Beneficial insect community of Moroccan citrus groves: assessment of their potential to enhance biocontrol services

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Abstract

In citrus groves, beneficial insects that reduce abundance of pests are considered a key component of integrated pest management strategies. The aim of this article was to assess the biodiversity of parasitoids and predators in citrus orchards in Morocco to facilitate future investigations on their potential as biocontrol agents. Data of 105 citrus beneficial insects were gathered and summarized in a data matrix. Variables such nature, target pests, type, establishment, and efficacy were assessed. More than two-thirds of parasitoids and predators species identified in citrus groves of Morocco (105 species) are native (> 70%). Both groups represent only a small fraction of the introduced species. The mostly attack armored scale insects (Diaspididae) and aphids (Aphididae). The ladybeetle Rodolia cardinalis (Mulsant) (Coleoptera: Coccinellidae) is the first beneficial species introduced in 1921 to the Moroccan citrus orchards to control the cottony cushion scale Icerya purchasi (Maskell) (Hemiptera: Monophlebidae). Major introductions of these parasitoids and predators were carried out during the ninetieth to control the main citrus pests whereas they were accidentally introduced. These purposely introduced species are mainly Aphelinidae, Encyrtidae, Eulophidae, Coccinellidae, and Phytoseiidae. Whereas a high proportion of the introduced beneficial insects was established and no species have been reported to be harmful to this date. Considering only the introduced species used in classical biological control context, about 20 and 40% of them are considered as effective or partially effective, respectively.

Keywords: Citrus, Biological control, Parasitoids, Predators, Species diversity, Morocco

Background

In Morocco, the citrus industry plays a very important socio-economic role in the national economy with an area of about 126,600 ha and a production of about 2.3 million tons (ASPAM 2018). This sector provides an important source of foreign currency per year and generates significant effects in employment through the creation about more than 35 million working days a year in orchards and at the packaging and processing industry and other activities related to citrus industry. In Morocco, citrus trees are infested by several phytophagous insects, mites, and snails, which significantly affect citrus yield quality and quantity by damaging leaves, young shoots, twigs, and fruits (Abbassi 2010; Smaili et al. 2001; Mazih 2015; Smaili 2017). Therefore, a need to develop new approaches to control these pests, using environment friendly approaches, as an alternative to chemical control is becoming a necessity for citrus producers. In the past, the control methods of the main citrus pests were applied with a few considerations of the abundance of beneficial insects and their impact on harmful pests in the Moroccan research studies (Smaili 2009; Smaili et al. 2014). However, now many reasons have greatly induced Moroccan citrus producers to enhance the IPM strategy: (i) the outbreak of new citrus pests problems such as whiteflies,
leafhoppers, ants, and thrips (Smaili and Benyahia 2018; Smaili et al. 2018); (ii) the new requirements of importers and local market, related to ship agreed quality of citrus fruits; (iii) the exporting companies have a certified orchards with the standards and requirements of importing the fresh citrus fruit with new rigorous control requirements (e.g., China and USA requirements for citrus exporting); (iv) available effective insecticides and acaricides on control citrus pests are probably not be commercialized in the near future in Morocco (e.g., Chlorpyri fos-ethyl); (v) the need of the citrus producers for the exploration possibility for large-scale exports to new foreign markets. Indeed, new management practices such as good plant protection practices, integrated pest management strategy, classical biological control, conserva tive biological control, and taken into account the side effects of these pesticides applied on citrus trees on natural enemies. In addition, worldwide, many effective species of parasitoids and predators have been found out and many species are currently available in the market. Almost 250 species of invertebrate biological control agents are used to enhance biological control and pest management worldwide (Van Lenteren et al. 2018).

