *et al*., 2004)

Monophlebidae	Pseudococcidae	Diaspididae	Coccidae
I. purchasi	*Pl. citri*	*A. aurantii*	*Coccus pseudomagnoliarum* (Kuwana, 1914)
	P. cryptus	*Aspidiotus nerii Bouché*	*Saissetia oleae* (Olivier)
	Pseudococcus longispinus (Targioni Tozzetti, 1868)	*Chrysomphalus aonidum* (Linnaeus)	*Ceroplastes japonicus Green*
	Pseudococcus calceolariae (Maskell)	*Chrysomphalus dictyospermi* (Morgan)	*Ceroplastes rusci* (Linnaeus)
	Pseudococcus viburni (Signoret)	*L. beckii*	*Ceroplastes sinensis* DelGuercio
	Nipaecoccus viridis (Newstead)	*Lepidosaphes gloverii* (Packard)	*Protopulvinaria pyriformis* (Cockerell)
		P. ziziphi	
		Parlatoria cinerea Hadden	

IV. Scale insect species of citrus in Tunisia

In Tunisia, the citrus is host to 41 arthropods species that are considered to be pests. Among them, 21 belong to the group of Hemipterans. The Mediterranean fruit fly *Ceratitis capitata* (Wiedmann) is the most important citrus pest followed by aphids, scales, thrips, mites, whiteflies and moths (Jerraya, 1974, 2003; Morse *et al*., 1996; Tena and Garcia Mari, 2011). Scale insects are present in a poor number in Tunisia. According history records, about 56 species of scales belonging to 8 families, are known to occur in Tunisia half a century earlier. Actually, twenty-one of them are recorded injuring citrus and 3 are key pests (EPPO, 2004; Jendoubi *et al*., 2008; Ben-Dov, 2010; Tena and Garcia Mari, 2011).

The following is a summary of different species reported feeding on citrus trees throughout Tunisia; including the species actually present and those not detected yet but reported previously in literature (Table. 4). The list was compiled from Pagliano, 1938, Jendoubi *et al*., 2008 and Ben-Dov, 2010.

Table 4. Citrus scale insect pest in Tunisia (Pagliano, 1938, Jendoubi *et al*., 2008; Ben-Dov, 2010)

Major pests	Minor pests	New records
C. dictyospermi	*A. nerii*	*C. floridensis*
I. purchasi	*A. aurantii*	*C. pseudomagnoliarum*
L. beckii	*C. aonidum*	*C. pinnulifer*
Pl. citri	*C. rusci*	
P. pergandii	*C. sinensis*	
P. ziziphi	*C. hesperidum*	
	Eucalymnatus tessellatus (Signoret, 1873)	
	Fiorinia theae Green, 1900	
	Parthenolecanium persicae (Fabricius, 1776)	
	Pulvinaria psidii Maskell, 1893	
	P. longispinus	
	S. oleae	

IV.1. Species newly recorded on citrus

There are three species found recently for the first time in Tunisia, *C. floridensis* and *C. pinnulifer* found during the current survey. The third species is a coccid named *C. pseudomagnoliarum* collected for the first time in 2007 from citrus orchards in Cap Bon region (Jendoubi *et al*., 2008).

IV.1.1. *Ceroplastes floridensis* Comstock 1881

IV.1.1.1. Identity of the species

Scientific name

Ceroplastes floridensis Comstock 1881

Synonym

Cerostegia floridensis De Lotto, 1969
Paracerostegia floridensis Tang, 1991
Ceroplastes vinsoni Ben-Dov, 1993

Common Name

French: la cochenille de floride
English: The Florida Ceroplastes
Florida wax scale
Spanich: Escama de cera

Taxonomic position

Class: Insecta
Order: Hemiptera
Sub-order: Sternorrhyncha
Superfamily: Coccoidea
Family: Coccidae (Gimpel *et al.,* 1974)

IV.1.1.2. Field Characters

Adult female Florida Wax Scales (FWS) are small, convex and circular in shape, white or grey in color; with a pinkish tint in younger specimens (Fig. 8) (Gimpel *et al.,* 1974).

Figure 8. Adult females of *C. floridensis*

IV.1.1.3. Origin, distribution and hosts

The Florida Wax Scale (FWS) was detected for the first time in the north of America, in 1881 by Comstock. Nowadays, it is widely distributed species in the world, predominantly in the Neotropical and Palaearctic regions but, its native area is still controversial between being America or Asia (Gimpel *et al*., 1974; Tang 1991; Qin *et al*., 1994; CABI, 2010; Ben-Dov and Miller, 2010).

It is a highly polyphagous soft scale, recorded mainly on ornamental plants and citrus; it is considered a serious pest on ornamentals in Florida State and through its U.S distribution (Ben-Dov and Miller, 2010; Hamon and Williams, 1984). While on citrus, Talhouk (1975) listed at least 13 countries in which FWS is responsible for economic damages; Israel heads this list, followed by Egypt, India, China, Japan and Mexico.

In Mediterranean basin, the presence of FWS has been known since 1900s, when it was first detected on citrus trees in Egypt (1905) and Israel (1911). Since then, this pest has spread in citrus groves, and has become one of the key-pest of citrus crop in the 1960's in both countries especially in the humid areas (Ben-Dov, 1976; Podoler *et al*., 1981; Swailem et Ismail, 1976). In that period, it expanded all over the countries neighbors: Malta, Turkey, Lebanon and Syria (Ben-Dov, 2010; CABI, 2010; Knorr, 1964). In the western countries, Balachowsky (1933) has detected FWS in the Southern of France in 1929 feeding on laurel plant (*Laurus nobilis L.*) (Lauraceae), and since there have been no records until it was perceived in 1979 in Libya by Lal and Naji (1979). Ten years later, this pest was detected in the south of Spain in citrus orchards (Garcia Mari, 1993).

IV.1.1.4. Economic importance and damages

Briefly, the wax scale is a major pest of citrus in Israel and of many ornamentals in U.S.A. (Gimpel *et al*., 1974). Feeding on leaves and green twigs, the main damage caused by FWS is due to the growth of sooty mold on the honeydew produced copiously by this scale insect during its development (Podoler *et al*., 1981; Hamon and Williams, 1984).

IV.1.1.5. Biology

FWS is known as a uniparental species, having a high fecundity reaching values of 75-100 eggs/female in Florida, 135-405 in India and up to 400-700 in Israel. According to several studies in Egypt, Greece and Israel, this coccid insect completes usually two (Israel) to three generations (Florida) a year and up to four (Egypt), with preference to highly humid climate with moderate temperatures. Smith *et al*., (1997) reported two generations per year for *C. floridensis* in Australia. High population density was registered during autumn and spring mainly in the coastal regions (Ben-Dov, 1976; Pellizzari and Camporese 1994; Podoler *et al*., 1981; Swailem and Ismail, 1976; Ben-Dov and Miller, 2010).

IV.1.1.6. Biological control

FWS is associated with many biological control agents that contribute significantly to limit its populations. There are around 2 predators and 10 parasites recorded in literature. *Tetrastichus ceroplastae* (Girault) is the main endoparasite of adult females, present in Greece and Israel; it can effectively reduce high populations of the pest during both generations. Additionally, the egg predator *Scutellista cyanea* Motschulsky was considered a successful agent of bio-control in Florida, Greece (40%) and Israel (30%). the control of larval stage is attributed to the activities of predators mainly *Chilocorus bipustulatus*. The natural enemies of FWS seem to play an important role and still needs more research (Argyriou and Kourmadas, 1980; Podoler *et al*., 1981; Hamon and Williams, 1984; Argov *et al*., 1992; Miller *et al*., 2010).

Other species include *Coccophagus caridei* (Brethes), *Coccophagus lycimnia* (Walker), *Coccophagus rusti* (Compere), *Coccophagus scutellaris*, *Encarsia*; *Anicetus quintanai* De Santis, *Cheiloneurus gahani* (Dozier), *Microterys nietneri* (Motschulsky); *Aprostocetus toddaliae* (Risbec), *Tetrastichus*, *Tetrastichus ceroplastae* (Girault); *Scutellista cyanea* (Motschulsky) (Williams, 2004).

IV.1.2. *Chrysomphalus pinnulifer* (Maskell, 1891)

IV.1.2.1. Identity of the species

<u>Scientific name</u>

Chrysomphalus pinnulifer (Maskell, 1891)

<u>Synonym</u>

Diaspis pinnulifera Leonardi, 1920
Chrysomphalus diversicolor Balachowsky, 1948
Chrysomphalus pinnulifer diversicolor Balachowsky, 1948

<u>Common Name</u>

Portuguese: pinta-amarela

<u>Taxonomic classification</u>

Class: Insecta
Order: Hemiptera
Sub-order: Sternorrhyncha
Superfamily: Coccoidea
Family: Diaspididae (Miller and Davidson, 2005; Ben-Dov, 2010)

IV.1.2.2. Field Characters

Scale cover of adult female in life is more or less circular, with a slight central peak, 1.5-2.0 mm diameter, mid- to dark reddish brown medially and paler brown to whitish towards the margin; exuviae central, yellow or tan, the centre sometimes is with white patch. Male scale is cover similar to that of the female but elongate oval with sub-terminal exuviae (Watson, 2006).

IV.1.2.3. Origin, distribution and hosts

The false circular purple scale is a tropicolitan species probably of oriental origin; whose range extends into temperate areas. It was originally described from Fiji in 1891 by Maskell, but has not been recorded from there since. The species has not been recorded from Australia. In Mediterranean Basin, it is known in Algeria, Turkey, Spain and Sicily (Maskell, 1891; Williams and Watson, 1988; Ben-Dov and Miller, 2010).

C. pinnulifer is a polyphagous species; Borchsenius (1966) records it from hosts belonging to 30 plant families, but its host range is probably wider than this and no serious injuries to plants are recorded.

IV.1.2.4. Economic importance and damages

There is no record of any damage caused by *C. pinnulifer* mentioned in the literature. However, it has been considered a tea pest in Kenya and India (Nagarkatti and Sankaran, 1990). Rose (1990) reported that *C. pinnulifer* could be a potential international invader of citrus growing regions and therefore may constitute new risks to this crop.

IV.1.2.5. Biology

The biology of this species has not been studied. Crawlers are the primary dispersal stage and move to new areas of the plant or are dispersed by wind or animal contact. Mortality due to abiotic factors is high in this stage. Dispersal of sessile adults and eggs occurs through human transport of infested plant material (Ben-Dov and Miller, 2010).

IV.1.2.6. Biological control

The natural enemies of *C. pinnulifer* have not been studied; Balachowsky (1948) recorded an aphelinididae *Aspidiotiphagus lounsburyi* Berlese and Paoli from this scale.

IV.1.3. *Coccus pseudomagnoliarum* (Kuwana, 1914)

IV.1.3.1. Identity of the species

Scientific name

Coccus pseudomagnoliarum (Kuwana, 1914)

Common Synonym

Coccus citricola Campbell, 1914

Lecanium (Eulecanium) pseudomagnoliarum Kuwana, 1914

Common Name

English: grey citrus scale

Spanich: citricola scale

Taxonomic classification

Class: Insecta

Order: Hemiptera

Sub-order: Sternorrhyncha

Superfamily: Coccoidea

Family: Coccidae (Gill, 1988)

IV.1.3.2. Field Characters

Adult female elongate oval, slightly convex, up to 7 mm long; dorsum of young female grey with dark brown mottling, while dark grey in older ones (Fig. 9) (Gill, 1988; Katsoyannos, 1996).

Figure 9. Young instars of *C. pseudomagnoliarum*

IV.1.3.3. Origin, distribution and hosts

Citricola scale is thought to be native to the arid regions of Asia. Currently, it is widespread in most of the citrus areas of the World. Citricola scale became the most important pest of citrus in San Joaquin Valley after the adoption of IPM strategies to control California red scale based on periodic releases of *A. melinus*. In the Mediterranean basin, citricola scale was first found in Turkey in 1972 and in Greece and Italy in 1973. Since then, it has remained under control in those countries (Franco *et al*., 2006; Tena and Garcia Mari, 2008).

IV.1.3.4. Economic importance and damages

For many years the citricola scale was known only from California, where it was occasionally a serious pest of citrus usually in isolated portions of affected groves, primarily before the advent of insecticides, DDT and other synthetic insecticides. Till 1970s, it has been found in the Mediterranean and Middle Eastern regions. It is also a minor pest of citrus in Australia and Israel (Barbagallo, 1974; Talhouk, 1975; Beattie and Gellatley, 1983; Trumble *et al*., 1995; Smith *et al*., 1997).

IV.1.3.5. Biology

The brown soft scale is univoltine species developing one annual generation in California, Israel, Greece, and Australia. Females reproduce as well by parthenogenetic. By late April, citricola scale mature and females lay 1.000 to 1.500 during the time from early may to early August. Eggs hatch after 2 to 3 days and crawlers move to leaves (Cancela da Fonseca, 1954-1956).

IV.1.3.6. Biological control

The effectiveness of the natural enemies of this species is well documented and it is completely controlled by *Metaphycus* parasites. *C. pseudomagnoliarum* is very sensitive to organophosphates and carbamates. Oil is the most selective pesticide available for it control but, should be applied every year (Smith *et al*., 1997).

IV.2. Species of economic importance

P. pergandii, *P. ziziphi* and *Pl. citri* are the three first key pests of citrus crop in Tunisia, causing important damages in many citrus orchards of Cap Bon region (Jendoubi *et al*., 2008; Tena and Garcia Mari, 2011). Complete overview is given for each species below.

The other species are less economically important than the previous three species. They are classified in order of importance and some of their distribution, life history and control strategies are covered too.

IV.2.1. *Parlatoria pergandii* Comstock 1881

IV.2.1.1. Identity of the species

Scientific name

Parlatoria pergandii Comstock 1881

Common Synonym

Parlatoria sinensis Maskell
Parlatoria proteus pergandei Comstock
Parlatorea pergandei (Comstock)
Parlatoria (Euparlatoria) pergandii Comstock,
Syngenaspis pergandei Comstock

Common Name

French: Parlatoria gris, le pou gris
English: Chaff scale
Black parlatoria scale
Chaffy scale
Spanich: Escama paja

Taxonomic classification

Class: Insecta
Order: Hemiptera
Sub-order: Sternorrhyncha
Superfamily: Coccoidea
Family: Diaspididae (Balachowsky, 1953; Miller and Davidson, 2005)

IV.2.1.2. Field Characters

The adult female cover is flat, round to oval, often with several wrinklers, translucent brown to gray; translucent brown to gray; shed skin marginal, yellowish brown, sometimes with longitudinal green stripe. The male cover is smaller, similar in texture to female cover, elongate ; shed skin marginal, yellowish brown, with central, green stripe; adult male winged, red with black eyes. Body of adult female, eggs and crawlers are purple (Fig. 10) (Balachowsky**,** 1953).

Figure 10. Second instar and females of *P. pergandii*

IV.2.1.3. Origin, distribution and hosts

The chaff scale is considered by many authors a cryptogenic species, of unknown origin. But, recently Miller and Davidson (2005) have reported that probably it is native to the oriental region. Nowadays, it is widely distributed throughout the tropical and subtropical areas of the world. It occurs in Europe (Corsica, France, Greece, Italy, Malta, Spain); Asia (Burma, China, Cyprus, Formosa, Iran, Israel, Syria etc.); AFRICA, Algeria, Cameroun, Canary Islands, Egypt, Libya, Morocco, Nigeria, Republic of South Africa, Tunisia etc.); Australasia and Pacific Islands; North America (U.S.A); Central America and West Indies; South America (Argentina, Brazil, Peru) (CABI, 1964; Bedford, 1998; Longo *et al*., 1999; Culik *et al*., 2008; Ben Dov, 2010).

P. pergandii is polyphagous species, reported from 36 families. Citrus is by far the most commonly reported host followed by Hibiscus, Jasminum and Viburnum (Heu, 2002; Ben-Dov, 2010: Pellizzari and Germain, 2010).

IV.2.1.4. Economic importance and damages

Miller and Davidson (1990) list this insect as a serious world and widespread pest; Danzing and Pellizzari (1998) described it as a pest in the palaerctic region. Since the 1970s, *P. pergandii* has become one of the main pests in all citrus-producing areas and has been recorded as such in several countries in the Mediterranean region. It is reported to be a very important pest in southern Japan and Italy, and an important pest in Spain, France, Turkey, Lebanon, Israel, Southeast Asia, Central America, Mexico, Florida, and Texas. In China, it causes damages to camphor trees, *Cinnamomum camphora*, and *Magnolia*, *Magnolia grandiflora* (Chao and Zeng 1997); and in India it is a pest of pepper, *Piper nigrum*. Although, some authors considered chaff scale to be a relatively minor pest of citrus (Talhouk, 1975; Rosen and DeBach, 1978; Miller and Davidson, 1990; Rose, 1990; Shen and Liu, 1990; Garrido and Ventura, 1993; Koya *et al*., 1996; Foldi, 2001; Miller and Davidson, 2005).

The presence of scales may be greater mainly on leaves along the main vein, on fruits around the calyx and in the zone of the style. This attack is generally important; a greenish blotch remains at the feeding point on mature fruit which making it unsalable as fresh fruit (Walker and Deitz, 1979). According to Bodenheimer (1951), *P. pergandii* prefers citrus trees over 10 years old. It forms dense colonies, composed of several strata, on the bark of citrus trees, causing in presence of a heavy infestation gumming, flaking and cracking of the bark, killing branches and sometimes whole trees.

IV.2.1.5. Biology

Chaff scale is reported to have 3 or 4 generations each year in Israel, 4 in Florida, 3 in Alabama, and 5 or 6 generations in Australia. A study in Spain, reported three peaks a year for *P. pergandii*, with a first peak in June, a second in August-September and a third at the end of the year. This pest overwinters in all stages in Israel, although it is reported to be predominately in the adult female form in the winter in Italy, with 14-15% of the population in the second instar. Under normal circumstances, field populations have overlapping generations with all stages present at all times during the year. Extensive overlap of generations probably is caused by the long oviposition period. Bodenheimer (1951) reported a single female that oviposited for a period of 76 days, laying 1 or 2 eggs each day, the reproduction is exclusively sexual. The average number of eggs laid by each female is about 88, and hatching may require up to 2 weeks. It was reported that crawlers were most abundant in Florida in March and April and again in September and October. Chaff scale prefers well established trees that are 10 years or older. It most often is found on the inner parts of the tree and apparently prefers shady, humid areas on the host (Bodenheimer, 1951; Gerson, 1967; Garcia Mari and Rodrigo, 1995; Miller and Davidson, 2005; Ben-Dov, 2010).

IV.2.1.6. Biological control

Indigenous predators and parasites have little or no effect. There are only a few polyphagous coccinellid predators (*C.bipustulatus* and *E. quadripustulatus*), the ectoparasite *A. hispanicus* and an endoparasite *Encarsia* (*Prospaltella*) *inquirenda*, which gives only partial control of *P. pergandei*. Biological control probably will be most successful with *A. comperei* and *A. paramaculicornis*; *A. hispanicus* frequently is collected from chaff scale but it is not always effective. The activity of the natural enemies of the chaff scale and their composition was studied in Greece. *P. pergandii* was parasitized by a hymenopterous endoparasite of the genus *Encarsia* and the extent of parasitization ranged between 5.2% and 14.1%. The parasitization percentage has increased gradually from 4% in mid-June to 94% around the end of September. The predominant predator was *Rhyzobius lophanthae* Blaisdell (84.3% of the larvae and 73.3% of the adults), which was active throughout the whole year in all of its developmental stages (Rosen and DeBach, 1979; Cave, 1994; Stathas, 2001; EPPO, 2004).

IV.2.1.7. Natural enemies

Parasitoids

- *Aphytis hispanicus*, attacking: eggs, nymphs, adults, in Italy; Spain; Israel; China; Mexico; USA, Texas; Caucasus; Ghana;
- *Aphytis melinus*, attacking: eggs, nymphs, adults, in India, Pakistan. Introduced: USA (California), South Africa, Australia, Argentina, Chile, Cyprus, Israel, Italy, Morocco
- *Encarsia citrina*, is attacking: nymphs, adults, in Japan, Ghana. Introduced to: USA; Australia; Mediterranean Basin; Turkey; Italy, Indonesia (Bali), Tahiti, Fiji, Cook islands, Africa
- *Encarsia inquirenda*, in Israel

Predators

- *Aleurodothrips fasciapennis*, attacking: eggs, nymphs, adults, in Indonesia;
- *Chilocorus bipustulatus*, attacking: nymphs, adults, in Israel, Spain, Morocco, Greece
- *Cybocephalus fodori* in Greece
- *Cybocephalus micans*, in Israel
- *Hemisarcoptes coccophagus*, attacking all stages apart from eggs, widespread including Israel;
- *Rhyzobius lophanthae* in Greece (Rosen and DeBach, 1979).

IV.2.1.8. Chemical control

In the absence of natural enemies, insecticides sprays are often needed. Two treatments may be applied in accordance with the life cycle of the pest: the first at the end of May/beginning of June; a second at the beginning of September (60% developed females with larvae). The main sprays insecticides used are: azinphos-methyl, chlorpyrifos, malathion, methidathion, pirimiphos-methyl and quinalphos. In spain, studies has shown that Chlorfenvinphos, methidathion and quinalphos were the most effective against *P. pergandii*, giving more than 80% control (Soto *et al*., 1994; EPPO, 2004).

No tolerance threshold is fixed to determine the period of pesticides application. There are two ways, weekly sampling throughout the year or the use of thermal integrals (degrees-days) that it is fixed at 720 degree-days, with a development zero at 11°C (EPPO, 2004).

If treatments are necessary in orchards with introduced or naturally occurring populations of natural enemies, they should either be localized treatments, or else applied to every 4 or 6 rows at 4 to 6 weeks intervals during August and September. Insecticide sprays mainly target populations on the trunk and branches, which carry the initial foci of infestation. If the pests occur in localized isolated patches, the affected wood can be painted with lime wash (EPPO, 2004).

IV.2.2. *Parlatoria ziziphi* (Lucas, 1853)

IV.2.2.1. Identity of the species

Scientific name

Parlatoria ziziphi (Lucas, 1853)

Common Synonym

Coccus ziziphi Lucas, 1853
Parlatoria lucasii Targioni Tozzetti
Parlatoria ziziphus (Lucas) Fernald
Parlatoria zizyphus (Lucas) Cockerell

Common Name

French: Cochenille noire de l'oranger
English: Black parlatoria scale
Black parlatoria
Citrus parlatoria
Leaf black scale
Mediterranean scale
Spanich: escama parlatoria negra

Taxonomic classification

Class: Insecta
Order: Hemiptera
Sub-order: Sternorrhyncha
Superfamily: Coccoidea
Family: Diaspididae (Balachowsky, 1953; Miller and Davidson, 2005)

IV.2.2.2. Field Characters

Scale cover of adult female is about 1.25-1.4mm long and 0.6-0.75mm wide; consisting of black second-instar exuviae, sub-rectanglar with rounded corners, with a narrow fringe of white wax on the posterior margin (Fig. 11). The first instar exuviae is attached to the anterior margin of the second instar exuviae. The scale cover of male is white; elongate, flat, with large black to brown terminal exuviae and about 1/3 the size of the female (Fasulo and Brooks, 2004; Miller and Davidson, 2005).

Figure 11. Adult and young populations of *P. ziziphi*

IV.2.2.3. Origin, distribution and hosts

P. ziziphi probably originated from southern China (Asia), established mainly on the tropics, but has also extended into temperate and Mediterranean regions. The species occurs in Africa, Asia, Central and South

America, Europe, Oceania, and the West Indies (Balachowsky, 1953; CABI, 1964; Miller and Davidson, 2005; Pellizzari and Germain, 2010).

Black parlatoria has a very limited host range. Blackburn and Miller (1984) provided evidence demonstrating that many of the records reported in the literature on hosts other than in the family *Rutaceae* are most likely erroneous. *Zizyphus* (Family Rhamnaceae) would seem to be an exception according to Miller and Davidson (2005) but Balachowsky (1953) considered this host plant as misidentified botanically by Lucas or this later associated it to *Coccus ziziphi* which is the black aleyrodid living on zizphus. Thus, hosts for this species probably are *Citrus*, *Murraya, Poncirus*, and *Severinia* with *Citrus spp* being the predominant host (Miller and Davidson, 2005).

IV.2.2.4. Economic importance and damages

Beardsley and González (1975) considered this scale to be one of 43 major armored scale pests; Miller and Davidson (1990) treated it as a serious world pest (Miller and Davidson, 2005) and many authors has long been considered the black parlatoria scale one of the major pests of citrus in many parts of the world. It was reported in the following countries: Brazil, China, Egypt, Iran, Italy, France, Libya, Nigeria, Puerto Rico, Taiwan, and Tunisia. It was noted that in some countries the scale may not be considered a pest, but populations occasionally become a problem in localized areas (Bénassy and Soria, 1964; Talhouk, 1975; Cruz and Segarra, 1991; Gravena *et al*., 1992; Coll and Abd-Rabou, 1998; Danzig and Pellizzari, 1998; Foldi, 2001; jendoubi *et al*., 2008).

Nevertheless, a few studies on losses costs associated to *P. ziziphi* are available in literature and generally, it is difficult to quantify losses caused by diaspids as Kosztarab (1990) has reported. Talhouk (1975) in his treatment of citrus pests of the world, listed black parlatoria scale as economically important pest in Algeria, Morocco, Tunisia, and southeast Asia. In France, Foldi (2001) listed it as well an important economic pest. Heavy infestations of this scale cause chlorosis and premature drop of leaves die back of twigs and branches, stunting and distortion of fruits, and premature fruit drop. Perhaps the most characteristic damage is the virtually irremovable scale cover on the fruit, causing rejection in most fresh fruit markets. *P. zizphi* is mentioned on quarantine lists. In the UK and USA, all fresh citrus material, especially leaves, should be thoroughly inspected (Burger and Ulenberg, 1990; Longo *et al*., 1995; Miller and Davidson, 2005).

IV.2.2.5. Biology

P. ziziphi is biparental and oviparous. All developmental stages are present throughout the year, indicating that the diaspidid completed several overlapping generations annually, numbering from two to seven. In the Levante region of Spain there are 3 to 5 generations each year (Gomez Clemente, 1943). There are 5 generations each year in Sicily, and the complete life cycle takes 30-40 days under favorable conditions (Monastero, 1962). In Egypt, there are two generations per year on sour oranges, and three on grapefruit as in Tunisia; in this latter a generation requires 75-80 days in Tunisia during warm periods, and up to 160 days during cool periods (Bénassy and Soria 1964; Salama *et al*., 1985; El-Bolok *et al*., 1984). In Greece, Stathas *et al*. (2008) report that *P. ziziphi* overwintered in all developmental stages and completed several overlapping generations each year. In China, *P. ziziphi* had three to four overlapping generations each year and overwintered at adult stage. In the Caucasus, the scale produces two and half generations each year, and overwinters in the second instar (Borchsenius, 1950). In Taiwan, there are up to 7 generations each year; a generation requires about 42 days to develop from June to August and about 93 days during cooler weather (Miller and Davidson, 2005).

The adult female lays about 34 eggs on average in Egypt. At natural temperatures (8.4-34.6°C) adult longevity varied from 50.8 to 88.2 days for females and 1.4 - 3.4 days for males. Depending on the season, the egg stage lasts 2-4 days, the first instar 6-13 days, the second instar 13-30 days, and the adult female lives 11-24 days the oviposition period lasts 7-18 days (Chang and Huang, 1963). The most favorable time for population increase was April and September. The number of crawlers was very low during January and February, followed by a sharp increase in April. Male nymphs increased during April, June and July. A generation time of about 62 days was observed on sour-orange in the laboratory (Stathas *et al*., 2008)

IV.2.2.6. Biological control

A number of parasites and predators have been recorded for *P. ziziphi* but it is unlikely that they will be effective biological control agents by themselves. Some of the parasites have been shown 40% of parasitism (Fasulo and Brooks, 2004).

IV.2.2.7. Natural enemies

Parasitoids

-*Aphytis proclia* attacking nymphs and adults
- *Encarsia citrina* attacking nymphs and adults (Algeria, China, Hawaii, Egypt)
-*Encarsia lounsburyi* attacking nymphs and adults (China)
-*Habrolepis aspidioti* (Egypt)

Predators

- *Chilocorus kuwanae* attacking nymphs and adults (China)
- Chilocorus nigrita attacking nymphs and adults (USA)
- *Cybocephalus nipponicus* attacking nymphs and adults (China)
- *Halmus chalybeus* attacking nymphs and adults (USA)
- *Leptodiplosis aonididiellae* attacking nymphs and adults (Morocco)
- *Rhyzobius lophanthae* attacking nymphs and adults (USA)
- *Telsimia emarginata* attacking nymphs and adults (China)

Pathogens

- *Nectria aurantiicola* attacking nymphs and adults (Taiwan)
- *Nectria diploa* attacking nymphs and adults (Taiwan)
- *Nectria flammea* attacking nymphs and adults (Java)
- *Podonectria aurantii* attacking nymphs and adults (Brazil, Taiwan)
- *Podonectria cocciola* attacking nymphs and adults (Japan, Taiwan) (Abd-Rabou, 1999).

IV.2.2.8. Chemical control

IPraloran (1971) qualify *P. ziziphi* as the most difficult species to control. Treatment for black scale must be timed to control the first generation crawlers between post bloom and summer sprays. Applications at other times are ineffective. In china, *P. ziziphi* was controlled efficiently using many pesticides as omethoate, chlorpyrifos, methidathion, quinalphos, lambda-cyhalothrine, fenvalerate or cypermethrine (Huang *et al*., 1988). In Florida, Dekle (1976) recommended the use of oil sprays, malathion with oils, dimethoate or parathion.

IV.2.3. *Planococcus citri* (Risso, 1813)

IV.2.3.1. Identity of the species

Scientific name

Planococcus citri (Risso, 1813)

Common Synonym

Planococcus lilacinus
Dactylopius farinosus

Common Name

French: cochenille farineuse
English: citrus mealybug
Spanish: piojo de los cítricos

cochonilha-algodao

Taxonomic classification

Class: Insecta
Order: Hemiptera
Sub-order: Sternorrhyncha
Superfamily: Coccoidea
Family: Pseudococcidae (Williams and Granara De Willink, 1992; Ben-Dov, 2010)

IV.2.3.2. Field Characters

The adult female is orangish covered with white-cottony wax and has a fringe of small waxy filaments that extend the periphery of the body. Fully grown, the female mealybug is about 3 mm long and 1.5 mm in width. The oblong, yellow eggs are enmeshed in a dense, fluffy, white ovisac. The young crawlers are oval and yellow, with red eyes; the antennae are rather distinct; Male nymphs are narrower and more elongated often occurring in a loose; winged adult males are generally about 4.5 mm in length with tail filaments (Mckenzie, 1967).

IV.2.3.3. Origin, distribution and hosts

The citrus mealybug is a highly polyphagous pest of citrus, grapevine, coffee and ornamental plants and is probably the most cosmopolitan and destructive species of the family Pseudococcidae. However, its origin is highly speculative. It has been suggested that the citrus mealybug is indigenous to South America, but an alternative hypothesis is that it is native to the Far East. However, recent findings concerning its principal parasitoids indicate that it has spread from central Africa, probably with the slave trade (Compere, 1939; Flanders, 1951; Ben-Dov, 2010; Franco *et al*., 2004).

IV.2.3.4. Economic importance and damages

According to several authors, *Pl. citri* is regarded as an injurious pest in most citrus-growing areas of the world, tropical, subtropical and Mediterranean such as Italy, Greece, Spain, Portugal, and France. In the Mediterranean Basin, the citrus mealybug is the major pest among the six mealybugs occurring there (Williams and Moghaddam, 2000; Franco *et al*., 2004; Ben-Dov and Miller, 2010; Dennis, 2008).

Pl. citri excretes large quantities of honeydew that encrust the leaves and clusters, resulting in further crop damage, defoliation, growth of sooty moulds and bunch rots (Godfrey *et al*., 2002). Severe infestations can result in 80% drop of flower buds and young fruits and 100% fruit drop. The damages are most severe in the summer. Moreover, *Pl. citri* is a vector of several grapevine viral diseases and therefore is considered as a dangerous pest even at low infestation levels (Cabaleiro and Segura, 1997; EPP0, 2004; Franco *et al*., 2004).

IV.2.3.5. Biology

The mode of reproduction is both sexual and parthenogenetic but a recent study has showed that *Pl. citri* is an obligate amphimictic (Silva *et al*., 2010). It can reproduce at high rates, each female lays up to hundreds of eggs, varying from 300 to 600 eggs, in clumps of 100. The length of the embryonic development is quite variable from 6 to 14 days. After hatching, first instars are very active and are often found congregated upon the ovisac or around the porous glands in citrus fruits. Under optimal conditions, the complete life cycle takes about 30 days and 6 weeks during the warmer summer months (Kerns *et al*., 2004).

The citrus mealybug overwinters as young larvae and adult females on trunk and lower branches of the tree. The overwintering stages emerge from their shelters at the beginning of April, and the crawlers will make their way to green twigs and fruit. These later constitute individuals of the first generation, establish on soft tissues, and can enter below the calyx of the young developing fruit. Others gather at the point of contact of two fruits, or fruit and leaves, where they form cotton-like masses of honeydew and sooty mould in the spring (EPP0, 2004).

The citrus mealybug can reach five generations per year, but this varies according to climatic conditions. In fact, it may have as many as eight generations indoors in United States; it has three to four generations per year in South Texas. Smith *et al*., (1997) reported from citrus in Australia, at least 6 annual generations. In Arizona, the citrus mealybugs will pass through 4 to 6 overlapping generations. Martinez-Ferrer *et al*., (2003) report 5 generations in Spain (Valencia). It was found to have 6 to 8 overlapping generations annually in Morocco; High population levels occurred during June-December (Abdelkhalek *et al*., 1998). There may be a continuous overlapping of generations and all stages can be found on the host at a given time, which makes control difficult (Kerns *et al*., 2004).

IV.2.3.6. Biological control

Mealybug management strategies in citrus have been based mostly on classical biological control and, to a lesser extent, on augmentative releases. However, chemical control is widely used, mainly because of the poor adaptation of the principal natural enemies to the climatic conditions of the Mediterranean. The application of pheromones is still restricted to monitoring the citrus mealybug, whose sex pheromone is commercially available (Franco *et al*., 2004).

