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The scale insect fauna of citrus in Tunisia: A critical overview

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Abstract
Faunistic studies are important to register new distributional data and notify researchers of potential exotic pests. A critical review of citrus scale insect literature dealing with Tunisian records revealed the presence of 18 species. Faunistic records are scarce and scattered in taxonomic papers. The available studies lack precision and reliability. In addition, the scale insects injuring citrus trees have historically been overlooked by farmers and authorities in Tunisia unless they become destructive pests. An extensive field-survey on scale insects in all citrus regions of Tunisia was initiated, relating the obtained data to those previously reported in literature over a period of seventy years. In the present paper, we document the first comprehensive overview of the scale insect fauna associated to citrus crop in Tunisia. Twenty-two scale insect species were recorded. They belong to four families emanating from five zoogeographical areas, mainly the Palearctic. Old publications as well as origin, host plant and potential injury for each species were checked. Changes in species composition and regional distribution that might occur in citrus ecosystems were also discussed and updated.

Keywords: Coccids, field survey, faunal studies, pest status

1. Introduction
Faunistic studies are important for documenting new distributional data and notify researchers to potential exotic pests. The establishment of new pests can be costly owing to increased crop damage, control programs, and quarantine restrictions on trade. Annual damages caused by exotic insects and mites in the United States have been estimated to be more than $17 billions [1]. Hence, an accurate documentation of exotic pest species is required for pest control and research programs that provide to quarantine treatments or other mitigation approaches to reduce or eliminate pest load in traded agricultural commodities.

Scale insects are successful invaders of new territories, frequently introduced and acclimatized in all terrestrial zoogeographical regions (except the cold extremes of the Arctic and Antarctic). 129 scales are established in Europe, representing hence one of the major groups of insects alien to Europe [2]. Most of them (Diaspididae and Pseudococcidae) originate from tropical regions and essentially from Asia. The trade of fruit and ornamental trees appears to be the usual pathway of their transfer, adding some distinctive features of scale insects such as their small size, wingless and concealment. Relative to most other insect groups, a high percentage of the estimated 8000 scale insect species have been moved indeed around the world by humans and many are now important economically pests of agriculture, horticulture and forestry [3-5]. Injury caused by scale insects is the ingestion of plant sap. Moreover, except for Diaspididae and Asterolecaniidae, they excrete honeydew that becomes a growth medium for a black sooty mold fungus and photosynthesis is reduced by 70%, leading to early senescence and loss of aesthetic value. They also inject toxic saliva and, are vectors of closteroviruses [5-8].

In many countries in the world, there is an abundant literature on scale insects including excellent regional monographs, systematic treatises and several review articles. In Tunisia, despite the economic implication of scale insects, very few studies have so far been carried out to provide a checklist of species injuring many strategic crops. At present, the most comprehensive list of scale insects present in Tunisia could be that catalogued in the online database "ScaleNet" [5, 9-11]. Accordingly, 68 species have been identified belonging to 10 families. The list looks very poor and non-exhaustive, compared with those recorded in neighboring countries such as Algeria (177), France (388), Morocco (172), Italy (376) and

Sicily (149) [10-12]. How could this very poor fauna of scale insects in Tunisia be explained? Is the country free of coccids (unattainable) or because of the scarcity of coccidological investigations? Undoubtedly, there exist unexplored scale insect species, not just among taxa of poorly studied regions of the world including Tunisia, but also disguised in morphological complexes of cryptic species as reported by Gullan & Cook (2007) [13]. Furthermore, populations of some species have recently reached the pest status in many crops in Tunisia. Some of which were reported as economic pests. We quote the citrus mealybug and the vine mealybug on grapevine; the San Jose scale on pear and other fruit trees, the date palm scale on palms and the black scale on olive trees [14-16].

Consequently, we deal with the citrus crop. The ultimate goal of conducting baseline inventories on citrus scale insects was to support the long-term monitoring techniques and control programs in citrus orchards. Citrus crop is a very important sector to Tunisian economy, growing mainly in the highland areas of Northern parts (25 000 ha; 96%). 76% of citrus groves are located in the northeast area (Cap Bon) and about 20% in the new citrus planting area (15 years old) which lies in the northwest [17]. Historically, the citrus scale insects have been given a low priority by farmers and authorities, and typically they were ignored unless they become key pests, difficult to maintain populations under the economic threshold. In literature, many species of citrus scale insects have long been listed in local papers among pests at various times in various parts of Cap Bon; but they were not generally considered to be the main pests on citrus. Perhaps, the first to mention the presence of scale insects species on citrus trees in Tunisia was Pagliano (1938, 1951) [18, 19] in his books entitled "Les parasites des vergers, des olivettes et des palmeraies (1ère et 2ème éditions)". He listed 17 species occurring on citrus trees in the main citrus growing regions of Cap Bon. Subsequently, a particular contribution was later made by Millet (1959) [20], recording only the species of economic importance. He mentioned at that time the dominance of four species on citrus trees from the same citrus region: the red california scale (*Aonidiella aurantii* (Maskell, 1879)), the red florida scale (*Chrysomphalus aonidum* (Linnaeus, 1758)), the red scale (*Chrysomphalus dictyospermi* (Morgan, 1889)) and the cottony cushion scale (*Icerya purchase* Maskell 1879).

