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Key Scale Insects (Hemiptera: Coccoidea) of High Economic Importance in a Mediterranean Area: Host Plants, Bio-Ecological Characteristics, Natural Enemies and Pest Management Strategies – a Review

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Abstract

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Key scale insects that have long been considered as having high economic importance in Tunisia and for which several research studies and pest management programs have been undertaken include the mealybug species *Planococcus ficus* (Signoret) and *Planococcus citri* Risso, the soft scale *Saissetia oleae* (Olivier) and the armoured scale *Parlatoria ziziphi* (Lucas). The host plants, bio-ecological aspects, auxiliary fauna of each of the aforementioned species as well as the related economic losses and pest management strategies adopted are explored and discussed. Among these species, *P. ficus* is considered herein as the most economically important in Tunisia. Still, the present contribution constitutes the first review article on key scale insects infesting plants in the South Mediterranean Maghreb area.

Keywords: *Planococcus ficus*; *Planococcus citri*; *Saissetia oleae*; *Parlatoria ziziphi*; grapevine; citrus; olive; Integrated Pest Management; Tunisia

Scale insects (Hemiptera: Coccoidea) are small phytophagous arthropods widely distributed in different ecosystems around the world. Their common name derives from the frequent presence of a protective covering (scale) or from the appearance of the insects themselves (Gullan & Cook 2007). The Coccoidea constitute with the aphids (Aphidoidea), jumping plant lice (Psylloidea), and whiteflies (Aleyrodoidea) the four superfamilies of the monophyletic suborder Sternorrhyncha within the order Hemiptera (Gullan & Martin 2003). The superfamily Coccoidea contains nearly 8000 species of plant-feeding hemipterans belonging to 32 families (Gullan & Cook 2007). The most commonly encountered families are those with the most species, namely the Diaspididae, Pseudococcidae, and Coccidae (Kondo *et al.* 2008). Among the 8000 scale insect species described worldwide, 2000 are known to occur in the Palearctic region (Foldi 2003).

Scale insect females are typically wingless and are often protected by waxy protective secretions or covers. The adult females may exhibit reduc-

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tion or loss of appendages, depending on the family and instar, and are often sedentary or sessile, in contrast to adult males which are usually winged and inconspicuous, do not feed and live a few days (Pellizzari & Germain 2010). Scale insects have diverse egg-protecting methods, a range of chromosome behaviours (including several methods of sex determination), marked sexual dimorphism, more rarely sexual dichronism (Gullan & Kosztarab 1997), and a wide range of genetic systems (Ross *et al.* 2010). Generally, there are three to four instars in the female and five instars in the male (Miller 2005). Crawlers (first instar nymphs) are generally the main agents of dispersal for these insects (Gullan & Kosztarab 1997; Ross *et al.* 2010).

Scale insects have been reported as serious pests attacking a huge number of host plants around the world (Miller *et al.* 2002; Miller 2005; Germain 2008; Kondo *et al.* 2008; Franco *et al.* 2009; Pellizzari & Germain 2010; Mazzeo *et al.* 2014). These insects are found on various parts of their hosts, and may infest leaves, twigs, branches and roots, and some live inside plant domatia (Kondo *et al.* 2008). They feed almost exclusively on the phloem of their host plants to which they cause direct damage, but they can also cause indirect damage by transmitting plant pathogens through injection or through the build-up of honeydew, promoting the attack of plant pathogens (Ross *et al.* 2010). However, some species feed on the parenchyma tissue by directly feeding on the contents of parenchyma cells (Kondo *et al.* 2008). Identification of scale insects is mainly based on morphological characters of adult females (Pellizzari & Germain 2010). Overall, scale insects that have worldwide been reported as economically important belong to the families Diaspididae, Coccidae, and Pseudococcidae. Research studies exploring the most effective pest management approaches have been performed worldwide to avoid serious phytosanitary problems caused by some key species of scale insects, which is also the case for Tunisia, a Mediterranean country.

In Tunisia, the number of research studies dealing with analyses of the status of scale insect fauna has been still progressively increasing during the last decade after a relatively long period of quasi-absence (especially between the 1950's and the 1980's) of studies related to this group of hemipterans. Based on literature, several scale insect species can be found on various host plants grown in Tunisia. According to Garcia Morales *et al.* (2016), 68 scale insect species have been reported to occur in Tunisia, but in addition other scale insect species have also been recorded in Tunisia. These are the armoured scales *Parlatoria pergandii* Comstock (Pagliano 1938), *Hemiberlesia lataniae* (Signoret) (Mansour *et al.* 2011a), *Chrysomphalus pinnulifer* (Maskell), *Chrysomphalus aonidum* (L.) (Jendoubi 2012), and *Quadraspidiotus perniciosus* (Comstock) (EPPO 2015), and the soft scales *Eucalymnatus tessellatus* (Signoret), *Parthenolecanium persicae* (Fabricius) (Pagliano 1938), and *Coccus pseudomagnoliarum* (Kuwana) (Jendoubi *et al.* 2008).