IV.2.3.7. Natural enemies

L. dactylopii (Hymenoptera: Encyrtidae) and *C. montrouzieri* (Coleoptera: Coccinellidae) are one of the most known auxiliaries, to control the citrus mealybug successfully. They are released often together or in a combination with other natural enemies (Cadee and Van Alphen, 1997; Franco *et al*., 2004).

L. dactylopii is an exotic endoparasitoid, native to Brazil, which showed a preference for the third larval stage and adults (Fig. 12) in which eggs are laid. The fecundity is about 60-100 eggs and the rate of parasitism is estimated at 95 %, the emergence of adults occur 2 weeks after introduction. The maximum activity was in September corresponding with second generation of *Pl. citri*. In fact, assays conducted in Italy (Sardinia) showed a high percentage of parasitism of the third instar citrus mealybug particularly in the autumn period extinding 64% in 1995 and 100% in 1998. Adults are released in the early spring in order to establish populations. It should be used 2-5 parasites per infested plant or 1-2 wasps/sq. meters and make 2-4 releases at 2-4 week intervals (Cadee and Van Alphen, 1997; Ortu and Marras, 2000; Anonymous, 2004).

C. montrouzieri is an exotic predator and a voracious feeder, at larval and adult stages of mealybug females and eggs stages. A single larva may consume up to 250 small mealybugs and it is most effective when mealybug populations are high. Although adults and young larvae prefer to feed on mealybug eggs, older larvae will attack any mealybug stage (Fig. 12). Adults can fly and cover large areas to search food. Once established, the predator is able to control heavy infestations in 2-3 months. However, cooler and warmer temperatures and humidity fluctuations may affect reproduction. *C. montrouzieri* doesn't undergo diapause and survive the winter well, so it must be reintroduced, as the case in Greece and Spain (Cliff, 1995; Smith *et al*., 1997; Anonymous, 2004).

Under mild climatic conditions, *C. montrouzieri* and *L. dactylopii* are the most efficient beneficial insects to control *Pl. citri* (France, Italy and Morocco) (Abdelkhalek *et al*., 1998). Biocontrol is implemented early, when the first foci appear at the end of April and the beginning of May, using *L. dactylopii* (1-2 adults per tree) and *C. montrouzieri* if third-stage larvae and young females are abundant. If females with egg masses are abundant, 3-10 adults of *C. montrouzieri* are released per tree (Cadee and Van Alphen, 1997; EPP0, 2004). Enhancement of biological control through management of ant populations is another promising tactic for the control of mealybugs.

Figure 12. *L. dactylopii* (a) and *C. montrouzieri* (b) attacking the citrus mealybugs (USDA, 2006)

IV.2.3.8. Chemical control

Chemical control is the most common management strategy. It is often the only therapeutic tactic used for the management of mealybugs on citrus. Because of the generally cryptic habits and due to the protection of the mealy cover, effective chemical control relies on materials of high vapor pressure. However, the arsenal of effective insecticides is very limited. Major insecticides used against mealybugs include diazinon, dimethoate, azinfosmethyl, chlorpyrifos, parathion, pyrimifos-methyl and malathion, which are applied singly or in mixtures that include mineral oils. Chlorpyrifos is the most commonly used insecticide against mealybugs, but its frequent use in Israel has led to the development of resistance in *Pl. citri*. Mass trapping and mating disruption should be considered for possible use in IPM programs as an alternative method to supplementary chemical treatments (Franco *et al*., 2004).

IV.2.4. *Icerya purchasi* Maskell 1879

Field chatacters

The early instars are bright red in color with reddish-brown antennae and thin black legs. By the third instar, the scale is broadly oval and reddish-brown. The adult female scale is oval and convex; its characteristic feature is a long white egg sac (10-15 mm) which has a cottony appearance (Fig. 13). The adult male scale is uncommon, small, and has well developed wings (Balachowsky, 1954; Fasulo and Brooks, 2004).

Origin, distribution and damages

I. purchasi is native to the Australasian region. It is considered a polyphagous pest, mainly of citrus trees throughout the world. The cottony cushion scale can severely damage trees, resets, and nursery stock. If infestations are heavy, leaf and fruit drop can occur, with twig dieback. This scale is seldom found on the fruit (Annecke and Moran, 1982; Austin *et al*., 2004; Fasulo and Brooks, 2004; Downie and Gullan, 2004).

Biology

I. purchasi is mentioned as an example of an adaptation in reproduction in which both eggs and sperm are produced in the same individual (hermaphrodite) in which fertilization takes place. The occasional male is capable of copulating with hermaphrodites, but hermaphrodites are incapable of fertilizing one another. The adult female is capable to lay about 500 to 800 eggs. The eggs can hatch without few days during the summer months but can take up to two months during the winter. The cottony cushion scale population increases most rapidly during the drier months and requires about four months for a generation. Fortunately, there is a heavy natural mortality among the eggs and the first instar nymphs. There are three generations per year: the first from February to June, the second from June to August and the third from August to October/November. 4 annual generations were observed in Morocco (Caltagirone, 1999).

Biological control

A predatory beetle and a parasitic fly provide an excellent biological control of the cottony cushion scale. The vedalia beetle, *Rodolia cardinalis* (Mulsant), is a very efficient predator due to its excellent searching ability. Both the larva and adult beetle feed on all stages of *I. purchasi* (Fig. 13). A generation of *R. cardinalis* requires only one month, which further explains the excellent control of the cottony cushion scale that requires four months for a generation. The vedalia beetle never entirely eliminates the cottony cushion scale, but keeps the population under control. The fly, *Cryptochetum iceryae* (Will), is a parasite that lays its eggs in the mature larvae and pupae of the cottony cushion scale. While not as noticeable as the vedalia beetle, this fly also significantly contributes to reductions in scale populations. The vedalia beetle won't feed on scale that has been parasitized by this fly. Chemical control of the cottony cushion scale is rarely needed except in nurseries and young groves. All insecticide treatments against this pest should be avoided, since they aggravate the problem and delay the solution (Mendel and Blumberg, 1991; Fasulo and Brooks, 2004).

Figure 13. Cottony cushion scale and vedalia beetle (Grafton-Cardwell, 2002)

IV.2.5. *Chrysomphalus dictyospermi* (Morgan, 1889)

Field Characters

The female scale is nearly circular, flat, greyish or reddish-brown, often with a coppery tinge. Exuviae is central, of an elongate oval shape, the centre of the larval skin is of a dark orange color, whilst the exuviae are light yellow; that of the male elongate oval, similar in color (Gill, 1997; Wong *et al*., 1999).

Origin, distribution and hosts

C. dictyospermi is probably native to the southern China and it is widespread in tropical and subtropical regions; it occurs under glass in temperate areas (Davidson and Miller, 1990; Longo *et al*., 1995; Gill, 1997). In spite of the record published in Danzig and Pellizzari (1998), *C. dictyospermi* has not been recorded in the United Kingdom in recent years and is regarded as absent.

The red scale is a highly polyphagous species; recorded from hosts belonging to 73 plant families, but its host range is probably wider than this. Favored hosts are palms, Dracaena and Citrus species.

Economic importance and damages

This species is known mainly as a serious pest of citrus (Zahradník, 1990). Danzig and Pellizzari (1998), refer *C. dictyospermi* as a dangerous pest in the Palaearctic region. Foldi (2001) lists this species as an economically important pest in France. In the western Mediterranean region and Florida, *C. dictyospermi* is a serious pest of citrus; while it is a minor pest of citrus, palms and young avocado trees in Mexico and South America (Chua and Wood, 1990; Gill, 1997). The species is of economic importance on several hosts in Brazil, and is regarded as a pest in Argentina, where it occurs on both cultivated and native plants; in Chile it is a primary pest on citrus and is common on ornamental plants (Claps *et al*., 2001). *C. dictyospermi* is a pest of olive in Italy, Spain and Turkey (Argyriou, 1990). Additionally, the species has been reported as a significant pest of citrus in a number of countries in the South Pacific Region (Williams and Watson, 1988).

It occurs especially on leaves; sometimes on fruit and occasionally on branches. Heavy infestations can cover the tree. The toxic saliva injected while feeding causes leaf chlorosis, and drying and death of the branches (Salama *et al*., 1985; Gill, 1997; Foldi, 2001).

Biology

Reproduction is sexual, and continuous in tropical conditions. Crawlers are the primary dispersal stage and move to new areas of the plant or are dispersed by wind or animal contact. During the summer, the life cycle of the red scale can be completed in less than six weeks while lower temperatures produce longer life cycles. In Florida, it has six generations a year, with the largest scale population increase occurs in June. In California, *C. dictyospermi* has 3 or 4 overlapping generations each year; in Egypt, only two (Salama, 1970; Gill, 1997; Foldi, 2001).

Biological control

Successful biological control of *C. dictyospermi* in the Mediterranean Basin was developed by capitalizing on the experience gained in California, USA, in controlling citrus scale insects. Various species of *Aphytis* that had been used for control of *A. aurantii* in California were introduced, but only *A. melinus* became widely established and effective against *C. dictyospermi*, often displacing the native *A. chrysomphali*. In Italy, *A. chrysomphali* was responsible for up to 40% parasitism of young adult female *C. dictyospermi* (Viggiani and Iannoconne, 1972; Argyriou, 1974). Chkhaidze and Yasnosh (2001) remarked that in the Republic of Georgia, the natural enemy complex considerably limits the presence of *C. dictyospermi*, but does not appear to be capable of eradicating it, so sometimes the use of additional control measures is necessary. *C. dictyospermi* can be successfully treated with white mineral oils if scale density on leaves at the beginning of summer exceeded a threshold of 3 scales/cm² (CABI, 2011).

IV.2.6. *Lepidosaphes beckii* (Newman, 1869)

Field characters

In life, scale cover of adult female 1.0-3.0mm long, convex, mussel-shaped (curved or straight, depending on the texture of the host and population density of the scales), strongly tapered towards the exuvial end, dark brown (occasionally with light tan edges and a purplish tinge) with yellowish-brown exuviae at the narrow end. Second instar exuviae of the female with a distinctive reddish-brown spot at the posterior end. Male scale cover is similar to female cover but smaller, straighter and narrower (Claps, 1991; Gill, 1997).

Origin, distribution and hosts

Gill (1997) suggested that *L. beckii* might originate from the Oriental region. It is widely distributed now, throughout the tropical and subtropical regions of the world (Davidson and Miller, 1990; DeBach and Rosen, 1991). In northern countries it is found only under glass (Danzig and Pellizzari, 1998). Like for *C.*

dictyospermi, *L. beckii* is not established in the United Kingdom as it was published by Danzig and Pellizzari (1998).

L. beckii is a polyphagous species that has been recorded from hosts belonging to 45 genera in 11 plant families (Davidson and Miller, 1990) but its host range may well be wider. Citrus species are favoured hosts, and *Murraya exotica* are often heavily infested (Williams and Watson, 1988; Miller and Davidson, 2005).

Economic impact and damages

L. beckii is one of the most important pests of citrus wherever it is grown (Williams and Watson, 1988), more important than *A. aurantii* as recorded by Gill, 1997. *L. beckii* is regarded as a serious pest in Argentina (Claps *et al*., 2001). Danzig and Pellizzari (1998) described it as a dangerous pest in the Palaearctic, and Foldi (2001) lists it as an economically important pest in France.

On citrus, heavy infestation causes chlorosis of the leaves, defoliation, discoloration and poor maturation of the fruit; and desiccation, weakening and dieback of the branches or even of the entire trees (Gill, 1997). On the fruits, infestation causes disfiguration and poor maturation, which decreases their market value and can make them unmarketable (Miller and Davidson, 2005).

Biology

Reproduction in *L. beckii* can be either sexual or parthenogenetic. Up to four generations may be produced each year, depending on climatic conditions. In California, there are 3-4 overlapping generations per year, and all stages are present through the winter (Gill, 1997); in colder climates, overwintering may occur in the egg stage. In southern Chile, there is one generation annually (Zuniga, 1971), and four in the Eastern Cape of South Africa (DeVilliers, 1998). Bénassy *et al*. (1975) reported that purple scale has 2 generations a year in France at Coast Azure, 4 in Italy at Naples, 4 in Egypt, and 3 in Tunisia. Smirnoff (1960) found 4 generations a year in Morocco. Development time varies considerably with temperature, In Israel, Avidov and Harpaz (1969) reported that summer development of purple scale required at least 50 days (44 days for males) while in winter about 110 days were needed.

Cohic (1955) mentioned that *L. beckii* prefers hot humid conditions and is found in the shady inner part of the canopy of Citrus until overcrowding makes it spread onto the leaves and fruit. Infestations are usually heaviest at the centre of trees and on northern sides. In California, *L. beckii* populations are particularly prevalent in coastal areas, which may reflect its low tolerance of extreme temperatures (Gill, 1997; Miller and Davidson, 2005).

Biological control

Purple scale has been under an excellent biological control since 1960 due to a parasitic wasp, *Aphytis lepidosaphes* (Compere), attacking the mature female. Chemical control of purple scale is complicated by its preference for a dense canopy. The spray coverage is important, but difficult to achieve in the center of the tree because of dense foliage (Fasulo and Brooks, 2004).

IV.3. Minor species

IV.3.1. *Aonidiella aurantii* (Maskell, 1879)

Historically, the red california scale is a major pest of Citrus in Africa, and in many other Citrus-growing areas. It is a cosmopolitan species throughout the tropics and subtropics, but with no records from West Africa (CABI, 1996; Durba Cabrelles *et al*., 2006).

The California red scale (CRS) is a biparental, ovoviviparous species. After copulation, the female scale produces living young ('crawlers') at the rate of about 2–3 per day. Using pheromonal sticky traps, it is found to have four to six generations per year on orange, and 5-7generations per year on lemon in South Africa, six in Argentina and four in Cyprus while only two or three generations per year in California (Roelofs *et al*., 1978; Davidson and Miller, 1990; Dennis, 2008).

Management of this pest is generally based on integrated control strategies supported by a monitoring system by means of pheromone traps. Narrow range of petroleum oil sprays can be used to reduce scale populations, with reduced negative effects on the complex of the natural enemies. Recommended sprays are diazinon or malathion in water with added white oil, as a full-cover spray using as high a nozzle pressure as possible. Trees should be sprayed when 25% of the fruits are infested with one or more red scales. A repeat spray should be made after 2–3 weeks (Dennis, 2008). In Chile, 100% control was achieved with a liquid formulation of systemic omethoate applied undiluted with a brush to the trunk at a rate of 20 ml per tree (Compere, 1961; Rosen and DeBach, 1978; Zappala, 2010).

Besides the extensive research on chemical control, there were extensive studies on biological control of this pest. Longo *et al*. (1994) note that the complex of natural enemies (*E. citrina*, *A. melinus* and the introduced *Chilocorus nigritus*) controls effectively *A. aurantii* in southern Italy. *A. melinus* has been employed with success as a biological control agent in many countries as Morocco, in Italy...etc .The fungus *C. lecanii*, predatory ladybirds (*Chilocorus sp.*) and parasitoid chalcid (Hymenoptera) are important natural enemies too (Davidson and Miller, 1990; Zappala, 2010).

IV.3.2. *Chrysomphalus aonidum* (Linnaeus, 1758)

The Florida red scale is widely distributed in many tropical and subtropical regions in North and South America, Africa, the Mediterranean Basin, the Far East, Pacific Islands and Australia. It has been recorded as a serious pest of citrus in Florida, Texas, Brazil, Mexico, Lebanon, Egypt, and Israel. Nowadays, it is being a common and frequent citrus pest in some countries (Bodenheimer, 1951; Ebeling, 1959; CABI, 2005).

It is a biparental species that infests leaves and fruits; and males are common. Up to six overlapping generations per year in the tropics and in greenhouses; lay up to 334 eggs per female; first instars prefer to settle on leaves, fruits, or green stems (Kosztarab, 1996; Miller and Davidson, 2005).

C. aonidum management is carried out in many countries through biological control. *A. holoxanthus* proved effective against this scale according to Rosen (1986), it can reach level of parasitism up to 90-100%. At least four chalcidoid parasites, and two lady beetles, one thrips, one lacewing, and several mites were reported as predators (Bedford and Cilliers, 1994; Kosztarab, 1996).

IV.3.3. *Ceroplastes sinensis* Del Guercio 1900

The Chinese wax scale is a polyphagous species, common on *Citrus* spp. and *Ilex* spp. It is reported a serious pest of citrus in Australia; it was first found on citrus in 1966 and has since displaying the other wax scale species as the most serious scale pest of citrus. It is only a sporadic pest in other citrus growing areas such as Italy and Spain, and it is a potential pest of *Citrus spp.* in California (Gill, 1988; Qin and Gullan, 1994; Kosztarab, 1996).

One annual generation was reported in Italy on citrus and in USA in Virginia (Kosztarab, 1996). Adult females overwinter outdoors. The fecundity can reach the value of 1,400 eggs laid in late May and hatch in late June. Crawlers usually feed on upper leaf surface. Third instars move to stems soon after molting (Gimpel *et al*., 1974).

Chemical control of *C. sinensis* is not effective enough because the pest is well protected by the wax cover. Biological control of the scale is the most efficient. A large range of natural enemies makes the pest not important in its natural area of distribution. The introduction and establishment of predators and parasitoids often gives beneficial economical and ecological effect. The following hymenopterous parasitoids present the highest interest: *A. beneficus*, *A. ohgushii*, *A. rarisetus*, *C. hawaiiensis*, *C. yoshidae* (Hymenoptera, Aphelinidae), *M. clauseni* (Hymenoptera, Encyrtidae), *M. ericeri*, *T. muracamii* (Hymenoptera, Chalcidoidea). Some Coccinellid predators, e.g. *C. bipustulatus*, *E. guadripustulatu*, *H. chalybeus* may also present interest for classical biological control. Good results were obtained with the use of a predator of scale eggs *S. coerulea* (Hymenoptera, Pteromalidae) (Pellizzari and Camporese, 1994; Lo PL Chapman, 2001).

IV.3.4. *Ceroplastes rusci* (Linnaeus, 1758)

C. rusci has a wide host range in the Mediterranean area and is usually a pest of *Ficus*. spp. and *Citrus*. spp. It has been detected on olive trees very rarely. *C. rusci* can be found in the littoral areas of that country where fig trees are most frequent. The fig wax scale has been reported as a pest of citrus in Italy (Barbagallo, 1981).

It develops two generations a year in Greece. Bénassy and Franco (1974) observed one annual generation on fig trees in Southern France. Infrequent major local infestations in the citrus-growing areas of Italy have been controlled with refined petroleum oils. Similar outbreaks occurring in Greece have been controlled by the application of oils in the summer. Some parasites are reported from this scale; *Coccophagus lycimnia* Walker (*Aphelinidae*) and *Scutellista cyanea* Motschulsky (*Pteromalidae*) aid in keeping populations of the fig wax scale under control (Talhouk, 1975; Argyriou and Santorini, 1980; Argyriou and Mourikis, 1981)

IV.3.5. *Coccus hesperidum* Linnaeus, 1758

The brown soft scale is one of the highly polyphagous and most widely distributed soft scale species. It is regarded a citrus pest in several countries over different regions; we quote Middle East, South Africa and Zimbabwe (Bartlett, 1978; Gill, 1997).

Females were reported to reproduce by parthenogenetic in most areas, males are rare. It is ovoviviparous; five to 19 eggs are laid per day and each female lays 80 to 250 eggs (Cancela da Fonseca, 1954-1956). The brown soft scale develops multiple generations, six annual generations in Israel; 3-5 generations in USA, southern California (Bodenheimer, 1951; Ebeling, 1959; Avidov and Harpaz, 1969; Ben-Dov, 2010).

However, it rarely becomes a pest of economic importance to citrus, since a complex of parasitoids regulate its populations. *C. hesperidum* is in fact under effective biological control and outbreaks only periodically require chemical control. There are over 30 known species of natural enemies of the soft brown able to keep populations under low levels (Hart, 1972; Copland and Ibrahim, 1985). It is very sensitive to organophosphates and carbamates, but oil is the most selective pesticide available for its control (Abd-Rabou *et al*., 2001; Ben-Dov, 2010).

IV.3.6. *Saissetia oleae* (Olivier, 1791)

S. oleae, the Mediterranean black scale, is one of the most important pests of olive in the Mediterranean region and of citrus trees in many countries, mainly California. It originated of the southern districts of South Africa (De Lotto, 1976). Now, *S. oleae* is widely distributed in many parts of the world, in particular the tropics and subtropics. Mediterranean black scale generally continues to be a problem in most coastal citrus growing areas of the world; examples are Middle East, Spain, Sicily, Israel (Talhouk, 1969; Gill, 1997; Ben-Dov, 2010; Pellizzari and Germain, 2010).

S. oleae is usually a parthenogenic species. Each female lays a mean of 399 to 150 eggs. Bodenheimer (1951) reported one generation on citrus in Israel, while Blumberg *et al*. (1975) observed bivoltine populations. Peleg (1965) recorded in Israel one generation on citrus, while two generations on irrigated olive. One generation per year in inner areas of California, while two in Coastal counties (Gill, 1988). Beingolea (1969) reported two generations on Citrulus and on sprouting potatoes in Peru. Two generations per year in Spain (Llorens Climent, 1984).

Biological control is the main control method of *S. oleae*. Depending of the countries, the effectiveness of the parasitoids was very significant. In its country of origin, it is kept always at low density thanks to its natural enemies. In Israel, the introduction and management of several parasitoids, especially *Metaphycus batletti* Annecke and Mynhardt, have been controlled the high populations of *S. oleae*. In California, with the release of several introduced parasitoids in 1937, mainly *Metaphycus helvolus* (Compere), only 0.5% of the citrus groves had economically important populations of black scale. These parasitoids are the most effective biocontrol agents at the moment; the coccinellid *Rhyzobius Forestieri* Mulsant has proved to be a promising biocontrol agent too when released in Greece and France (Waterhouse and Sands, 2001; Tena-Barreda and Garcia Mari, 2006).

IV.4. Other species occurring on citrus

IV.4.1. *Aspidiotus nerii* (Bouché, 1833)

A. nerii is senior synonym of oleander scale. Taxonomic interpretation of this species has gradually evolved through studies of Signoret (1869), Comstock (1883), Newstead (1901) and Dietz and Morrison (1916) (cited in Ben-Dov, 2010). Currently, its taxonomy is widely recognized and established in accordance with taxonomic facies elucidated by Ferris (1938), Balachowsky (1956) and Borchsenius (1966) (cited in Ben-Dov, 2010).

Scale of the female is white or pale gray, circular and flat with a subcentral exuviae (Ferris, 1938). The oleander scale ranks among the most highly polyphagous scale insects and widely distributed in almost all zoogeographical regions (CABI, 1970). It has been recorded as a pest of citrus and olive in several Mediterranean countries (Argyriou, 1990); it damages kiwifruit in Chile and avocado in Israel; it is considered a troublesome pest of many ornamental plants (Gill, 1997; Vargas *et al*., 2008).

Unisexual and bisexual populations of this species have been reported. Up to 6 overlapping generations per year are registered in the tropics and in greenhouses, one female lays up to 334 eggs. First instars prefer to settle on leaves, fruits or green stems. The sex pheromone emitted by female oleander scale has been isolated and characterized as cyclobutane-ethanol acetate. The structure of this pheromone is new in the Coccoidea and in the pheromone field in general (Miller and Davidson, 2005).

One chalcid wasp, several species of lady beetles, and a fungus are known. In fact, the tea scale apparently is not a serious problem on tea in certain parts of India because it is kept in check by a complex of natural enemies including several parasites in the genera *Aphytis* and *Encarsia*, a complex of predators, and fungi in the genera *Aschersonia* and *Fusarium* (Nagarkatti and Sankaran, 1990; Ben-Dov, 2010).

IV.4.2. *Eucalymnatus tessellatus* (Signoret, 1873)

Adult female 2-5 mm long; oval or pyriform in outline; flat; colour red to dark brown. Fully grown female is distinguished by the dorsal pattern of polygonal areas (tessellations). The tessellated scale is an occasional pest in greenhouses in United States, Florida, where it is found often on the leaves and stems of mango (Ben-Dov, 2010). It is ovoviviparous, producing 1-2 generations a year. In the 1920's, oils were recommended for its control in Florida. *Metaphycus stanleyi* Compere is the only parasitoid listed by Krombein *et al*. (1979) for *E. tessellates*. Recently, Sugonyaev (2002) reported three chalcids from Vietnam, *Metaphycus stanleyi* (Compere), *Microterys frontatus* Mercet, *Tonkinencyrtus paradoxus* Sugonyaev. This latter has been bred from a female of the *Pseudococcid Eucalymnatus* Tessellatus living on *Citrus grandis*.

IV.4.3. *Fiorinia theae* Green, 1900

Female pupillarial, thus composed mainly of sclerotized second exuviae covered with a thin layer of wax; dark brown to black and elongate to oval with a median ridge and pointed posteriorly; first exuviae terminal, grayish, sometimes with a tinge of yellow (Kosztarab, 1996).

Many authors classify this species as an injuring pest of crops and a serious world pest (Miller and Davidson, 2005). Miller and Davidson (1990) list this insect as a serious and widespread pest, feeding on several host plants. Some common hosts are *Camellia*, *Citrus*, *Eurya*, *Ilex*, and *Theae* (Nakahara, 1982). This scale has been considered also the most important pest of camellias in the southeastern U.S. (English 1990) and one of the ten most important scale pests in Florida. Gill (1997) states *F. theae* as a serious pest of camellias and other ornamental plants. Beardsley and González (1975) consider this scale to be one of 43 serious armored scale pests.

Several generations are observed per year in the southern United States. Fecundity can reach 10-16 eggs with an average of 32 eggs per female (Westcott, 1973). English and Turnipseed (1940) reported a 60-70 day life cycle in warm weather in Alabama with nymphs hatching throughout the year. They noted overlapping generations with continuous crawler production from March to November. Life cycle completed in 40-65 days in the south. Winged males often are abundant and apparently are required for the production of viable crawlers (Ben-Dov, 2010).

IV.4.4. *Parthenolecanium persicae* (Fabricius, 1776)

The european peach scale is a common palearctic species presently known from north and South America, Australia and New Zealand. It is polyphagous, infesting many species of shrubs and fruit trees, mainly vine. It is common in European vineyards, e.g, in Portugal, Spain, France, Italy, Switzerland, Hungary but economically important damages are only occasional. It is rare in vineyards of California and is of no economic importance. However, it is considered to be key pest of grapevine in Western Australia, Chile and Brazil and some outbreaks have also been recorded in Australia (Foldi and Soria, 1989; Ben-Dov and Hodgson, 1997).

Males are apparently very rare and have not recorded recently. Reproduction is therefore, usually parthenogenetic. *P. persicae* is univoltine species and its biology has proved to be similar throughout its distribution area. But Ben-Dov (1993) assumed to have two generations in central Asia. *P. persicae* overwinters as the adult female on old wood and lays its eggs in the early spring; each female can lay between 1000 and 2600 eggs. The crawlers settle on underside of the leaves near veins, producing large amounts of honeydew. In the fall, the third instar nymphs move to the wood and moult to the adult stage before overwintering.

Parasitoids often play an important role in the control of *P. persicae*; populations are always kept under control thanks to many parasits and predators. Williams and Kosztarab (1972) reported 87 and 6% parasitism by the aphelinid *C. lycimnia* in Hungary and 50% in Virginia. Where there is a heavy infestation, light mineral oil treatments or organo-phosphate products are applied at the end of winter or in August against the nymphs (Ben-Dov and Hodgson, 1997).

IV.4.5. *Pseudococcus longispinus* (Targioni Tozzetti, 1868)

The longtailed mealybug is widely distributed in the nature, on a large range of plants, over most territories of the tropical and subtropical regions. It is a common pest in greenhouses in the temperate climate; also an important pest of citrus in U.S.A (California and Florida), Israel and south Africa; and of avocado in Chile (Ripa *et al*., 2008). In addition, in 1980s Rosciglione and Castellano (1985) and Tanne *et al*. (1989) showed that this mealybug is able to transmit the grapevine virus A and Leafroll virus (Ben-Dov, 1994).

Smith *et al*. (1997) indicated that on citrus in Australia (Queensland and Northern Territory), it develops 4-6 generations per year, while 3-4 generations in New South Wales, Victoria and South Australia. It feeds on foliage or branches of host, developing several generations per year; it produces about 200 eggs or young per female (Williams, 2004).

P. longispinus is a target pest for biological control. At least 17 chalcidoid wasps are known as parasits of this species, including the encyrtid wasps *A. fusciventris*, *A. sydneyensis*, and species of coccinellids and brown lacewings. In Israel, effective control has been accomplished using the indigenous parasitoid *H. peregrine* and the introduction of *A. fusciventris* from Austria (Williams, 2004; Ben-Dov, 2010).

IV.4.6. *Pulvinaria psidii* Maskell, 1893

The female cover is circular, white or yellowish, or light brown and the exuviae is subcentral. The green shield scale has originally described from Hawaii on *Psidium spp*, widely spread mainly in the pantropical area. It has been recorded on coffee in East Africa, Ceylon and Southern India, Java and Sumatra, Micronesia, Uganda, and many West Indian and Pacific islands (Ben-Dov and Hodgson, 1997).

It is an extremely polyphagous species with host plants belonging to more than sixty families. It is considered to be a serious pest of mango in Egypt; occasionally found in nurseries in U.S.A and citrus counties (Nada *et al*., 1990).

The overlapping generations is present in greenhouses. Apparently there are both uniparental and biparental populations in nature. Heavy infestations of this pest have been controlled by the predacious ladybird beetle, *C. montrouzieri* that also controls sugarcane mealybug. Parasites include *Microterys kotinskyi* (Fullaway), and *Microterys flavus* (Howard). In greenhouses, all plant material going into should be thoroughly inspected for scales and even other insects before being introduced (Copland and Ibrahim, 1985). Chemicals used on scales are usually the same; the Acephate 12420 was found effective on all stages causing a mean mortality of 98.8%. Dicrotophos and monocrotophos were 94.8% and 92.8% effective respectively (Ben-Dov and Hodgson, 1997). To note, Acephate 12420, diazinon, dimethoate, and malathion are not labelled as from April 2007 (Ronald *et al*., 2007).

CHAPTER 2. MATERIAL & METHODS

I. Survey of citrus scale insect fauna in Tunisia

I.1. Study area

An intensive survey was conducted in the northern part of Tunisia, over a period of 4 months from August to November 2009 in the main citrus growing regions, Nabeul (36° 66'N; 10° 44'E), Beja (36° 43'N; 9° 10'E) and Jendouba (36° 30'N; 8° 46'E) (Fig. 14). In the northeast in Nabeul, survey focused mainly on the sub-localities Menzel Bou Zalfa, Beni Khalled and Soliman, because of the importance of citrus groves and the high infestation level, and in Korba, Beni Khiar, Dar Chaabane and Hammamett sub-localities. In the northwest region, in Beja and Jendouba delegations, the survey was carried out in four localities that contain almost all citrus groves: Nefza, Bousalem, Tabarka and Oued Mliz (Fig. 14).

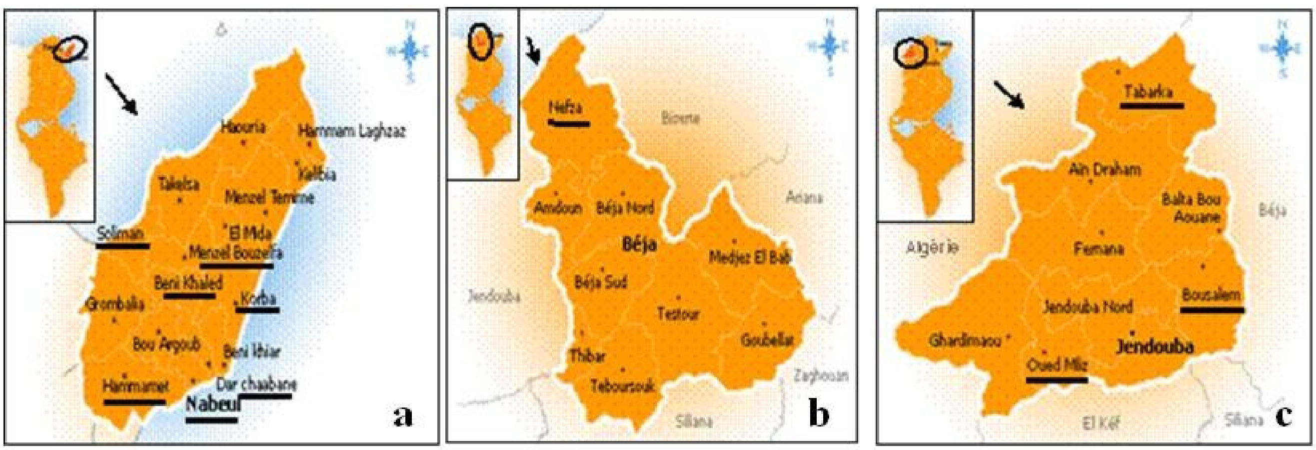

Figure 14. Inspected localities in Nabeul (a), Béja (b) and Jendouba (c)

A total of 60 orchards (84 samples) in 24 sub-localities, in seven and four localities of the eastern and the western parts, respectively, were selected to form the core sampling area of this survey, (Table. 5). These orchards were of varying ages (12 – 40 years), consisting of a wide range of species and varieties of citrus such as oranges (*C. sinensis* (L.) Osbeck) (Maltaise demi sanguine, Thomson navel), clemetine mandarins (*C. reticulata* (Blanco)) and grapefruit (*C. paradise*), presenting different levels of infestation with scale insects.

Table 5. Inspected sites and number of samples

Regions	Localities	Sub-localities	Number of samples
Northeast	**Nabeul**	Beni Khalled	17
		Menzel Bou Zalfa	11
		Soliman	11
		Korba	6
		Nabeul	6
		Dar chaabane	2
		Hammamett	11
	Total	**7**	**64**
Northwest	**Beja**	Nefza	5
		Bousalem	3
	Jendouba	Tabarka	8
		Oued Mliz	4
	Total	**4**	**20**
	Total	**11**	**84**

I.2. Inspections and sampling

Orchard inspections were conducted in irregular way at the different locations of the study area and a selective sampling of infested material was applied. Each citrus orchard was subdivided into equal subplots of 1 ha and a portion of 10% of citrus trees was surveyed in each subplot. After 5 minutes of visual examination of the different tree parts, a sample of fruits (1-5), leaves (10) and twigs (5 of 20 cm in length) was picked randomly from the five quadrants at various heights of each tree. Samples were also taken from fruit trees growing alongside citrus orchards, when present, including the pomegranate (*Punica granatum* Linnaeus), laurel (*Laurus nobilis* Linnaeus) and the common medlar (*Eriobotrya japonica* (Thunb.) Lindl) (Fig. 15).