However, no well published data documenting the pest status, local distribution and biology or control strategy were available for these species according to historical records. We cite, at this fact, the only work of Bénassy & Soria (1964) [21] who carried out one field study on the life cycle of the black scale on citrus trees in Cap Bon. Systematic and Faunistic papers treating the scale insects of fruit trees from North Africa or Mediterranean basin are scarce and scattered in the literature; some of them have become quite old. We rely on Balachowsky (1932, 1948, 1950) [22-24] who illustrated the taxonomic position and the morphology of many species of scale insects (including citrus species in Tunisia) in his books "Étude biologique des coccides du bassin occidental de la Méditerranée" and "Monographie des Coccoidea (1ère et 2ème parties)". CAB International maps (1964a, b, 1969, 1970, 1971, 1982, 1984, 1994, 1996, 2016) [25-34] also provide an excellent bibliographic database on the geographical distribution and host plant of scale insects that was very useful for this survey. Recently, Jendoubi *et al*. (2008, 2011) [36, 36], instigated some field surveys on citrus scale insects in the Cap Bon area to assess their incidence. They reported the occurrence of 11 species, while 10 species are recorded to feed on citrus in Tunisia in the most recent scale insect database [10, 11]. In addition, Jendoubi *et al*. (2008, 2011) [35, 36] reported the citricola scale (*Coccus pseudomagnoliarum* (Kuwana, 1914)), the false circular purple scale (*Chrysomphalus pinnulifer* (Maskell, 1891)) and the florida wax scale (*Ceroplastes floridensis* Comstock 1881) as three new records for Tunisian fauna in the Palearctic region. They also pointed out that the black scale and the chaff scale were the most abundant species on citrus orchards in the Cap Bon.

Actually, three aspects should be underlined: (1) faunistic records regarding Tunisia could be not precise enough, requiring further studies for confirmation, (2) the occurrence of species on citrus in Tunisia varies extremely between published papers and (3) Scale insect fauna of citrus is poorly documented, having never been comprehensively surveyed. This investigation was imperative 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 Coccids. Therefore, we decided to enlarge the study area in all the northern parts, inspecting especially the localities that were not suspected in Cap Bon region in the survey made by Jendoubi *et al*. (2008) [35] and the new planting citrus groves of 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 in order to give the most complete list. The work is neither a taxonomic revision nor a biological treatise; it rather clarifies the historical records (by a recent field-survey) and summarizes basic biology features, host plant range, geographical distribution, and potential harmfulness for each species present in Tunisian citrus orchards.

2. Materials and methods

This report includes records of species collected from field sampling and literature survey.

2.1 Field survey and sampling

Three main locations from northern Tunisia were investigated during 2010 to determine scale insect species composition, their relative occurrence and relative abundance in relation to citrus grove locations.

Sixty orchards from the the eastern part, Nabeul (36° 66'N; 10° 44'E), and 20 from the Western parts, Béja (36° 43'N;9° 10'E) and Jendouba (36° 30'N; 8° 46'E), were surveyed from June to November 2010 (Table 1). Field trips were randomly conducted in the different locations of the study area. Each citrus orchard was subdivided into subplots of 1 ha and 10% of infested citrus trees were selected in one subplot. Sampling was selective, with only scale insect-infested plant parts being collected. After visual examination of the different plant parts, a sample of fruit (1-5), leaves (10) and twigs (5 of 20 cm of length) was picked randomly from the five quadrants of each tree. Samples were also taken from fruit trees growing alongside citrus orchards, where present, including the pomegranate (*Punica granatum* Linnaeus), laurel (*Laurus nobilis* Linnaeus) and common medlar (*Eriobotrya japonica* (Thunb.) Lindl). In all, 84 samples were collected during the survey and carried to the laboratory of Entomology at the National Agronomic Institute of Tunisia (INAT) for further examination.