The great majority of these species found in Tunisia are of minor economic importance since they have no negative impact on either crop health or yield, but a few other species are considered as having high economic importance, implying that they are capable of seriously damaging host plants and causing noteworthy economic losses. Only the species that have been shown to cause major economic losses throughout Tunisian agro-ecosystems are considered herein as key scale insects. These latter include the vine mealybug (VM) *Planococcus ficus* (Signoret) and the citrus mealybug (CM) *Planococcus citri* Risso (family Pseudococcidae), the soft scale *Saissetia oleae* (Olivier) (family Coccidae), and the armoured scale *Parlatoria ziziphi* (Lucas) (family Diaspididae). The main host plants of these four species are grapevine, citrus and olive trees, all of them considered as strategic horticultural crops in Tunisia, which has been for example the world's top olive oil exporter in the 2014/2015 campaign, followed by Spain.

In this review article, an up-to-date overview of host plants, bio-ecological characteristics, natural enemies of these key scale insects, damage caused by them, as well as pest management strategies implemented until recently against these species are emphasised and discussed.

Key families of scale insects reported in Tunisia: main morphological and biological aspects

Diaspididae (Armoured scales)

Armoured scales represent the most speciose family of scale insects including more than 2500 described species (Garcia Morales *et al.* 2016). These insects are the commonest alien scales incidentally introduced all over the world and this is probably due to their small dimension and camouflage (Pellizzari & Germain 2010). The Diaspididae are

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usually pests on plants that survive for more than a single year including fruit and nut crops, forest trees, and ornamentals, such as landscape perennials, shrubs, shade trees, and greenhouse plants (Miller & Davidson 2005). These insects have three female instars and five male instars with the crawler instar which is the only one that is mobile (Williams & Watson 1988a). Most armoured scales species are biparental and mating is required for egg production; they overwinter in many different life stages including eggs, second-instar males and females, or mated adult females and most species produce less than 100 eggs per female (Miller & Davidson 2005). Contrary to both families Coccidae and Pseudococcidae, which are phloem-feeders, Diaspididae feed on the parenchyma tissue of their host plants, and accordingly they do not produce honeydew (Sforza 2008). In Tunisia, the armoured scale species that has been considered of high economic importance is the black parlatoria scale *P. ziziphi*.

Pseudococcidae (Mealybugs)

Pseudococcidae are the second most species-rich family of scale insects, just after the Diaspididae, with about 2020 described species (Garcia Morales *et al.* 2016). Mealybugs are named in this way because they usually have a covering of white mealy wax over the surface of the body (Williams & Watson 1988b). Morphologically, females resemble nymphs and all developmental stages are mobile (Sforza 2008). Males are about 1 mm long; they do not feed, live a few days and die just after mating. Mealybugs in life are almost impossible to identify to species, therefore they should be preserved in 70–80% alcohol before to be prepared on microscope slides for ensuring the appropriate identification based on main microscopic characters (Williams & Watson 1988b) (Table 1). These insects (females and nymphs), as plant sap-sucking pests, often constitute a threat to agriculture because they are able of causing substantial economic losses on crops. Miller *et al.* (2002) indicated that 158 species of mealybugs are recognised as pests worldwide. In Tunisia, the most serious mealybug species attacking host plants have been proven to be both the vine mealybug *P. ficus* and the citrus mealybug *P. citri.*

Coccidae (Soft scales)

The Coccidae is the third largest family in the Coccoidea, after the Diaspididae and Pseudococcidae, with about 1150 described species (Garcia Morales *et al.* 2016). The adult males are usually alate, fragile, short-lived, and lack functional mouthparts (Hodgson 1994). Soft scale species may be oviparous, ovoviviparous or viviparous and are easily recognisable by the presence of a pair of anal plates at the base of an anal cleft; each plate is usually triangular or the lateral edges are rounded, and in all but a few genera the inner edges are contiguous (Williams & Watson 1988c). Generally, two nymphal stages are present in male and female, but in other cases, some species can develop three nymphal stages before to reach the adult female stage (Sforza 2008). In Tunisia, the Mediterranean black scale *S. oleae* has long been considered to be the most damaging soft scale species.

Mealybugs of high economic importance

The vine mealybug *Planococcus ficus* (Signoret)

Mealybugs may be considered the most universally important vineyard pests (Daane *et al.* 2012). Among mealybug species, the VM *P. ficus* constitutes the major and most damaging species in Tunisian vineyards (Mansour *et al.* 2011a; Mansour 2012), which is also the case for several other grape-growing areas around the world (Trjapitzin & Trjapitzin 1999; Dalla Montà *et al.* 2001; Walton *et al.* 2009; Fal-

Table 1. Main distinctive microscopic characters between the two closely related mealybug species *Planococcus citri* Rissoand and *Planococcus ficus* (Signoret) (Tranfaglia & Tremblay 1982; Cox 1989; Williams & Granara de Willink 1992)

Planococcus citri	*Planococcus ficus*
Venter of head with 14–35 tubular ducts	Venter of head with 0–4 tubular ducts
Thorax with 7–30 tubular ducts near eight pair of cerarii	Thorax with 0–4 tubular ducts near eight pair of cerarii
Multilocular disc pores situated behind front coxae totalling 0–6	Multilocular disc pores situated behind front coxae totalling 0–17
Multilocular disc pores absent near second spiracle, behind femur of metathorax	Multilocular disc pores present near second spiracle, behind femur of metathorax

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lahzadeh *et al.* 2011; Daane *et al.* 2012). Despite the economic importance of the VM on grapevine in Tunisia, research works studying the bio-ecology and the implementation of potential pest management programs of this pest in this country began just a few years ago. Finding adequate pest management tactics against the VM in Tunisia has been a challenging issue for researchers. Basically, some important steps should be carefully achieved before to implement sustainable control strategies against this pest.