Figure 15. Laurel trees planted around citrus orchard (Tunisia (Soliman), 2009)

The eighty-four samples collected during this survey were taken to the laboratory of Entomology at the National Agronomic Institute of Tunisia (INAT) for further examination. Scale insect species were identified, their densities were assessed, and the present life stages were recorded.

I.3. Data analysis

In sections "incidence and distribution of species" the following classification method described by Douglass and Davidson (1990) was used to assess the intensity of infestation of different species of scale insect and define foci of infestation for each species. There are five categories: 0 = no infestations; 1 = isolated infestation (only scattered single individuals found); 2 = medium infestation (small colonies of 2-10 individuals); 3 = severe infestation (large colonies of 11-100 individuals); 4 = general or layered infestation (scales completely cover the infested parts of the plant).

The distribution "limited" is attributed to scale species that occupied less than 15% of inspected sites, "frequent" for species those occupying between 15% and 50% and "widespread" to those occupying more than 50% of inspected sites. "Infrequent" term is used for the species which are occurring in Tunisia but not more detectable. The relative scale species abundance is calculated by dividing the number of individuals from one species by the total number of individuals from all species. The occurrence of at least one individual of a species per sample or even per location was considered to be an occurrence. It should be noted that field trip and sampling efforts had been much higher in Jendouba, in particular Oued Mliz, because of the low infestation, in order to collect the maximum of informations about species.

II. Identification of scale insects species

II.1. Preserving, mounting and identification

- **Preserving**

At least 20 females of each species from each sample (collected during the survey) were carefully removed from the infested plant surfaces and placed in vials of 75% alcohol. Each vial was marked with relative coordinates, farmer name, location, citrus variety and sampling date. Then, all the stored materials were transported to the University of Catania for the specific identification, using morphological techniques.

- **Mounting**

There are numerous methods of preparation; those given by Howell and Kosztarab (1972), MacGregor (1972), McKenzie (1967), Cox (1987) and Wilkey (1990) are widely accepted. Therefore, representative specimens were mounted on microscopic slides using the protocol of Williams and Watson (1987) reported in the book of Williams and Granara de Willink (1992) for the mealybugs, soft scales and monophlebids and that described by Wilkey (1990) (cited in Miller and Davidson, 2005) for armored scale.

In total, around 200 adult females were mounted for identification. The method of preparation is given here. For the armored scales, two steps of the mounting scales on slides are not done: the incision in the mid-dorsal thorax and the acid alcohol bath.

Method of preparation

a. An incision is gently made with a needle in the mid-dorsal thorax. Specimens are placed in 10% of KOH and heat for about 10 minutes.
b. After, specimens are removed to distilled water and, when necessary, pressed the body contents by gentle pressure. Mature specimens often contain numerous eggs or embryos which must be removed by incisions. Occasionally waxy droplets may remain inside the body; they can be removed by first placing in 95%-100% alcohol, then transferring to carbol xylene for about 10 minutes. After the specimens are cleared, placed in alcohol again to remove the carbol xylene.
c. Specimens are transferred from the water, or if the last method has been used, from alcohol, to an acid alcohol bath made up of: glacial acetic acid-20 parts, 50% alcohol – 80 parts, and left for few minutes.
d. They are stained for about one hour in: acid fuchsine 0.5g, 10%HCL - 24ml, distilled water 300 ml.
e. They are transferred from the stain to 95% alcohol for very few minutes to remove surplus stain: then transferred to absolute alcohol.
f. After, they are transferred to clove oil for 20 minutes.
g. Finally, the specimens are placed, dorso-ventrally flattened, on a slide, removing surplus clove oil by means of fine filter paper. A drop of Canada balsam is put on the specimen and gently lowers the cover slip by its own weight
h. Mark the accession number on the slides with temporary labeling and place them in a drying oven or warming tray at 40°C for about 2 weeks before final labeling and study.

Identification

Identification of species in this work was based on the morphology of adult females. Many good keys are available in literature diagnosing the species of America, Austria, Pacific region etc… For Tunisian species keys for tropical or sub-tropical species could be the most adapted. Hence, keys described by Unruh and Gullan (2008a, b) (Monophlebidae, *Icerya* genus); Balachowsky (1954, 1956, 1953 and 1948) (Diaspididae); Hamon and Williams (1984), Pellizzari and Camporese (1994) and Gill (1988) (Coccidae); and by Marotta (1990) and Williams and Granara de Willink (1992) (Pseudococcidae, genus *Planococcus*) were used. Additionally, others works were checked for further or more detailed description, as those of McKenzie (1956, 1967); Williams and Watson (1988a, b, c) and Miller and Davidson (2005).

II.2. Data Analysis

In the section "taxonomy of species" the families are treated in phylogenetic order, genera and species in alphabetical order. The main paragraphs for each species are listed in a uniform order under scientific name, material examined (number of mounted specimens, locations, instar etc…), un-mounted specimens, mounted specimens, comments. More morphological details are provided for the new recorded species and for similar closed species in comments paragraphs.

The keys to the species are provided only for those identified during the current survey. A description of the main features of each genus and each species is given. In the case of species, identification is based on the characters of Tunisian mounted specimens. Only the adult females have been described for all species of scale insects, and keys and descriptions are for slide-mounted adult females.

Each family and each species is illustrated with a basic diagram of a slide-mounted female. Illustrations of the main figure of the species show the dorsal surface on the left and the ventral surface on the right half (families). Important details are enlarged and placed around the perimeter of the main figure. Some figures represent the morphology of species, collected and prepared during this work.

III. Review on scale insect species recorded on citrus in Tunisia
III.1. Historical records

In order to update and review the list of species occurring in Tunisia on citrus, a literature search of scale insect species occurring in Tunisia on citrus was performed firstly on the ScaleNet database and used to list the historical records of these insects (Ben-Dov *et al*., 2010). A first query of ScaleNet was done for listing all scale insects recorded in Tunisia, then a query for each species to determine on which host plant it has been recorded. Also, another query of ScaleNet was done for listing all scale insects found on *Citrus spp.* worldwide, followed by a cross search in order to determine which of these had been recorded in Tunisia.

Other sources dealing with scale insects in this country, including keys, illustrated morphological description, distribution, hosts, biology/life cycle, economic importance, have been compiled. The main references used in the present study are: Balachowsky (1932, 1953, 1954); Pagliano (1938), Millet (1956), Jerraya (1974, 2003), FAO (1996), Jendoubi *et al*., (2008).

III.2. Data analysis

Obviously, all species of scale insect recorded occurring on citrus in Tunisia are listed in a table. They are arranged alphabetically by family and species (with the actual valid name) and separated by host plant, origin, and status before and after the current survey; I added the correspondent references to each species. The origin of species is given according to Miller *et al*., (2002), Ben-Dov and Miller (2010) and Pellizzari and Germain (2010).

IV. Life tables of *P. ziziphi*

The experiment reported here was carried out, from February to October 2011, in the laboratory of Entomology in the Mediterranean Agroforestal Institute, Polytechnic University of Valencia, Spain. It consisted in studying the life tables of *P. ziziphi* at two constant temperatures (20°C and 24°C) using two plant substrates, fruits of green lemon and leaves of seedling plants of sour orange.

IV.1. Experimental setup
IV.1.1. Transferring of infestation

In order to conduct the experiments, we need a rearing of *P. ziziphi* in laboratory. Hence, a technique was adopted; it consisted in putting infested materials in contact with clean vegetal material in order to transfer infestation to this latter; once infested materials become dried, new emerged crawlers will move to the fresh materials, choosing hence better suitable site for their settlement and feeding.

In this experiments, two plant substrates were used, clean fruits of green lemon coated partially with paraffin (Fig. 16) and seedlings plants of sour orange growing in small plastic pots and of 15 cm length (Fig. 17).

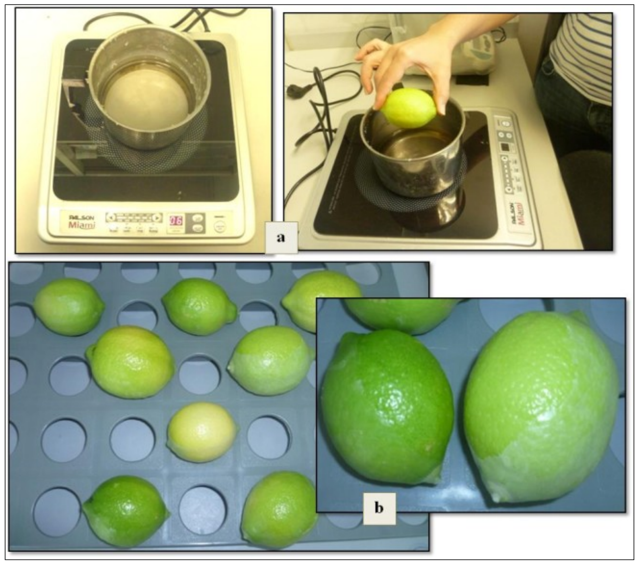

Figure 16. Waxing process: a. Coating of fruits with paraffin after ebullition, b. Waxed lemon fruits

Figure 17. Seedlings plant of sour orange

Infested leaves with *P. ziziphi* were collected from citrus trees growing in the botanical garden of Valencia and kept to the laboratory. Small pieces of leaves containing ovipositing females were cut, then inserted in like a small bouquet of flowers made with muslin of fine mesh and placed up on each fruit (Fig. 18). In the case of the seedlings plants, infested leaves were attached to different clean leaves of plants by clips (Fig. 19). Finally, both fruits and plants were arranged in small plastic cages (20×15×12 cm) and left 1-3 days in growth chamber in darkness under 24°C and 80% RH for settlement of crawlers (Fig. 18, 19). Once fixed, fruits and plants with colonies of *P. ziziphi* were managed and moved to the appropriate chambers.

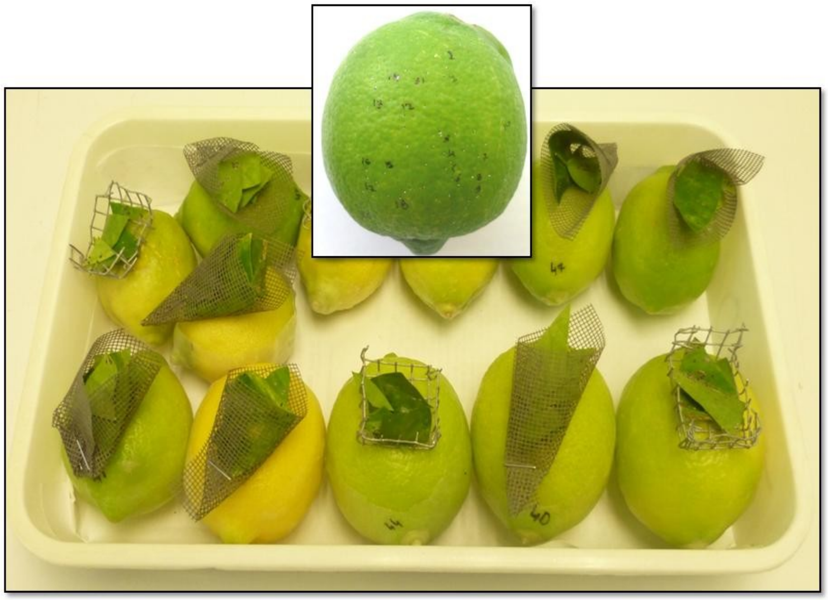

Figure 18. Transferring of infestation on fruits

Figure 19. Transferring of infestation on plants

IV.1.2. Experimental design

Two trials were conducted in a climatic chambers at 14L:10D, 75±10% RH and approximately 5500 Lux at plant height. Each chamber was set at one of two target temperatures (20 and 24°C) which were maintained to an error of ± 1ºC throughout the experiment.

Each tray contained two plants and approximately five to 10 fruits. Seventy settled crawlers were randomly selected on the different fruits and others 70 on leaves of plants; they were assigned a number and the settling date was recorded. Then, fruits and plants were put separately into 2 plastic cages (45×35×30 cm) and placed in the climatic chambers. The relative humidity was maintained constant by using saturated salt solutions of potassium chloride (74.55 g/mole), placed inside the cages. Cages were continuously monitored using datalogers (Delta-OHM, model HD226-1) to establish the precise temperature and humidity to which the black scale populations were exposed. The plants were watered twice a week. Experiments at different temperatures were run simultaneously, and the cages were monitored periodically for pest development (Fig. 20).

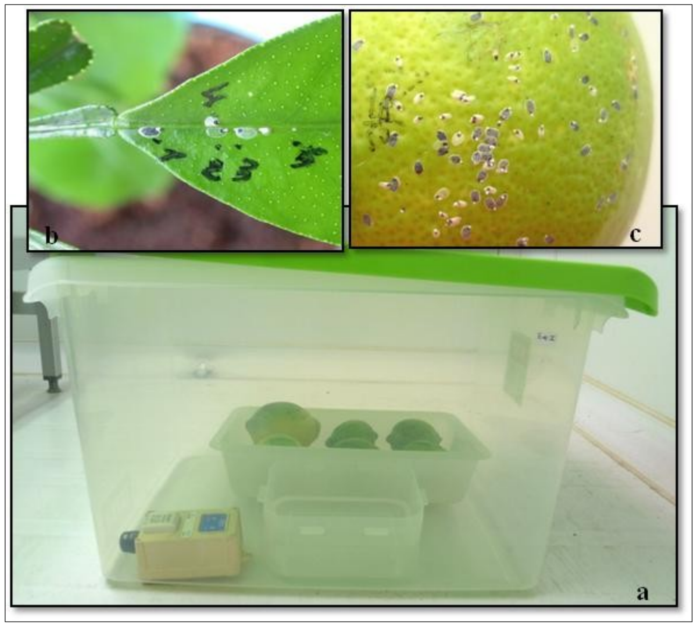

Figure 20. Rearing and growth of *P. ziziphi* under controlled conditions (a), on leaves (b), and fruits (c).

IV.2. Study of *P. ziziphi* life tables

IV.2.1. Nymphal and adult development and survival

Mean development duration and survival in each immature stage as well as in each adult stage for both females and males was recorded each 2 days at the two target temperatures. Dead specimens were replaced by new ones in the same or similar development stage if the total number of surviving specimens entering a stage was below 30.

IV.2.2. Fecundity and fertility

To calculate the fecundity and fertility of *P. ziziphi*, it was not possible to observe the eggs laid and the egg hatching process of this insect because eggs are laid under the scale cover and removing the cover caused the death of the female. For that reason to study the reproduction capability of each female, we referred to the number of crawlers (offspring) that emerge. Hence, all gravid females were encircled with glue (Tanglefoot) in order to catch emerged crawlers by this sticky substance (Fig. 21). Emergence of crawlers was monitored twice a week and their number was recorded at each day of observation. When no more crawlers emerged, the scale cover was removed for all females, and their status was noted counting also the number of un-hatched eggs and crawlers died under the scale.

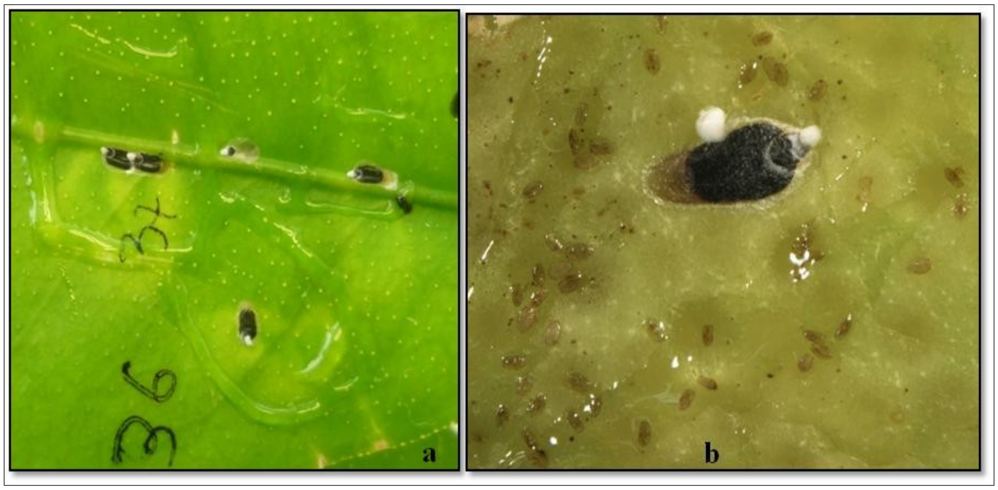

Figure 21. Ovipositing females encircled with glue (a) and catches of crawlers (b)

IV.2.3. Life table parameters

Life-table data of all the initial selected specimens (n = 70) obtained from periodic observations on both leaves and fruits were used to define the following population parameters:

- **Age specific survival (l_x)**

It is the number of living or surviving specimens at the beginning of a given age x (out of initial total number N).

- **Age specific fertility (m_x)** (born females/female)

It records the number of living females born per female in each age interval.

- **Net reproductive Rate: $R_0 = \sum_{i=x} l_x.m_x$** (females/female/generation)

It describes the number of times a population will multiply per generation.

- **Intrinsic rate of increase: r_m** (females/female/day)

It means the maximum value of the parameter *r* which describes the population growth under a given physical and biotic environment. The r_m value is estimated by using the iterative bisection method from $\sum_{x=0}^{n} e^{-r_m.x}.\,l\mathbf{x}\,.\,m\mathbf{x} = 1$ with age indexed from 0 (Birch, 1948). The *'x'* value is the age of the individuals in days; *'l_x'* is the proportion of individuals alive entering day 'x' and 'm_x' is the number of female offspring/female at day 'x'.

- **Mean generation time: T_0**

It is defined as the length of time that a population needs to increase Ro fold of its size. It is calculated as the sum of mean time of embryonic development, plus mean time of immature post-embryonic development, plus mean time of pre-ovipositing female, plus mean time needed by a female to lay half its total egg load.

The age-specific survival rate (l_x) and the age specific fecundity (m_x) were measured. The intrinsic rate of increase (r_m), the net reproduction ratio (R_0) and the mean generation time (T_0) were calculated according to Southwood and Henderson (2000).

The data on immature and adult durations were subjected to the analysis of variance to one factor and the means were compared by LSD-test (*P* = 0.05), using STATGRAPHICS program (Centurion XVI, 2009).

CHAPTER 3. RESULTS

I. Identification of scale insects species detected during the survey

I.1. Key to families of Coccoidea

Many keys for the scale insect fauna living in European, extra-european or American countries are currently used, but many times they have been unusable or not adapted to the Mediterranean species. We mention those described by Kozar and Kosztarab (1988) and Williams and Watson (1988) for species of Central Europe and Pacific region. Marotta (1990) has published an Italian key to 15 families and 160 genera including quasi all scale insect species recorded in Italy. This key was used in this section to recognize the family of each specimen, thinking that could be the most appropriate key to Tunisian fauna of scale insects.

Twelve species were collected and identified during the survey. They belong to 4 families Monophlebidae (Margarodidae), Pseudococcidae, Coccidae and Diaspididae within the Superfamily Coccoidea. Herein, we insert the key to families elaborated by Marotta (1990).

- **Key to families Margarodidae, Pseudococcidae, Coccidae and Diaspididae**

1. – Abdominal spiracles present……………………………………………………………………….2
   Abdominal spiracles absent……………………………………………………………………………….3
2. – Anal ring distinct, with pores and setae…………………………………………………………Ortheziidae
   Anal ring reduced, without pores and setae……………………………………………………Margarodidae
3. – Anal opening surrounded or covered with 2 anal plates…………………………………………………4
   Anal opening free or covered with 1 anal plate……………………………………………………………5
4. – Anal ring with 6-8 setae; spiracles without multilocular pores in the artia………………………**Coccidae**
   Anal ring with 10-12 setae; spiracles with multilocular pores in the artia……………………Micrococcidae
5. – With 8-shaped pores on dorsum……………………………………………………………………………6
   Without 8-shaped pores on dorsum………………………………………………………………………….9
9. – Anal plates present……………………………………………………………………………Acleridae
   Anal plates absent…………………………………………………………………………………………10
10. – Dorsum with truncate spines; 3, 4 and 5 locular pores in clusters……………………………Dactyopiidae
    Dorsum with truncate spines; pores not arranged as above………………………………………………11
11. – Abdomen terminating in fused segments forming a pygidium……………………………………**Diaspididae**
    Abdomen without posterior fused segments…………………………………………………………………12
12. – Cluster pore plate present just below each posterior thoracic spiracle………………Cryptococcidae
    Cluster pore plate absent………………………………………………………………………………………13
13. – Small irregularities present on derm…………………………………………………………Phoenicococcidae
    Dermal irregularities absent…………………………………………………………………………………14
14. –Tubular ducts not invaginated; dorsal ostioles, cerarii and trilocular pores usually present……………………………………………………………………………………………**Pseudococcidae**
    Tubular ducts invaginated; dorsal ostioles, cerarii and trilocular pores absent……………………15
15. – Ventral tubular ducts scattered over body surface; with protruding anal lobes…………Eriococcidae
    Ventral tubular ducts arranged in submarginal band; without protruding anal lobe……………………………………………………………………(part of Kermesidae)

I.2. List of genera and species

I. purchasi, *Pl. citri*, *C. floridensis*, *C. hesperidum*, *S. oleae*, *A. aurantii*, *C. aonidum*, *C. dictyospermi*, *C. pinnulifer*, *L. beckii*, *P. pergandii* and *P. ziziphi* were the species collected during the survey, mounted on microscope-slides and identified. Their taxonomic position is given below.

Monophlebidae
Iceryini
Icerya
I. purchasi
Pseudococcidae
Planococcus
Pl. citri
Cocccidae
Ceroplastinae
Ceroplastini
Ceroplastes
C. floridensis
Coccinae
Coccini
Coccus
C. hesperidum
Saissetiini
Saissetia
S. oleae
Diaspididae
Aspidiotinae
Aonidiella
A. aurantii
Chrysomphalus
C. aonidum
C. dictyospermi
C. pinnulifer
Diaspidinae
Lepidosaphes
L. beckii
Parlatorinii
Parlatoria
P. pergandii
P. ziziphi

I.3. Description of species

I.3.1. Genus *Icerya* Signoret, 1876

Description. *Icerya* spp. is defined by the absence of compound multilocular pores in all species, the presence of open-centre pores in some species as well as the occurrence of pore types seen in no other genus. Adult female elongate, elliptical or round, 2.7–10.4 mm long, 2.0–6.2 mm wide. Antennae 9 to 11 segmented. Labium 3 segmented. Hair-like setae scattered over entire surface, longest medially and marginally, sometimes in marginal clusters. Flagellate setae scant, scattered. Simple multilocular pores of varying types generally found over entire surface, sometimes in marginal and/or dorsal medial clusters. Open-centre pores absent or, if present, in marginal clusters on all body segments and sometimes on dorsum in medial clusters or transverse rows on head and thorax. Ovisac band absent or present. Marsupium absent or, if present, marsupial band forming a complete circle of setae and multilocular pores with bilocular centre; posterior portion of band becoming sclerotized at maturity. Cicatrices circular to elliptical, numbering 1 or 3. Abdominal spiracles in 2 (Icerya group) or 3 (Pericerya group) pairs on abdominal segments VII–VIII or VI–VIII; simple multilocular pores sometimes clustered on derm at thoracic and/or abdominal spiracular opening. Dorsal derm may become very sclerotized and form distinct sclerotized patches in some species (Fig. 22) (Unruh and Gullan, 2008a, b; Ben-Dov, 2010).

Only one species belonging to the genus *Icerya* was identified as *I. purchasi*

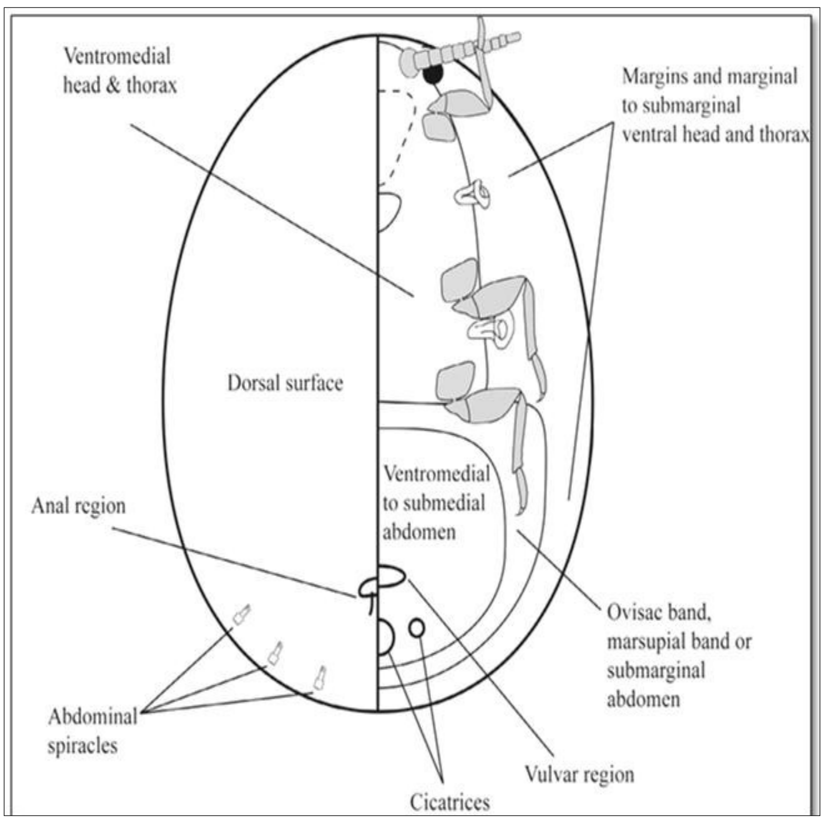

Figure 22. General morphology of mounted adult female of Monophlebidae (Unruh and Gullan, 2008a)

I.3.1.1. *Icerya purchasi* Maskell, 1879

Material examined. Twelve slide-mounted specimens of adult females were identified as *I. purchasi* and three as young instars of *Icerya* sp. Individuals were collected from twigs of citrus trees and all developmental stages from crawlers to ovipositing females were present. Samples were kept during September and the first two weeks of October in Cap Bon localities and during the last week of November in the north-west regions in Nefza and Tabarka.

Unmounted material. In life, dorsum of adult female sparsely covered in waxy secretion with medial ridge of wax and segmental waxy tufts projecting from ventral margin around body; glassy filaments also projecting from margins. Ovisac fluted, projecting from posterior of body

Mounted material. Adult female oval, 5–10 mm long, 4–6 mm wide. *Venter*. Antennae 11 segmented. Cicatrices round to oval, numbering 3, central cicatrix largest or all subequal in size. Open-centre pores with 6–8 outer loculi, present in marginal clusters and densely dispersed across dorsal head. Simple multilocular pores with bilocular centre and 6–8 outer loculi, covering dorsal surface. Ovisac band made of simple multilocular pores of two types: (i) pores forming inner ovisac band, 2–4 pores wide at anterior edge, 10–12 pores wide around lateral and posterior edges, each pore with bilocular centre and 8–10 outer loculi; and (ii) smaller pores forming outer ovisac band on anterior edge only, 1–3 pores wide, each pore with bilocular or trilocular centre and 4–6 outer loculi; also forming segmental clusters on submarginal ventral abdomen. *Dorsum*. Dark hair-like setae covering dorsal surface in dense clusters and clustered with open-centre pores around margin; scattered across ventral head and thorax. Simple multilocular pores, with bilocular centre and 4 or 5 outer loculi, scattered on ventromedial head and thorax and scattered across ventromedial to submedial abdomen. Abdominal spiracles in 2 pairs. Anal opening, surrounded by long, robust hair-like setae (Fig. 23).

Comments. Unruh and Gullan (2008a) recently revised the tribe Iceryini based on a molecular phylogenetic hypothesis and supporting morphological evidence. Accordingly, Iceryini tribe and *Icerya* genus belong actually to the family Monophlebidae not the Margarodidae as previously. Additionally, all Tunisian specimens collected during the survey belonging to *Icerya* genus are included precisely in the informal “Pericerya” group. This is the generic name which was created by Silvestri (1939) (cited in Unruh and Gullan, 2008b) to describe all Iceryine species with only two pairs of abdominal spiracles and have open-centre pores present in marginal clusters.

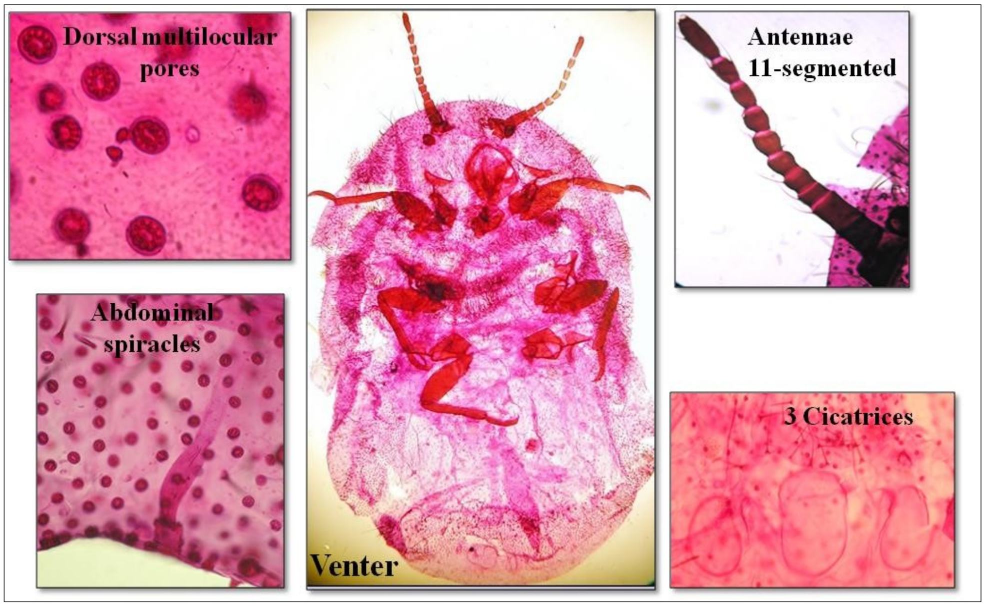

Figure 23. Mounted adult female of *I. purchasi*: main features

I.3.2. Genus *Planococcus* Ferris, 1950

Description. Adult female is normally oval. Cerarii numbering 18 pairs, each with 2 conical setae. Oral collar tubular ducts usually present on venter. Ostioles represented by anterior and posterior pairs (4). Anal ring apical, bearing 6 setae. Antennae each normally with 8 segments. Legs well developed; claws each without a denticle. Translucent pores normally present on hind coxae and tibiae. Circulus well developed. Anal lobes each with anal lobe bar, with some trilocular pores. Multilocular disc pores evenly distributed (Fig. 24) Williams and Granara de Willink (1992).

Two species were reported in Tunisia *Pl. citri* on citrus, detected during the survey, and *Pl. ficus* on grapevine.

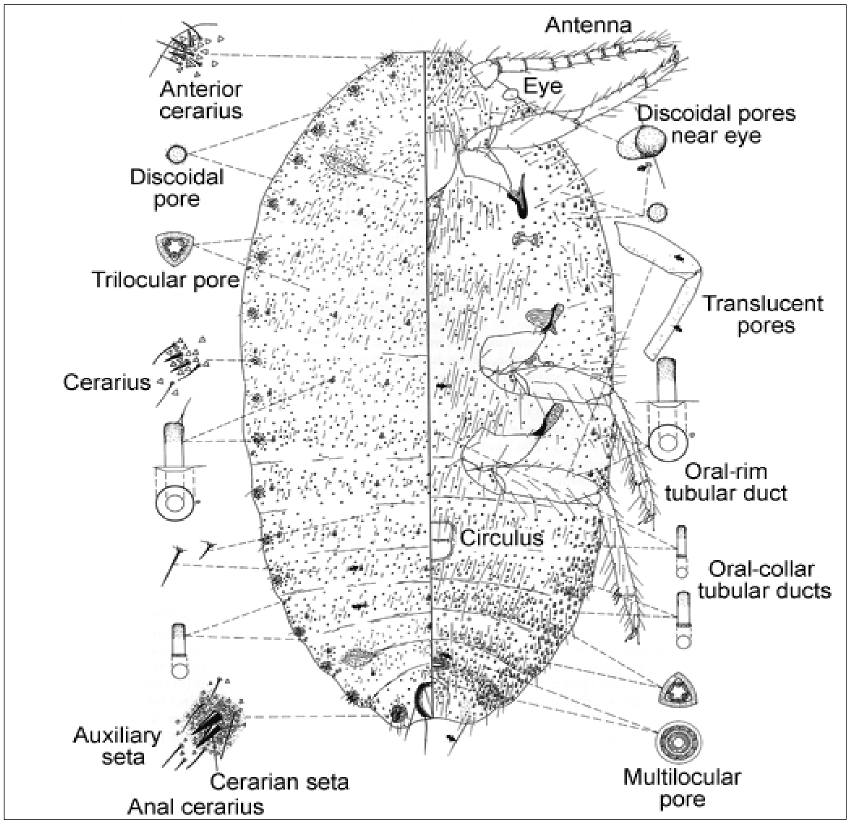

Figure 24. General morphology of mounted adult female of Pseudococcidae (Ben-Dov *et al*., 2010)

I.3.2.1. *Planococcus citri* (Risso) 1813

Material examined. Fifty-five samples of mealybugs were collected from the different sites in all the northern citrus regions (Cap Bon, Beja and Jendouba) during the three months of survey September, October and November. Populations, present at all developmental stages, were found feeding on two host plants, pomegranate (fruits) and citrus trees (fruits, leaves, twigs). Fourty specimens were mounted and examined under microscope; all were identified as *Pl. citri*. However individuals, lacking vulva, were considered as *Planococcus* spp.

Unmounted material. Body of female oval, flat, distinctly segmented forming a fringe of long wax. Waxy secretions make it look as if it is covered with flour.