Table 1: Survey sites made on citrus scale insects in Tunisia; showing the number of checked localities by county

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
	Jendouba	Bousalem	3
		Tabarka	8
		Oued Mliz	4
	Total	4	20
	Total	11	84

In laboratory, scale insects were carefully removed from the infested plant surface and at least 20 females for each species from each sample were stored in 70% alcohol. Vials were labeled with relative coordinates, farmer name, location, citrus variety and sampling date. Then, all stored materials were brought to Department of Agriculture, Food and Environment at the University of Catania in Italy for the specific identification. All specimens were slide-mounted using the methodology of Williams & Granara de Willink (1992) [37] and identified using the keys of McKenzie (1956) [38] and Balachowsky (1948, 1953, 1954, 1956) [23-41] (Diaspdidae); Unruh & Gullan (2008a, b) [42, 43] and Williams & Watson (1988a, b) [44, 45] (Monophlobidae); Hamon & Williams (1984) [46], Pellizzari & Camporese (1994) [47] and Gill (1988) [48] (Coccidae); Marotta (1990) [49] and Williams & Granara de Willink (1992) [37] (Pseudoccocidae). In total, around 180 adult females were mounted and identified by the first author and then checked by Pr. Agatino Russo. In case of doubtful or new records, representative specimens were sent to various taxonomic specialists for confirmation after our identification.

2.2 Data analysis

In section "incidence and distribution of species", the following classification method described by Douglass & Davidson (1990) [50] was used to assess the infestation intensity of different scale insect 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 occupying between 15% and 50% and "widespread" to those occupying more than 50% of inspected sites. "Infrequent" is used for the species which occur in Tunisia but are little 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 were much higher in Jendouba because of the low infestation.

Obviously, all species of scale insects present on citrus in Tunisia are listed and grouped by family and species (with the actual valid name) and separated by host plant, origin, and pest status before and after the current survey with the correspondent references to each species. The origin of species is given according to Miller *et al*. (2002) and García Morales *et al*. (2017d) [11, 51].

2.3 Historical review

In order to update the fauna of scale insects occurring on citrus in Tunisia, an online literature search was performed [5, 9-11]. A first query of the Scale Net database was done to list all scale insects recorded in Tunisia. Then, a second query was done for each species to determine on which host plant it has been recorded in Tunisia. Also, another query of Scale Net was conducted for listing all scale insects found on Citrus spp. worldwide, followed by a cross search in order to determine which of these insects had been recorded in Tunisia. Then, the obtained historical records related to scale insects injuring citrus in Tunisia were checked.

Other sources dealing with scale insects associated to citrus crop in Tunisia, including keys, morphological illustrations, distribution, hosts, biology/life cycle, economic importance, were explored. The main references used in the present study are: Balachowsky (1932, 1953, 1954) [22, 39, 40], EPPO (2004) [52], Jendoubi *et al*. (2008, 2011) [35, 36], Jerraya (1974, 2003) [15, 53], Millet (1959) [20] and Pagliano (1938, 1951) [18, 19]. All previously published data were carefully examined and a list of scale insect species was included. In this list, we provide currently accepted names, the sources of publication with reference to the Tunisian literature and any other relevant information.

4. Results

4.1 Review of the citrus scale insect literature dealing with Tunisian records

A historical review on the occurrence and pest status of scale insects in Tunisian citrus orchards available prior to the current field study is given in table 2. Species are grouped alphabetically by family and species, adding the origin, host plant and references.

The previous studies of scale insects occurring on citrus were carried out in the Cap Bon region, Northeast of Tunisia. Most of these publications are unreliable; give a brief description on the species occurrence and do not precise the pest status or biological behavior of scale insects. Most important contributions are that of Pagliano (1938) and Millet (1959) [18, 20] who listed the pests of citrus trees in Tunisia. Then, Jendoubi *et al*. (2008) [35] updated the list of citrus scale insect fauna through a preliminary field survey, giving an idea on the incidence of scale insects affecting citrus trees.

The species number differs between authors and their abundance fluctuates with time. In fact, Pagliano (1938, 1951) [18, 19] reported 17 species; Jendoubi *et al*. (2008) [35], 11 species; While García Morales *et al*. (2017a, c, d) [5, 10, 11] listed only 10 species in the most recent online database of scale insects. Accordingly, a total of 18 species of scale insects were recorded on citrus trees in Cap Bon region. Among them, the black scale and the chaff scale are revealed to be serious pests according to Millet (1959) and Jendoubi *et al*. (2008) [35, 20]. The red california scale, the red scale and the dictyospermum scale have spread during the last years in Tunisia at low densities [35], whereas fifty years ago, they

spread at a harmful level to the citrus crop in Cap Bon as reported by Millet (1959) [20].