The first necessary step is the right identification of mealybug species, through morphological and/or molecular tools (Mansour *et al.* 2009, 2011a, 2012b). Indeed, it always remains possible to make misidentification when biparental (closely related morphologically) species such as *P. ficus* and *P. citri* occur in the same vineyard, which has been the case in Tunisia (Mansour *et al.* 2009, 2011a). Recently, the VM has been recorded as the most abundant, and almost the only scale insect species infesting grapevine in major and minor grape-growing areas in Tunisia (Mansour *et al.* 2011a).

In Tunisia, all developmental stages of the VM can be found year-round on all parts of the grapevine. The overwintering stage of this insect is the adult female residing under the grapevine trunk bark. Based on monitoring data using delta traps baited with mealybug's sex pheromone lure (Figure 1), the male flight activity of the VM extends from April to November in the Cap-Bon region (northeastern Tunisia) with the occurrence of 5–6 flight peaks per year (Mansour 2008). On grapevine, the VM is more damaging than the CM due to the higher amount of honeydew and to its role in transmitting viruses. In this context, Cid *et al.* (2010) indicated that the citrus mealybug is a less important pest of grapevine, compared to the VM, because it affects smaller areas and produces fewer direct economic losses. Each mealybug species attacking grapevine has different biological attributes, resulting in different development and reproductive rates, honeydew excretion and feeding locations (Daane *et al.* 2005).

Worldwide, the VM was proved to transmit *Grapevine virus A* (GVA) (Rosciglione & Castellano 1985; Minafra & Haididi 1994; Bertin *et al.* 2010), *Grapevine virus B* (GVB) (Tanne *et al.* 1989; Minafra & Haididi 1994), *Grapevine leafroll-associated Virus III* (GLRaV-III) (Mahfoudhi *et al.* 2009; Bertin *et al.* 2010; Tsai *et al.* 2010), and other GLRaV (Mahfoudhi *et al.* 2009; Bertin *et al.* 2010; Tsai *et al.* 2010). In Tunisia, the most common grapevine viruses are the leafroll associated viruses, mainly GLRaV-3 and other GLRaV (Mahfoudhi *et al.* 2009). Some studies estimated yield losses, due to leafroll viral disease transmitted by the VM, of as much as 30% to 40% in California vineyards (Golino *et al.* 2002).

Many natural enemies can be found associated with the VM in Tunisia. During the season 2003–2004, Cecidomyiidae were the most important predators, and their larvae were particularly active in the predation of mealybug eggs, followed by two species of Coccinellidae, namely *Rhyzobius lophanthae* (Blaisdell) and *Scymnus* sp., which were present at a lower number compared to Cecidomyiidae; however, *Anagyrus pseudococci* was the most widespread parasitoid species associated with mealybugs in Tunisian vineyards (Mahfoudhi & Dhouibi 2009). Moreover, Mansour (2008) reported the mealybug ladybird *Cryptolaemus montrouzieri* Mulsant (Coleoptera: Coccinelllidae), the green lacewing *Chrysoperla carnea* (Stephens) (Neuroptera: Chrysopidae), and larvae of a cecidomid species (Diptera: Cecidomyiidae) as the most abundant natural enemies feeding on mealybugs in Cap-Bon vineyards. Additionally,

Figure 1. Monitoring of male vine mealybugs in a Tunisian vineyard: Delta-shaped trap hung in the vine canopy (about 1.5 m above the ground) (left) and Vine mealybug sex pheromone lure placed inside the trap used (right)

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Mansour *et al.* (2009) found the recently recognized encyrtid *Anagyrus* sp. near *pseudococci* sensu Triapitsyn *et al.* (2007) as the primary parasitoid reared from mealybug mummies collected from grapevines in Cap-Bon vineyards. Similarly, more recently Mansour (2012) found *Anagyrus* sp. near *pseudococci* as the most common parasitoid of the VM in vineyards located in the northeastern and central southern regions of Tunisia. In addition to *Anagyrus* sp. near *pseudococci*, the same author reported two other parasitoid species inside VM mummies: these are a primary parasitoid, *Coccophagus* sp. (Hymenoptera: Aphelinidae) and a hyperparasitoid, *Chartocerus* sp. (Hymenoptera: Signiphoridae).