Several parasitoids and predators have been reported in Moroccan citrus groves and some of them play an important role in maintaining some pests under economic threshold levels (Abbassi 1990, 2010; Smaili et al. 2010, 2013, 2014). Most of them are native species while some have been accidently introduced or deliberately released to control certain pests. The use of natural enemies in Morocco is very old especially in citrus orchards (Smirnoff 1954, 1956; Delucchi 1963; Delucchi and Merle 1963). The first introduction of the parasitoids and/or predators to the Moroccan citrus groves (e.g., coccinellid beetles and aphelids wasps) started almost a century ago (Smirnoff 1955; Bennassy and Euverte 1967; Euverte 1967 and EPPO 2011) already in 1921, the vedalia beetle Rodolia cardinalis (Mulsant, 1850) (Coleoptera: Coccinellidae) was introduced to the Moroccan citrus groves to control the cottony cushion scale Icerya purchasi (Maskell, 1878) (Hemiptera: Diaspi didae); citrus leaf miner (mainly Phyllocnistis citrella Stain lon) (Lepidoptera: Gracillariidae). Unknown: when there is a lack of information on targeted pests of these beneficial insects.

**Information sources**

Available information on the parasitoids and predators associated with citrus orchards in Morocco was collected using several sources: (1) direct communication with researchers and actual users of these beneficial insects for biological control; (2) peer reviewed articles; (3) database of the European and Mediterranean Plant Protection Organization (EPPO) (www.eppo.org), the Natural History Museum (NHM) (www.nhm.ac.uk), the Centre for Agriculture and Biosciences International (CABI) (www.cabi.org), and Scholar Google (www.google.com); (4) available papers published in the national proceeding, and (5) available thesis and validated scientific reports. The species data gathered from 1920 to 2018 were summarized in a data matrix including the following variables:

**Nature and target pests**

Beneficial insects are indigenous (native) or exogenous (introduced) and traditionally known as parasitoids and predators. Their main hosts or prey are mostly aphids (Aphididae); scale insects (armored scale Diaspididae); soft scale from Saissetia and Coccus genera (Coccidae); Pseudococcidae (genus Planococcus); Monophlebidae (cottony cushion scale Lpurchasi); whiteflies (Aleyrodidae); mites (mainly Tetranychidae); Tortricidae (mainly Cacoecimorpha genus); fruit flies (Tephritidae); Grac ilariidae; citrus leaf miner (mainly Phyllocnistis citrella Stain lon) (Lepidoptera: Gracillariidae). Unknown: when there is a lack of information on targeted pests of these beneficial insects.

**Type of introduction and establishment**

The introduction of the parasitoids and/or predators in the Moroccan citrus orchards was considered as intentionally introduced, when the species were introduced deliberately to control targeted citrus pest and accidentally introduced, and when they were introduced by an unknown manner. The status of the introduced beneficial insects was considered as established, when the species is known to be established and observed every year; not established, when the species has not
been established and/or has not been found after their release, and unknown, when there is a lack of information on acclimatization of this beneficial insects.

**Efficacy**

Efficacy is considered the real impact of the parasitoids and/or predators to control one or more target pests. Five levels were proposed (adapted by Jacas et al. 2006): Effective, when the parasitoids and/or predators can reduce population of the target pest and infestation level significantly (e.g., do not exceed the economic threshold); partially effective, when the parasitoids and/or predators can control partly the population of the target pest, but with non significant reduction of infestation; low efficacy, when the beneficial species has a little impact on the population of the target pest coupled with establishment of this species once released; failure, when the parasitoids and/or predators has no effect or a very little impact on the targeted pest coupled with no real establishment (sporadic, or no establishment) of this species once released; unknown, when no information is available on the efficacy of the parasitoids and/or predators under Moroccan conditions.

**Additional information and assessment**

Further information on the parasitoids and/or predators in the EPPO was also provided: date reported by the EPPO; date reported in Morocco; first references to Morocco. All the above variables were estimated by a percentage (%) with the number of the parasitoids and/or predators reported out of the total number of all identified beneficial insects in citrus, called here as “Percentage of presence” (%). Jacas et al. 2006; Roy et al. 2011. For some variables (e.g., introduced species), the percentage was also calculated by the number of the parasitoids and/or predators reported over the total number of introduced beneficial insects.