4.1.1 Host plant and origin

All scale insects are polyphagous species, with the exception of *P. ziziphi* (also *P. pergandii* and *C. aonidum*) which is recorded as monophagous on Citrus spp. in many countries of the world, causing chlorosis and premature drop of leaves, die back of twigs and branches. Perhaps the most characteristic common damage between these species is the virtually irremovable scale cover on the fruit. A few polyphagous species as *C. hesperidum*, *C. pseudomagnoliarum*, *C. sinensis* and *P. psiidi* known on trees and ornamentals in gardens were absent or rare in the Tunisian citrus orchards. The oligophagous scales (fruit trees pests) such as *L. beckii* and *S. oleae* are dispersed in Cap Bon areas at low densities on citrus trees and neighboring plants. The Tunisian citrus groves host a large community of exotic scale insects. In fact, the geographical origin of reported species shows a large dominance of species from tropical areas (15 scales), essentially Palearctic with 9 species, followed by Australian species. Two scales remain with an unknown origin, *P. pergandii* and *L. beckii* (Table 2).

Table 2: Summary of archive data made on citrus scale insects in Tunisia

Valid scientific name	Origin	Host plant	[1]Pest status	References
Monophlebidae				
Icerya purchasi Maskell 1879	Australasian	Polyphagous	Minor pest	[18, 20, 29]
Pseudococcidae				
Planococcus citri (Risso, 1813)	Palaearctic	Polyphagous	No data	[18, 27]
Pseudococcus longispinus (Targioni Tozzetti, 1868)	Australasian	Polyphagous	No data	[18, 31]
Coccidae				
Ceroplastes rusci (Linnaeus, 1758)	Afrotropical	Polyphagous	No data	[18]
Ceroplastes sinensis Del Guercio 1900	Neotropical	Polyphagous	No data	[18]
Coccus hesperidum Linnaeus, 1758	Palaearctic	Polyphagous	No data	[18, 53]
Eucalymnatus tessellatus (Signoret, 1873)	Neotropical	Polyphagous	No data	[18]
Pulvinaria psidii Maskell, 1893	Palaearctic	Polyphagous	No data	[18, 32]
Saissetia oleae (Olivier, 1791)	Afrotropical	Polyphagous Olive	Minor pest	[18, 20, 22, 53]
Diaspididae				
Aonidiella aurantii (Maskell, 1879)	Palaearctic	Polyphagous	Serious pest	[18, 20, 22, 33]
Aspidiotus nerii (Bouché, 1833)	Afrotropical	Polyphagous, nerium Citrus, oleander	No data	[18, 28]
Chrysomphalus aonidum (Linnaeus, 1758)	Neotropical	Polyphagous	Serious pest	[20, 34]
Chrysomphalus dictyospermi (Morgan, 1889)	Palaearctic	Citrus Polyphagous	Serious pest	[18, 20, 54]
Fiorinia theae Green, 1900	Palaearctic	Camellias Polyphagous	No data	[18]
Lepidosaphes beckii (Newman, 1869)	Cryptogenic	Polyphagous	No data	[18, 30]
*Lepidosaphes ul*mi (Linnaeus, 1980)	Nearctic	Lilacs, willow ash, citrus	Minor pest	[22]
Parlatoria pergandii Comstock 1881	Cryptogenic	Citrus Polyphagous	Serious pest	[18, 25]
Parlatoria ziziphi (Lucas, 1853)	Palaearctic	Citrus, Rutaceae	Serious pest	[18, 26]

[1]Period going from 1927 to before 2008; [2]Aspidiotus nerii Bouche, 1833 is the valid synonym of oleander scale [11]; it was recorded by Pagliano (1938) [18] as *Aspidiotus hederae* Signoret 1869.

4.2 Scale insect species occurring in citrus orchards (field studies)

4.2.1 Faunal diversity

A total of 14 scale species were recorded in the Tunisian citrus orchards from the northern part during the current field study: *Icerya purchase purchase* Maskell (Monophlebidae); *Planococcus citri* (Risso) (Pseudococcidae); *Ceroplastes floridensis* (Linnaeus), *Ceroplastes rusci* (Linné), *Coccus hesperidum* Linnaeus, *Coccus pseudomagnoliarum* (Kuwana, 1914) and *Saissetia oleae* (Olivier) (Coccidae); *Aonidiella aurantii* (Maskell), *Chrysomphalus aonidum* (Linnaeus), *Chrysomphalus dictyospermi* (Morgan), *Chrysomphalus pinnulifer* (Maskell), *Lepidosaphes beckii* (Newman), *Parlatoria pergandii* Comstock and *Parlatoria ziziphi* (Lucas) (Diaspididae).