Over the last decade, a number of control tactics have been tested and applied against the VM in Tunisia. In this country, application of insecticide treatments is the main and most effective control measure used against this insect. The control of VM using systemic insecticides was shown to be more adequate than using contact insecticides due to the fact that mealybugs often reside in hidden locations of the vine such as bark of the trunk. Mansour *et al.* (2010c) suggested that the systemic nicotinoid insecticide imidacloprid, when applied through a drip irrigation system, could be a promising option to control mealybugs in Tunisian vineyards. Indeed, this insecticide was found to be more effective (100% of efficacy) than methidathion on all mealybug developmental stages on grapevines. Likewise, foliar sprays with the systemic tetramic acid insecticide spirotetramat provided the greatest control performance of VM populations in Tunisia (Mansour *et al.* 2010a). The same authors found that the biopesticide Prev-Am® resulted in the highest level of VM young instar nymph decrease, involving that this product might prove useful for VM management in Tunisia. Both insecticides spirotetramat (applied at 120 ml/hl) and Prev-Am® (a biopesticide containing orange oil, borax and organic surfactants, applied at 300 ml/hl) were shown to have no negative effect on the parasitoid *Anagyrus* sp. near *pseudococci*, implying that the application of both pesticides would be compatible with biological control of the VM (Mansour *et al.* 2011c).

Biological control using encyrtid parasitoids may also be another way to control the VM in Tunisia. The encyrtid *Anagyrus* sp. near *pseudococci* (Figure 2) was found as the most common VM parasitoid in Tunisia, therefore, laboratory mass rearing and field releases of this parasitoid might prove to be a powerful biological control tool to be used against VM populations. Future laboratory and field research studies following this direction are therefore strongly recommended.

Figure 2. *Anagyrus* sp. near *pseudococci* female found as the most common parasitoid of mealybugs in Tunisian vineyards

However, Mansour *et al.* (2012a) demonstrated that the ant *Tapinoma nigerrimum* (Nylander) significantly disrupted the parasitisation potential of the encyrtid parasitoid *Anagyrus* sp. near *pseudococci*, indicating that this ant species constitutes a threat to the biological control of VM using mass releases of *Anagyrus* sp. near *pseudococci*. Despite this fact, ants, which are important generalist predators in most terrestrial ecosystems, should not be excluded from the latter because the exclusion of a predator not only has direct effects on the abundance of its prey, but also may alter the nature and intensity of other predatory, competitive and mutualistic interactions among species in the community (Pinol *et al.* 2012). Interestingly, the performance of this parasitoid can be enhanced by applying a kairomone-based attracting system in vineyards. Indeed, Mansour *et al.* (2010b) showed that the application of VM sex pheromone as kairomone increased parasitism rates of mealybugs by *Anagyrus* sp. near *pseudococci* within Sicilian vineyards. This new approach could be tested and applied successfully as an IPM program component in Tunisia in the near future. Furthermore, mating disruption, a technique using pheromone dispensers to reduce the ability of males to locate and mate with females, which proved to be very effective in decreasing VM densities in Californian and Italian vineyards (Daane *et al.* 2006; Walton *et al.* 2006; Cocco *et al.* 2014; Langone *et al.* 2014), has recently been tested against this pest in Tunisian vineyards (Mansour, unpublished data) and could, whenever possible, be incorporated into future IPM programs against the VM in Tunisia.

The citrus mealybug *Planococcus citri* Risso

The CM *P. citri* is a serious polyphagous species infesting a broad range of subtropical fruit plants

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and ornamentals worldwide. Franco *et al.* (2009) pointed out that the CM was found on plants from 70 botanical families, 60% of which were characterised as non-woody plants. The same authors indicated that the CM can attack subtropical and tropical crops including for example citrus (*Citrus* spp.), persimmon (*Diospyros kaki*), banana (*Musa paradisiaca*), and custard apple (*Annona* spp.), or it damages plants in interior landscapes, especially in greenhouses. In Tunisia, the CM has long been considered as an economic pest mainly in citrus orchards, and to a lesser extent, in vineyards where the VM is by far the most abundant and injurious pseudococcid species.

In citrus orchards. Currently, the CM is the key, most damaging scale insect species present throughout citrus orchards in Tunisia. Based on two-season field surveys conducted a few years ago in citrus orchards of Cap-Bon and of northwestern Tunisia, the CM was recorded, with two other armoured scales, as the most abundant and frequent scale insect species occurring on citrus trees (Jendoubi 2007, 2012). According to the same author, the CM was found to occur in all prospected citrus-growing areas of the Cap-Bon region which constitutes the first citrus-producing area in Tunisia. These findings indicate that the CM is a principal scale insect species in Tunisian citrus orchards. In terms of biological aspects, during the period March–August, males of the CM develop four generations on citrus in the Cap-Bon region; the highest male flight activity occurs during summer (Jendoubi 2007).

The CM can be an essential prey of coccinellid predators worldwide. These latter include *C. montrouzieri*, *Diomus austrinus* Gordon, *Exochomus quadripustulatus* (L.), *Nephus bisignatus* (Boheman), and *Nephus includens* (Kirsch) (Hodek & Honek 2009). Regarding auxiliary fauna in Tunisia, *Leptomastidea abnormis* (Girault) (Hymenoptera: Encyrtidae) was found to be the main (almost only) parasitoid of the CM in citrus orchards of the Cap-Bon region (Jendoubi 2007). Surprisingly, in contrast to other Mediterranean citrus-growing areas, *Anagyrus pseudococci* s.l. was not found associated with the CM in Tunisian citrus orchards. Franco *et al.* (2009) stated that only the VM and the CM may be considered to be the principal hosts for *A. pseudococci* s.l. Thus, further studies focused on collecting a higher number of parasitised citrus mealybugs would be required to refine our knowledge of the parasitisation level of this encyrtid on the CM under Tunisian citrus orchard conditions.