**Results and discussion**

**Nature and type**

Parasitoids and predators species are fundamental for the implementation of integrated pest management (Bonsignore and Vacante 2012; Van Lenteren et al. 2018). The parasitoids and/or predators identified in citrus counted about 105 species, 76 native species, and 29 introduced species (with 72.38 and 27.61%, respectively) (Tables 1 and 2). For the native species, predators (47.61%) are more abundant than parasitoids (24.76%). The parasitoids species belong mainly to the families: Aphelinidae, Braconidae, Encyrtidae, Eulophidae, while the predators’ species belong to Coccinellidae and Phytoseidae families. For the introduced species, their ratios are 10.47 and 17.14% for parasitoids and predators, respectively. Parasitoids and predators species belong mainly to 2 main orders: Coleoptera with 39.05% (31.43% for the natives and 7.62 % for the introduced species) and Hymenoptera with 41.90% (24.76% for the natives and 17.14% for the introduced). The other insect orders are still low and does not exceed 8.6%. The distribution of the parasitoids and/or predators grouped by the insect families is given in Fig. 1. The rate of coccinellid species was about 34.29% (26.67% for the natives and 7.62% for the introduced) and the aphelinid species about 16.19% (10.48% for the natives and 5.71% for the introduced). Species belong to families Encyrtidae, Eulophidae, Braconidae, and Phytoseiidae ranged between 7.62-9.52%, while the other families do not exceed 3%.

**Target pests**

Present percentage of parasitoid and predator species in Moroccan citrus groves based on target pests are given at Fig. 2. In Moroccan citrus groves, the diaspids and aphidids are the most targeted pests for the parasitoids and/or predators. For all parasitoids and/or predators species, targeted pests were mainly Diaspididae with 30.47% (21.90 and 8.57% for the native and introduced species, respectively) and Aphididae with 17.14% (15.23 and 1.90%, respectively). This percentage did not exceed 10% for the others trophic groups. Among the introduced species, diaspidid were (34.48%), followed by the leafminer *P. citrella* (17.24%), and the white fly (17.24%) (Fig. 3). For others, trophic group percentage of presence did not exceed 7%. This is a consequence of the important richness and abundance of their main hosts, the armored scale insects and aphids, which remain the preferred target pests of many natural enemies in citrus orchards in Morocco (Abbassi 1990, 2010; Smaili et al. 2009, 2014; and Smaili 2017). In addition, arthropod pests that are exposed and not hidden and are less mobile have been more successfully controlled because their natural enemies have the capability to reach the pest (Hajek and Eilenberg 2018). Considering the introduced species only, trophic groups preferred target pests like armored scale, citrus leafminer, and white fly. This is explained in the fact that the scale insects, especially California red scale *A. aurantii*, the Chaff scale *P. pergandii*, citrus leafminer *P. citrella*, and several whiteflies species have been considered over years the most important pests in citrus orchards (Abbassi 1975b, 1975c, Abbassi 1980, Abbassi 1990, Abbassi 2010; Rizqi et al. 1997a, 1997b, 2003; Benziane 2003; Boutaleb and El Hardouni 2010 and Smaili 2009, 2017).