Among them, two species were recorded for the first time in Tunisia. All species belong to nine genera and four families. The Pseudococcidae and Monophlebidae are under-represented, constituting each only 8% of the scale insect fauna. The Diaspididae family is highly represented and comprises 58% of the scale insect species listed, followed by the Coccidae with 25%. Dominant citrus scale genera are *Parlatoria* and *Chrysomphalus* from the family of Diaspididae, and *Coccus* from the family of Coccidae.

4.2.2 New records

Three species were recorded for the first time in Tunisia on citrus crop since authors have started field surveys last years in Cap Bon region: *C. pseudomagnoliarum* was collected in 2007 and *C. floridensis* and *C. pinnulifer* in 2010 [35, 36]. These three species showed different patterns of abundance and spreading but there were no records on dates and places of their introduction and subsequent dispersion in the citrus areas. It is expected from *C. floridensis* to cause important damages on citrus crops but not from *C. pinnulifer* and *C. pseudomagnoliarum* due to the limited spreading of populations. Undoubtedly, it is a clear increase of new record number in Tunisia, particularly in the Coccidae family, with three new species found during two years within one crop. This has added up to the actual scale insect fauna by over 50% as compared with the fauna (10 species) published in the Scale Net, the most recent database of scale insects in the world.

4.2.3 Occurrence and abundance

The scale species were observed at 75 out of 84 locations, in

90% of inspected orchards. They invaded a large part of northern Tunisia, mainly in the Northeast and scarce in the Northwest (Fig. 1). The chaff scale had the highest number of occurrences (59), followed by the citrus mealybug (55) and the black scale (53). The latter shows a higher number of scale insects, registering a relative abundance of 28%; *P. pergandii* and *Pl. citri* share the similar relative abundance with the primer, as well high, 20% and 19%, respectively. *I. purchase* had 13% of the records, whereas *L. beckii* had 7% and *C. dictyospermii* 5%. The other eight species *C. hesperidum*, *C. pseudomagnoliarum*, *C. floridensis*, *C. rusci*, *S. oleae*, *A. aurantii*, *C. aonidum* and *C. pinnulifer* were rare to very rare, each occupying 1% to 3% of the number of records and the number of scale insects.

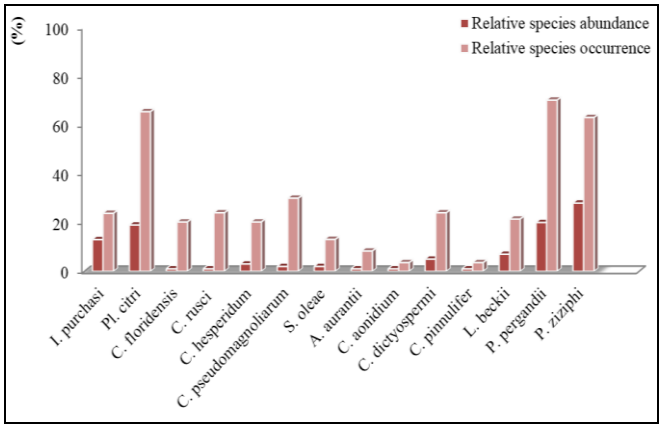

Fig 1: Total relative occurrence and abundance of scale insect species present in citrus orchards during the current field study

4.2.4 Habitat preference and climate

The highest number of occurrences (93%) and the highest scale insect populations observed (> 45%) for the 14 collected species in Tunisia occurred mainly in the coastal region in the Northeast (Cap Bon) (Fig. 2). All species of scale insects, except the purple scale, spread together in big numbers within the orchards, showing a preference to the southeast (Hammamet and Korba) and central (Beni Khalled, Menzel Bou Zalfa and Soliman) citrus areas of Cap Bon. In fact, *P. pergandii*, *P. ziziphi* and *Pl. citri* tended to show higher frequency and abundance, mainly in the localities Beni Khalled, Menzel Bou Zalfa and Soliman as compared to the other regions. While *I. purchase* and *Pl. citri* tended to be more abundant in Hammamet and Korba and lesser in Nabeul. The other species (*A. aurantii*, *C. aonidum* and *C. pinnulifer*) were extremely rare, collected from three to seven orchards in Hammamet, Menzel Bou Zalfa and Nabeul at very low population densities. Whereas the remaining four species (*C. dictyospermii*, *C. floridensis*, *C. hesperidum* and *S. oleae*) were spread commonly over sites without showing a particular preference for one locality.

In the Northwest of Tunisia, the incidence of species was minimal (Fig. 2). Locations void of scale insects were recorded mostly in Oued Mliz. Only four species (*P. pergandii*, *P. ziziphi*, *Pl. citri* and *I. purchase*) thrived the mountainous regions of Nefza, Tabarka, and Boussalem. The species occurrences declined to less than 6% for *P. pergandii* and *I. purchase*, but increased to 100% for *Pl. citri*, which was found in 80% of sites. The Florida wax scale and the citrus mealy bug were found feeding on other fruit trees growing alongside of citrus orchards, the primer were collected 3 times from laurel and medlar and the latter 13 times from pomegranate.