The activity of the natural enemies of mealybugs can be disrupted by some tending ants since honeydew constitutes an important food source for the latter. Hence, it is particularly important to know which ant species can hamper the parasitisation or predatory activity of mealybug's natural enemies in Tunisian citrus orchards. In such a context, Jendoubi (2007) found two species of tending ants, namely *Crematogaster scutellaris* (Olivier) and *T. nigerrimum*, within colonies of the CM in Tunisian citrus orchards, but neither quantitative nor qualitative data linked to the occurrence of these species were provided. More recently, Mansour *et al.* (2012a) demonstrated that the ant *T. nigerrimum* negatively affects both the parasitisation potential of the parasitoid *L. dactylopii* on the CM and predatory activity of larvae of the ladybird *C. montrouzieri* when feeding on citrus mealybugs. In this context, ant exclusion from tree canopies could not be regarded as a sound management alternative in citrus plantations in the Mediterranean (Pinol *et al.* 2012). In Tunisia, the chemical control of CM in citrus orchards can be successful when using the lipid biosynthesis inhibitor Spirotetramat. The use of other active ingredients, such as imidacloprid or chlorpyriphos-ethyl, to control this insect is not recommended due to the limited effectiveness of these chemical compounds on CM populations in Tunisia.

Coccinellids as predators of coccids play vital roles in classical and augmentative biological control programs, and in this context, the ladybird *C. montrouzieri* can be an excellent biological control agent against the CM in citrus groves (Hodek & Honek 2009). In Tunisia, biological control programs against the CM using either the encyrtid parasitoid *L. abnormis* or the introduced predatory beetle *C. montrouzieri* have been, and are currently, performed in Cap-Bon citrus orchards. *C. montrouzieri*, which was introduced into Tunisia in 2006 and since then mass-reared in laboratories, has been released in some northeastern Tunisian citrus orchards where it provided sufficient control, maintaining CM populations at an economically tolerable threshold (Rahmouni & Chermiti 2013). However, in general, these strategies have not supplied promising results in reducing CM populations in Tunisia. This might most likely be due to the presence of tending ants, especially *T. nigerrimum*, which was shown recently to negatively impact the foraging activity of mealybugs' natural enemies. Another reason for this limited effectiveness might be the repetitive use

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of broad-spectrum insecticides that could be harmful, showing adverse side effects on biocontrol agents.

In vineyards. In grape-growing areas around the world, except for the case of Spain and Brazil, it is generally assumed that the CM is by far less abundant than the VM (or even absent) on grapevines. Recently Mansour *et al.* (2011a) provided evidence that the CM is a minor (rarely found) pest on grapevines based on field surveys in major and minor grape-growing regions in Tunisia. Basically, vineyards that are infested by the CM in Tunisia are generally located close to citrus orchards. The CM was also recorded on grapevines in other citrus-growing countries including Spain (Cid *et al.* 2010), Italy (Dalla Montà *et al.* 2001; Buonocore *et al.* 2008), Portugal, Greece, France (Sforza 2008), and Brazil (Pacheco-da-Silva *et al.* 2014; Morandi Filho *et al.* 2015). Then, controlling the CM in citrus orchards could play an important role in limiting the spread of high numbers of this mealybug species to grapevines located in surrounding vineyards.

The number of the CM generations is still very hard to estimate especially when mixed populations of two closely related species (*P. citri* and *P. ficus*) occur in the same vineyard, which is the case, at least, for the vineyards of Mraïssa locality in the Cap-Bon region (Mansour *et al.* 2009). In Mraïssa, the male flight activity of the CM extends from April to November with the occurrence of seven flight peaks among which five peaks can be observed during summer when populations have overlapping generations (Mansour 2008; Mansour *et al.* 2009). These data indicate that the summer CM populations are the most important and accordingly the most injurious (higher amounts of honeydew and development of sooty mould fungi) to grapevine. Then, this should be taken into account when developing control programs for the CM in vineyards.

Although the CM has been proven to be not common (or even rare) on grapevine in Tunisia (Mansour *et al.* 2011a), it has been revealed that this mealybug species has been capable of transmitting *Grapevine leafroll-associated virus 3* (GLRaV-3) in vineyards (Cabaleiro & Segura 1997; Golino *et al.* 2002). Hence, sustainable management of the CM should be adopted yearly to avoid economic losses due to grapevine viruses.

Effective control of the CM in Tunisian vineyards can be achieved using the same pest management tools adopted against the VM, except for the case of biological control using species-specific encyrtid parasitoids. Indeed, *L. dactylopii* is more effective than *Anagyrus pseudococci* s.l. in decreasing the CM populations. Similarly to the case for citrus orchards, an adequate biological control program against the CM in vineyards can be performed through field releases of both the parasitoid *L. dactylopii* and predatory beetle *C. montrouzieri*.