Mounted material. Adult female broadly oval. *Venter*. Antennae well developed. Legs elongate; hind-trochanter + femur 220-350µm long, hind-tibia + tarsus 260-420 µm long. Translucent pores present on hind coxa and hind tibia. Oral collar tubular ducts of 2 sizes; a small type sparse, present across median areas of abdominal segments Circulus quadrate. Cerarii numbering 18 pairs. Anal lobe cerarii each with 2 conical setae. Anterior cerarii each with 2 conical setae, but preocular cerarii sometimes each with 1 or 3 setae. Multilocular disc pores present in single to double rows across anterior edges of most abdominal segments and in single rows across anterior edges of segments V-VII, in marginal groups on abdominal segments IV-VII; some often present in median areas of head and thorax. *Dorsum*. Surface with flagellate setae, the longest on abdominal segments VI or VII. Oral collar tubular ducts without apparent rims, present next to some cerarii (Fig. 25).

Comments. The genus *Planococcus* is probably of old world origin according to Cox (1989) (cited in Williams and Granara de Willink (1992)) and comprising 37 species. During the identification, two populations groups of *Pl. citri* were revealed; (i) 9 specimens having a few tubular ducts, 4 to 9, in the venter of head and 2 to 4 ducts next to the eigth pair of cerarii, and (ii) of 31 specimens having numerous tubular ducts, 14 to 20, in the venter of head and till 7 ducts next to the eigth pair of cerarii.

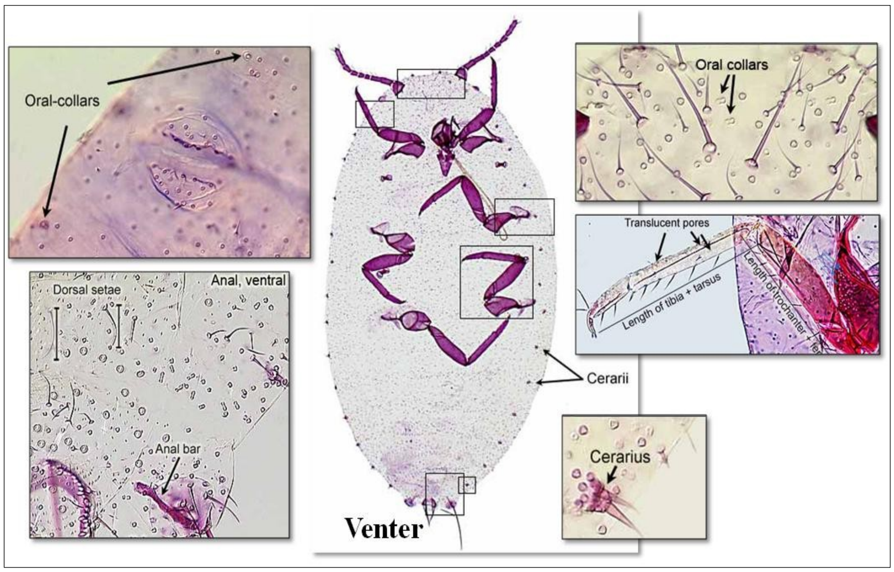

Figure 25. Mounted adult female of *Pl. citri*: main features (Ben-Dov *et al*., 2010)

I.3.3. Identification of young instar for soft scales

Clearly, this work is about the identification of genera or species based on the adult females. But this is only useful if it is sure that specimens are adult. During the identification of coccid species, some slide-mounted specimens were at immature stages and it wasn't easy to be identified. Therefore, we used to refer to the following key, reported in Hodgson (1994), to separate the scale instars of all slide-mounted specimens and then proceed with the specific identification of adult specimens. Basically, immature stages lack pregenital disc-pores preopercular pores and articulatory scleroses between the tibia and tarsus. In addition, immature stages generally lack dorsal setae and appear never to have both claw digitules.

- **key to young soft scale**

1. – Anal plates with 1 pair of apical setae longer than half the length of anal plates; legs and antennae well developed…………………………………………………….…………....**1st instar nymph**

– Anal plates with apical setae less than half the length of anal plates; legs and antennae may be reduced……………………………...…………………………………………...………………………...………2

2. – Preopercular pores and/or pregenital disc-pores present; claw digitules both broad in some species and genera…………………...……………..……………………………...………………..……………..…**adult female**

– Preopercular pores and/or pregenital disc-pores absent; with at least one claw digitule thin and similar to those of tarsus - never both broad……………………………………………….………………………………….…..3

3. – Dorsal tubular ducts present in at least a narrow band along abdominal segment III or IV but may be widespread over dorsum…………………….………………….…………………...……………..……...**2nd instar male**

– Dorsal tubular ducts very scarce or absent from dorsum.………………………………...**2nd and 3rd instar females**

Referring to the key to genera of Coccidae, reported in Williams and Watson (1988), the different coccid specimens examined, are grouped in three genera; *Coccus* sp., *Ceroplastes* sp. and *Saissetia* sp. The three genera have the anal plates less than 1.5 times as long as wide plates or posterior part longer than anterior part and dorsal setae not truncate. *Saissetia* genus is distinguished from the others genus by two features: (i) dorsal derm with small oval clear areas of polygonal reticulations; and (ii) anal plates with discal setae. In fact, in *Ceroplastes* genus, the anal plates are in sclerotized process and the derm around it is sclerotized. In the genus *Coccus*, the derm around anal plates is membranous and the process is absent. Also, spiracular setae are numerous in the primer and lesser in the second.

I.3.4. Genus *Ceroplastes* Gray, 1828

Description. Body is round, oval, or irregular in outline, usually convex. Females covered with dense amorphous wax, usually white, and may or may not be divided into plates. Derm heavily sclerotized in adults. Numerous trilocular pores present. Body setae variable in size, shape, and distribution. Submarginal tubercules absent. Anal opening usually longer than wide, situated at apex of sclerotized caudal process. Anal plate setae variable. Hypopygial setae present or absent depend of species. Anal ring with 8 setae. Antennae 6 to 8-segmented. Legs usually well developed, tibiotarsal sclerosis present or absent. Quinquelocular pores in spiracular furrows. Multilocular pores variables, present in vulvar area and abdomen. Tubular ducts variable. Marginal setae variable in size, shape, and distribution. Spiracular setae numerous, conical, hemispherical or bullet-shaped (Fig. 26) (Gill, 1988).

C. rusci, *C. sinensis*, *C. floridensis* were reported in Tunisia but only the latter is described below.

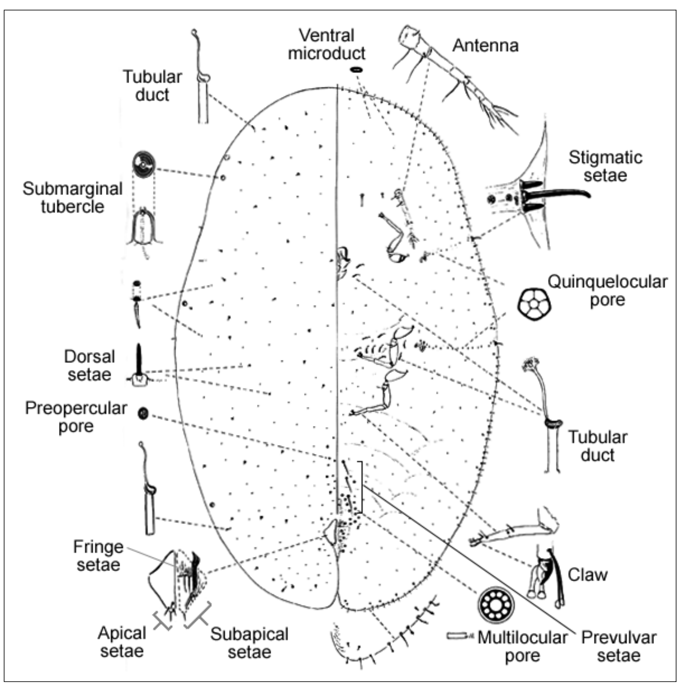

Figure 26. General morphology of mounted adult female of Coccidae (Gill, 1988)

I.3.4.1. *Ceroplastes floridensis* Comstock, 1881

Material examined. Twenty specimens were mounted and identified as *C. floridensis* except some young specimens which were considered as *Ceroplastes* sp. Individuals at first and second instars mainly and at adult stages were found only on leaves of citrus and laurel trees. Samples were collected during September, and first weeks of October and November in Cap Bon.

Unmounted material. Body covered with dirty white wax, convex and circular in outline, often with a pinkish tint in younger specimens.

Mounted material. Body oval in shape. *Margin*. Stigmatic setae numerous, lanceolate, with pointed apices; 9-15 marginal setae between groups of spiracular setae or 21-40 setae in the anterior group and 23-43 in the posterior group; conical spiracular setae in 2-3 rows. *Venter*. 6-segmented antennae. Legs well developed without tibio-tarsal scleroses. Claw without denticule. Spiracular setae, 20-30, conical pointed, in 2-3 rows. Tubular ducts with enlarged inner filament distributed in a submarginal band from the eye spot to the anterior anal cleft. Multilocular pores in the other abdominal segments. *Dorsum*. Dorsal pores mostly trilocular, scattered. Caudal process conical, short, heavily sclerotized. Anal plates twice as long as wide, with 3 dorsal and ventral setae. Anal ring oval to circular with 6 long and 2 short setae (Fig. 27).

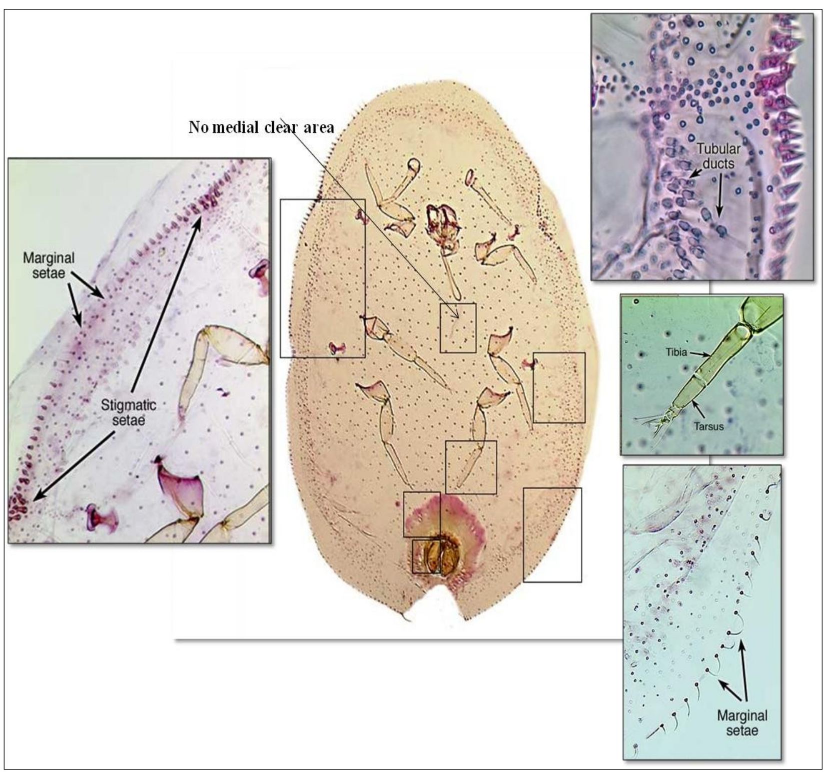

Figure 27. Mounted adult female of *C. floridensis*: main features
(Ben-Dov *et al*., 2010)

I.3.5. Genus *Coccus* Linnaeus 1758

Description. This genus is one of the oldest genera of Coccoidea, best recognized by its general lack of outstanding taxonomic characters. It is characterized by drab, ovoid or elongate species which are flat in profile throughout life, slightly convex; naked or with a slight film of wax, membranous or sclerotized derm. Morphologically, the ventral sub-marginal tubular duct bands and freely articulating tibio-tarsal joints are not present. Anal plates are usually triangular, with varying numbers of apical and sub-apical setae. Anal ring, with numerous wax pores and 8 anal ring setae (Fig. 26) (Gill, 1988; Hodgson, 1994; Kosztarab, 1996).

Two species are known from Tunisia; *C. hesperidum* and *C. pseudomagnaliarum*, here the former is described.

I.3.5.1. *Coccus hesperidum* Linnaeus, 1758

Material examined. Twenty-two specimens were mounted and examined. Among them: 10 were at 2nd instars stage remain unidentifiable, 10 mature females were identified as *C. hesperidum* and 2 old females with some small pale areolation on the derm, indicating sclerotized area. All samples were collected from citrus trees mainly leaves and twigs in all Cap Bon districts during September and October. Most populations in the field were young stages.

Unmounted material. In the field, body elongate-oval, fairly flat. Color between yellowish-green (young) and yellowish-brown (mature); flecked with brown spots which are considered by many authors a field recognized characters.

Mounted material. Body usually elongate-oval, with distinct stigmatic indentations; anal cleft about 1/6-1/7th body length. *Margin*. Stigmatic clefts often slightly indented, marginal setae finely spinose, each typically with a flattened fimbriate apex or pointed; 8-14 sub-marginal setae on each side between stigmatic clefts. *Venter*. Antennae each with 7 segments; 3rd and 4th segments sub-equal. Legs slender; each with a distinct tibio-tarsal articulation and a small articulatory sclerosis which appears sometimes absent in some legs; each claw without or with a very small denticule; claw digitules shorter than tarsal digitules. Microducts small and rather sparse throught. Pre-genital disc pores each usually with 10 loculi; spiracular disc-pores each mainly with 5 loculi. Tubular ducts confined to thorax. *Dorsum*. Derm membranous throughout, only slightly sclerotized. Discoidal pores few, anterior of anal plates. Simple disc pores scattered over dorsum in an irregular row around margin. Sub-marginal tubercules 6-12. Body setae stout and pointed. Marginal setae pointed, slightly fimbriate. Anal plates together quadrate, posterior margin longer than anterior margin, each with 4 sub-terminal setae. Anal tube, long, anal ring 2 times its diameter anterior to anal plates, with 6 setae (Fig. 28).

Comments. *C. pseudomagnoliarum* is very similar to *C. hesperidum* but normally has 8-segmened antennae and lack of sub-marginal duct tubercules and therefore microscopic distinction is evident. In the field, basically *C. pseudomagnoliarum* has a distinctive color pattern, gray with dark brown in adult females while *C. hesperidum* is yellow but distinction between both species mainly at young stage is still difficult.

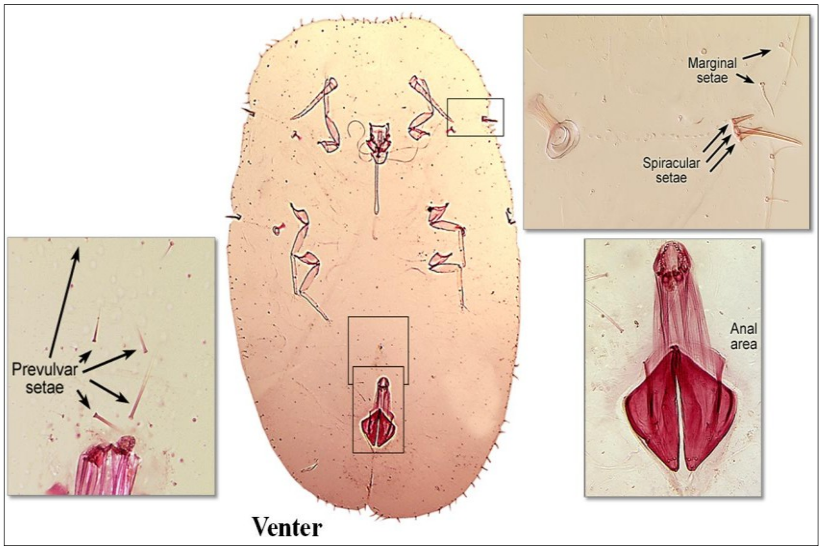

Figure 28. Mounted adult female of *C. hesperidum*: main features (Ben-Dov *et al*., 2010)

I.3.6. Genus *Saissetia* Déplanche, 1859

Description. Body of adult female convex to hemispherical, often with H-shaped ridges on dorsum. Derm heavily sclerotized at maturity, with pale areas, cellular patterns, or polygonal reticulations. Sub-marginal tubercules present. Anal plates each with a large discal seta, varying numbers of apical, sub-apical, and fringe setae. Hypopygial setae absent. Anal ring with 8 setae. Antennae well developed, 7 or 8-segmented. Legs well developed; tibiotarsal sclerosis present or absent. Quinquelocular pores in spiracular furrows. Multilocular pores in vulvar region and in transverse rows on abdominal segments. Tubular ducts ventrally on abdomen, in sub-marginal band around body. Marginal setae stout, slender, pointed, blunt, or variously frayed. Spiracular setae in groups of 3, median setae longer than laterals (Fig. 26) (Gill, 1988).

Species reported in Tunisia include only *S. oleae*

I.3.6.1. *Saissetia oleae* (Olivier, 1791

Material examined. 15 slide-mounted specimens of old females were examined and identified as *S. oleae*. Populations found on citrus and olive trees, were scattered on twigs at ovipositing female stages, majority died. Sampling were undertaken during September and first week of October from citrus orchards located in Hammamett, Korba, Nabeul and Menzal Bou Zalfa.

Unmounted material. Mature female dark brown to blackish brown, nearly round, oval, very convex; surface rough, with H-shaped ridges, very characteristic of this genus.

Mounted material. Adult female longer than wide. Derm with cell-like clear areas. *Margin*. Marginal setae of 2 sizes, larger ones robust, tapering towards apex, tips rounded or with few minute indentations; smaller setae usually finely pointed. Spiracular setae in groups of 3, medial seta longer than laterals. *Venter*. Antennae 8-segmented. Legs normally without tibiotarsal scleroses. Multilocular pores concentrated around vulvar area, in transverse rows on preceding abdominal segments. Quinquelocular pores in spiracular furrows 1 or 2 pores wide. Tubular ducts with slender filaments in submarginal band. *Dorsum*. setae robust, spinelike, slightly blunt at apex, scattered. 4-16 Sub-marginal tubercles, around body. Discoidal pores in loose group of 3-46 anterior to anal plates. Each anal plate with large discal seta (Fig. 29).

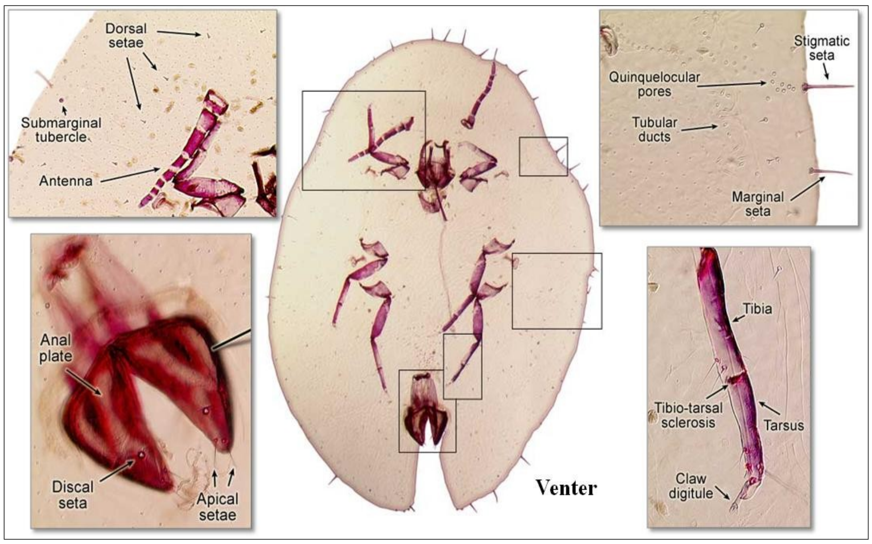

Figure 29. Mounted adult female of *S. oleae*: main features (Ben-Dov *et al*., 2010)

I.3.7. Genus *Aonidiella* Berlese and Leonardi, 1859

Description. *Aonidiella* g. is distinguished by a cephalothorax strongly developed on both sides of the pygidium, sclerotised and swollen laterally; paraphyses usually small and reduced. Pygidium not deltoid and margin of segment 5 rounded. Six species are known native to the palearctic region, between them only *A. aurantii* is reported in Tunisia (Fig. 30).

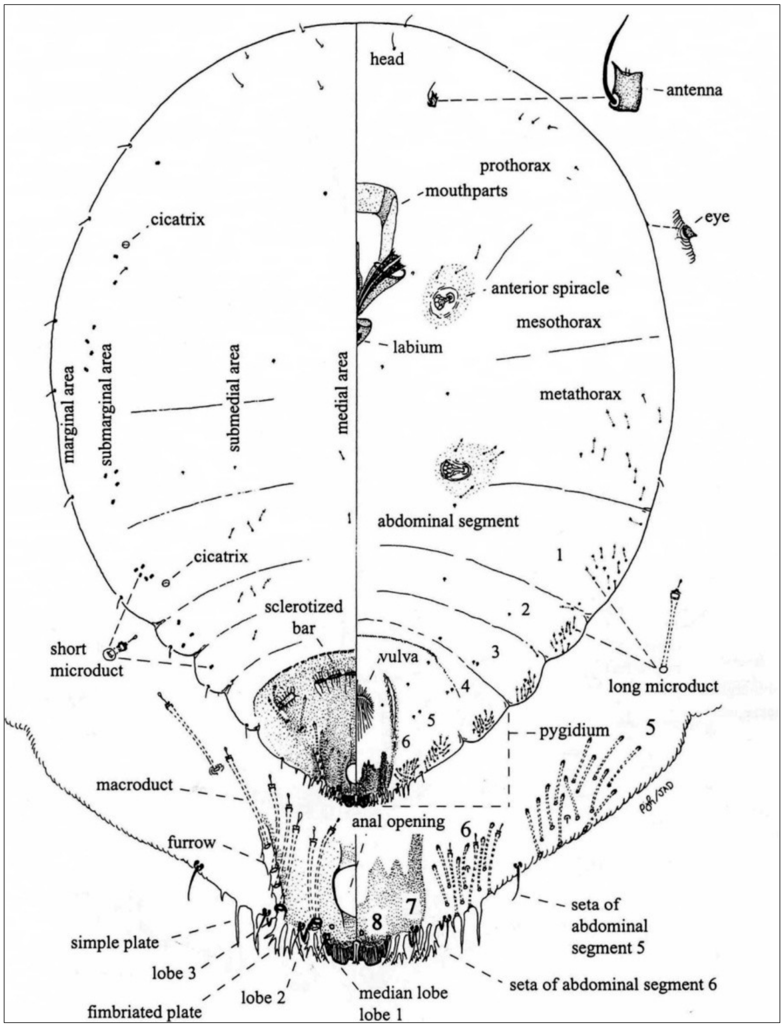

Figure 30. General morphology of mounted adult female of Aspidiotinae (Miller and Davidson, 2005)

I.3.7.1. *Aonidiella aurantii* (Maskell, 1879)

Material examined. Ten old and eight young females were mounted and identified as *A. aurantii*. Individuals were feeding on leaves of citrus trees at ovipositing female and young stages. Infestations were present in three districts of Cap Bon during September and first weeks of November.

Unmounted material. Female scale cover circular, quite flat with central exuviae. The scale itself quite thin and pale permitting the red-brown colour of the heavily sclerotized adult female to show throw.

Mounted material. Body with lateral areas of thorax and segment one swollen to surround pygidium in mature specimens giving the typical reniform shape; marginal and sub-marginal areas heavily sclerotized. Cuticule thick. Eyes absent or represented by small spur. Antennae each, with one setae. *Pygidium*. Each apophysis anterolateral of vulva with two associated scleroses. Median lobes simple equal to or slightly bigger than second lobes, with two lateral and medial notches, symmetric as long as width. Third lobe simple, about same size as second lobe with 1-3 lateral notches rarely with one notch; fourth lobe represented by series of sclerotized points. Median plates fimbriate, those in 3rd space deeply bifurcate; plates formula 2-2-3; apically fringed between median lobes; equal to or longer than median lobes. Macroducts of one variable size, all about same width, long and cylindrical. Prepygidial macroducts absent. Perivulvar and perispiracular pores absent. Anal opening sub-circular, diameter inferior than width Lobe 1 (Fig. 31).

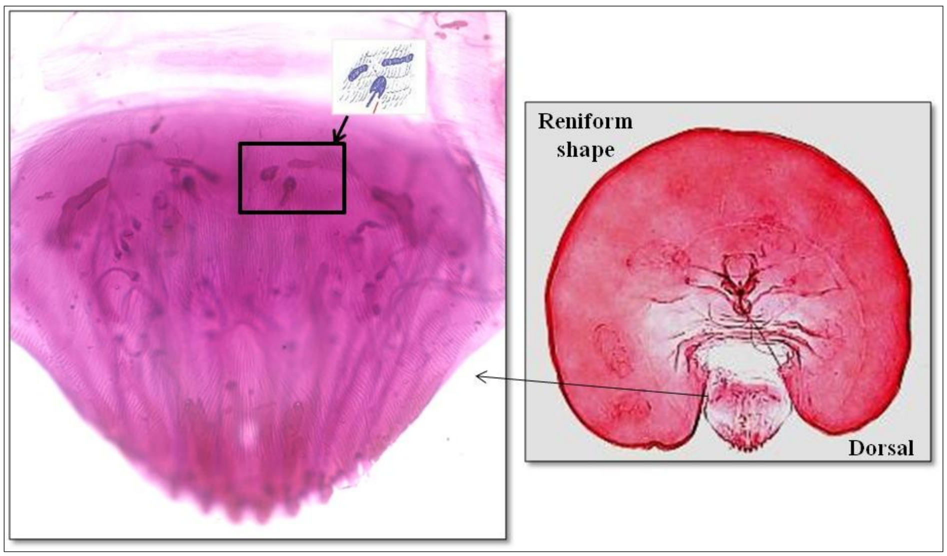

Figure 31. Mounted adult female of *A. aurantii*: main features

I.3.8. Genus *Chrysomphalus* Ashmed

Description. Body of female pear-shaped with large and membranous prosoma. Abdominal segments 2 à 4 not compressed. *Pygidium*. Deltoid with rectilinear margin on segment 5. Possessing one-barred ducts; well definite fringed plates; and three pairs of well-developed lobes (L1, L2, L3); median lobes elongate, notched on outer margin; second and third lobes not bilobed; fourth lobe absent or reduced to a minute sclerotized point in the marginal pygidium, slightly fimbriate. Paraphyses 5 to 7 pairs, larges and fusiformes, except on margin of segment 5. Three external plates more developed, robust, with conspicious fimbriations. Macroducts numerous arranged in furrows, as definite rows of variable lengths and sizes, but usually long and slender. Vulva at center of pygidium. Perivulvar pores absent or present, arranged in 4 to 5 groups. Anus circular at one-third of Pygidium and equal or inferior to the diameter of L1 (Fig. 30) (Balachowsky, 1950).

Three species belonging to *Chrysomphalus* g. occur in Tunisia, *C. aonidum*, *C. dictyospermi* and *C. pinnulifer*, which are described below.

I.3.8.1. Key to *C. aonidum*, *C. dictyospermi* and *C. pinnulifer*

1. - Plates anterior to third lobe clavate……………………………………………………..………………..2
   - Plates anterior to third lobe not clavate, fringed and fimbriate. Cover purplish-black, with red nymphal exuvie………...………..……………………………………………………...…….…………..**aonidum**
2. - Thoracic spur conical and prominent. Plates anterior to third lobe with a smooth process on the external face. 2nd abdominal segment with 6 to 8 marginal dorsal macroducts. Cover of various colors and opaque…...……………………………………………………………………………………...….**pinnulifer**
   - Thoracic spur small, not well sclerotized. Plates anterior to third lobe with toothed appendage on outer margin. 2nd abdominal segment with only two marginal dorsal macroducts. Cover reddish brown and slightly translucide…......…………………………………………………………….………...**dictyospermi**

I.3.8.2. *Chrysomphalus aonidum* (Linnaeus, 1758)

Material examined. A few specimens, numbering three, were named as *C. aonidum*. Some young and adult individuals were scattered on leaves and fruits of *Citrus* spp. Samples were collected during September from three citrus orchards located in Hammamett and Menzel Bou Zalfa.

Unmounted material. Adult female cover slightly convex, circular, dark brown, black, or reddish brown; sheld skins central, lighter than scale produced by adult, reddish yellow.

Mounted material. Body pear shaped. Earlike fin and spinelike. Eyes spurlike, on mesothorax. Antennae each with 1 long setae. *Pygidium*. Three lobes of similar size. Median lobes asymmetric converging slightly. L3 simple with 2-3 lateral noches. Plates between lobes fimbriates, as long as L1 and L2. Three to four plates in third space, with fimbriate and toothed or spinelike appendages. Paraphyses slender, 5 in each side and absent after L3. As *C. dictyospermi*, opening anal is subcirculaire, diameter equal to width of L1, located at ¼ of pygidium. Perivulvar pores always present, arranged in four groups. Pores absent near spirascles. Opening anal diameter equal to width of L1, located ¼ from the base of pygidium. But Macroducts are disposed in 3 furrows in the different areas, long and cylindrical, 25 to 30 on each second and third pygidial areas, extending the fourth segment (Fig. 32)

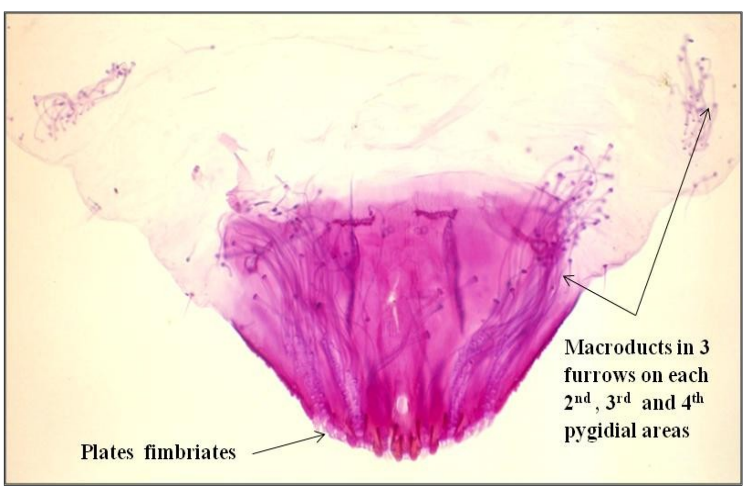

Figure 32. Pygidium margins of *C. aonidum*: main features

I.3.8.3. *Chrysomphalus dictyospermi* (Morgan, 1889)

Material examined. 15 specimens of adult females were slide-mounted and identified. Populations were feeding on citrus trees at adult stages; *C. dictyospermi* were present in 6 sub-localities of Cap Bon region during the prospections undertook between September and November.

Unmounted material. Adult females cover regularly circular, center slightly convex, thin and of various colors (reddish brown, copper, or gray, slightly translucide). Second shed skins, central, pointed of brown dark or yellow color.

Mounted material. Eyes variables, flat sclerotized area. Antennae each with 1 setae. *Pygidium*. Lobes four pairs. Median lobes similar, rather elongate and slender; with axes sub-parallel or converging slightly. Third lobes simples, slightly smaller than second lobes, serrate on outer margin or tri-toothed. Fourth lobe forming an acute triangle. Median plates and first group of lateral plates fimbriate, as long as L1 and L2. Plates in third space each with conspicuous clavate appendage, characteristic of the species, apically large and slightly toothed on external margin. Next lateral plates fimbriate and spinelike. Paraphyses formula 2-2-0; thick and spinelike; small in 4th space. Dorsal macroducts cylindrical, numerous, arranged in oblique furrows in different pygidial areas; with few number in the first space and 8-10 in the second and third space, total 22-34 macroducts on each side of body. Perivulvar pores arranged in 4 groups, 5-6 pores on each side of body. Anal opening sub-circular, inferior to the diameter of L1 and at one-fourth of pygidium (Fig. 33).

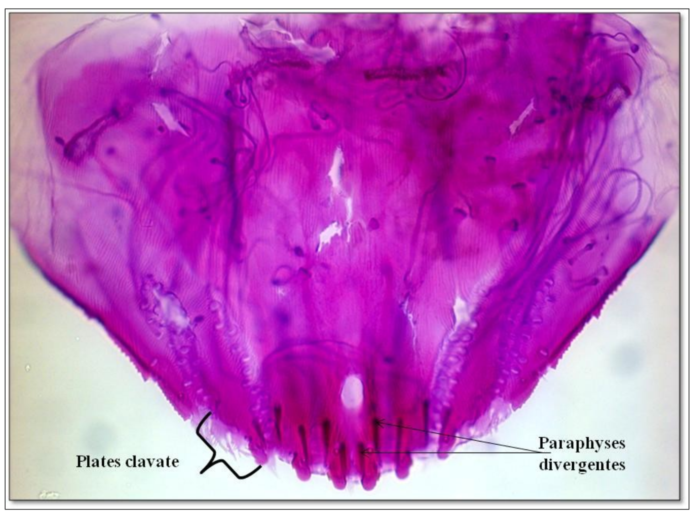

Figure 33. Pygidium Margins of *C. dictyospermi*: main features

3.I.3.8.4. *Chrysomphalus pinnulifer* (Maskell, 1891)

Material examined. Three adult specimens were identified as *C. pinnulifer*. Samples were collected from leaves of *Citrus* spp in Menzel Bou Zalfa and Nabeul during October.

Unmounted material. Scale cover of adult female in life more or less circular, with a slight central peak but not plate; mid- to dark-reddish brown medially and paler brown to whitish towards the margin; aspect opaque and not translucide; exuviae central, yellow or tan, center sometimes with white patch.

Mounted material. Adult female membranous, pear-shaped. Front of head rounded. Presence of small earlike (spur) in mesothorax. Pre-pygidial segments each with fewer than five sub-marginal ducts on each side. *Pygidium*. broad, subtended by an angle greater than 90°, with three pairs of rounded lobes. Perivulvar pores present. Paraphyses present. Second furrow (between segments 6 and 7) on each side containing 11 or more macroducts in a double to tripple row (Fig. 34).

Comments on *Chrysomphalus* species. *C. dictyospermi* is easily recognizable among the economic species of *Chrysomphalus* g. because it lacks submarginal clusters of macroducts on the pre-pygidium, has strongly clavate appendages of the two plates between lobes 3 and 4, and small dorsal microducts present on the sub-margin from the head to the anterior abdominal segments. *C. aonidum* has only 1 cluster of prepygidial macroducts on segment 2, lacks clavate processes on the plates between lobes 3 and 4, and has small dorsal microducts on the submargin from the mesothorax to the anterior. *C. pinnulifer* was described by Balachowsky (1950) who diagnosed deeply the morphological differences between this species and the other species mainly *C. dictyospermi*. In fact, *C. pinnulifer* could be misidentified easily as *C. dictyospermi*, but differs mainly from this latter by possessing: thoracic eyelike robust and conical; plates in third space with conspicuous smooth process; medians lobes and paraphyses parallels to each other; perivulvar pores of high group are parallels to the median axe of the body. In contrast, *C. dictyospermi* has not or very small earlike lobes, clavate plates between lobes 3 and 4 with conspicuous fimbriate or toothed process in the external side, medians lobes slightly convergents and medians paraphyses divergents; perivulvar pores of high group converge to the median axe of the body. These were the main microscopic features to separate between both species.