Fig 2: Map of the northern part of Tunisia, showing the incidence of scale insects species (1-14) collected during the survey (with notation scale of infestation intensity according to Douglass and Davidson, 1990) [50].

N.	Species
1	*I. purchasi*
2	*Pl. citri*
3	*C. floridensis*
4	*C. rusci*
5	*C. hesperidum*
6	*C. pseudomagnoliarum*
7	*S. oleae*
8	*A. aurantii*
9	*C. aonidum*
10	*C. dictyospermi*
11	*C. pinnulifer*
12	*L. beckii*
13	*P. pergandii*
14	*P. ziziphi*

Symbole	Infestation	Class	Colonies	Individuals
	No infestations	0	No individuals	0
	Isolated infestation	1	Only scattered single individuals	1
	Medium infestation	2	Small colonies	2 - 10
	Severe infestation	3	Large colonies	11 - 100
	Layered infestation	4	Scales completely cover the infested plant parts	Layered individuals

5. Discussion

5.1 Changes in species composition and regional distribution in citrus ecosystems

According to data collected from recent surveys (14 species) and old records (18 species), twenty-two species of alien scale insects, belonging to four families within fifteen genera, have been established in Tunisia on citrus trees. They have been introduced from five zoogeographical areas of the world, mainly the Palearctic region. Most of them are polyphagous and widespread pests, 7 species have been recorded as serious pests of citrus in many countries from Africa, Austria and America. This shows a high faunal biodiversity and richness as compared with the Sicilian citrus scale insect fauna (28 species). Nevertheless, it seems to be a relative higher number compared with the total species already recorded in neighboring countries with very large citrus planting areas: Algeria (10), Morocco (12) and Israel (9) [55, 56].

C. pseudomagnoliarum, *C. floridensis* and *C. pinnulifer* are added as new records of citrus scale insects to Tunisian fauna during three years within one crop. This completes the existing number of species and enlightens the emergence of new potential species and genera through the next years in the bordering countries. Actually, *C. floridensis* which has become a key pest of citrus crops in most northeastern Mediterranean countries (Israel and Egypt), is a potential citrus pest in the coastal region of Tunisia [11, 57-59]. Moreover, the temperate weather, high humidity and cultivation of different fruit trees in citrus orchards by Tunisian farmers are all suitable conditions for the settlement and spread of this polyphagous pest. Absolutely, the faunistic studies are extremely important for the rapid detection of new pest introductions, obtaining eventually an early control of threats to citrus such as *C. floridensis* and other insects.

The particular geographic position of Tunisia, encompassing high mountains, continental to Mediterranean, has allowed the establishment of numerous exotic species from very different geographical areas. In this study, the scale insect infestation on citrus trees was higher in the Northeast coastal region (semi-arid climate) than in the northwest mountainous regions (humid climate). This means that environments and habitat in Cap Bon are much more suitable for the large settlements of scale insects, endowing these exotic insects with better surviving and population growth in all the area.

The high concentration of citrus trees in Cap Bon may also result in a higher probability of interception of coccids arriving in a given location, either by means of transportation or brought by the wind over long distances. In addition, farming practices have deeply affected the dispersal of scale species in the region after their entry and the expansion of new foci: Citrus is grown in Cap Bon as a traditional familial compound crop where citrus orchards are scattered overall the area, some of them were abandoned and have become a pests foci. Citrus trees are usually intercropped with either fruit trees such as pomegranate, laurel, medlar, olive, and fig, being to some species (as *Pl. citri* and *C. floridensis*) the alternative or primary host plants, maintaining hence the permanent development of coccids in the orchard.

The citrus planting groves in the northwest seem to be suitable for few species like the citrus mealybug and the cottony cushion scale but not for many others. Most of species have completely "disappeared" from citrus trees or were to be found only as occasional insects on some trees in the different citrus orchards of Nefsa, Tabarka, and Boussalem. This long-distance dispersal of scale insects from Northeast to Northwest is associated mainly to human activities such as farming practice exchange (pruning) and trade movements of citrus plant material between both regions. Actually, the limited occurrence of species in the northwest may result in a high probability of three factors: absence of pests in the area newly planted in citrus trees, the severe weather conditions (hotter summer and colder winter) and the young planting age of citrus trees (5-12 years).