Key soft scales

Mediterranean black scale *Saissetia oleae* (Olivier)

The Mediterranean black scale *S. oleae*, which is thought to be native to South Africa (de Lotto 1965), is a polyphagous species that can occur on several host plants. Damage to the latter caused by this insect is variable from one host plant species to another. Ben-Dov & Hodgson (1997) considered that *S. oleae* was regarded as a pest on only olive and citrus cultivated in temperate regions of the world. In the Mediterranean basin including Tunisia, *S. oleae* is an economic pest on both olive and citrus trees.

In olive groves. In Tunisia, *S. oleae* is considered the key scale insect species infesting olive trees (Jarraya 2003; Mansour *et al.* 2011b). Mansour *et al.* (2011b) found *S. oleae* as the predominant scale insect species occurring throughout northeastern Tunisian olive groves, but this species was totally absent on olive trees located in the northwestern region of Tunisia, which does not really constitute an important olive-growing area in this country. Jarraya (2003) indicated that *S. oleae* is localised mainly throughout the eastern coastal areas of Tunisia, from Bouficha (northeastern Tunisia) to the south of Sfax (southeastern Tunisia). This insect can develop typically one generation per year on olive in Tunisia, during which mature females are observed in early May and lay eggs on olive trees until the end of this month. All three larval stages originating from these females are present and are very mobile on olive during summer-autumn months (Jarraya 2003). However, under some favourable ecological conditions, a second generation of *S. oleae* may occur on olive during autumn months, considering that mature females of this second generation, which originated from only a portion of summer nymphs of the first generation, appear in September (Jarraya 2003). The Mediterranean black scale, as honeydew-excreting hemipteran like mealybugs, was reported as the most serious scale insect species due to its noteworthy damage: honeydew and sooty mould fungi widely widespread on infested olive trees in Tunisia (Mansour *et al.* 2011b). In addition to such indirect

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damage, *S. oleae* can directly damage olive trees by sucking large quantities of plant sap. The presence of sooty mould fungi on leaves significantly affects both respiration and photosynthesis processes in attacked olive trees. This can usually result in a reduction of the tree vigour and twig dieback in the case of heavy infestations by this pest. Furthermore, the presence of sooty mould fungus can result in obtaining a lower quantity of olive oil from harvested olive trees.

Regarding the auxiliary fauna of *S. oleae*, larvae of both the noctuid moth *Eublemma scitula* (Rambur) and the coccinellid *Chilocorus bipustulatus* L. were reported feeding on *S. oleae*; whereas, the two hymenopterans *Scutellista cyanea* Motschulsky and *Metaphycus* sp. were recorded as the main parasitoids of *S. oleae* in northeastern Tunisian olive groves (Mansour *et al.* 2011b). In Tunisia, the action of these natural enemies can be limited by the occurrence of tending ants such as *Crematogaster* spp., which is known to protect *S. oleae* against its natural enemies in order to ensure the continuous availability of a primary food resource: the sugar-rich honeydew secreted by this soft scale.

The control of *S. oleae* in Tunisia has been based on effective insecticide treatments applied during the opportune period. Insect growth regulators such as buprofezin and pyriproxyfen applied during summer are known to be very effective against *S. oleae* nymphs, reducing significantly populations of this insect. Besides, applying mineral oils against *S. oleae* is another promising pest management way to achieve the sufficient control of all life stages of this insect on olives in Tunisia.

In citrus orchards. In addition to olives, *S. oleae* can also be present on citrus for which it can constitute a real threat. Jarraya (2003) stated that among the Coccidae that can infest citrus trees in Tunisia, only *S. oleae* can be considered as having a significant economic impact. Jarraya (1974) demonstrated that *S. oleae* has one generation yearly on citrus in the area of Tunis where adult females lay eggs from May to July. As such, Ben Salah and Cheikh (1987) indicated that *S. oleae* can develop one generation per year on citrus in both Cap-Bon and northern regions of Tunisia. Developmental stages of *S. oleae* include eggs, first, second and third instar nymphs, and adult females; however, the overwintering stages of this species on citrus trees are both second and third instar nymphs (Ben Salah & Cheikh 1987). The adult females appear in May, begin laying eggs in June and reach their highest numbers on citrus trees in August (Ben Salah & Cheikh 1987). In terms of abundance, Jendoubi (2007, 2012) pointed out that *S. oleae* was not commonly found on citrus trees in several prospected citrus-producing areas (north-east and north-west) in Tunisia, relative to other scale insect damaging species such as CM and armoured scale *P. ziziphi*.

In both Cap-Bon and northern regions of Tunisia, *S. oleae* can be parasitised by three hymenopterans: *Metaphycus* sp. parasitising first instar larvae, and both *Metaphycus lounsbury* (Howard) and *S. cyanea* parasitising adults. The highest parasitism rates on *S. oleae* are observed during the period from August to November, with the encyrtid *M. lounsbury* being the most efficient parasitoid of *S. oleae* adult females (Ben Salah & Cheikh 1987). This insect can be attacked by two predators: *Berginus tamarasci* Wollaston (Coleoptera: Mycetophagidae) and *C. bipustulatus* (Ben Salah & Cheikh 1987). Likewise, *S. oleae* can be an essential prey of coccinellid predators such as *E. quadripustulatus* and *Pullus mediterraneus* L. (Hodek & Honek 2009).