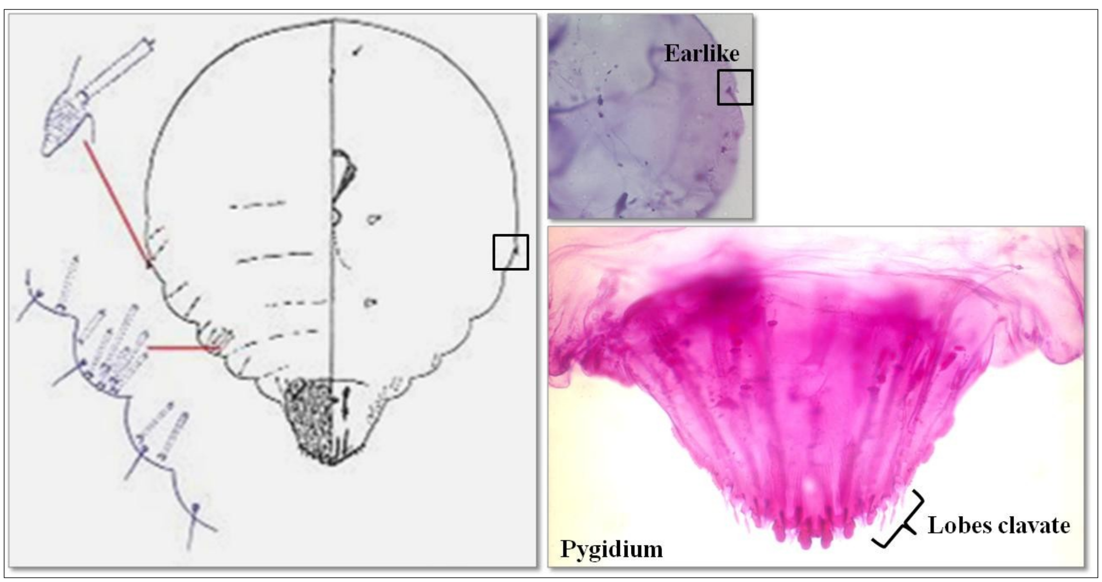

Figure 34. Mounted adult female of *C. pinnulifer*: main features

I.3.9. Genus *Lepidosaphes* Shimer

Description. Main features of this genus were described by Balachowsky (1954). Body of female elongated, with maximum of width in the metathorax or first abdominal segment. Cephalic zone glabrous. Antennal nipple with 2 or many setae. L2 always present with an external second lobe. Presence of 6 to 7 dorsal mega-ducts in the marginal area of the pygidium. Dorsal macroducts or microducts present in the sub-median area in segments 4 and sometimes 7. Gland spines well definite, present in lobes of the last pre-pygidial segments. Gland tubercules always present in the thorax or first abdominal segments. Moreover, perispiracular pores in the anterior not in the posterior spiracles (Fig. 35).

Lepidosaphes g. includes 13 species in the palaearctic region. *L. beckii* is the only species occurring in Tunisia.

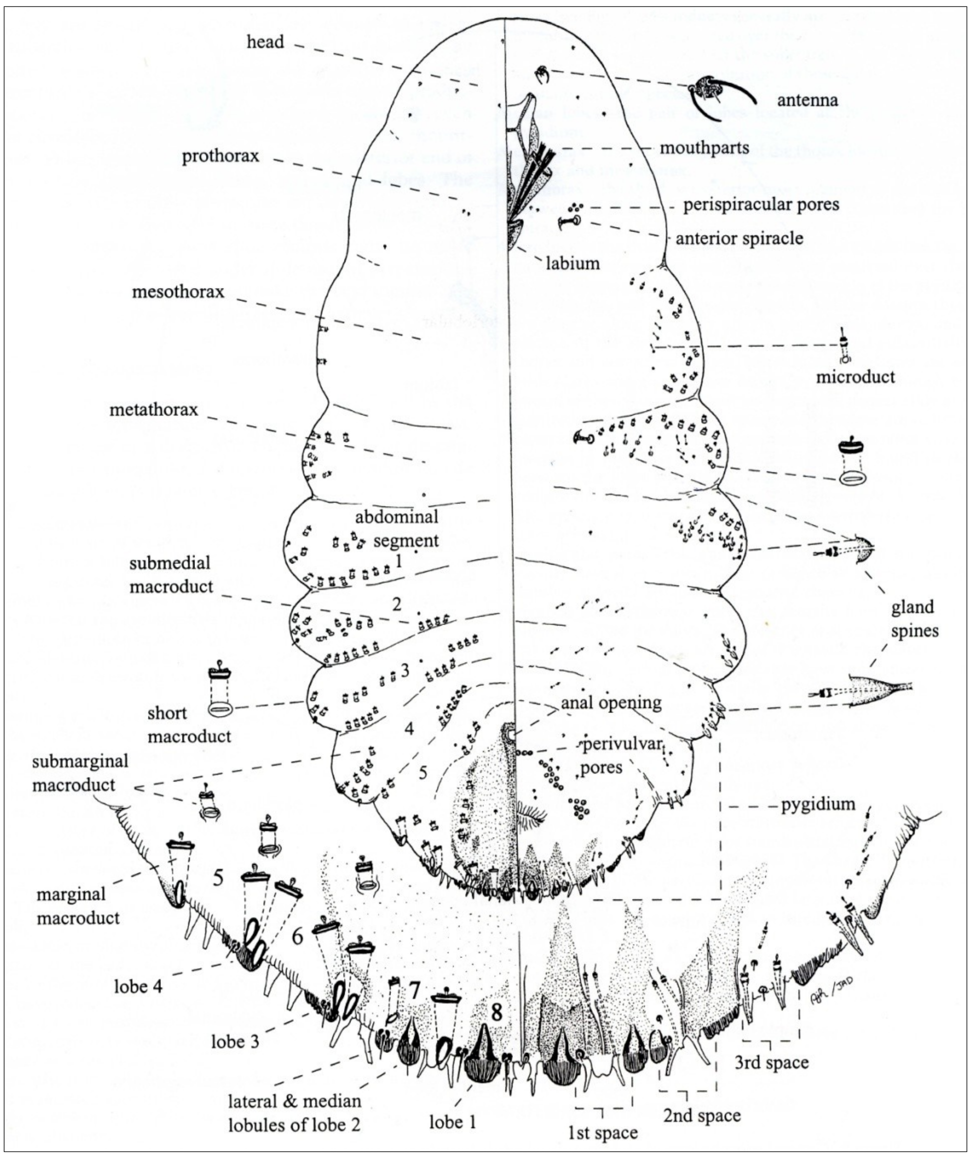

Figure 35. General morphology of mounted adult female of Diaspidinae (Miller and Davidson, 2005)

I.3.9.1. *Lepidosaphes beckii* (Newman, 1869)

Material examined. 30 specimens were mounted and identified. *L. beckii* were present on citrus trees at adult and young stages, mainly males. Populations were found in 3 sub-localities of Cap Bon region during the prospections undertook in September.

Unmounted material. Adult females cover oyster-shell shaped, straight or curved; slightly to moderate convex, thick; purplish brown to pale yellow brown.

Mounted material. Body elongated, wider at the first abdominal segments. Cephalic zone glabrous, antennal nipple with two or many setae. Eyes normally represented by small, flat, sclerotized area. Antennae each with two large setae. *Pygidium*. Two pairs of definite conical lobes; third and fourth lobes sometimes represented by series of small points; median lobes without basal sclerosis or yoke; second lobe bilobed, about one-half size of median lobe. Gland spines each with microduct; formula 2-2-2. Macroducts of two sizes, larger size on margin; smaller size abundant. Pygidial microducts on venter in submarginal clusters on segments 5 and 6. prepygidial ducts scatered along body margin; pygidial ducts absent on dorsum. Perivulvar pores in 5 groups, with 17-30 pores on each side of pygidium. Perispiracular pores with 3 loculi. Anal opening circular, diameter inferior than width of L1. Briefly, *L. beckii* is well characterized by median lobes very prominent, with gland spines and by the presence of the sclerotized areas or bosses in the prepygidial segments (Fig. 36).

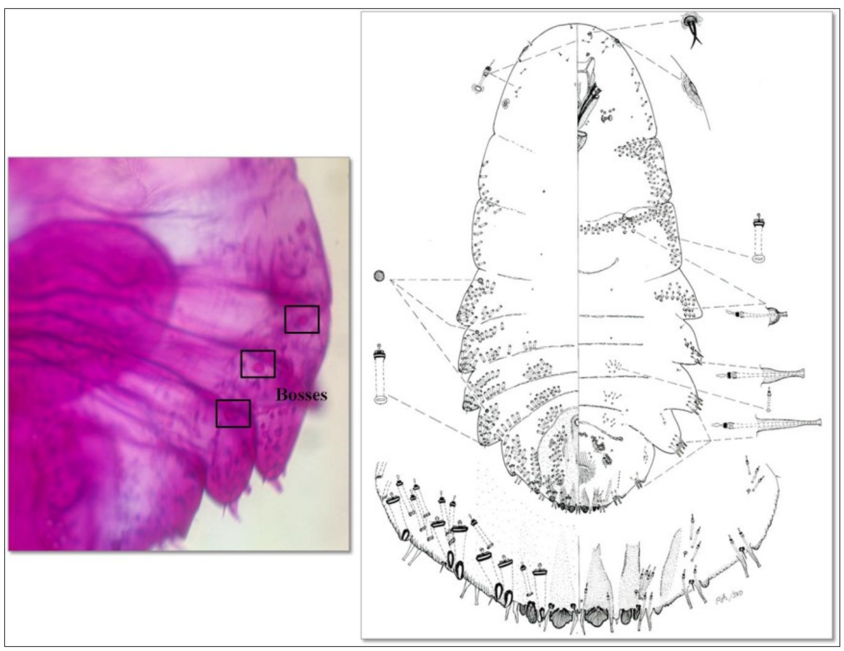

Figure 36. Mounted adult female of *L. beckii*: main features

I.3.10. Genus *Parlatoria* Targioni Tozzetti

Description. Body of female usually broadly oval; usually with two-barred dorsal ducts. *Pygidium*. Median lobes non-zygotic; second and third lobes never bilobed, but notched on outer margin. Plates short, broad, and more or less fimbriate apically, or serrate laterally; each with only a single microduct; usually arranged in a continuous marginal series. Dorsal macroducts on pygidial margins with an opening surrounded by a conspicuous sclerotized ring. Duct tubercules common on submargin of prosomatic venter. Anus near the center of pygidium. Perivulvar pores present in 4 groups (Fig. 35, 37) (Balachowsky, 1953).

P. theae, *P. oleae*, *P. ziziphi* and *P. pergandii* are recorded in many Mediterranean countries including Tunisia as pests of citrus crop. The two latter are diagnosed in the following paragraph.

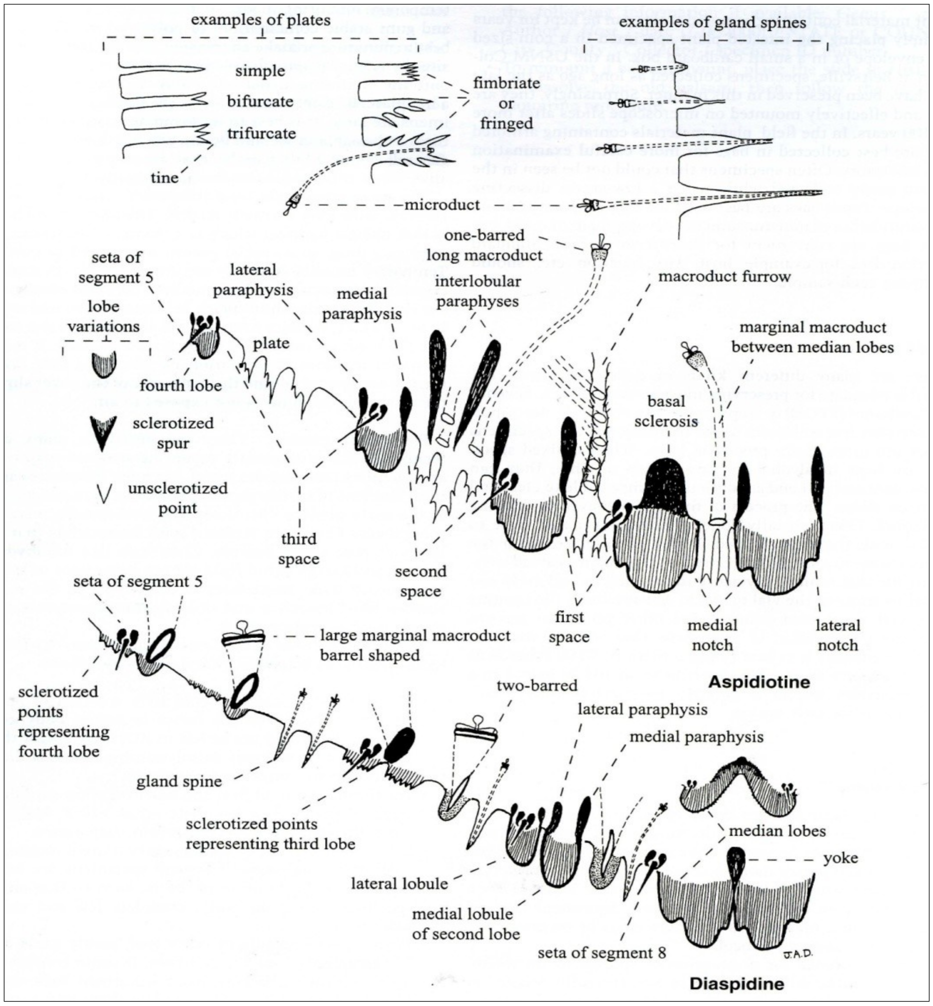

Figure 37. General morphology of pygidium margins (Miller and Davidson, 2005)

I.3.10.1. Key to *P. ziziphi* and *P. pergandii*

1. – Presence of strong earlike lobes round, on the marginal part of the prothorax. Female cover, dark black with 2 longitudinal ridges………………………………………………………….………..**ziziphi**

– Earlike lobes absent. Female cover flat, round to oval, of grey, yellowish brown color ………………………………………………………………………..…………………...**pergandii**

I.3.10.2. *Parlatoria pergandii* Comstock 1881

Material examined. 59 samples, infested with *P. pergandii*, were collected during the survey from almost suspected localities in the north-west and north-east of Tunisia overall the period of survey from September until November. All stages of development, mainly ovipositing females were present together, feeding on leaves, twigs and fruits of citrus trees. More than 50% of the materials were mounted and examined under microscope.

Unmounted material. Adult female cover flat, round to oval, often with several wrinkles, translucent brown to gray; shed skins marginal, yellowish brown, sometimes with longitudinal green stripe.

Mounted material. Body shape broadly oval. Antennae each with one conspicuous seta. Eyes variable, absent, or represented by flat un-sclerotized area. Posterior spiracle without associated dermal pocket. Earlike lateral of anterior spiracles lobes absent. *Pygidium*. 5 and rarely 6 pairs of well developed lobes; 1st three pairs of lobes with rounded apices and each, with two lateral notches; other lobes with acute apices; 4th and 5th smaller and proportionally broader than first three pairs of lobes; 6th lobes represented by single small point. Plate formula normally 2-2-3; broadly fimbriate; plates in the 3 first spaces with 3 tines. Macroducts on pygidium of 2 sizes, marginal ducts slightly larger than submarginal ducts. Dermal pattern anterior of vulva transverse. Perivulvar pores in 4 groups, 11-15 pores on each side of body. Perispiracular pores normally with 5 loculi, anterior spiracles each with 2-4 pores. Anal opening circular and central, diameter inferior than width of L1 (Fig. 38).

Comments. 80% mounted specimens identified as *P. pergandii,* had the main features of this species. However, some of them are closely related to *P. theae* by two features (i) in possessing a higher number of perivulvar pores (12-14/13-15); and (ii) the 4th lobe (which is less prominent in *P. theae* than in *P. pergandii*), was not a constant character between specimens examined. Hence, identification was based mainly on the presence or absence of the derm pocket. Specimens have not the derm pocket and then they were identified as *P. pergandii*. It is interesting to bridge with further massive collecting in order to diagnose carefully both species.

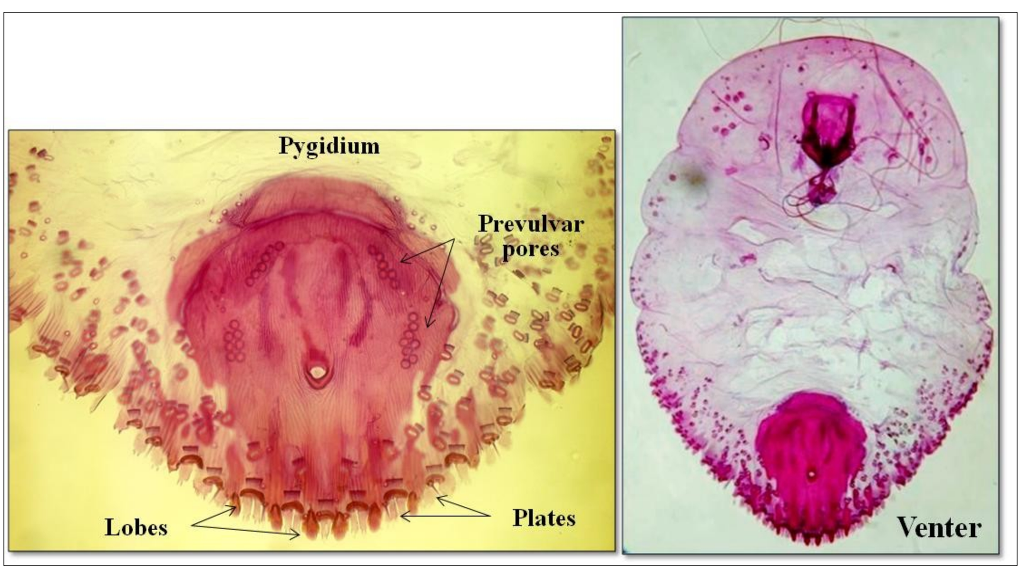

Figure 38. Mounted adult female of *P. pergandii*: main features

I.3.10.3. *Parlatoria ziziphi* (Lucas, 1853)

Material examined. Individuals of *P. ziziphi* were present in 53 samples collected overall the period of survey (September to November) from almost suspected localities in the north-west and north-east of Tunisia. All stages were present on citrus trees injuring leaves and fruits. As it is easy to distinguish this species from all *Parlatoria* species by the sub-quadrangular shape and the intense black color of the cover; only 5 specimens were mounted in order to diagnose the morphology of *P. ziziphi* under microscope.

Unmounted material. Adult female cover flat, broadly elongate oval, black, with narrow white fringe, with 2 or 3 longitudinal ridges.

Mounted material. The presence of a strong earlike lobes lateral to the anterior spiracles is the strong character of recognition of *P. ziziphi* under microscope. Then, L1, L2 and L3 equal in size and shape, with lateral notches and round apices, symmetric; L4 shorter and narrow; L5 absent on segment four but according to Miller and Davidson (2005) L5 could be present in some specimens. In this case, fifth lobe simple, equal or smaller than fourth lobe, without notches. Plates broadly fimbriate. Macroducts on pygidium of 2 sizes, marginal ducts slightly largen than submarginals. Usually with a band of microducts from body margin to anterior spiracles. Perispiracular pores normally with 5 loculi, anterior spiracles each with 2-4 pores, posterior spiracles without pores. Perivulvar pores in 4 rarely 5 groups, 13 – 18 (15) pores on each side of body (Fig. 39).

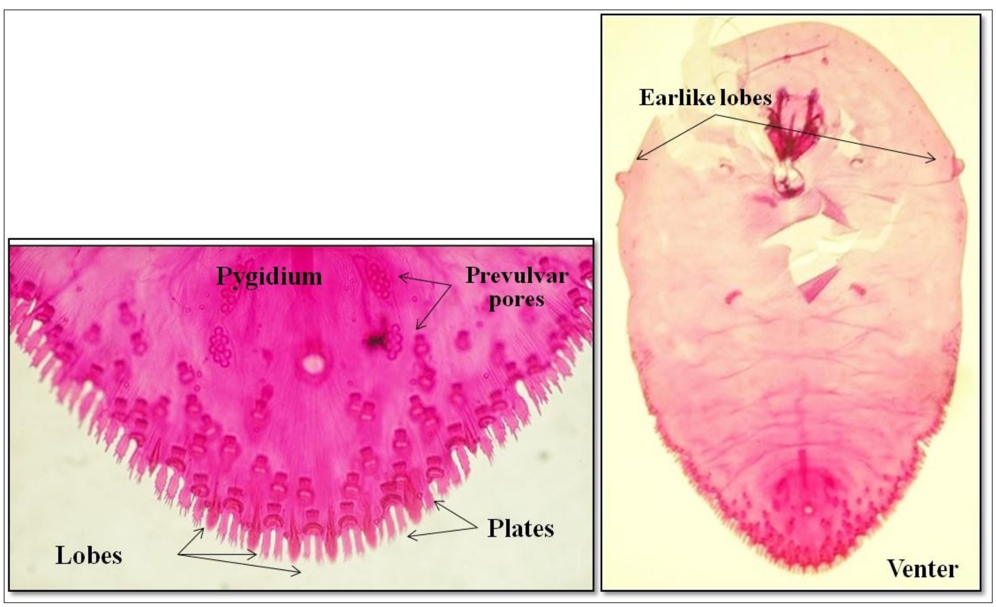

Figure 39. Mounted adult female of *P. ziziphi*: main features

II. Study of the scale insect fauna in the northern citrus area

II.1. Richness

Twelve species of scale insects belonging to nine different genera and four families were identified from citrus trees in the three districts Nabeul, Beja and Jendouba: *I. purchasi* (Monophlebidae); *Pl. citri* (Pseudococcidae); *C. floridensis*, *C. hesperidum* and *S. oleae* (Coccidae); *A. aurantii*, *C. aonidum*, *C. dictyospermi*, *C. pinnulifer*, *L. beckii*, *P. pergandii* and *P. ziziphi* (Diaspididae). Among them, two species were recorded for the first time in Tunisia. The greatest diversity was found within the families Diaspididae and Coccidae each with seven (58% of total species) and three species (25% of total species), respectively.

II.2. Frequency of new records

C. floridensis and *C. pinnulifer* were encounterd for the first time from Tunisia during the current survey. The frequency of new species described on citrus crops since 2008 is shown in figure 40 and it is clear that there has been a steady increase, particularly in the Coccidae family, with three species (*C. floridensis*, *C. pseudomagnaliarum, C. pinnulifer*) new in four years, associated to one crop.

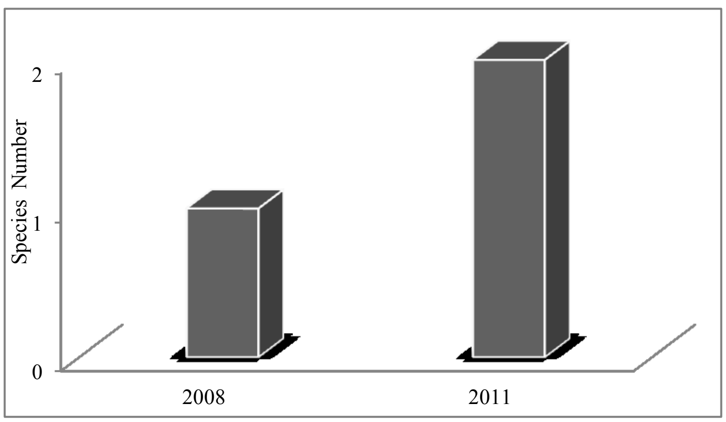

Figure 40. Frequency of new records in Tunisia on citrus crop (Jendoubi *et al*., 2008; current results)

- ***C. floridensis***

In Africa, FWS has not yet been detected in Morocco and Algeria, according to Pellizzari and Camporese (1994) and (Ben-Dov and Miller, 2010); therefore, this report represents its third known occurrence in North Africa and first record in Tunisia. The date or factors of the introduction of this pest in Tunisia are not clear; some farmers claim that the infestation appeared in their orchards 5-10 years ago. Infestation was detected in Cap Bon in five sublocalities in 17 orchards: Hammamett (5), Korba (4), Soliman (3), Menzel Bou Zalfa (3) and Beni Khalled (2). Moreover, it has been collected from three host plants: citrus trees (*Citrus* spp.), the laurel (*Laurus nobilis*) and the common medlar (*Eriobotrya japonica* (Thunb.) Lindl). The population density was low on laurel and medlar trees, varying between 1-5 specimens per leaf, and somewhat higher on citrus trees, reaching 10 specimens per leaf.

- ***C. pinnulifer***

To the best of our knowledge, this is the first record of *C. pinnulifer* in Tunisia and the second in North Africa. *C. pinnulifer* is known only from Algeria in Africa according to Danzing and Pellizzari (1998) and Ben-Dov and Miller (2010). In Tunisia, this rare species appears to have a very limited distribution. It was found in two citrus orchards in the northeast part of the country (Menzel Bou Zalfa and Nabeul), in very low numbers.

- ***C. pseudomagnoliarum***

The brown soft scale was not encountered during the current survey. However, it was recently reported for the first time in Tunisia by Jendoubi *et al*. (2008) during a survey conducted in Cap-Bon region on citrus crop. Accordingly, it has been spread sporadically in densities which were harmless for citrus, reaching 4 specimens per leaf in Beni Khalled.

II.3. Abundance and occurrence

As regard to total frequency and abundance (Fig. 41), *P. pergandii*, *P. ziziphi* and *Pl. citri* were the most relevant. They had shown in fact to be the most frequent and abundant species in all the study area.

P. pergandii had the highest number of occurrences, it was detected in 59 sites, occupying hence 70% of the total number recorded, followed by *Pl. citri* and *P. ziziphi* which were detected in 55 and 53 sites and occupying 65% and 63%, respectively. However, *P. ziziphi* was the most abundant species, registering a relative abundance of 28%; *P. pergandii* and *Pl. citri* share quasi similar relative abundance with *P. ziziphi* as well high, 20% and 19%, respectively.

I. purchasi, *C. dictyospermi*, *L. beckii*, *C. hesperidum* and *C. floridensis* were much less frequent than the previous species. They were encountered in around 20 to 24% of all sites, with low populations. Among them, *I. purchasi* (13%) was the most common followed by *L. beckii* (7%) and *C. dictyospermi* (5%).

A. aurantii and *S. oleae* occurred, respectively, in a few sites (7-11), while the last two armored species *C. aonidum* and *C. pinnulifer* were very rare, each one occupying less than 4% of the number of records. Each one was detected only in 3 samples within a total of 84 samples.

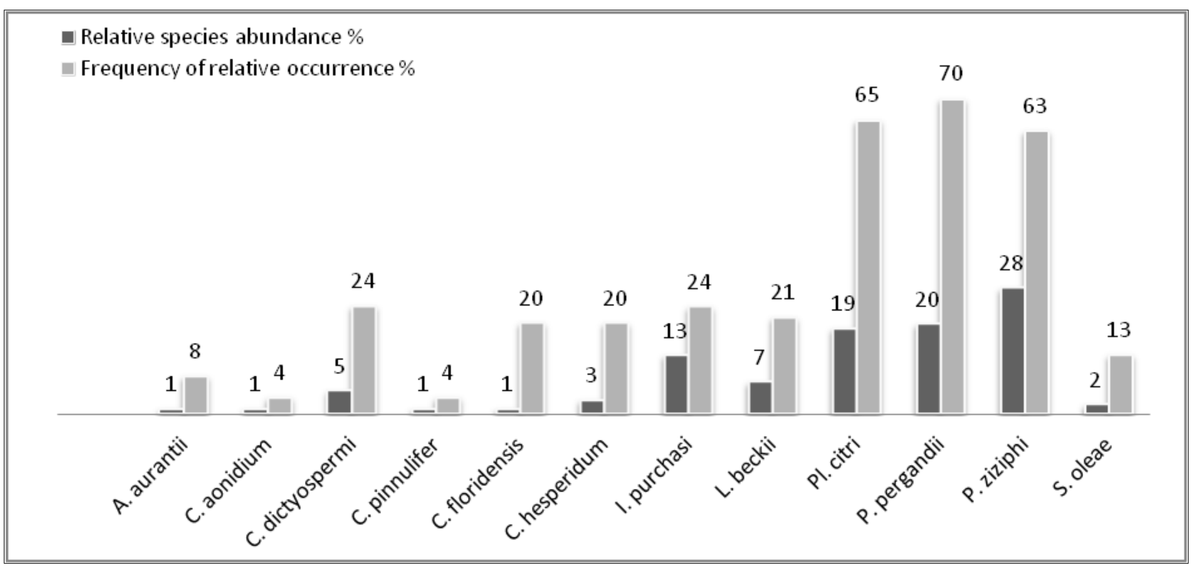

Figure 41. Total abundance and occurrence of scale insect species in the study area.

II.4. Distribution between regions

The relative species abundance and the frequency of relative occurrence for each species separated by locality and sub-localities are arranged in table 6. Scale insect species were observed at 9 out of 10 localities and in 95% of inspected orchards. They had invaded a large part of northern Tunisia, while concentrating in Nabeul and becoming scarce in Beja and Jendouba.

In the Northwest, occurrence of species was minimal. The majority of sites without the presence of any infestation were recorded only in this part, mainly in the locality Oued Mliz which was completely free of scale insects; all citrus orchards were inspected but no infestation was observed. *P. pergandii, P. ziziphi, Pl. citri* and *I. purchasi* were the only 4 species encountered in the three districts Nefza, Tabarka, and Boussalem with different incidence levels. The occurrences of species decreased to less than 1-3% for *P. ziziphi*, *I. purchasi* and *P. pergandii*. However, *Pl. citri* was much more common; spreading with large colonies (76-100%) in 80% of sites.

In the Northeast all species of scale insects, except *L. beckii*, are well diffused between all surveyed sites and localities in a homogenous way. In fact, most of citrus orchards are colonised by more than 6 species and some of them are infested by less than 4 species. The highest occurrences and the highest scale insects populations were registered in the central part (Menzel Bou Zalfa, Soliman and Beni Khalled), followed by those in the southeast of Cap Bon (Korba and Hammamett).

In fact, the chaff scale, the black scale and the citrus mealybug tended to show higher frequency and higher abundance, mainly in the localities Menzel Bou Zalfa, Soliman and Beni Khalled as compared to the other regions. While *I. purchasi* tended to be more abundant in Soliman (18.6%), Nabeul (18.14%) and Hammamett (13.54%). Concerning the other species *C. dictyospermi*, *C. floridensis*, *C. hesperidum* and *S.oleae*, they spread commonly over all the sites without showing particular preference for one locality. Whereas, *A. aurantii*, *C. aonidum* and *C. pinnulifer* are extremely rare species found in only three to seven orchards (Hammamet, Menzel Bou Zalfa and Nabeul) at a very low population densities.

C. floridensis and *Pl. citri* were found feeding on other fruit trees growing alongside of citrus orchards, first species was collected 3 times on laurel and medlar and the second species 13 times from pomegranate.

Table 6. Number of records (N) of scale insect species and their abundance (%) in the northern citrus area

Localities	Nabeul									
Sub-localities	Soliman		Menzel Bou Zalfa		Beni Khalled		Korba		*Nabeul	
Species	Records	Abundance	Records	Abundance	Records	Abundance	Records	Abundance	Records	Abundance
A. aurantii	0	0	4	1.9	2	2.0	0	0	0	0
C. aonidum	0	0	1	1	0	0	0	0	0	0
C. dictyospermi	4	2.7	7	12.3	3	3.2	1	1.9	4	10.1
C. floridensis	3	2.7	3	1	2	1.2	4	2.3	0	0
C. hesperidum	4	4.9	4	3.6	4	3.5	4	11.1	1	1.0
C. pinnulifer	0	0	1	1.0	0	0	0	0	2	1.7
I. purchasi	3	18.6	4	11.4	4	3.2	1	7.7	3	18.1
Pl. citri	8	16.3	7	10.7	11	19.1	5	21.5	4	6.8
P. pergandii	9	23.2	11	21.9	16	33.3	4	11.5	7	14.8
P. ziziphi	7	26.4	9	34.5	17	34.6	4	14.6	5	44.7
L. beckii	0	0	0	0	0	0	6	26.1	3	3.0
S. oleae	2	5.3	2	1.9	0	0	4	3.5	1	1.0

* Data recorded in Nabeul and Dar Chaabane were added.

Table 6. Be continued

Localities	Nabeul		Beja		Jendouba					
Sub-localities	Hammamett		Nefza		Tabarka		Boussalem		Oued Mliz	
Species	Records	Abundance	Records	Abundance	Records	Abundance	Records	Abundance	Records	Abundance
A. aurantii	1	1	0	0	0	0	0	0	0	0
C. aonidum	2	2	0	0	0	0	0	0	0	0
C. dictyospermi	1	1.9	0	0	0	0	0	0	0	0
C. floridensis	5	1.4	0	0	0	0	0	0	0	0
C. hesperidum	0	0.0	0	0	0	0	0	0	0	0
C. pinnulifer	0	0	0	0	0	0	0	0	0	0
I. purchasi	2	13.5	1	29.8	2	18.1	0	0	0	0
Pl. citri	8	16.1	5	26.8	4	76.1	3	100	0	0
P. pergandii	10	15.8	0	0.0	2	5.8	0	0	0	0
P. ziziphi	8	19.1	3	43.5	0	0.0	0	0	0	0
L. beckii	9	28	0	0	0	0	0	0	0	0
S. oleae	2	1.3	0	0.0	0	0	0	0	0	0

II.5. Infestation foci

The pattern of infestation foci in the study area as well as their number and the intensity of infestation vary considerably between species (Table. 7).

The highest classes of densities, in which the colonies of pest cover parts of the tree, are associated exclusively with the black scale. In fact, nine large infestations were spread between regions. However, the infestation is concentrated mainly in Beni Khalled where 11 citrus orchards presented medium to very severe infestations.