**Type of introduction**

According to the types of introduction into the Moroccan citrus orchards, percentage of presence of introduced species belong to the families of Aphelinidae...
| Species | Nature | Family | Date of first use by EPPO area | Reported by EPPO for Morocco | Date of first report/use in Moroccan citrus groves | First references |
|---------|--------|--------|-------------------------------|-----------------------------|-----------------------------------------------|------------------|
| **Ablerus (Azotus) chrysomphali** (Ghesquière 1960) | Par | Aphelinidae | No | No | 1950/No | (Smirnoff 1950), (Ghesquière 1960), (Bénassy and Evénte 1988a, 1988b) |
| **Aphytis chrysomphali** (Mercet, 1912) | Par | Aphelinidae | No | No | 1956/No | (Thompson 1953), (Smirnoff 1956) |
| **Aphytis hispanicus** (Mercet, 1912) | Par | Aphelinidae | No | No | ? / No | (Abbassi 1975c), (Rosen and DeBach 1979) |
| **Coccophagus semicircularis** (Forster, 1841) | Par | Aphelinidae | No | No | 1929/No | (Smirnoff 1956) |
| **Coccophagus lyamnia** (Walker, 1839) | Par | Aphelinidae | No | No | 1949/No | (Smirnoff 1956) |
| **Coccophagus scutellaris** (Dalman, 1825) | Par | Aphelinidae | No | No | 1929/No | (Smirnoff 1956) |
| **Encarsia atina** (Crawford, 1891) | Par | Aphelinidae | 1984 | Yes | ? / No | (Thompson 1953) |
| **Encarsia sp.** | Par | Aphelinidae | /No | /No | ? / No | (Smaili et al. 2013) |
| **Encarsia sophia** (Guérin-Méneville, 1844) | Par | Aphelinidae | No | No | 1975/No | (Abbassi and Lakhli 1994) |
| **Encarsia bousbouyi** (Besse and Paoli, 1918) | Par | Aphelinidae | No | No | 1948/No | (Smirnoff 1956) |
| **Marietta leopardina** (Motschulsky, 1863) | Par | Aphelinidae | /No | /No | ? / No | (Ghesquière 1960), (Bénassy and Evénte 1967), (Hayat 1988) |
| **Aphidius ervi** (Haliday, 1834) | Par | Braconidae | 1995 | Yes | ? / No | (Stary and Sekkat 1987) |
| **Aphidius sp.** (probably *Aphidius colemani* (Viereck)) | Par | Braconidae | No | No | ? / No | (Smaili et al. 2009, 2013) |
| **Lysiphlebus fabarum** (Marshall, 1896) | Par | Braconidae | No | No | ? / No | (Stary and Sekkat 1987) |
| **Microgaster sp1.** (Latreille, 1804) | Par | Braconidae | /No | /No | ? / No | (Delucchi and Merle 1962) |
| **Microgaster sp2.** (Latreille, 1804) | Par | Braconidae | /No | /No | ? / No | (Delucchi and Merle 1962) |
| **Pseudapis condolis** (Szepligeti, 1910) | Par | Encyrtidae | No | No | 1914/No | (Maloua et al. 2008) |
| **Anagyrus pseudococci** (Girault, 1915) | Par | Encyrtidae | 1995 | Yes | ? / No | (Smaili et al. 2013), Rizqi and Bihi Com. Pers. |
| **Goccidodenoides perminutus** (Girault, 1915) | Par | Encyrtidae | No | No | ? / No | (Smaili et al. 2013), Rizqi and Bihi Com. Pers. |
| **Habrolepis diaspidi** (Risbec, 1951) | Par | Encyrtidae | No | No | 1965/No | (Compe and Annecke 1961), (Delucchi and Traboulbi 1965), (Bénassy and Evénte 1967) |
| **Habrolepis dalmanni** (Westwood, 1837) | Par | Encyrtidae | No | No | 1950/No | (Thompson 1953), (Smirnoff 1956) |
| **Leptomastidea abnormis** (Girault, 1915) | Par | Encyrtidae | 1984 | Yes | ? / No | (OLB 1971), (Noyes and Hayat 1994), (Abdelkhalek et al. 1998) |
| **Elachertus affinis** (Masi, 1911) (syn. *Artaeus Walker*) | Par | Eulophidae | ? | /No | ? / No | (Delucchi and Merle 1962) |
| **Girospikus pictus** (Nees, 1834) | Par | Eulophidae | No | No | /No | (FAO 1996), (Smaili et al. 1999b) |
| **Girospikus vitatus** (Walker, 1838) | Par | Eulophidae | No | No | /No | (FAO 1996) |
| **Pnigalio sp.** | Par | Eulophidae | No | No | /No | (FAO 1996) |
| **Euseius scutalis** (Athias-Henriot, 1958) | Pred | Phytoseiidae | No | No | ? / No | (Meyerdirk and Caprio 1986), (McMurtry and Bounfour 1989) |
Table 1  Date of first use by EPPO area, reported by EPPO for Morocco and date of first report and/or use in Moroccan citrus groves, related to native benefit species in citrus groves in Morocco (Continued)