5.2 Potential pest status of main scale insect species in citrus groves

The three species *P. pergandii*, *P. ziziphi* and *Pl. citri* make a global notorious problem in all Tunisian citrus regions (northeast and northwest), showing a large ability to adapt to different environments. Similar results were achieved by Pagliano (1951) and Franco *et al*. (2006) [19, 56] in Tunisia and other Mediterranean citrus-growing countries as Algeria, Italy, Portugal, Spain and Turkey. This raises the question: why populations of these three species are increasing over time despite the regular control in Tunisian orchards? According to observations made with farmers during surveys, chemical treatment is frequently applied by farmers late in summer when they start to see mealybugs and diaspids on fruits and branches. While, control of scale insects must be done earlier in summer in citrus groves. Some other farmers prefer to not control this group of pest and resolve the problem by cleaning fruits after harvest. Also, many distinctive biological parameters of Coccids, mainly the generation overlapping, cryptic behavior, small size and concealment, due to the protected scale cover, make the chemical control inefficient or useless for farmers.

With this situation, it is compulsory to manage and improve the monitoring techniques in the field at the level of farmer in order to make the treatment periods accurate and increase the efficacy of agro-chemicals products. For the mealybug species, the infestation ratio represents the important biological capacity of the species (high fecundity, mobility, exponential growth…) and suggests the beginning of invasion in the Northwestern citrus area. This species will undoubtedly invade the entire groves in Tunisia within a few years and the same dramatic situation of Cap bon will be witnessed in Beja and Jendouba. Therefore, it is essential to monitor regularly the area in order to prevent the spreading out of *Pl. citri* and others diaspids; the control of the first foci that appeared in Tabarka is compulsory.

As a margarodid species, *I. purhase* is considered as a potential pest of citrus in many Mediterranean countries such as Greece, Israel, Italy, Spain and Turkey; populations are kept naturally under threshold by its predator, the vedalia beetle *Rodolia cardinalis* (Mulsant) (Coleoptera, Coccinellidae) [56, 63]. In the Tunisian citrus groves, the pest status of this species is different: populations were increasing considerably during the last years, being harmful to citrus crop in some regions like Takelsa and Soliman (Cap Bon). The outbreak of this species should be related directly to the decline of the vedalia beetle populations in nature probably because of the use of non-selective pesticides.

Among coccid species, the citricola scale *C. pseudomagnoliarum* and the brown scale, *C. hesperidum* were found with a significant abundance in the citrus region, without causing damages. Many parasites were found within colonies of these two coccids like *Microterys nietneri*

(Motschulsky), *Metaphycus flavus* (Howard), *Metaphycus* sp. and *Coccophagus* sp. successfully controlling their populations. However, a further spread of species, mainly the brown soft scale, along the citrus cultivated area may include them among the serious species present in the area.

As far as other coccids are concerned, we identified five polyphagous species *S. oleae*, *C. sinensis*, *E. tessellatus*, *P. psidii* and *C. rusci*. The populations of these species were either at low to very low level either not perceived again in the field during the collection of 2010. As it was reported by many authors in literature, coccids rarely become pests of economic importance to citrus because they are usually under natural effective biological control as it is noticed in Tunisian groves.

As for Diaspididae, two species have been previously reported as key pests of citrus in Tunisia: the chaff scale and the black scale. Nine other Diaspids were found on citrus trees in the northern part of the country at different times and locations; most of them are polyphagous and potential pests of many fruit crops. The recent rediscovery of most species after 70 years, without records, illustrates the ability of small populations of Diaspididae to persist unobtrusively over time. The three species, the red california scale, the red florida scale and the red scale, had been considered among the most injurious scale insect species in Tunisian citrus groves for more than seventy years according to Bénassy (1975) [60]. Today, populations have been reduced, but pest status may change over time to reach a high infestation level. Therefore, it is necessary to pay attention to its future occurrence and its possible economic importance. A case in point, the red california scale, *A. aurantii*, which was considered the most injurious species to citrus in many Mediterranean countries at different times [61-63]. It has kept a limited diffusion for many years in Spain and Italy, and then the pest outbroke and became 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 in Tunisia.

We should eventually consider the species *Aspidiotus nerii*, *F. theae*, *P. persicae*, *C. sinensis*, *P. psidii*, *P. longispinus* and *E. tessellatus*, which have not been recorded for 40 to 70 years or may not remain established in Tunisia. They have occurred probably at very low densities till they become undetectable. At all levels of species discussed in the present work, we include in table 3 the potential pest species, emerging pest species and well-established pest species, even undescribed or unplaced species that requires further studies; giving hence an initial summary for all species occurring on citrus in Tunisia.

Table 3: List of citrus scale insects in Tunisia, (pest status of each species is giving according to the time of report).