The chaff scale had two important infestations foci, concentrated in Menzel Bou Zalfa and Hammamett regions. Medium to severe infestations are recorded in around 20 orchards. Soliman and Beni Khalled could be considered too as foci of spread for *P. pergandii*.

However, the citrus mealybug did not seem to colonize a particular region, it was spread at high densities in the northeast regions (Hammamet, Korba, Beni Khalled, Menzel Bou Zalfa) as well as in the northwest in Beja.

Equally, *I. purchasi*, *C. dictyospermi* and *C. hesperidum*, each one presented an important focus of infestation in Menzel Bou Zalfa while populations of *L. beckii* are concentrated in Hammamett.

Table 7. Classes of densities and foci of infestation of the different scale insect species (0 = no infestations; 1 = isolated infestation; 2 = medium infestation (2-10 specimens); 3 = severe infestation (11-100 specimens); 4 = general or layered infestation (more than 100 specimens))

Localities	Sub-localities	*A. aurantii*	*C. aonidum*	*C. dictyospermi*	*C. floridensis*	*C. hesperidum*	*C. pinnulifer*	*I. purchasi*	*Pl. citri*	*P. pergandii*	*P. ziziphi*	*L. beckii*	*S. oleae*
Nabeul	**Soliman**												
	0	0	0	0	0	0	0	0	0	0	0	0	0
	1	0	0	1	1	1	0	0	1	0	1	0	0
	2	0	0	3	2	3	0	1	2	4	0	0	1
	3	0	0	0	0	0	0	2	3	4	5	0	1
	4	0	0	0	0	0	0	0	0	0	1	0	0
	Menzel Bou Zalfa												
	0	0	0	0	0	0	0	0	0	0	0	0	0
	1	0	0	0	1	0	1	2	0	0	0	0	0
	2	4	2	3	2	4	0	0	6	9	3	0	2
	3	0	0	4	0	0	0	3	0	0	3	0	0
	4	0	0	0	0	0	0	0	1	2	3	0	0
	Beni Khalled												
	0	0	0	0	0	0	0	1	0	0	0	0	0
	1	0	0	0	0	0	0	0	0	0	0	0	0
	2	2	0	3	2	3	0	1	5	3	9	0	0
	3	0	0	0	0	1	0	0	4	2	4	0	0
	4	0	0	0	0	0	0	0	0	0	2	0	0
	Korba												
	0	0	0	0	0	0	0	0	0	0	0	0	0
	1	0	0	0	1	1	0	0	0	0	0	0	1
	2	0	0	1	3	2	0	0	3	3	2	3	3
	3	0	0	0	2	1	0	1	2	1	2	2	0
	4	0	0	0	0	0	0	0	0	0	0	0	0
	Nabeul												
	0	0	0	0	0	0	0	0	0	0	0	0	0
	1	0	0	0	0	1	0	0	0	2	0	1	1
	2	0	0	4	0	0	2	1	3	3	1	2	0
	3	0	0	0	0	0	0	0	0	0	1	0	0
	4	0	0	0	0	0	0	0	0	0	1	0	0

Table 7. (be continued)

Localities	Sub-localities	*A. aurantii*	*C. aonidum*	*C. dictyospermi*	*C. floridensis*	*C. hesperidum*	*C. pinnulifer*	*I. purchasi*	*Pl. citri*	*P. pergandii*	*P. ziziphi*	*L. beckii*	*S. oleae*
Nabeul	Hammamett												
	0	0	0	0	0	0	0	0	0	0	0	0	0
	1	0	0	0	3	0	0	0	0	0	0	0	0
	2	1	2	0	2	0	0	0	4	7	4	2	2
	3	0	0	1	0	0	0	1	4	3	3	7	0
	4	0	0	0	0	0	0	1	0	0	1	0	0
Beja	Nefza												
	0	0	0	0	0	0	0	0	0	0	0	0	0
	1	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	1	1	1	0	0
	3	0	0	0	0	0	0	0	4	0	1	0	0
	4	0	0	0	0	0	0	1	0	0	1	0	0
Jendouba	Tabarka												
	0	0	0	0	0	0	0	0	0	0	0	0	0
	1	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	1	1	1	0	0	0
	3	0	0	0	0	0	0	1	2	0	0	0	0
	4	0	0	0	0	0	0	0	1	0	0	0	0
	Boussalem												
	0	0	0	0	0	0	0	0	0	0	0	0	0
	1	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	3	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0	0
	4	0	0	0	0	0	0	0	0	0	0	0	0
	Oued Mliz												
	0	0	0	0	0	0	0	0	0	0	0	0	0
	1	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0	0
	4	0	0	0	0	0	0	0	0	0	0	0	0

III. Literature review of the citrus scale insect fauna in Tunisia

There are few useful published data concerning the citrus scale insect fauna in Tunisia. One of the most important contributions was that of Pagliano (1938) who analyzed the pests of citrus trees and other fruit trees in Tunisia. Some information is given also by Millet (1959) who listed the main pests. The most recent publications are those of Jendoubi *et al*. (2008) who made an update to the list of scale insect fauna and Ben-Dov (2011), the online database Scale Net. All of these studies on scale insects were carried out in citrus orchards of Cap Bon (Table. 8).

Number of species of scale insects occurring in Tunisia varies considerably between authors. Pagliano (1938) reported 17 species; Jendoubi *et al*. (2008), 11; while Ben-Dov (2011) listed only 10 in the most recent online database (Table. 8). Counting all records, the total number of species is 19; 8 are included in the family of Diaspididae, 8 in the family of Coccidae, 2 in the family of Pseudococcidae and 1 in the family of Monophlebidae. Among these, 9 species are Palearctic, 3 Neotropical, 3 Afrotropical, 2 Cryptogenic and 2 Australasian. Nearly all of the recorded species are polyphagous, feeding on a wide range of host plant. However, *Citrus* spp. are the most favoured host for almost species, mainly *C. aonidum*, *C. dictyospermi*, *C. pseudomagnoliarum*, *P. pergandii* and *P. ziziphi.*

Comparing the occurrence of species individually, *P. longispinus*, *C. sinensis*, *P. psidii*, *P. persicae, E. tessellatus*, *A. nerii* and *F. theae* were mentioned to be present in Tunisia on citrus mainly by Pagliano (1938) and CABI (1970, 1984 and 1994) but they were not recorded recently by Jendoubi *et al*. (2008). However, other species like *C. rusci* which were described fifty years ago (Millet, 1959; Pagliano, 1938), were found again in Cap Bon area showing a very limited spread (Jendoubi *et al*., 2008). In addition, authors have confirmed the presence of *P. pergandii, C. pseudomagnoliarum*, and *C. rusci* in Tunisia on citrus, except Ben-Dov (2010); in fact it is not yet listed in the scale insects query of Tunisia from the online database.

No data about the pest status of scale insect species were available for 14 species according to historical records. Neverless, *S. oleae* and *I. purchasi* were considered minor pests. The california red scale, the red scale and the dictyospermum scale, occurred last years in Tunisia at low to medium densities (Jendoubi *et al*., 2008) while fifty years ago they were spreading at a level harmful to the citrus crop in Cap Bon as reported by Millet (1959). *P. pergandii* and *P. ziziphi* were considered serious pests according to Millet (1959) and jendoubi *et al*., (2008).

Table 8. Collected data on species of scale insects recorded in Tunisia on *Citrus* spp.

Valid scientific names	**Origin**	**Major host plant**	***Previous pest status**	**References**
Monophlebidae				
Icerya purchasi Maskell 1879	Australasian	Polyphagous	Minor pest	Pagliano, 1938; Millet, 1959; CABI, 1971; Jendoubi *et al*., 2008; Ben-Dov, 2010
Pseudococcidae				
Planococcus citri (Risso, 1813)	Palaearctic	Polyphagous	No data	Pagliano, 1938; CABI, 1969; Jendoubi *et al.*, 2008; Ben-Dov, 2010
Pseudococcus longispinus (Targioni Tozzetti, 1868)	Australasian	Polyphagous	No data	Pagliano, 1938; CABI, 1984; Ben-Dov (1994, 2010)
Coccidae				
Coccus hesperidum Linnaeus, 1758	Palaearctic	Polyphagous	No data	Pagliano, 1938; Jerraya, 1970; Jendoubi *et al*., 2008; Ben-Dov, 2010
Coccus pseudomagnoliarum (Kuwana, 1914)	Palaearctic	Citrus	No data	Jendoubi *et al*., 2008
Ceroplastes rusci (Linnaeus, 1758)	Afrotropical	Polyphagous	No data	Pagliano, 1938; Jendoubi *et al*., 2008
Ceroplastes sinensis Del Guercio 1900	Neotropical	Polyphagous	No data	Pagliano, 1938
Pulvinaria psidii Maskell, 1893	Palaearctic	Polyphagous	No data	Pagliano, 1938; Ben-Dov, 2010; CABI, 1994
Saissetia oleae (Olivier, 1791)	Afrotropical	Polyphagous, olive	Minor pest	Balachowsky, 1927; Pagliano, 1938; Millet, 1959; Jerraya, 1970; Jendoubi *et al*., 2008; Ben-Dov, 2010
Parthenolecanium persicae (Fabricius, 1776)	Palaearctic	Polyphagous, grapevine	No data	Pagliano, 1938
Eucalymnatus tessellatus (Signoret, 1873)	Neotropical	Polyphagous	No data	Pagliano, 1938
Diaspididae				
Aonidiella aurantii (Maskell, 1879)	Palaearctic	Polyphagous	Serious pest	Pagliano, 1938; Balachowsky, 1932; Millet, 1959; CABI, 1996; Jendoubi *et al*., 2008; Ben-Dov, 2010
***Aspidiotus nerii* (Bouché, 1833)	Afrotropical	Polyphagous, nerium, oleander	No data	Pagliano, 1938; CABI, 1970
Chrysomphalus aonidum (Linnaeus, 1758)	Neotropical	Citrus, polyphagous	Serious pest	Millet, 1959; CABI, 1988
Chrysomphalus dictyospermi (Morgan, 1889)	Palaearctic	Citrus, polyphagous	Serious pest	Pagliano, 1938; Millet, 1959; Danzig and Pellizzari, 1998; Jendoubi *et al*., 2008; Ben-Dov, 2010
Fiorinia theae Green, 1900	Palaearctic	Camellias, polyphagous	No data	Pagliano, 1938
Lepidosaphes beckii (Newman, 1869)	Cryptogenic	Polyphagous	No data	Pagliano, 1938; CABI, 1982; Jendoubi *et al*., 2008; Ben-Dov, 2010
Parlatoria pergandii Comstock 1881	Cryptogenic	Citrus, polyphagous	Serious pest	Pagliano, 1938; CABI, 1964; Jendoubi *et al*., 2008
Parlatoria ziziphi (Lucas, 1853)	Palaearctic	Citrus, Rutaceae	Serious pest	Pagliano, 1938; CABI, 1964; Jendoubi *et al*., 2008; Ben-Dov, 2010

*. Period from 1927 until 2008; **. *Aspidiotus nerii* Bouche, 1833 is the valid synonym of oleander scale (Ben-Dov, 2010); it was recorded by Pagliano (1938) as *Aspidiotus hederae* Signoret 1869.

IV. Macro-morphological and Biological studies on *P. ziziphi*
IV.1. Recognition of immature and adult stages of *P. ziziphi*

To ensure a better understanding and distinction of the different stages of *P. ziziphi*, we have included a "field identification key" based on stereoscopic pictures and observations made on individuals in rearing. This study was done during the progress of the experiment of life table in order to limit exactly the beginning and the end of each instar.

IV.1.1. First instar

The crawler, white cap and nipple stages are all first instar nymphs; it is the only stage where the cover hasn't black pigmentation. After settlement, crawlers secrete circularly laminate layers of white wax that cover the scale body; it is the white cap stage. The nipple stage starts when insect cements wax, forming a distinct oval ridge cover of white color (Fig. 42).

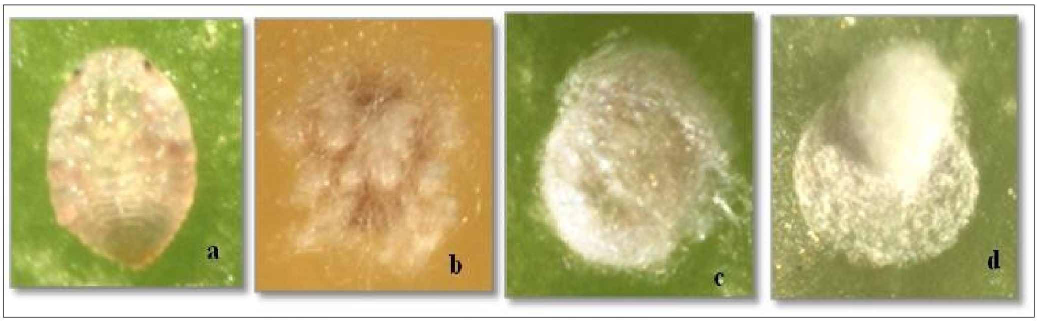

Figure 42. 1st instar of *P. ziziph*i: a. crawler newly emerged, b. settled crawler, producing filaments of wax, c. white cap stage, d. nipple stage

IV.1.2. First molt stage

The black pigmentation of the scale cover (beginning of moult) and the orange molt ring (end of moult) indicate the molting process (Fig. 43). The first molt is the same for male and female stage, the sex differentiation starts after this stage.

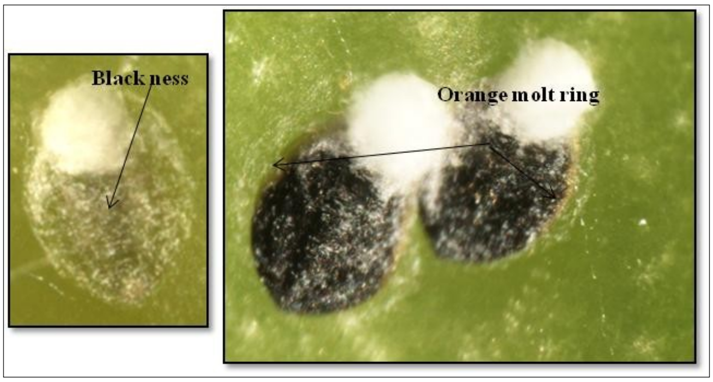

Figure 43. 1st moult stage

IV.1.3. Female stages

The new secretion of white wax around the later molt ring indicates always the beginning of the next stage. This criterion is used to determine the second instar (Fig. 44) and young female (Fig. 46).

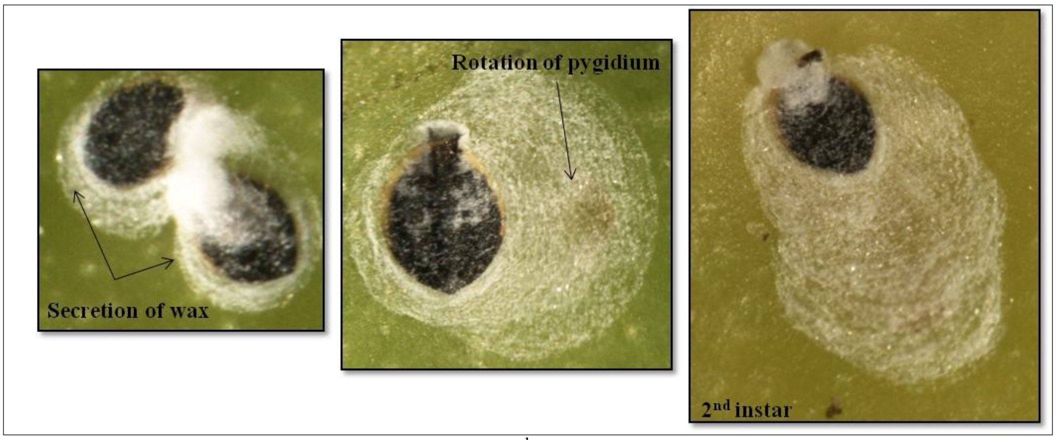

Figure 44. 2nd instar female

Similarly to the first molt, black pigmentation of the scale cover of second instar (beginning of moult) and the orange molt ring around it (end of moult) indicate the molting process. The second molt is illustrated by the following photos.

Figure 45. 2nd moult female stage

After second moult, the young female is detected by the secretion of new layer of white wax around the later molt ring as is showed in the following figure.

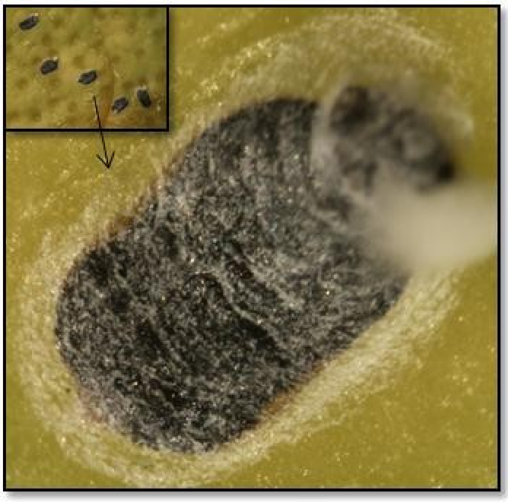

Figure 46. Young female

After mating, the females produce immediately white wax at the posterior end of the scale; it is the gravid female (Fig. 47a). To identify the pre-ovipositing and ovipositing females, a study based on the examination of the shape, size and color of the fringe of wax produced by the female at the posterior end, was done on 30 specimens reared under the same controlled conditions (Fig. 47b, c) (Table. 9).

Table 9. Relation between wax fringe and female stage

Fringe of wax (size and color)	**State of female**
Small, oval, white	Gravid female
Developed, v-shaped, Yellowish	Pre-ovipositing female
Well developed, v-shaped, brown clear	Ovipositing female
Well developed, v-shaped, dark brown	Ovipositing female
Developed, v-shaped, white	Ovipositing females*

* On females developed at 20°C on fruits, the posterior secretion of wax does not colorate to brown and females lay eggs.

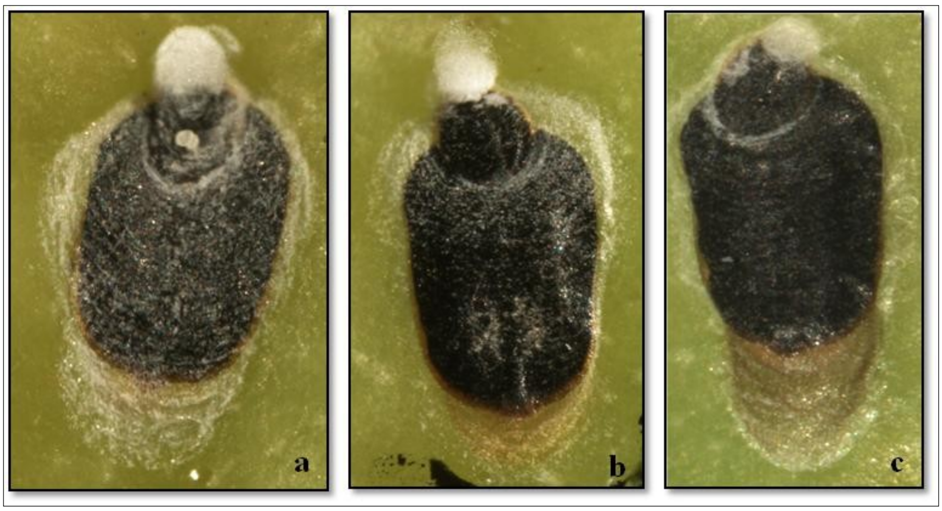

Figure 47. Mature female stage: a. Gravid female, b. Pre-ovipositing female, c. Ovipositing female

IV.1.4. Male stages

Male scale complete one distinct immature stage (2nd instar male), and three mature stages, pre-pupa, pupa and adult.

Second instar males are distinguished by the purplish pigmentation of the posterior end or pygidium which is v-shaped (Fig. 48). Evenly, the scale after 1st molt swells and forms an elongate white cover.

Figure 48. Second instar male

The presence of exuvium rejected by the male outside the scale on leaves or fruits was used as criterion for successful molting to the next each male stage (pre-pupa, pupa and adult) (Fig. 49). Second instar male begins to pupate till rejecting the 1st exuviae which has a pygidial form; this is called the pre-pupa stage. Then the pre-pupa male grows and rejects again the second exuviae, which has distinctly pointed genitalia, giving the pupae stage. Similarly, the pupa stage transforms into male adult and put out the 3rd exuviae which is perfectly similar to a pre-adult (Fig. 49). Adult males emerge a few days after pupation leaving the cover empty (Fig. 50).

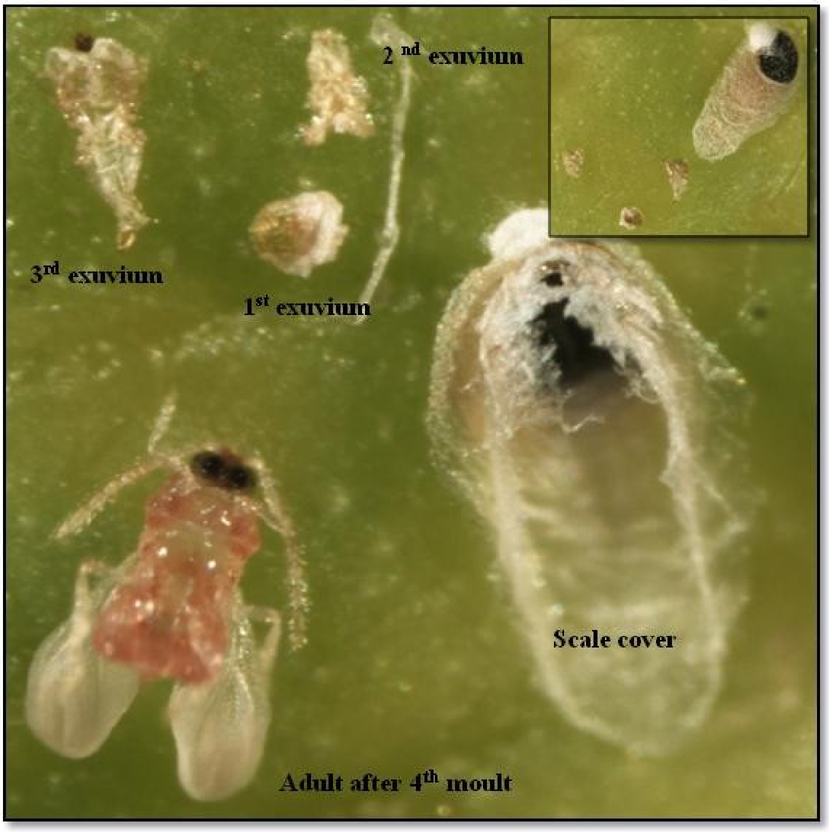

Figure 49. Mature male stages


Figure 50. Emergence of adult male

IV.2. Life table studies of *P. ziziphi*

IV.2.1. Survivorship and mortality

According to the results obtained with the studies on the survival rate of *P. ziziphi* (Table. 10), the cumulative survival was constantly higher at 24°C than at 20°C, whereas the plant substrate has much lower influence, if any.

At 24°C, very low mortality occurred mainly during the development of adult female when 92% and 95.7% survived from egg hatching to gravid and pre-ovipositing females, respectively. Total survival was little higher on fruits than on leaves reaching 95.7% and 84.6%, respectively.

At 20°C, data on total survival indicated that important mortality occurred mainly during female development, reaching the lowest global values on leaves (37.8%) comparing with the 40.7% recorded on fruits. Looking at the different development stages, the lowest proportion of survival was recorded at white cap stage; 70% on leaves and 88.6% on fruits. First moult and female pre-ovipositing were also affected stages, with proportion of survival lower on leaves (with 81.0% and 83.3%. respectively) than on fruits (91.9% and 79.3%, respectively). The survival recorded with male stages was lowest on fruits, precisely at the emergence of adults (66.7%) and to a lesser importance at the second stage (81.8%). Nevertheless near half of the initial population reached the male adulthood at 20°C.

Table 10. Survival (%) for the egg development, immature and adult stages of *P. ziziphi* at two constant temperatures on two plant substrates

Temperature (°C)	**20°C**		**24°C**	
Plant substrate	**Fruit**	**Leaf**	**Fruit**	**Leaf**
Egg	100	100	100	100
L_1 – Crawler	100	100	100	100
L_1 - White cap	88.6	70.0	100	100
L_1 – Nipple	100	100	100	100
First moult	91.9	81.0	100	100
Total before sex differentiation	**81.4**	**56.7**	**100**	**100**
L_2 female	89.1	87	100	100
Second moult female	90.2	100	100	100
Young adult female	81.1	100	100	96.2
Gravid adult female	96.7	92.3	100	92.0
Pre-ovipositing adult female	79.3	83.3	95.7	95.7
Total female (from egg to oviposition)	**40.7**	**37.8**	**95.7**	**84.6**
L_2 male	81.8	100	100	100
Pre-pupa	100	100	100	100
Pupa	100	100	100	100
Adult male (until emergence)	66.7	100	100	100
Total male (from egg to adult emergence)	**44.4**	**56.7**	**100**	**100**

IV.2.2. Duration of developmental stages

The effects of temperature and food on development are summarized in table 11. The significant interaction between the temperature and plant substrate factors in most female and male stages indicate that the growth of *P. ziziphi* responded differently to a change in temperature and plant substrate (Table 11).

Table 11. Summary of one-way analysis of variance (ANOVA) results of the effect of Temperature and plant substrate on developmental time of female and male stages of *P. ziziphi*

	Factor		
	Temperature	**Plant substrate**	**Interaction**
Egg	<0	<0.0242	1
Female stage			
L1 - White cap	<0	0.1177	<0.0002
L1 – Nipple	<0	<0.0003	<0.0058
First moult	<0	0.844	<0
L2	<0.0441	<0	<0
Second moult	<0	0.3362	<0.0063
Young adult	0.8082	0.188	<0
Gravid adult	<0	<0.0137	<0.0027
Pre-ovipositing adult	<0	<0	<0.0015
Male stage			
L1 - White cap	<0	<0.0007	<0.0017
L1 – Nipple	<0	0.3493	0.3682
First moult	<0	0.4997	0.2993
L2	<0	<0	<0.0022
Pre-pupa	<0.0446	<0.0136	<0
Pupa	0.0833	0.1009	<0.0004
Adult	0.2336	0.0356	0.8704

Temperature significantly affected all nymphal and mature female stages except the second moult stage (Table. 12). On fruits at 20°C, embryonic development was completed in 35.6 days which was the longest time required, and less than the half of that time was necessary at 24°C. Duration of female nymphal stages reflected the trend observed during the previous stage; about 10 and 14 days were needed to complete the first and second instars, respectively at 20°C; while at 24°C insect needed less than the half of that time. Ten days more were necessary for the adult female stages at 20°C (27 days) compared with 24°C (17 days), noting that pre-ovipositing period was the longest. Total female development approached globally four months at 20ºC, whereas it was of around two months at 24ºC.

Significant differences of temperature were recorded in major male stages. Immature durations ranged from 50 days to 25 days at 20°C and 24°C, respectively on fruits, and 45 days to 18 days at 20°C and 24°C, respectively on leaves. Duration of adult stages required around 12 days on fruits at both temperatures while on leaves required longer time at 20°C (15 days) than at 24°C (5.7 days).

Host plants (leaves on plant of sour orange and fruits of lemon) had a lower effect on the duration of female and male stages. Total development time appeared to be shorter on leaves than on fruits for both temperatures. At 20°C, duration of all immature stages was longer on fruits than on leaves, and then this trend was reversed for adult stages. At 24 °C, durations of developmental stages were indifferent between plant substrates except for moult stages which were shorter on leaves than on fruits.

Table 12. Mean developmental time (days ± SE) of immature and adult stages of *P. ziziphi* at two constant temperatures, on two plant substrates.

Temperature	**20°C**		**24°C**	
Plant substrate	**Fruit**	**Leaf**	**Fruit**	**Leaf**
Egg	35.6 ± 2.9a	32.7 ± 0.9a	14.4 ± 0.6a	11.5 ± 0.5a
Female stages				
L1 - White cap	5.2 ± 0.4b	6.7 ± 0.6a	1.6 ± 0.1a	1.0 ± 0.0b
L1 – Nipple	4.8 ± 0.4b	7.4 ± 0.7a	2.3 ± 0.1b	2.6 ± 0.4a
First moult	18.2 ± 0.5b	21.3 ± 1.4a	14.3 ± 0.3a	11.4 ± 0.6b
L2	13.9 ± 0.6a	6.9 ± 0.3b	5.7 ± 0.3a	6.4 ± 0.7a
Second moult	13.6 ± 1.0a	15.3 ± 1.4a	14.3 ± 0.5a	10.9 ± 0.6b
Young adult	13.9 ± 0.7a	6.9 ± 0.7b	2.3 ± 0.4b	7.7 ± 0.4a
Gravid adult	4.1 ± 0.4a	1.9 ± 0.3b	2.8 ± 03a	3.0 ± 0.6a
Pre-ovipositing adult*	16.2 ± 1.8a	9.6 ± 0.6b	9.0 ± 0.4a	7.7 ± 0.1a
Male stages				
L1 - White cap	4.0 ± 0.3b	7.7 ± 3.8a	1.2 ± 0.1a	1.3 ± 0.1a
L1 – Nipple	5.7 ± 0.5a	5.7 ± 2.1a	3.1 ± 0.1a	2.1 ± 0.3b
First moult	20.5 ± 1.2a	21.0 ± 1.0a	15.0 ± 0.6a	12.6 ± 0.5a
L2	21.8 ± 0.5a	12.9 ± 0.3a	6.2 ± 0.7a	2.3 ± 0.3b
Pre-pupa	1.9 ± 0.9b	6.4 ± 1.2a	3.6 ± 0.2a	2.2 ± 03b
Pupa	1.7 ± 0.5b	5.0 ± 0.4a	3.0 ± 0.4a	1.6 ± 0.5a
Adult	7.5 ± 0.5a	3.6 ± 0.4a	5.2 ± 1.0a	1.9 ± 0.1a

Means within a row and at the same temperature followed by the same letter are not significantly different (LSD, $P > 0.05$); *: Duration between the 1st egg produced and the 1st crawler emerged.

IV.2.3. Fecundity and oviposition period

P. ziziphi has shown a similar irregular pattern of fecundity during all the reproductive period at all treatments tested. In fact, the age-specific fecundity curves tended to overlap between variable values (Fig. 51).

The daily fecundity rate is more affected by temperature than by plant substrate; it was higher at 24 °C than at 20°C and on plants than on fruits. Mean values increased from 0.32 to 0.54 at 20°C and 24 °C, respectively on fruits, and similarly from 0.42 to 0.87 on plants. The highest peaks occurred at 24 °C from 70th to 97th days on plants and from 94th to 102nd days on fruits, with a maximum daily fecundity of 1.52 female eggs per female. While, many peaks were recorded at 20°C at different intervals of times, during the oviposition period.

Survival of adult female of *P. ziziphi* remained constant through the oviposition period and then decreased at both temperatures in both plant substrates.

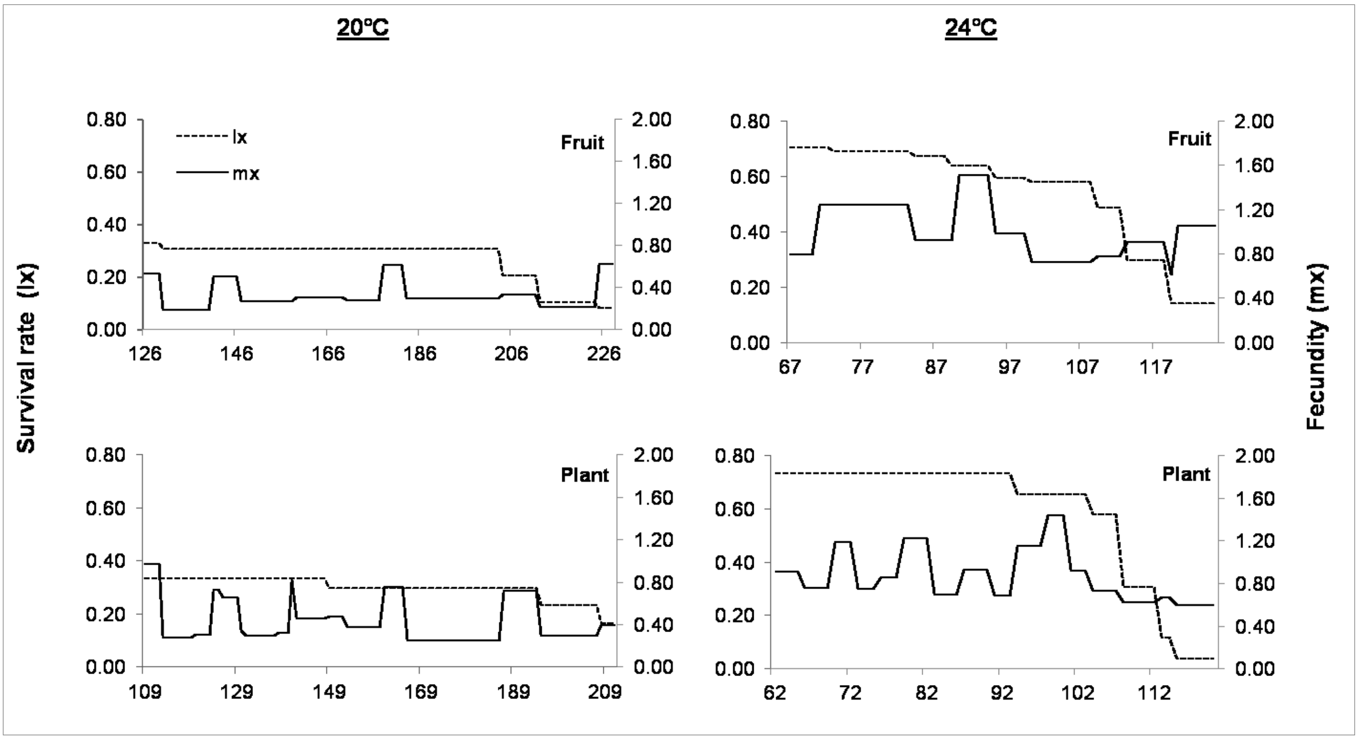

Figure 51. Age-specific survival rate and age-specific fecundity rate of *P. ziziphi* at two constant temperatures on plants and fruits

The oviposition period was shorter at higher temperatures with mean duration ranging from 89.5±3.38 and 54.51±5.38 days at 20°C to 47.19±1.44 and 43.95±1.63 days at 24 °C ($P < 0.05$) on fruits and leaves, respectively. Ovipositing females of *P. ziziphi* lived as long on plants as on fruits at 24°C but much longer on fruits than on leaves at low temperatures (Table. 11). Despite the long oviposition period registered at 20°C on fruit, females laid a very few eggs (28.8 eggs/female) whereas on plants, the mean fecundity reached quasi similar values to those obtained at 24°C (Table. 13).