| Species | Nature | Family | Date of first use by EPPO area | Reported by EPPO for Morocco | Date of first report/use in Moroccan citrus groves | First references |
|---------|--------|--------|--------------------------------|-------------------------------|-----------------------------------------------|-----------------|
| Euseius stipulatus (Athias-Henriot, 1960) | Pred  | Phytoseiidae | No | No | ? /No | (Bounfour and McMurtry 1987) |
| Iphiseius degenerans (Berlese, 1889) | Pred  | Phytoseiidae | 1993 | No | 1981 /No | (McMurtry and Bounfour 1989) |
| Phytoseius persimilis (Athias-Henriot, 1957) | Pred  | Phytoseiidae | 1968 | No | ? /No | (McMurtry and Bounfour 1989) |
| Typhlodromus philadus (Athias-Henriot, 1960) | Pred  | Phytoseiidae | No | No | 1989 /No | (McMurtry and Bounfour 1989) |
| Amblyseius andersoni (Chant, 1957) | Pred  | Phytoseiidae | No | No | 2003 /No | (Tixier 2013) |
| Typhlodromus foenilis (Oudemans, 1930) | Pred  | Phytoseiidae | No | No | 2013 /No | (Tixier 2013, Tixier et al. 2016) |
| Harpalus sp. | Pred  | Carabidae | No | No | 2009 /No | (Smaili 2009, Smaili et al. 2013) |
| Pseudoophonus rufipes (De Geer, 1774) | Pred  | Carabidae | No | No | 2009 /No | (Smaili et al. 2009) |
| Cicindella sp. | Pred  | Cicindellidae | No | No | 2009 /No | (Smaili et al. 2009) |
| Adalia bipunctata (L., 1758) | Pred  | Coccinellidae | Yes | Yes | ? /No | (Smaili et al. 2006, Smaili et al. 2010a, Smaili et al. 2013) |
| Chilocorus bipustulatus (L., 1758) | Pred  | Coccinellidae | 1959 | Oui | 1954 /Yes* | (Smaili et al. 2006, Smaili et al. 2010a, Smaili et al. 2013) |
| Olotosthus arcestus (Rossi, 1794) | Pred  | Coccinellidae | No | No | 1931 /No | (Smaili et al. 2006, Smaili et al. 2010a, Smaili et al. 2013) |
| Coccinella septempunctata (L., 1758) | Pred  | Coccinellidae | 1980 | Yes | 1929 /No | (Smaili et al. 2006, Smaili et al. 2010a, Smaili et al. 2013) |
| Exochomus nigromaculatus (Goeze, 1777) | Pred  | Coccinellidae | No | No | 1933 /No | (Smaili et al. 2006, Smaili et al. 2010a, Smaili et al. 2013) |
| Exochomus quadripustulatus (L., 1758) | Pred  | Coccinellidae | No | No | 1948 /No | (Smaili et al. 2006, Smaili et al. 2010a, Smaili et al. 2013) |
| Harmonia quadripunctata (Poncoppidan, 1763) | Pred  | Coccinellidae | No | No | 1956 /No | (Smaili et al. 2006, Smaili et al. 2010a, Smaili et al. 2013) |
| Hippodamia variegata (Goeze, 1777) | Pred  | Coccinellidae | no | no | 1931 /No | (Smaili et al. 2006, Smaili et al. 2010a, Smaili et al. 2013) |
| Hyperaspis aspersa (Herbst, 1783) | Pred  | Coccinellidae | No | No | 1953 /No | (Smaili et al. 2006, Smaili et al. 2010a, Smaili et al. 2013) |
| Nephus albicornis (Fursch, 1977) | Pred  | Coccinellidae | No | No | 1949 /No | (Smaili et al. 2006, Smaili et al. 2010a, Smaili et al. 2013) |
| Oenopia conglobata (L., 1758) | Pred  | Coccinellidae | No | No | 2010 (1956 in Morocco) /No | (Smaili et al. 2006, Smaili et al. 2010a, Smaili et al. 2013) |
| Oenopia quadrivittata (Mulkant, 1846) | Pred  | Coccinellidae | No | No | 1953 /No | (Smaili et al. 2006, Smaili et al. 2010a, Smaili et al. 2013) |
| Platynaspis luteorubra (Goeze, 1777) | Pred  | Coccinellidae | No | No | 1933 /No | (Smaili et al. 2006, Smaili et al. 2010a, Smaili et al. 2013) |
| Phoracryptus setulatus (Chevelet, 1861) | Pred  | Coccinellidae | No | No | 2011 (1952 in Morocco) /No | (Smaili et al. 2006, Smaili et al. 2010a, Smaili et al. 2013) |
| Pseudapis quadrimaculata (L., 1758) | Pred  | Coccinellidae | No | No | 2007 /No | (Smaili et al. 2006, Smaili et al. 2010a, Smaili et al. 2013) |
| Rhyzobius chrysomelaeides (Herbst, 1792) | Pred  | Coccinellidae | No | No | Before 1990 /No | (Abbassi 1990) |
Table 1  Date of first use by EPPO area, reported by EPPO for Morocco and date of first report and/or use in Moroccan citrus groves, related to native benefit species in citrus groves in Morocco (Continued)