Pest management of the Mediterranean black scale on citrus in Tunisia relies mainly on the use of some insecticides. Jarraya (1973) assessed the efficacy of two insecticide treatments (oleoparathion and methidathion) on *S. oleae* populations infesting citrus in Tunisia. This author found that when both insecticides are applied in May, they have no effect on young females, whereas, when applied in September, both insecticides were proven to be very effective in decreasing densities of *S. oleae* first instar nymphs, the most abundant developmental stage in September. Similarly, the use of either buprofezin or pyriproxyfen during summer could generate excellent efficacy against *S. oleae* nymphs. Therefore, it is clearly understandable that the efficiency of insecticides against *S. oleae* is dependent on the period of treatment during which first instar nymphs, the most vulnerable life stage to insecticides, are present on citrus.

Key armoured scales

Black parlatoria scale *Parlatoria ziziphi* (Lucas)

The armoured scale *P. ziziphi* is a serious insect pest infesting citrus trees worldwide and causing noteworthy economic losses. Miller and Davidson (2005) pointed out that citrus is the first host plant for *P. ziziphi*. In Tunisia, *P. ziziphi* is a major scale

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insect species occurring throughout citrus orchards (Jarraya 2003). More recently, *P. ziziphi* was found to be the most abundant species present throughout Tunisian (both Cap-Bon and northwestern) citrus orchards and the highest infestations were reported mainly in Beni-Khalled locality of the Cap-Bon region (Jendoubi 2012).

Benassy and Soria (1964) showed that *P. ziziphi* has three generations per year under agro-ecological conditions of Cap-Bon citrus orchards: the first generation occurs in May, the second in August, and the third in September. In northeastern Tunisian citrus orchards, four life stages can be found on citrus trees: these are eggs, two larval stages (L1 – first instar nymphs that are mobile and L2 – second instar nymphs that are immobile) and females (young and adult or mated females) (Harrathi 2008). From early February to late April, eggs represent the primary developmental stage of *P. ziziphi* on citrus, whereas in late May L1 is the predominant life stage, and about one week later, in early June, L2 constitutes the dominant stage of the armoured scale on citrus before moulting to females during summer (Harrathi 2008).

Regarded as a serious pest, *P. ziziphi* can cause several types of plant damage in all Tunisian citrus-producing areas. Heavy infestations of this scale cause chlorosis and premature drop of leaves, dieback of twigs and branches, stunting and distortion of fruit, and fruit drop before it is mature; the most characteristic damage is the unremovable scale cover on the fruit, causing rejection in most fresh fruit markets (Fasulo & Brooks 2013). Although *P. ziziphi* is a key pest on citrus in Tunisia, research studies on setting up pest control strategies are scarce in this country. Still, whenever possible, this pest might be the target of several future studies in this country, as it constitutes a real threat to the strategic citrus-producing sector.

To cope with serious phytosanitary problems caused by *P. ziziphi*, a number of chemical active ingredients such as deltamethrin, methidathion, chlorpyriphos, and mineral oils can be used to control this pest in Tunisian citrus orchards. Both insecticides methidathion (an organophosphate) and mineral oil were shown to be effective in reducing larval populations of *P. ziziphi* on citrus in northeastern Tunisia (Harrathi 2008). In that context, Harrathi (2008) suggested the use of mineral oils against *P. ziziphi* instead of using methidathion since mineral oils are known to be harmless towards its natural enemies, such as the coccinellid predator *C. bipustulatus*, commonly found feeding on this armoured scale on citrus trees in Tunisia. The promising performance of mineral oils against *P. ziziphi* was also shown in Egypt, another South Mediterranean country like Tunisia. Coll and Abd-Rabou (1998) assessed the effect of two experimental spray oils on *P. ziziphi* and two associated primary parasitoid species in a citrus orchard located in northern Egypt. The results of this study showed that Triona oil was more effective than Shecrona oil and reduced populations of *P. ziziphi* by up to 99%. The same authors demonstrated that the two spray oils used did not significantly affect the activity of the parasitoid *Encarsia citrina* (Craw); moreover, Triona oil was slightly harmful to *Habrolepis aspidioti* Compere and Annecke (Hymenoptera: Encyrtidae), another primary parasitoid of *P. ziziphi*. Mangoud (2008) demonstrated that Misrona oil and buprofezin, showing a long-term insecticidal effect on *P. ziziphi*, significantly decreased densities of nymphs and adults of this insect on citrus in Egypt. Therefore, based on these results, the application of Triona (paraffin oil 81%) and/or Misrona (paraffin oil 95%) oils applied at a rate of 15 ml/l of water and buprofezin treatments could be tested before to be applied as an alternative option to other synthetic insecticides used for controlling *P. zizphi* in Tunisian citrus orchards.