According to results obtained on sex ratio, sex differentiation is affected mainly by temperature not by the food quality. Most of the populations are males at 20°C and females at 24°C, showing average values of 33.09% females and 68.81% females, respectively.

Table 13. Oviposition period (Means ± SE), female fecundity (Means ± SE) and sex ratio of *P. ziziphi* at two constant temperatures, on two plant substrates

Temperature (°C)	**20°C**		**24°C**	
Plant substrate	**Fruit**	**leaf**	**Fruit**	**Leaf**
Oviposition female longevity (days)	89.5±3.38	54.51±5.83	47.19±1.44	43.95±1.63
Mean fecundity (eggs/female)	28.8±3	46.2±4	51.04±2	43.89±1
Sex ratio (% females)	32.86	33.33	64.29	73.33

IV.2.4. Life table parameters

The population parameters are listed in table 14. Differences in the response of the black scale to the temperature are further evidenced by their intrinsic rate of increase. Based on the calculated values of r_m, the highest potential of *P. ziziphi* was recorded at 24°C (0.042) on leaves, and lowest performance were observed at 20°C (0.013) on fruits. In overall, the intrinsic rate of increase was only affected by temperatures and not by the substrates. Similarly, the net reproductive rate was much higher for individual of *P. ziziphi* reared at 24°C than those reared at 20°C for both plant substrates used in this experiment. The highest values recorded were 33.104 at 24°C on fruits and 13.278 at 20°C but on plants.

The other parameter, the mean generation time, has shown decreases with temperatures and substrate. It decreased from 171 to 88 days on fruits and from 152 to 84 days on plants from 20°C to 24°C, respectively.

Table 14. Life table parameters of *P. ziziphi* at two constant temperatures, on two plant substrates

Temperature (°C)	**20°C**		**24°C**	
Plant substrate	**Fruit**	**Leaf**	**Fruit**	**Leaf**
The net reproductive Rate (R_0)	8.881	13.278	33.104	31.600
The intrinsic rate of increase (r_m) ($days^{-1}$)	0.013	0.018	0.040	0.042
The mean generation time (T_0) (days)	171	152	88	84

CHAPTER 4. DISCUSSION

I. The situation of scale insects in the northern citrus area of Tunisia

I.1. Controversies in the occurrences of scale insects

The occurrence of species on citrus in Tunisia had shown to vary remarkably between published papers and authors. *C. floridensis* and *C. pinnulifer* were encountered during the current survey but not in the previous one of jendoubi *et al*. (2008); contrary *C. rusci* and *C. pseudomagnoliarum* were found in the previous survey but not during the current one. In addition, other species like *C. aonidum* and *C. rusci* which were described more than fifty years ago (Millet, 1959; Pagliano, 1938), were found again in Cap Bon area showing a very limited spread (Jendoubi *et al*., 2008; current results). Moreover, *P. longispinus*, *C. sinensis*, *P. psidii*, *P. persicae, E. tessellatus*, *A. nerii* and *F. theae* which were recorded before by Pagliano (1938) and CABI (1970, 1984 and 1994) are still not detected at present. These differences could be related to the different periods of sampling of two surveys, autumn (current survey) and winter (previous survey) and/or to the very low densities at which species occurred till they become not more detectable.

Jointing the results obtained in both recent surveys with the list published by Pagliano (1938) and other records, the Tunisian scale insect fauna of citrus include 21 species (three new records). It is a poor fauna compared with that of Italy where 28 species of scale insects were recorded injuring citrus crop but it is much richer than those of Israel (9), Algeria (10), Morocco (12), and France (13) (Longo *et al*., 1994; Franco *et al*., 2006). On the other hand, the known scale insect fauna has increased by over 50% and therefore the number of Tunisian scale insects will probably increase and new species and genera will be found through the next years.

I.2. Changes in abundance of scale insects and potential damages

P. pergandii, *P. ziziphi* and *Pl. citri* make a generalized phytosanitary problem in all the study area mainly Cap Bon region. Similar results were obtained by Jendoubi *et al*. (2008) and Pagliano (1938). However, Franco *et al*., (2006) recorded different data on the pest status of these species in Mediterranean citrus-growing countries: while, *P. pergandii* and *P. ziziphi* were considered a serious pest of citrus in Tunisia, it was a potential or occasional pest in many countries as Greece, Israel, Italy, Spain, Turkey and Portugal and it was reported a notorious pest only in Algeria; the citrus mealybug is still a key pest of citrus in almost of Mediterranean countries as in Tunisia. The situation of these three species is remarkable and unclear; populations remain at high level since long time. The harmful status of these species could be related to the inefficient chemical sprays and the low parasitism action. In fact, little number of parasits (*Encarsia* spp, *Aphtyis* spp.) has been determined for *Parlatoria* species. The citrus mealybug is actually under biological control program in Tunisia (Personnal communication, 2008) using the endogenous parasitoid wasp, *Leptomastidea abnormis* (Girault) (Hymenoptera, Encyrtidae) and the introduced predator *Cryptolaemus montrouzieri* Mulsant (Coleoptera, Coccinellidae) but seems that they are unable to maintain *Pl. citri* populations below the economic threshold.

About the margarodid scale species, *I. purchasi* was reported a potential pest in many Mediterranean countries such as Greece, Israel, Italy, Spain and Turkey (Franco *et al*., 2006; Tena and Garcia Mari, 2011). In the citrus area of Cap Bon, the pest status is different; populations of *I. purchasi* are increasing considerably during last years, and being harmfull to citrus crop. This could be related directly to the deficient control of its predator, the vedalia beetle *Rodolia cardinalis* (Mulsant) (Coleoptera, Coccinellidae) due to the inadequate use of pesticides.

In relation to the california red scale, the red scale and the dictyospermum scale, populations have been effectively reduced actually. In the Mediterranean area, these species were considered notorious pests of citrus at different times (Raymond, 1997; Rose, 1997; Tena and Garcia Mari, 2011); *A. aurantii* for example has kept a limited diffusion for many years in Spain and Italy, then the pest outbreaks recently and become a very dangerous species to citrus crops in both countries, causing important damages. These species mainly *A. aurantii*, could in fact represent a real menace for citrus groves and fruit cultivations, then occasional outbreaks have to be expected in the near future also in Tunisia. Differently, the Mediterranean black scale, *Saissetia oleae* and the citricola scale *Coccus hesperidum* rarely become a pest of economic importance to citrus and they are in fact under natural effective biological control as it was widely reported in literature (Ben-Dov and Miller, 2010). In Tunisia, populations of both species have been kept regularly at low level and seem that effectiveness of associated parasitoids (e.g. *Microterys* and *Metaphycus* spp.), is very significant.

According to results on new records illustrated in figure 41, the frequency of new records on *Citrus* spp. in Tunisia appears to be interesting compared with those reported in other countries; e.i. In Africa and Italy, 9 and 3 new species were added to the fauna of Guinea-Bissau and Sicily, respectively (Germain *et al*., 2010; Pellizzari, 2010). *C. floridensis* has the potential to be an injurious pest of citrus crops in the coastal region of Tunisia, because of the present suitable conditions for its spread, high humidity and moderate temperatures. In fact, it has become one of the key pests of citrus crops in most of the northeastern Mediterranean countries, mainly the humid regions (e.g. Israel and Egypt) (Ben-Dov, 1976; Swailem *et al*., 1976; Podoler *et al*., 1981; Ben-Dov and Miller, 2010). Moreover, Tunisian farmers commonly cultivate adjacent different fruit trees in citrus orchards that favor the establishment of this polyphagous pest. In relation to *C. pinnulifer*, it is not expected that this species cause damages to citrus crops due to the low densities registerd. Rose (1990), however, considers it as a potential international invader of citrus-growing regions and may constitute a new risk to citriculture. At the end, the brown soft scale, *C. pseudomagnoliarum*, was not encountered during the current survey. But according to Jendoubi *et al*., (2008), a further spread of the species along the citrus cultivated area may determine its inclusion among the dangerous species present in the area.

I.3. Variation in the distribution of scale insects

Between regions

According to the distribution of species shown in table 6, we understand that toward the northern citrus area, the frequency with which the scale insects occurred on citrus decreased remarkably, from the East (semi-arid weather) to the West (humid and sub-humid weather). Most of species "disappeared" completely from citrus or were to be found only as occasional insects on some of the trees in different citrus orchards of Nefsa, Tabarka, and Boussalem. Therefore, most of the species appeared to show a decided preference for the maritime moderate weather, particularly semi-arid conditions as indicated by their high occurrences and abundances in Cap Bon (coastal region). The richest regions were Menzel Bou Zalfa, Korba, Nabeul and Hammamett, containing the highest species numbers (11, 9, 9, and 10, respectively). According to Jendoubi *et al*. (2008), similar important dispersal and repartition of scale insects was registered in in Cap Bon in Menzel Bou Zalfa and Beni Khalled.

Between species

The distribution of *P. ziziphi* and *P. pergandii* was restricted to the northeast mainly in the semi-arid central of Cap Bon (Soliman, Beni Khalled and Menzel Bou Zelfa); and therefore scale insect species seemed to thrive well under moderate climatic conditions. Unlike some others species, *Pl. citri* and *I. purchasi* were collected in abundance in both the northeast and the northwest citrus zones. Jendoubi *et al*. (2008) reported that both species were found spreading in all the prospected areas in Cap Bon showing main foci of infestation in Takelssa region which is characterized by a humid climate. These insects appeared hence to show a considerable climatic adaptability, as demonstrated by their ability to thrive in citrus zones where climatic conditions are humid as well as semi arid, with preference to the humid conditions. *C. dictyospermi*, *C. floridensis*, *C. hesperidum*, *L. beckii* were common in the northern east area which may reflect their preference to temperate weather with hot and humid conditions. In fact, many authors (Gill, 1997; Miller and Davidson, 2005) mentioned that these species are common in coastal areas.

Variations in the dispersal of scale species could be affected by the differences in climatic conditions between regions, host plants, farming practices and chemical sprays. We pointed out that in Cap Bon region, Citrus is grown as a traditional familial compound crop, where citrus orchards are scattered overall the area, some of them were left and become a foci of pests. Citrus trees are usually intercropped with either fruit trees such as pomegranate, laurel, medlar, olive, and fig; being to some species the alternative or primary host plants. These practices could contribute to the buildup of infestation and development of new foci. In the northwest, scale insects were not common as a result to the extreme climatic conditions (hotter summer and colder winter) and probably to the young planting age of Citrus trees mainly in Oued Mliz (5-10 years).

In conclusion, the analysis of scale insects occurring on citrus trees in Tunisia, based on literature review and the results of current survey, actually revealed the occurrence of 21 species, showing an important biodiversity of the fauna of scale insects. Consequently, we divided the citrus scale insect fauna into six major groups according to their incidence as is illustrated in table 15.

Table 15. List and main characteristics of the scale species occurring on citrus crop in Tunisia.

Groups	Species	Change in abundance over time	Infestation	Spread	Region	Host plant
Serious pest	***P. pergandii***	Stable	Very high	Widespread	North	Citrus
	P. ziziphi	Stable	Very high	Widespread	North	Citrus
	Pl. citri	Stable	Very high	Widespread	North	Citrus, pomegranate
Outbreak pest	***I. purchasi***	Increasing	High	Frequent	North	Citrus
Common pest	***C. dictyospermi***	Decreasing	Medium	Frequent	Northeast	Citrus
	L. beckii	Stable	Medium	Frequent	Northeast	Citrus
	C. hesperidum	Stable	Low	Frequent	Northeast	Citrus
Occasional pest	***S. oleae***	Stable	Low	Limited	Northeast	Citrus, olive
	C. rusci	Stable	Very low	Frequent	Northeast	Citrus
Potential pest	***A. aurantii***	Decreasing	Low	Limited	Northeast	Citrus
	C. aonidum	Decreasing	Low	Limited	Northeast	Citrus
	C. floridensis	New record	Low	Frequent	Northeast	Citrus, laurell, medlar
	C. pseudomagnoliarum	New record	Medium	Frequent	Northeast	Citrus
Minor pest	***A. nerii***	Unknown	Very low	Infrequent	Northeast	Citrus
	C. sinensis	Unknown	Very low	Infrequent	Northeast	Citrus
	C. pinnulifer	New record	Very low	Limited	Northeast	Citrus
	E. tessellatus	Unknown	Very low	Infrequent	Northeast	Citrus
	F. theae	Unknown	Very low	Infrequent	Northeast	Citrus
	P. persicae	Unknown	Very low	Infrequent	Northeast	Citrus
	P. longispinus	Unknown	Very low	Infrequent	Northeast	Citrus
	P. psidii	Unknown	Very low	Infrequent	Northeast	Citrus

II. Effect of temperature and plant substrate on survival, development times, fecundity and life table parameters of *P. ziziphi*

No studies have been reported on the effect of temperature on survival, development times, fecundity and life table parameters of *P. ziziphi* under controlled conditions. Partial studies on life cycle of this pest under semi field conditions were conducted by Sweilem *et al*. (1985); and some biological studies at 25°C were published by Stathas *et al*. (2008). However, it is not feasible to establish a complete comparison with the data here obtained because of the different temperature or plant substrate used in their researches. For that reason, a comparison of these data with those of diaspidid species that live and can develop in high populations in citrus trees in similar agroecosystems, such as *P. pergandii*, *C. dictyospermi*, *C. aonidum* and *A. aurantii* will be considered too.

This study has shown that black scale survival can decline noticeably at 20°C, affecting mainly first nymphal instar and female stages. Compared with *A. aurantii*, similar rate of mortalities were mentioned by Willard (1972) at 19°C. At 25°C on sour orange plant, Stathas *et al*. (2008) reported 19%, 14.5% and 4.5% of mortalities occurring at first and second nymphal instars and ovipositing female, respectively. This is in contrast with the current results, where only at pre-ovipositing stage 15.5% of individual died at 24°C.

Apart the data of Sweilem *et al*. (1985) who reported the viability and the duration of egg stage at 20°C and 24°C on sour orange plants, no such studies have been reported otherwise. The percentages of egg hatching (82% and 90%, respectively) recorded by Sweilem *et al*. (1985) were similar to those obtained in this study (100% and 100%, respectively). On the contrary, incubation times recorded on eggs in their studies (11 days and 8 days, respectively) were noticeably lower than those reported in the current study (32.7 days and 11.5 days, respectively).

The development times of *P. ziziphi* in this study were shorter than those reported in previous studies. For example at 24°C, periods of 14.1, 19.3, and 25.5 days were reported by Sweilem *et al*. (1985) for the first and second instars and pre-ovipositing females, respectively, while in this study development took 3.6, 6.4 and 7.7 days, respectively. In addition, previous data reported by Sweilem *et al*. (1985) indicated as for male development ten days more were needed to be completed. These differences could be attributed to the different temperature conditions adopted in the experimental protocol. At constant temperatures, and comparing with the development of two armored scales, *P. pergandii* and *A. aurantii*, results on development times of female stages at 24°C showed that *P. ziziphi* developed similarly to the former but more quickly than the latter according to Gerson (1967) and Badary and Abd-Rabou (2010). At low temperature, same trend to 24°C was observed; *P. ziziphi* needed much shorter time varying between 28 to 38 days to complete L1, L2 and L3 female stages, while for *A. aurantii* higher values were recorded in literature 89.1, 105.6, 96.2, 115.0, 111.3 (Willard, 1972).

Few data in literature are available on the duration of generation for *P. ziziphi*. During this experiment, a generation required 62-67 days at 24°C and up to 126 days at low temperature. Stathas *et al*. (2008) estimated at 25°C on sour orange plant a similar period to these results.

Lowest fecundities were observed at 20°C on fruits; these values could be related to the inefficient copulating. In fact, more than the half of males died during their emergence (Table. 10). Consequently, not all females were fertilized and such females pushed out their pygidium and extruded their whole bodies remaining alive in this position for long periods (2 months), subsequently shriveling and becoming reddish. While on plants, mortality of males is lower and emergence of males occurred on three different times, hence most females were mated. At 24°C similar results on fecundity on plants were found by Sweilem *et al*. (1985) and in this current study.

Previous field studies carried out by Gomez Clemente (1943) on the fecundity of *P. ziziphi* gave much lower values (8-20 eggs/female) than those obtained in the current assay. We can explain these differences by the difficulty to monitor all the oviposition period of *P. ziziphi* females and counting all the eggs laid or emerged crawlers during that period. Probably, sampling consisted in counting the number of eggs laid under the scale cover of females at each day of observation, which doesn't reflect in fact the total number of eggs laid by female. In comparing with the mean fecundity of other armored scales injuring citrus trees, *P. ziziphi* presented a low average of fecundity. Averages of 100-150; 38-224; 80-100; 60-150; 27-46 and 88 are quoted in literature for *A. aurantii*, *C. aonidum*, *C. dictyospermi*, *L. beckii*, *L. gloverii*, and *P. pergandii*, respectively (Miller and Davidson, 2005).

Related to the intrinsic rate of increase, r_m becomes better estimated and capacity of growth increases too with increasing temperature (24°C). Observations in the field showed in fact that the greatest increase in population occurred in April or September when the mean temperature varies between 23.3°C and 26.3°C (Sweilem *et al*., 1985).

CONCLUSION AND RECOMMENDATIONS

Conclusion

The present study aimed to analyze the citrus scale insect fauna status in the northern regions of Tunisia and study the biological potential of the black scale *P. ziziphi* in the laboratory at 20ºC and 24°C and 70% RH on fruits of green lemon and leaves of plants of sour orange.

The citrus scale insect fauna shows a richness and great biodiversity in the citrus region. At present, it includes 21 species belonging to nine genera and 4 families: *I. purchasi* (Monophlebidae); *Pl. citri, P. longispinus* (Pseudococcidae); *C. floridensis*, *C. rusci, C. sinensis*, *C. hesperidum*, *C. pseudomagnoliarum, E. tessellates*, *P. persicae, P. psidii* and *S. oleae* (Coccidae); *A. aurantii*, *A. nerii*, *C. aonidum*, *C. dictyospermi*, *C. pinnulifer*, *F. theae, L. beckii*, *P. pergandii* and *P. ziziphi* (Diaspididae). Among them, three species were newly recorded in Tunisia; and seven were poorly studied and still undetectable. The greatest diversity was found within the families Diaspididae and Coccidae each one with nine species . Majority of species are represented from the Palearctic region (43% of total scale fauna) and the Neotropical (19%).

The scale species are widespread in all the planting citrus areas of the north, invading a large part of the east regions and becoming scarce in the west regions. In Cap Bon, the highest occurrences and abundances of scale insects were registered mainly in the centre east (Beni Khalled, Menzel Bou Zalfa and Soliman) and the southeast (Korba, Hammamett) districts, being an important focus of infestations for many species. In addition, species appeared to show a preference for the maritime weather of Cap Bon.

The global analysis of the citrus scale insect fauna divides it into six major groups according to their actual pest status. *P. pergandii*, *P. ziziphi* and *Pl. citri* are the first serious pests of citrus, keeping continuously a high infestation in Cap Bon. *I. purchasi* is the only species of the second group pest in outbreak and its populations are spreading considerably last years in citrus orchards. *C. hesperidum*, *C. dictyospermi*, *L. beckii* are considered as common pest and the two species *S. oleae* and *C. rusci* as occasional pests. While the red scale, the California red scale, the florida wax scale and the brown scale could represent a real menace for citrus groves next years, being potential pests. The other species are grouped as minor pests, occurring in very limited areas at very low density

The biological studies on *P. ziziphi* indicated that temperature consistently had higher influence than the plant substrate on the black scale survival, sex ratio, development and fecundity. The pest was adapted to both temperatures, showing higher performance at 24°C. Very low mortality, high fecundity and short life cycle were recorded in fact at warm temperature. In addition, *P. ziziphi* didn't present an important reproductive potential and life table parameters were weakly estimated. The plant substrate could have an effect at low temperature; and leaves of sour orange seemed to provide a better food than fruits for *P. ziziphi*.

Recommendations

- **for the scale insect fauna**

This work represents a starting point for many further zoo-geographical studies of scale insect fauna in Tunisia; with further surveys will surely be found to contain many more genera and species.

* For species not yet detected, more intensive surveys at different periods through a year, and mainly with checking the collection of the Tunisian slide-mounted specimens, a complete knowledge on species associated with the citrus trees in Tunisia will be achieved.
* For *P. pergandii*, *P. ziziphi* and *Pl. citri,* a serious and urgent management is necessary for controlling these pests with specific control interventions.
* For *I. purchasi*, field studies on population dynamic host-predator are evidently needed to improve and maintain the role of the vedalia ladybird in order to provide an excellent biological control of the cottony cushion scale as previously.
* For the potential pests, regular monitoring prevents the eventual damages.

- **For *P. ziziphi***

This is the first life table study of this species; studying more temperatures should contribute to a better understanding of the biological potential of the black scale in laboratory conditions and of its population dynamics in the field. However, these results should be used with caution and carefulness in the field.

REFERENCES CITED

1. **Abdelkhalek, L., Afellah, M. and Smaili, C.** (1998). Bioecologie et lutte biologique contre *Planococcus citri* R. (Pseudococcidae) sur agrumes dans la région du Loukos au Maroc. *Mededelingen Gent* 63(2): 483-488.
2. **Abd-Rabou, S.** (1999). An annotated list of the Hymenopterous parasitoids of the Diaspididae (Hemiptera: coccoidea) in Egypt, with new records. *Entomologica* 33: 173-177.
3. **Abd-Rabou, S., Hanafi, A. and Hussein, N.** (2001). Notes on the parasitoids of the soft brown scale, *Coccus hesperidum* (Hemiptera: Coccidae) in Egypt. *Entomologica* 33: 179-184.
4. **Annecke, D.P. and Moran, V.C**. (1982). Insects and Mites of Cultivated Plants in South Africa. Butterworths, Durban, Pretoria. 383 pp.
5. **Argov, Y., Schneider, B. and Rosen, D.** (1992). Parasitism of Florida wax scale, *Ceroplastes floridensis* Comstock, on citrus in Israel. *Journal of the Entomological Society of Southern Africa* 55(1): 21-31.
6. **Argyriou, L.C.** (1974). Data on the biological control of Citrus scales in Greece. *Bulletin SROP* 3:89-94.
7. **Argyriou, L.C.** (1990). Olive. *In*. Rosen, D. (eds.). Armored Scale Insects, Their Biology, Natural Enemies and Control, World Crop Pests, vol 4B. Elsevier, Amsterdam, London, pp. 579-583.
8. **Argyriou, L.C. and Kourmadas, A.L.** (1980). *Ceroplastes floridensis* Comstock an important pest of citrus trees in Aegean islands. *Fruits* 35: 705-708.
9. **Argyriou, L.C. and Mourikis, P.A.** (1981). Current status of citrus pests in Greece, Pseudococcidae. Introduced Parasites and Predators of Arthropod Pests and Weeds. Proceedings of the International Society of Citriculture 2: 623-627.
10. **Austin, A.D., Yeates, D.K., Cassis, G., Fletcher, M.J., La Salle, J., Lawrence, J.F., McQuillan, P.B., Mound, L.A., Bickel, D.J. and Gullan, P.J**. (2004). Insects 'Down Under', Diversity, endemism and evolution of the Australian insect fauna: examples from select orders. *Australian Journal of Entomology* 43: 216-234.
11. **Avidov, Z. and Harpaz, I**. (1969). Plant Pests of Israel. Israel Universities Press, Jerusalem. 549 pp.
12. **Badary, H. and Abd-Rabou, S.** (2010). Biological studies of the California red scale, Aonidiella aurantii (Maskell) (Hemiptera: Diaspididae) bunder different host plants and temperatures with an annotated list of natural enemies of this pest in Egypt. Egypt. *Academic Journal biological Sciences* 3(1): 235 – 242.
13. **Balachowsky, A.S.** (1927). Contribution à l'étude des coccides de l'Afrique mineure (1ère note). *Annales de la Société Entomologique de France* 96: 175-207.
14. **Balachowsky, A.S.** (1932). Étude biologique des coccides du bassin occidental de la Méditerranée. Lechevalier & Fils, Paris, France. 214 pp.
15. **Balachowsky, A.S.** (1933). Sur la biologie de *'Ceroplastes floridensis'* Comst. et sur la repartition géographique des *Ceroplastes* dans la region palearctique (Hem. Coccidae). 5ème Congrès International d'Entomologie, Paris, France, pp. 79-87.
16. **Balachowsky, A.S.** (1948). Les cochenilles de France, d'Europe, du nord de l'Afrique et du bassin Méditerranéen IV, Monographie des Coccoidea, classification; Diaspidinae (Première partie). *Entomologie Appliquée Actualités Scientifiques et Industrielles* 1054: 243-394.
17. **Balachowsky, A.S.** (1950). Les cochenilles de France, d'Europe, du nord de l'Afrique, et du bassin Méditerranéen V, Monographie des Coccoidea; Diaspidinae (Deuxième partie) Aspidiotini. *Actualités Scientifiques et Industrielles, Entomologie Appliquée* 1087: 397-557.
18. **Balachowsky, A.S.** (1953). Les cochenilles de France d'Europe, du Nord de l'Afrique, et du bassin Méditerranéen VII, Monographie des Coccoidea; Diaspidinae IV, Odonaspidini, Parlatorini. *Entomologie Appliquée Actualités Scientifiques et Industrielles* 1202: 725-929.
19. **Balachowsky, A.S.** (1954). Les cochenilles Paléarctiques de la tribu des Diaspidini. Mémoires Scientifiques de l'Institut Pasteur, Paris. 450 pp.
20. **Balachowsky, A.S.** (1956). Les cochenilles du continent Africain Noir V. 1; Aspidiotini (1ère partie). Annales du Musée Royal du Congo Belge (Sciences Zoologiques). *Tervuren* 3: 1-142.

21. **Barbagallo, S**. (1974). Notizie sulla presenza in Sicilia di una nuova cocciniglia degli agrumi *Coccus pseudomagnoliarum* (Kuwana) (Homoptera, Coccidae) osservazioni biologiche preliminari. *Entomologica* 10: 121-139.
22. **Barbagallo, S.** (1981). Integrated control of citrus pests in Italy. *Proceedings of the International Society of Citriculture* 2: 620-623.
23. **Bartlett, B.R.** (1978). Coccidae. *In*. Clausen, C.P. (eds.). Introduced Parasites and Predators of Arthropod Pests and Weeds: A World Review. Agricultural Research Service, United States Department of Agriculture, Washington, U.S.A., pp. 57-74.
24. **Beattie, G.A.C. and Gellatley, J.G.** (1983). Citrus scale insects. Agfacts, Department of Agriculture, New South Wales. 226pp.
25. **Beardsley, J.W. and Gonzalez, R.H**. (1975). The biology and ecology of armored scales. *Annual Review of Entomology* 20: 47-73.
26. **Bedford, E.C.G.** (1998). Other scale insects of minor importance. *In*. (eds.). Bedford, E.C.G., Van den Berg, M.A. and De Villiers, E.A. Citrus Pests in the Republic of South Africa. Institute for Tropical and Subtropical Crops, Nelspruit, South Africa, pp. 158-160.
27. **Bedford, E.C.G. and Cilliers, C.J. (**1994). The role of *Aphytis* in the biological control of armoured scale insects on citrus in South Africa. *In*. Rosen, D. (eds.). Advances in the Study of ***Aphytis*** (Hymenoptera: Aphelinidae).Andover, U.K., pp. 143-179.
28. **Beingolea, G.** (1969). Biological control of citrus pests in Peru. Proceedings of the first International Citrus Symposium. Riverside, California, U.S.A., pp. 839-848.
29. **Ben-Dov, Y.** (1976). Phenology of the Florida wax scale, *Ceroplastes floridensis* Comstock (Homoptera: Coccidae) on citrus in Israel. *Phytoparasitica* 4: 3-7.
30. **Ben-Dov, Y.** (1993). A systematic catalogue of the soft scale insects of the world (Homoptera: Coccoidea: Coccidae). Sandhill Crane Press, Gainesville, U.S.A. 536 pp.
31. **Ben-Dov, Y.** (1994). A systematic catalogue of the mealybugs of the world (Insecta: Homoptera: Coccoidea: Pseudococcidae and Putoidae) with data on geographical distribution, host plants, biology and economic importance. Andover, U.K. 686pp.
32. **Ben-Dov, Y.** (2011). An updated checklist of the scale insects (Hemiptera: Coccoidea) of the Margarodidae *sensu lato* group. *Zootaxa* 2859: 1-62.
33. **Ben-Dov, Y. and Hodgson, C.J.** (1997). Soft Scale Insects: their Biology, Natural Enemies and Control, 7B. Elsevier, Amsterdam and New York. 442 pp.
34. **Bénassy, C.** (1975). Les cochenilles des agrumes dans le bassin méditerranéen. *Annales de l'Institut National Agronomique d'Algerie* 4: 118-137.
35. **Bénassy, C. and Franco, E. (**1974). Sur l'ecologie de *Ceroplastes rusci* L. (Homoptera, Lecanoidae) dans les Alpes-Maritimes. *Annales de Zoologie - Ecologie Animale* 6: 11-39.
36. **Bénassy, C. and Soria, F.** (1964). Observations écologiques sur les cochenilles diaspines nuisibles aux agrumes en Tunisie. *Annales de l' INRAT* 37: 193-222.
37. **Blackburn, V.L. and Miller, D.R.** (1984). Pests not known to occur in the United States or of limited distribution, Black parlatoria scale. *Animal and Plant Health Inspection* 44: 81-45 and 1-13.
38. **Blumberg, D., Swirski, E. and Greenberg, S.** (1975). Evidence for bivoltine populations of the Mediterranean black scale *Saissetia oleae* (Olivier) on citrus in Israel. *Israel Journal of Entomology* 10: 19-24.
39. **Bodenheimer F. S.** (1951). Citrus Entomology in the Middle East. Junk W. Publisher, Hague, Netherland. 663 pp.
40. **Borchsenius, N.S.** (1950). Mealybugs and scale insects of the USSR (Coccoidea) Zoological Institute, Akademii Nauk SSSR, Moscow, Russia. 250 pp.
41. **Borchsenius, N.S.** (1966). A catalogue of the armoured scale insects (Diaspidoidea) of the world Nauka, Moscow, Leningrad, Russia. 449 pp.
42. **Birch, L.C.** (1948). The intrinsic rate of natural increase of an insect population. *Journal Animal Ecology* 17: 15-26.
43. **Burger, H.C. and Ulenberg, S.A.** (1990). Quarantine problems and procedures. *In*. Rosen D. (eds.). Armoured scale insects, their biology, natural enemies and control, vol 4B. Elsevier Science, Amsterdam, Netherland, pp. 313-327.
44. **Cabaleiro, C. and Segura, S.** (1997). Field transmission of grapevine leafroll associated virus 3 (GLRaV-3) by the mealybug *Planococcus citri*. *Plant Disease* 81: 283-287.

45. **CABI**. (1964). Distribution Maps of Plant Pests, *Parlatoria ziziphi*; series A Map N° 186. International Institute of Entomology, the Eastern Press Ltd, London, UK. 2pp.
46. **CABI**. (1970). Distribution Maps of Plant Pests, *Aspidiotus nerii*; series A Map N° 268. Common Wealth Institute of Entomology, the Eastern Press Ltd, London, UK. 2pp.
47. **CABI**. (1982). Distribution Maps of Plant Pests, *Lepidosaphes beckii*; series A Map N° 49. International Institute of Entomology, the Eastern Press Ltd, London, UK. 2pp.
48. **CABI**. (1984). Distribution Maps of Plant Pests, *Pseudococcus longispinus*; series A Map N° 93. Common Wealth Institute of Entomology, the Eastern Press Ltd, London, UK. 2pp.
49. **CABI**. (1994). Distribution Maps of Plant Pests, *Pulvinaria psidii*; series A Map N° 59. International Institute of Entomology, the Eastern Press Ltd, London, UK. 3pp.
50. **CABI**. (1996). Distribution Maps of Plant Pests, *Aonidiella aurantii*; series A Map N° 2. International Institute of Entomology, the Eastern Press Ltd, London, UK. 2pp.
51. **Caltagirone, L.E.** (1999). Adaptations of insects to modes of life. In. (eds.). Huffaker, C.R. and Gutierrez, A.P. Ecological Entomology. John Wiley & Sons, New York, pp: 201-230.
52. **Cancela da Fonseca, J.** (1954-1956). Contribuicao para o estudo do *Coccus hesperidum* L., Subsidios para o estudo da sua biologia e ecologia. *Broteria* 50(2-3): 53-93; 51(1): 38-51; 51(4): 161-173; 52(1): 19-35.
53. **Cave, R.D. and Márquez, C.G.** (1994). Parasitoides de Diaspididae, Coccidae and Aleyrodidae atancando cítricos en Honduras. *CEIBA* 35(1): 3-8.
54. **Chang, K.C. and Huang, L.L.** (1963). A preliminary study on the control of cottony cushion scale by Australian ladybeetle. *Acta Entomologica Sinica* 12(5/6): 688-700.
55. **Chao, J. and Zeng, X.H.** (1997). Control of *Parlatoria pergandii* Comstock with buprofezin. *Grassland of China* 5: 1-46.
56. **Chkhaidze, L., Yasnosh, V.** (2001). The Dictyospermum scale *Chrysomphalus dictyospermi* (Morgan) (Coccinea: Diaspididae), pest of fruit and ornamental plants in the Black Sea coast of Georgia. *Bollettino di Zoologia Agraria e di Bachicoltura* 33(3): 495-499.
57. **Chua, T.H. and Wood, B.J.** (1990). Other tropical fruit trees and shrubs. *In*. (eds.). Rosen, D. Armored scale insects, their biology, natural enemies and control, vol 4B, World Crop Pests. Elsevier, Amsterdam, pp. 543-552.
58. **Claps, L.E.** (1991). El genero *Eudinaspis* Lizer y Trelles, 1942 con descripcion de una especie nueva (Homoptera; Coccoidea; Diaspididae). *Acta Zoologica Lilloana* 40(2): 33-37.
59. **Claps, L.E., Wolff, V.R.S. and González, R.H.** (2001). Catálogo de las especies de Diaspididae (Hemiptera: Coccoidea) nativas de Argentina, Brasil y Chile. *Insecta Mundi* 13: 239-256.
60. **Cohic, F.** (1955). Rapport d'une mission aux établissements français d'l'Océanie III, enquête sur les parasites animaux des cultures. Institut Français d'Océanie, Nouméa, ORSTOM. 68 pp.
61. **Copland, M.J.W. and Ibrahim, A.G.** (1985). Biology of Glasshouse Scale Insects and Their Parasitoids. *In.* Hussey, N. W. (eds.). Biological Pest Control. Cornell University Press, New York, pp. 87-90.
62. **Coll, M. and Abd-Rabou, S.** (1998). Effect of oil emulsion sprays on parasitoids of the black parlatoria, *Parlatoria ziziphi*, in grapefruit. *BioControl* 43:29-37.
63. **Cruz, C. and Segarra, A.** (1991). Recent biological control experiences in Puerto Rico. Caribbean Meetings on Biological Control, Guadeloupe, France, pp. 10-18.
64. **Culik, M.P., Martins, D.S., Ventura, J.A. and Wolff, V.S.** (2008). Diaspididae (Hemiptera: Coccoidea) of Espírito Santo, Brazil. *Journal of Insect Science* 8(17): 1-6.
65. **Danzig, E.M. and Pellizzari, G.** (1998). Diaspididae. In: Kozár F. (eds.). Catalogue of Palaearctic Coccoidea. Hungarian Academy of Sciences. Akaprint Nyomdaipari Kft, Budapest, Hungary, pp. 172-370.
66. **Davidson, J.A. and Miller, D.R.** (1990). Ornamental plants. *In.* Rosen, D. (eds.). Armoured scale insects, their biology, natural enemies and control, vol 4B. Elsevier, Amsterdam, pp. 603-632.
67. **DeBach, P. and Rosen, D.** (1991). Biological control by natural enemies. Cambridge University Press, Cambridge, UK. 440 pp.
68. **De Lotto, G.** (1976). On the black scales of southern Europe (Homoptera: Coccoidea, Coccidae). *Journal of the Entomological Society of southern Africa* 39: 147-149.