Incidence	Pest status	Species	Occurrence	Abundance	Dynamic over time	Dispersal	Distribution	Host plant
Major pests	**Notorious pests**	*P. pergandii*	Very frequent	Very high	Stable	Widespread	North, mainly N.east	Citrus
		P. ziziphi	Very frequent	Very high	Stable	Widespread	North, mainly N.east	Citrus
		Pl. citri	Very frequent	High	Stable	Widespread	North, mainly N.west	Citrus, pomegranate
	Outbreak pests	*I. purchase*	Frequent	High	Increasing	Widespread	North, mainly N.east	Citrus
Common pests	**Common pests**	*C. dictyospermi*	Frequent	Medium	Decreasing	Localized	Northeast	Citrus
		C. hesperidum	Frequent	Low	Stable	Localized	Northeast	Citrus
		L. beckii	Frequent	Medium	Stable	Localized	Northeast	Citrus, Olive
	Occasional pests	*C. rusci*	Unfrequent	Very low	Stable	Limited	Northeast	Citrus
		S. oleae	Few frequent	Low	Stable	Limited	Northeast	Citrus, Olive
	Potentiel pests	*A. aurantii*	Few frequent	Low	Decreasing	Localized	Northeast	Citrus
		C. floridensis	Frequent	Low	New record	Localized	Northeast	Citrus, Laurell, medlar
		C. aonidum	Unfrequent	Low	Decreasing	Localized	Northeast	Citrus
		C. pseudomagnoliarum	Frequent	Medium	New record	Localized	Northeast	Citrus
Minor pests	**Rare pests**	*A. nerii*	Infrequent	Very low	Unknown	Limited	Northeast	Citrus, Olive
		C. pinnulifer	Infrequent	Very low	New record	Limited	Northeast	Citrus
		C. sinensis	Infrequent	Very low	Unknown	Limited	Northeast	Citrus
		E. tessellatus	Infrequent	Very low	Unknown	Limited	Northeast	Citrus
		F. theae	Infrequent	Very low	Unknown	Limited	Northeast	Citrus
		L. ulmi	Infrequent	Very low	Unknown	Limited	Northeast	Citrus
		P. persicae	Infrequent	Very low	Unknown	Limited	Northeast	Citrus
		P. longispinus	Infrequent	Very low	Unknown	Limited	Northeast	Citrus
		P. psidii	Infrequent	Very low	Unknown	Limited	Northeast	Citrus

6. Conclusion

This paper is the second in a series of reports dealing with the citrus scale insects fauna in Tunisia. It is intended to present new data on the taxonomy, occurrence, economic importance, host plant relationships and biogeography of several species of scale insects (Homoptera: Coccoidea) which have appeared in this region since the first contribution was published in 1938. The object of this study was to prepare an inventory of citrus scale insect species, which will be helpful for the future researchers working on development of pest management programs in citrus orchards. It is hoped as well that this updated listing of scale insects will serve as a basis reference for further Faunal and zoogeographical studies of this insect group in the area. The review of results demonstrates that we have achieved at least a great knowledge, enough complete, on coccids associated to citrus crop in Tunisia in all important growing citrus regions. In reality, further searches on scale insect species present in the planted citrus area from the south

of Tunisia (Gabès) are needed to identify additional geographic records and undescribed species. We give at the end of this study a first summary for the twenty-two species which were described as: new species with pest potential, emerging and well-established pest species, even undescribed or unplaced species occurring on citrus in Tunisia. Accordingly, the twenty-two scale insects species were classified in six groups according to their incidence on citrus trees: 1.Notorious pests, 2.Outbreak pests, 3.Common pests, 4.Occasional pests, 5.Potentiel pests and 6.Rare pests (Table 3). *P. pergandii*, *P. ziziphi* and *Pl. citri* are major pests of citrus in all Tunisian citrus regions (northeast and northwest) and North African countries showing a large ability to be adapted to different environments.

At the moment, the real problem occurring in the citrus groves is the high incidence of invasive species of scale insects in citrus orchards and their management. Hence after listing species, the second step is how to keep scale insects populations below the threshold? In order to develop management strategies for the different scale insects species, we should firstly deepen studies on the population dynamics of key pests (*P. pergandii*, *P. ziziphi*, *Pl. citri* and *I. purhase*) and their interactions with environment and auxiliaries. Secondly, we recommend developing appropriate sampling methods and monitoring techniques in order to acquire the useful information to determine the right treatment time and prevent insect outbreaks for potential species as the red california scale. Thirdly, it is necessary to assess all control interventions for species, mainly the chemical tool which should be applied in reasonable way. Finally, it is important to introduce alternative control methods as the Biocontrol in the integrated pest management strategies; Biocontrol should be used as a fundamental compound of IPM programs in citrus orchards not as a method under testing.

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