Conclusion and future outlooks

In Tunisia, about 75 scale insect species have been recorded until recently. The great majority of these species are of no or minor (occasional) economic importance, whereas four species have long been considered as key pests on their host plants in Tunisian agro-ecosystems. These four species are: the vine mealybug (VM) *P. ficus*, the citrus mealybug (CM) *P. citri*, the soft scale *S. oleae*, and the armoured scale *P. ziziphi*. Of great importance is that all of the plants that constitute principal host(s) for each of these key insect species are strategic cultivations providing higher added value (exportations) for the Tunisian economy. These host plants are: grapevine (principal host for *P. ficus*, and to a lesser extent for *P. citri*), citrus (principal host for *P. citri*, *P. ziziphi*, and to a lesser extent for *S. oleae*), and olive (principal host for *S. oleae*). The alarming phytosanitary situation caused by severe attacks of these scale insects has clearly demonstrated that finding, developing and applying effective and sustainable control measures against these pests

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have been an issue of major concern in Tunisia. These control measures are in fact needed to maintain existing pest populations at acceptable levels, to avoid the potential spread of these insects in areas that were not previously infested, and to limit serious crop damage and major economic losses. However, before setting up pest control strategies, some necessary steps should be performed adequately, which are: (*i*) Appropriate identification, through specific morphological and molecular techniques, of the scale insect species present on plants in a given area to avoid misidentification of closely related species; (*ii*) Careful investigation of population dynamics assessing bio-ecological aspects of nymphs and females of all the key species during a two-year study period at least, and (*iii*) Monitoring of male scale insects using traps baited with specific sex pheromones for early pest detection and to highlight flight activity and related season-long peaks.

Due to their high economic importance in Tunisia and worldwide, research studies dealing with practical evaluation of various control options against mealybugs in Tunisia have received more attention than those linked to either armoured or soft scales. Control methods that can be adopted against these insects in Tunisia include prophylactic tools, pheromone-based tactics such as mating disruption or enhancement of parasitoid host-searching activity and its performance through integration of induced kairomonal attraction, chemical control using effective insecticide treatments, and biological control using predators and/or specific parasitoids. All of these control methods are in fact dependent on both the bio-ecology of each target scale insect species and its geographical localisation in Tunisia.

Most of IPM programs against key scale insects in Tunisia have historically relied heavily on the use of insecticides. The satisfactory chemical control of VM or CM occurring on either grapevine or citrus in Tunisia can mainly be achieved using the systemic lipid biosynthesis inhibitor insecticide spirotetramat, applied as foliar sprays during summer. This insecticide is very effective and does not present any toxicity risks towards natural enemies associated to both mealybug species. Insecticide treatments using buprofezin, pyriproxyfen, and mineral oils can reduce populations of the black scale *S. oleae* to acceptable levels on either olives or citrus in Tunisia. Additionally, the application of either methidathion insecticides or newer mineral oils can provide a sufficient decrease in populations of the black parlatoria scale *P. ziziphi* in Tunisian citrus orchards.

On the other hand, recent research studies attempted to investigate the possibility of using environmentally-sound alternatives to insecticide treatments due to the occurrence of insect resistance to the chemical compounds used and to serious ecotoxicity risks towards ecosystem components. In this regard, biological (use of predators and/or parasitoids) and biotechnological (use of insect female's sex pheromone as behaviour-monitoring tools) control tactics can provide valuable alternative strategies to scale insect pest management based on broad-spectrum insecticides. Biological control, which is defined as the use of an organism to reduce the population density of another organism, is considered to be the most environmentally safe and economically profitable pest management method (Van Lenteren 2012). To improve the action of natural enemies of scale insects, it is suggested to protect the latter from the disruptive effects of non-selective insecticides widely used in Tunisian agro-ecosystems. Eventually, choosing the most selective insecticides towards these natural enemies is a crucial condition for setting up appropriate IPM programs. The lower activity of natural enemies in areas infested by honeydew-excreting scale insects (i.e. mealybugs and soft scales) is likely due, in part, to the presence of tending ants that protect these scale insects against their natural enemies for getting easier access to carbohydrate-rich honeydew as food. Also interesting as an eco-friendly and powerful way is the use of insect's sex pheromones in a mating disruption program or as a kairomonal source to improve the parasitisation potential of mealybug parasitoids.

To ensure the sustainable pest management of key scale insects, some components should be included in future IPM programs for scale insects in Tunisia:

– Conducting extensive field surveys throughout all Tunisian ecosystems in an attempt to determine the complete list of species of the auxiliary fauna associated with each of these key scale insect pests.
– Testing newer with novel modes of action, more effective and safer tools, such as biopesticides and pheromone-based approaches as viable alternatives to treatments based on the repetitive use of the same insecticide(s).
– Deploying research efforts aiming to achieve the satisfactory control of tending ants for the case of VM and CM, before implementing biological control programs using either the parasitoid *Anagyrus* sp. near *pseudococci* or *L. dactylopii*, or larvae of the predatory beetle *C. montrouzieri*.

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– Providing and explaining easy-to-follow IPM guidelines and organising outreach programs for field technicians and farmers could be a promising future avenue of work towards refining pest management programs of key scale insects in Tunisia.

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