69. **Downie, D.A. and Gullan, P.J.** (2004). Phylogenetic analysis of mealybugs (Hemiptera: Coccoidea: Pseudococcidae) based on DNA sequences from three nuclear genes, and a review of the higher classification. *Systematic Entomology* 29(2): 238-259.
70. **Driesche, Van. R.G. and Bellows, T.S.** (1996). Biological Control. Chapman and Hall, London. 539pp.
71. **Ebeling, W.** (1959). Subtropical Fruit Pests. University of California, Los Angeles, USA. 436 pp.
72. **El-Bolok, M.M., Sweilem, S.M. and Abdel-Aleem, R.Y.** (1984). Seasonal variation in the population of *Parlatoria zizyphus* (Lucas) at Giza region. *Bulletin de la Société Entomologique d'Egypte* 65: 281-288.
73. **Emberger, L.** (1960). L'exploitation traditionnelle du maquis du nord de la Tunisie: Possibilité d'une meilleure utilisation. Ministère de l'Agriculture Tunisienne, République Fédérale d'Allemagne, Eschborn. 50pp.
74. **EPPO.** (2004). Good plant protection practices, Citrus. *Bulletin EPPO* 34: 43-56.
75. **Foldi, I. and Soria, S.J.** (1989). Les cochenilles nuisibles à la vigne en Amérique du sud (Homoptera: Coccoidea). *Annales de la Société entomologique de France* 25(4): 411-430.
76. **Foldi, I.** (2001). Liste des cochenilles de France (Hemiptera, Coccoidea). *Bulletin de la Société entomologique de France* 106: 303-308.
77. **Forster, L.D., Luck, R.F. and Grafton-Cardwell, E.E.** (1995). Life stages of California red scale and its parasitoid. University of California, Division of Agriculture and Natural Resources Publ 21529, Oakland, CA. 12pp.
78. **Franco, C.J., Garcia-Marí, F., Ramos, A.P. and Besri, M.** (2006). Survey on the situation of citrus pest management in Mediterranean countries. *Bulletin IOBC/wprs* 29 (3): 335-346.
79. **Franco, J.C., Suma, P., Silva, E.B., Blumberg, D. and Mendel, Z.** (2004). Management strategies of mealybug pests of citrus in Mediterranean countries. *Phytoparasitica* 32(5): 507-522.
80. **Garcia Mari, F.** (1993). Tres caparretas blancas que pueden causar danos en citricos: *Ceroplastes sinensis*, *C. rusci* y *C. floridensis*. *Levante Agricola* 324(3):1-8.
81. **García Marí, F. and Rodrigo, E.** (1995). Life cycle of the diaspidids *Aonidiella aurantii, Lepidosaphes beckii* and *Parlatoria pergandii* in an orange grove in Valencia (Spain). *Bulletin IOBC/wprs* 18(5): 118-125.
82. **Garrido, V.A. and Ventura, J.J.R.** (1993). Plagas de los citricos: bases para el manejo integrado. Ministerio de Agricultura, Pesca y Alimentacion. Dirección General de Sanidad de la Producción Agraria, Madrid. 35pp.
83. **Germain, J.F., Vayssieres, J.F. and Matile-Ferrero, D.** (2010). Preliminary inventory of scale insects on mango trees in Benin. *Entomologia Hellenica* 19: 124-131.
84. **Gerson, U.** (1967). The scale insect *Parlatoria pergandei* Comstock and its natural enemies in Israel, seminar on biological control of scale-insects and aleurodids on citrus. *Fitopatologica* 3: 21-53.
85. **Gill, R.J.** (1988). The Scale Insects of California: Part 1, the Soft Scales (Homoptera : Coccoidea : Coccidae). California Department of Food and Agriculture, Sacramento, CA. 132 pp.
86. **Gill, R.J.** (1997). The Scale Insects of California: Part 3, the Armored Scales (Homoptera: Diaspididae). California Department of Food & Agriculture, Sacramento, CA. 307 pp.
87. **Gimpel, W.F., Miller, D.R. and Davidson, J.A.** (1974). A systematic revision of the wax scales, genus *Ceroplastes*, in the United States (Homoptera; Coccoidea; Coccidae). *Miscellaneous Publication* 841: 1-85.
88. **Gomez Clemente, F.** (1943). Cochinillas que atacan a los agrios en la región de Levante. *Boletín de Patología Vegetal y Entomología Agrícola* 12: 299-328.
89. **Godfrey, K.E., Daane, K.M., Bentley, W.J., Gill, R.J. and Malakar-Kuenen, R.** (2002). Mealybugs in California vineyards (Publication 21612). University of California, Agriculture and Natural Resources, Oakland, California. 16 pp.
90. **Grafton-Cardwell, E.E., Striggow, R.A. and Ouyang, Y.** (1996). Pesticide resistance in armored scale influences citrus IPM in California. *Proceeding International Society* 1: 553-555.
91. **Gravena, S., Yamamoto, P.T., Fernandes, O.D., and Benetoli, I.** (1992). Effect of ethion and aldicarb against ***Selenaspidus articulatus*** (Morgan), ***Parlatoria ziziphus*** (Lucas) (Hemiptera: Diaspididae) and influence on beneficial fungus. *Anais da Sociedade Entomologica do Brasil* 21(2): 101-111.

92. **Gullan, P.J. and Cook, L.G.** (2007). Phylogeny and higher classification of the scale insects (Hemiptera: Sternorrhyncha: Coccoidea). *Zootaxa* 1668: 413-425.
93. **Hamon, A.B. and Williams, M.L.** (1984). The soft scale insects of Florida (Homoptera: Coccoidea: Coccidae), Arthropods of Florida and Neighboring Land Areas. Fla. Dept. of Agric. & Consumer Serv. Div. Plant Ind., Gainesville. 194 pp.
94. **Heu, R.A.** (2002). Distribution and Host Records of Agricultural Pests and Other Organisms in Hawaii. Survey Program, Plant Pest Control Branch, Plant Industry Division, Department of Agriculture. Honolulu, Hawaii. 69 pp.
95. **Hodgson, C.J.** (1994a). The scale insect family Coccidae: an identification manual to genera. CAB International, Wallingford, Oxon, U.K. 639 pp.
96. **Hollingsworth, R.G.** (2005). Limonene, a citrus extract, for control of mealybugs and scale insects. *Journal Economy Entomology* 98(3):772-9.
97. **IPraloran, J.C.** (1971). Les agrumes. Maison neuve et Larousse, Paris, France. 82pp.
98. **Itioka, T. and Inoue, T.** (1996). The role of predators and attendant ants in regulation and persistence of a population of the Citrus Mealybug *Pseudococcus citriculus* in a Satsuma orange orchard. *Applied Entomological Zoology* 31: 195–202.
99. **Jahn, G.C. and Beardsley, J.W.** (1998). Presence/absence sampling of mealybugs, ants, and major predators in pineapple. *Journal Plant Protection in the Tropics,* 11(1):73-79.
100. **Jahn, G.C., Beardsley, J.W. and González-Hernández, H.** (2003). A review of the association of ants with mealybug wilts disease of pineapple. *Hawaiian Entomological Society* 36: 9-28.
101. **Jerraya, A.** (1974). Observations bioécologiques sur une cochenille citricole dans la région de Tunis, *Saissetia oleae (*Homoptera, Coccidae). *Bullutein OILB/SROP* 3 :135-158.
102. **Jerraya, A.** (2003). Principaux nuisibles des plantes cultivées et des denrées stockées en Afrique du Nord : Leur biologie, leurs ennemis naturels, leurs dégâts et leur contrôle. Climat Pub, Tunisie. 225 pp.
103. **Jendoubi, H., Grissa, K.L., Suma, P. and Russo, A.** (2008). Scale insect fauna (Hemiptera, Coccoidea) of citrus in Cap Bon region (Tunisia). *Bullutein IOBC/wprs Bulletin* 38:87-93.
104. **Katsoyannos, P.** (1996). Northern Mediterranean countries. *In*. (eds.). Morse, J.G., Luck, R.F. and Gumpf, D.J. Citrus Pest Problems and their Control in the Near East. FAO, Rome, pp. 221-255.
105. **Kosztarab, M. and Kozar, F**. (1988). Scale insects of Central Europe. Akadémiai Kiadò, Budapest. 456 pp.
106. **Kosztarab, M.** (1990). Economic importance, Armored scale insects as pests. *In.* Rosen, D. (eds.). Armored scale insects: their biology, natural enemies and control, Word Crop Pests, vol 4B, Elsevier, Amsterdam, pp. 307-311.
107. **Kosztarab, M.** (1996). Scale insects of Northeastern North America. Identification, biology, and distribution. Virginia Museum of Natural History, Martinsburg, Virginia. 650 pp.
108. **Kosztarab, M. and Raymond, G.J. (**1997). Pest status of soft scale insects, economic importance. *In*. (eds.). Ben-Dov, Y. and Hodgson, C.J. Soft scale insects – their biology, natural enemies and control (7B). Elsevier Science, Amsterdam, pp. 161-163.
109. **Koya, K.M.A., Devasahayam, S., Selvakumaran, S. and Kallil, M.** (1996). Distribution and damage caused by scale insects and mealy bugs associated with black pepper (***Piper nigrum*** Linnaeus) in India. *Journal of Entomological Research*. 20: 129-136.
110. **Longo, S., Mazzeo, G., Russo, A. and Siscaro, G.** (1994). *Aonidiella citrina*, a new pest of citrus in Italy. *Informatore Fitopatologico,* 34 (12): 19-25.
111. **Longo, S., Marotta, S., Pellizzari, G., Russo, A. and Tranfaglia, A.** (1995). An annotated list of the scale insects (Homoptera: Coccoidea) of Italy. *Israel Journal of Entomology* 29:113-130.
112. **Longo, S., Marotta, S., Pellizzari, G., Russo, A. and Tranfaglia, A.** (1999). A zoogeographical analysis of the Italian scale insect fauna. Eighth International Symposium on Scale Insect Studies, Wye, UK, pp. 1-41.
113. **Lo PL Chapman, R.B.** (2001). Predation by *Halmus chalybeus* (Coleoptera, Coccinellidae) on *Ceroplastes destructor* and *C. sinensis* (Hemiptera, Coccidae, Ceroplastinae) infesting citrus in Northland, New Zealand. *Biocontrol Science and Technology* 11(1): 57 – 66.
114. **Mahfoudhi, N. and Dhouibi, M.H.** (2009). Survey of mealybugs (Hemiptera: Pseudococcidae) and their natural enemies in Tunisian vineyards. *Africain Entomology* 17(2): 154–160.

115. **Marotta, S.** (1990). Studio morfo-sistematico delle specie italiane della famiglia Pseudococcidae (Homoptera: Coccoidea). Thesis di dottorati. Università degli studi di Napoli, Italy. 104 pp.
116. **Martinez-Ferrer, M.T., Grafton-Cardwell, E.E. and Shorey, H.H.** 2003. Disruption of parasitism of the California red scale (Homoptera: Diaspididae) by three ant species (Hymenoptera: Formicidae). *Biological Control* 26(3): 279-286.
117. **McKenzie, H.L.** (1956). The armored scale insects of California. *Bulletin California Insect Survey* 5: 1-209.
118. **McKenzie, H.L.** (1967). Mealybugs of California with taxonomy, biology, and control of North American species (Homoptera: Coccoidea: Pseudococcidae). University of California Press, Berkeley. 526 pp.
119. **Mendel, Z. and Blumberg, D.** (1991). Colonization trials with *Cryptochetum iceryae* and *Rodolia iceryae*, for improved biological control of *Icerya purchasi* in Israel. *Biological Contro* 1: 68-74.
120. **Mendrec, G., Prast, J.Y. and Retournard, D.** (1998). Soignez toutes les plantes potagères espèce par espèce. Rustica, Paris, Franca. 113pp.
121. **Millet, E.R.** (1959). Summary of insect conditions in Tunisia. *Entomological Bereich* 16: 45-46.
122. **Miller, D.R. and Davidson, J.A.** (1990). A list of the armored scale insect pests. *In*. (eds.). Rosen, D. Armored scale insects: their biology, natural enemies and control. Word Crop Pests, vol. 4B. Elsevier, Amsterdam, pp. 299-306.
123. **Miller, D.R. and Kosztarab, M.** (1979). Recent advances in the study of scale insects. *Annual Review of Entomology* 24: 1-27.
124. **Miller, D.R. and Davidson, J.A.** (2005). Armored Scale Insect Pests of Trees and Shrubs. Cornell Univ Press, Ithaca, NY. 442 pp.
125. **Miller, D.R., Miller, G.L. and Watson, G.W.** (2002). Invasive species of mealybugs (Hemiptera: Pseudococcidae) and their threat to U.S. agriculture. *Proceedings of the Entomological Society of Washington* 104(4): 825-836.
126. **Monastero, S.** (1962). Le cocciniglie degli agrumi in Sicilia (*Mytilococcus beckii* New, *Parlatoria zizyphus* Lucas, *Coccus hesperidum* L., *Pseudococcus adonidum* L., *Coccus oleae* Bern., *Ceroplastes rusci* L.). *Bollettino dell' Istituto di Entomologia Agraria dell Università Palmero* 4: 65-151.
127. **Moran, V.C., Gunn, B.H. and Walter, G.H.** (1982). Wind dispersal and settling of first-instar crawlers of the cochineal insect *Dactylopius austrinus* (Homoptera: Coccoidea: Dactylopiidae). *Ecological Entomology* 7: 409-419.
128. **Morse, J. G., Luck, R. F. and Gumpf, D.J**. (1996). Citrus pest problems and their control in the Near East. Food and Agriculture Organisation of the United Nations (FAO), Rome. 398 pp.
129. **Nakahara, S.** (1982). Checklist of the armored scales (Homoptera: Diaspididae) of the conterminous United States. United States Department of Agriculture, USA. 110 pp.
130. **Nada, S., Abd Rabo, S. and Hussein, G.E.D.** (1990). Scale insects infesting mango trees in Egypt (Homoptera: Coccoidea). Proceedings of the Sixth International Symposium of Scale Insects Studies, Cracow, Poland, pp. 133-134.
131. **Ortu, S. and Marras, P.** (2000). Biological control of *Planococcus citri* (Risso) with Leptomastix dactylopii (How.) for reducing insecticide use in citrus production in Sardinian. *Electronic Journal of Biotechnology* : 17-34.
132. **Pagliano, Th.** (1938). Les parasites des vergers, des olivettes et des palmeraies. Imprimerie centrale, Tunis. 300 pp.
133. **Pasotti, L., Maroli, M., Giannetto, S. and Brianti, E.** (2006). Agrometeorology and models for the parasite cycle forecast. *Parassitologia* 48(1-2): 81-3.
134. **Peleg, B.A.** (1965). Observations on the life cycle of the black scale, *Saissetia oleae* Bern., on citrus and olive trees in Israel. *Israel Journal of Agricultural Research* 15: 21-26.
135. **Pellizzari, G.** (1997). Olive. *In.* (eds.). Ben-Dov, Y. and Hodgson, C.J. Soft Scale Insects: their Biology, Natural Enemies and Control, 7B. Elsevier, Amsterdam and New York, pp. 217-227.
136. **Pellizzari, G**. (2010). New Data on the Italian Scale Insect Fauna (Hemiptera, Coccoidea). *Acta Phytopathologica et Entomologica Hungarica* 45(1): 89-92.
137. **Pellizzari, G. and Germain, J.F.** (2010). Scales (Hemiptera, Superfamily Coccoidea). *BioRisk* 4(1): 475-510.

138. **Pellizzari, G. and Camporese, P.** (1994). The *Ceroplastes* species (Homoptera: Coccoidea) of the Mediterranean basin with emphasis on *C. japonicus* Green. *Annales de la Société entomologique de France* 30(2): 175-192.
139. **Petersen, C.L. and Charles, J.G.** (1997). Transmission of grapevine leafroll-associated closteroviruses by *Pseudococcus longispinus* and *P. calceolariae. Plant Pathology* 46(4): 509–515.
140. **Podoler, H., Dreishpoun, Y. and Rosen, D.** (1981). Population dynamics of the Florida wax scale, *Ceroplastes floridensis* (Homoptera: Coccidae) on citrus in Israel, 1-A partial life-table. *Acta Oecologica* 2: 81-91.
141. **Qin, T.K. and Gullan, P.J.** (1994). Taxonomy of the wax scales (Hemiptera: Coccidae: Ceroplastinae) in Australia. *Invertebrate Taxonomy* 8: 923-959.
142. **Qin, T.K., Gullan, P.J. and Beattie, G.A.C.** (1994). The current distribution and geographical origin of the scale insect pest *Ceroplastes sinensis* Del Guercio (Hemiptera: Coccidae). *Bulletin of Entomological Research* 84: 541– 54.
143. **Ripa, R., Larral, Luppichini, P., Guajardo, V. and Rojas, S.** (2008). Chanchito blanco de Cola larga, Cochinilla harinosa de los invernáculos, Cochinilla algodonosa de los invernáculos , Long-tailed mealybug *Pseudococcus longispinus* (Targioni Tozzetti). *In.* (eds.). Ripa, R. and Larral, P. Manejo de plagas en paltos y cítricos. Instituto de Investigaciones Agropecuarias-Ministerio de Agricultura, Collečión Libros INIA 23, Chile, pp. 180-191.
144. **Roelofs, W.L., Gieselmann, M.J., Carde, A.M., Tashiro, H., Moreno, D.S., Henrick, C.A. and Anderson, R.J.** (1978). Identification of the California red scale sex pheromone. *Journal of Chemical Ecology* 4: 211-224.
145. **Rose, M.** (1997). Diaspidid pest problems and control in crops, citrus. *In.* Ben-Dov, Y. and Hodgson, C.J. (eds.). Armoured scale insects, their biology, natural enemies and control (4B). Elsevier Science, Amsterdam, pp. 345-350.
146. **Rosen, D.** (1990). Armored scale insects, their biology, natural enemies and control, vol 4A, World Crop Pests. Elsevier, Amsterdam. 384 pp.
147. **Rosen, D.** (1986). Methodologies and strategies of pest control in citriculture. *In*. Cavalloro, R. and Di Martino, E. (eds.). Integrated pest control in citrus-groves. Balkema, Rotterdam, the Netherlands, pp. 521-530.
148. **Rosen, D. and DeBach, P.** (1978). Diaspididae. *In*. Clausen, C.P. (eds.). Introduced parasites and predators of arthropod pests and weeds, a world review. United States Department of Agriculture, Agricultural Handbook, pp. 78-128.
149. **Rosen, D. and DeBach, P.** (1979). Species of ***Aphytis*** of the world (Hymenoptera: Aphelinidae). *In*. (eds.). Junk, W. Series Entomologica 17. The Hague, Boston, pp. 780-801.
150. **Russo, A. and Mazzeo, G.** (1997). Contributo allo studio zoogeografico della coccidiofauna della Sicilia. *Naturalista siciliano* 4(21): 45-55.
151. **Rust, M.K., Reierson, D.A., Paine, E. and Blum, L.J.** (2000). Seasonal activity and bait preferences of the Argentine ant (Hymenoptera: Formicidae). *Journal Agricultural Urban Entomology* 17(4): 201–212.
152. **Salama, H.S., Abdel Salam, A.L., Donia, A. and Megahed, M.I.** (1985). Studies on the population and distribution pattern of *Parlatoria ziziphus* (Lucas) in citrus orchards in Egypt. *Insect Science and its Application* 6: 43-47.
153. **Shen, G.P. and Liu, H.M.** (1990). Research on scale insect species in camphor trees in the Nanchang area. *Acta Agricultural Universitatis Jiangxiensis* 12: 10-17.
154. **Silva, E.B. and Mexia, A.** (1997). The damage caused by *Planococcus citri* (Risso) on Citrus groves. *In.* (eds.). Franco, J.C., Suma, P., Silva, E.B., Blumberg, D. and Mendel, Z. Management strategies of mealybug pests of citrus in Mediterranean countries. *Bulletin IOBC/wprs* 20: 26-31.
155. **Silva, E.B. and Mexia, A.** (1999). The pest complex Crytoblabes gnidiella (Milliere) (Lepidoptera: pyralidae) and *Planococcus citri* (Risso) (Homoptera: pseudococcidae) on sweet orange groves (*Citrus sinensis* L. Osbeck) in Portugal: interspecific association. *Bolletino Sandibad Vegetal Plagas* 25: 89-98.
156. **Silva, E.B., Mendel, Z. and Franco, J.C.** (2010). Can facultative parthenogenesis occur in biparental mealybug species? *Phytoparasitica* 38: 19-21.
157. **Smith, D., Beattie, G.A.C. and Broadly, R**. (1997). Citrus pests and their natural enemies: Integrated Pest Management in Australia. Queensland DPI & HRDC, Brisbane, Australia. 75 pp.

158. **Southwood, T.R.E. and Henderson, P.A.** (2000). Ecological Methods, third edition. Blackwell Science logo, London, UK. 574pp.
159. **Soto, A.J., Costa-Comelles, A.A. and Rodriguez, J.M.** (1994). Eficacia de algunos plaguicidas sobre los cóccidos diaspinos *Lepidosaphes beckii* (Newman) y *Parlatoria pergandii* Comstock (Homoptera, Diaspididae) en cítricos y efectos secundarios. *Boletín Sandibad Vegetal Plagas* 20: 357-369.
160. **Stathas, G.J.** (2001). Ecological data on predators of *Parlatoria pergandii* on sour orange trees in southern Greece. *Phytoparasitica* 29(3): 207-214.
161. **Stathas, G.J., Eliopoulos, P.A. and Japoshvili, G.** 2008. A study on the biology of the diaspidid scale ***Parlatoria ziziphi*** (Lucas) (Hemiptera: Coccoidea: Diaspididae) in Greece. Proceedings of the XI International Symposium on Scale Insect Studies, Lisbon, Portugal, pp. 95-101.
162. **Swailem, S. M., Ismail, I. I. and Sayed Ahmed, N. M. A. (**1976). Populations studies on the citrus wax scale insect, *Ceroplastes floridensis* Comstock, in different regions in Egypt (Homoptera, Coccidae). *Bulletin Society of Entomology* 60: 229-237.
163. **Sweilem, S.M., El Bolok, M.M. and Abdel Aleem, R.Y.** (1985). Biological studies on ***Parlatoria zizyphus*** Lucas (Homoptera: Diaspididae). *Bulletin de la Societé Entomologique d'Egypte* (65): 301-318.
164. **Talhouk, A.M.S.** (1969). Insects and mites injurious to crops in Middle Eastern countries. *Monographien zur Angewandte Entomologie* 21: 1-239.
165. **Talhouk, A. M.S.** (1975). Citrus pests throughout the world. *Technical Monograph* 4: 1-21.
166. **Tang, F.T.** (1991). The Coccidae of China. Shanxi United Universities Press, China. 377 pp.
167. **Tanne, E., Naveh, L. and Sela, I.** (1989). Serological and molecular evidence for the complexity of the leafroll disease of grapevine. *Plant Pathology* 38: 183–189.
168. **Tena, A. and Garcia Mari, F.** (2008). Suitability of citricola scale Coccus pseudomagnoliarum (Hemiptera: Coccidae) as host of Metaphycus helvolus (Hymenoptera: Encyrtidae): Influence of host size and encapsulation. *Biological Control* 46(3): 341-347.
169. **Tena, A. and Garcia Mari, F.** (2011). Current situation of citrus pests and diseases in the Mediterranean basin. *Bulletin IOBC/wrps* 62: 365 – 378.
170. **Tena, A., Soto, A., Vercher, R. and Garcia Marí, F.** (2006). Density and Structure of *Saissetia oleae* (Hemiptera: Coccidae) populations on Citrus and Olives: Relative Importance of the Two Annual Generations. *Environmental entomology* 4 (36): 700-706.
171. **Tollerup, K.E., Rust, M.K., Dorschner, K.W., Phillips P.A. and Klotz J.H.** (2004). Low-toxicity baits control ants in citrus orchards and grape vineyards. **California Agriculture** 58 (4): 214-217.
172. **Trumble, J.T., Grafton-Cardwell, E.E. and Brewer, M.J.** (1995). Spatial dispersion and binomial sequential sampling for citricola scale (Homoptera: Coccidae) on citrus. *Journal of Economic Entomology* 88: 897-902.
173. **Unruh, C.M. and Gullan, P.J.** (2008a). Identification guide to species in the scale insect tribe Iceryini (Coccoidea: Monophlebidae). *Zootaxa* 1803: 1–106.
174. **Unruh, C.M. and Gullan, P.J.** (2008b). Molecular data reveal convergent reproductive strategies in iceryine scale insects (Hemiptera: Coccoidea: Monophlebidae), allowing the re-interpretation of morphology and a revised generic classification.*Systematic Entomology* 33, 8–50.
175. **Vargas, R., Ripa, R. and Rodríguez, S.** (2008). Escama blanca de la hiedra, oleander scale. ***Aspidiotus nerii*** (Bouché). *In*. (eds.). Ripa, R. and Larral, P. Manejo de plagas en paltos y cítricos. Collectión Libros INIA 23, La Cruz, Chile, pp. 171-172.
176. **Viggiani, G. and Iannaccone, F.** (1972). Observations on the biology and on the parasites of the Diaspini *Chrysomphalus dictyospermi* (Morg.) and *Lepidosaphes beckii* (Newm.) carried out in Campania in the three-year period 1969-1971. *Bollettino 'Filippo Silvestri' Portici* 30:104-116.
177. **Vranjic, J.A.** (1997). Ecology, effect on host plant. *In*. (eds.). Ben-Dov, Y. and Hodgson, C.J. Soft scale insects, their biology, natural enemies and control, vol 7B. Elsevier Science, Amsterdam, pp. 207-213.
178. **Walker, A.K. and Deitz, L.L.** (1979). A review of entomophagous insects in the Cook Islands. *New Zealand Entomological* 7: 70-82.
179. **Waterhouse, D.F. and Sands, D.P.A.** (2001). Classical Biological Control of Arthropods in Australia. CSIRO Entomology, Australian Centre for International Agricultural Research, Canberra, Australia. 559 pp.

180. **Watson G.W.** (2006). Arthropods of economic importance, superfamilies of coccoidea (scale insects). *In*. (eds.). Naumann, I.D. The insects of Australia, Second edition, Vol I.Melbourne University Press, Australia, pp. 457-464.
181. **Webber, H.J., Reuther, W., and Batchelor, L.D. (**1967). The Citrus Industry vol. I. History, World Distribution, Botany and Varieties. University of California, Division of Agricultural Sciences, California. 933pp.
182. **Westcott, C.** (1973). The gardener's bug book. Doubleday and Co. Garden City. 689 pp.
183. **Willard, J.R.** (1972). Studies on the rates of development and reproduction of California red scale, ***Aonidiella aurantii*** (Mask.) (Homoptera: Diaspididae) on citrus. *Australian Journal of Zoology. Melbourne* 20: 37-47.
184. **Williams, D.J.** (2004). Mealybugs of Southern Asia. The Natural History Museum, Kuala Lumpur, Southdene. 896 pp.
185. **Williams, D.J. and Granara de Willink, M.C.** (1992). Mealybugs of Central and South America. CAB International, London, England. 635 pp.
186. **Williams, D.J. and Moghaddam, M.** (2000). Mealybug species of the genus *Planococcus* Ferries in Iran (Homoptera: Coccoidea: Pseudococcidae) with a discussion of *Planococcus vovae (*Nasonov*). Journal Entomological Society Iran* 18(1, 2): 32- 42.
187. **Williams, D.J. and Watson G.W.** (1988a). The scale insects of the tropical South Pacific region, part 2, the mealybugs (Pseudococcidae). CAB International, UK. 290 pp.
188. **Williams, D.J. and Watson G.W.** (1988b). The scale insects of the tropical South Pacific region, part 1, the armored scales (Diaspididae). CAB International, UK. 287pp.
189. **Williams, D.J. and Watson G.W**. (1988c). The scale insects of the tropical South Pacific region, part 3, the soft scales (Coccidae) and other families. CAB International, UK. 290 pp.
190. **Williams, M.L. and Kosztarab, M.** (1972). Morphology and systematics of the Coccidae of Virginia with notes on their biology (Homoptera: Coccoidea). *Research Division Bulletin* 74: 1-215.
191. **Wong, C.Y., Chen, S.P. and Chou, L.Y.** (1999). Guidebook to Scale Insects of Taiwan. Taiwan Agricultural Research Institute Wufeng, Taichung, Taiwan. 98 pp.
192. **Zappala, L**. (2010). Citrus integrated management in Italy. Integrated Management of Arthropod Pests and Insect Borne Diseases. *Springer Science* 5: 73-100.
193. **Zuniga, S.E.** (1971). Biología de la conchuela morada, *Lepidosaphes beckii* (Newm.) en trea areas citricolas de Chile (Homoptera: Diaspididae). *Revista Peruana de Entomología* 14: 285-290.

ELECTRONIC RESSOURCES

1. **Anonymous**. (2004). Biocontrols: Scale Insect and Mealybug <http://greenmethods.gbhxonline.com/Crypts>.
2. **Ben-Dov, Y.** (2010). ScaleNet: Find a Valid Name and Catalogue Query for a species. http://www.sel.barc.usda.gov/scalenet/valid.htm.
3. **Ben-Dov, Y. and Miller, D.R.** (2010). ScaleNet: a database of the scale insects (Hemiptera; Coccoidea) of the world. http://www.sel.barc.usda.gov/scalenet/htm**.**
4. **Ben-Dov, Y., Miller, D.R. and Gibson G.** (2010). Keys to scale insects. http://www.ars.usda.gov/Services/docs.htm?docid=11385.
5. **CABI.** (1968). International Distribution Maps of Plant Pests, *Parlatoria pergandii*. http://www.cababstractsplus.org/DMPP/Reviews.asp?action=display&openMenu=relatedItems&ReviewID=12800&SubjectID.
6. **CABI** (1971). International Distribution Maps of Plant Pests, *Icerya purchasi*. http://www.cababstractsplus.org/.
7. **CABI.** (1988). International Distribution Maps of Plant Pests, *Chrysomphalus aonidum*. http://www.cababstractsplus.org/.
8. **CABI.** (2010). Invasive Species Compendium, management, *C. floridensis*. http://www.cabi.org/.
9. **CABI.** (2011). Crop Protection Compendium, management, *C. dictyospermi*. http://www.cabi.org/.
10. **CLAM**. (2006). Comité de Liaisons Méditerranéennes d'Agrumes, Rapport des prévisions de récolte agrumicole 2005-2006. www.clamcitrus.org.

11. **Cliff, S.** (1995). Mealybug Destroyer, Midwest Biological Control News. http://www.nysaes.cornell.edu/ent/biocontrol/predators/cryptolaemus_m.html.
12. **Fasulo, T.R. and Brooks, R.F.** (2004). Scale Pests of Florida Citrus, series ENY-814 of the Entomology and Nematology. http:// www. edis.ifas.ufl.edu/.
13. **Grafton-Cardwell, E.E.** (2002). Pest Management and Identification, *Rodolia cardinalis*. http://www.ipm.ucdavis.edu/PMG/NE/vedalia_beetle.html.
14. **Kerns, D., Wright, G. and Loghry, J.** (2004). Citrus Arthropod Pest Management in Arizona, Citrus Mealybug (*Planococcus citri*). http://cals.arizona.edu/crops/citrus/insects/citrusinsect.html.
15. **Mau, R.F.L. and Martin Kessing, J.L**. (2007). U.S.A. and the World Situation: Citrus. http://www.fas.usda.gov/htp/horticulture/citrus/2004%20Citrus.pdf.
16. **USDA**. (2006). ARS United States National Collection of Scale Insects, Photographs Archives. <http:// www.insectimages.org.
17. **Ronald, F.L., Mau, R.F.L. and Martin Kessing, J.L.** (2007). *Pulvinaria psidii*. http://www.extento.hawaii.edu/kbase/crop/type/p_psidii.htm.
18. **Spreen, T. H.** (2010). Projections of World Production and Consumption of Citrus to 2010. http://www.fao.org/.

قال تعالى :

وَمَا أُوتِيتُمْ مِنَ الْعِلْمِ إِلَّا قَلِيلًا

Allah said
"And mankinds have not been given of knowledge except a little."

صدق الله العظيم

(الإسراء: 85)