| Species | Nature | Family | Date of first use by EPPO area | Reported by EPPO for Morocco | Date of first report /use in Moroccan citrus groves | First references |
|---------|--------|--------|-------------------------------|-------------------------------|-----------------------------------------------|------------------|
| Rhyzobius litura (Fabricius, 1787) | Pred | Coccinellidae | No | No | 1956/No | (Smirnoff 1956) |
| Scymnus apetzi (Mulsant, 1846) | Pred | Coccinellidae | No | No | 1930/No | (Smirnoff 1956), (Smaili et al. 2010, 2013) |
| Scymnus biguttatus (Mulsant, 1850) | Pred | Coccinellidae | No | No | 1956/No | (Smirnoff 1956), (Smaili et al. 2013) |
| Scymnus levaillantii (Mulsant, 1850) | Pred | Coccinellidae | No | No | 1951/No | (Smirnoff 1956) |
| Scymnus interruptus (Goeze, 1777) | Pred | Coccinellidae | No | No | 1931/No | (Smirnoff 1956) |
| Scymnus marinus (Mulsant, 1850) | Pred | Coccinellidae | No | No | 1931/No | (Smirnoff 1956) |
| Stethorus punctillum (Meise, 1891) | Pred | Coccinellidae | Yes | ? | /No | (Smaili et al. 1999a, 2010) |
| Scymnus sp.1 | Pred | Coccinellidae | No | No | 2007/No | (Smaili et al. 2010, 2013) |
| Scymnus sp.2; probably Scymnus rufipes (Fabricius, 1798) | Pred | Coccinellidae | No | No | 2008/No | (Smaili et al. 2010, 2013) |
| Scymnus subtubulosus (Goze, 1777) | Pred | Coccinellidae | No | No | 1931/No | (Smirnoff 1956), (Smaili et al. 2009, 2010) |
| Scymnus saturatus (Thunberg, 1795) | Pred | Coccinellidae | No | No | 1927/No | (Smirnoff 1956) |
| Cyborephalus sp. | Pred | Nitidulidae | No | No | 1956 /No | (Smirnoff 1956) |
| Cyborephalus rubricatus (Smirnoff 1956) | Pred | Nitidulidae | No | No | 1952/No | (Smirnoff 1991), (Aahou 2008) |
| Aphidoletes Aphidimyza (Rondani, 1847) | Pred | Coccinellidae | Yes | ? | /No | ? |
| Leucoptes griseola (Fallén, 1823) | Pred | Chamaemyiidae | No | No | 1956 /No | (Smirnoff 1956) |
| Simosyrphus sp. | Pred | Syrphidae | No | No | 1956 /No | (Smirnoff 1956) |
| Anthares sp. | Pred | Anthocoridae | No | No | 1956 /No | (Smaili 2009) |
| Orius sp. | Pred | Anthocoridae | No | No | ? | /No | (Smaili 2009) |
| Cardostethus nazarenus (Reuter, 1884) | Pred | Anthocoridae | No | No | 1956 /No | (Smirnoff 1956) |
| Chrysoperla carnea (Stephens, 1836) | Pred | Chrysopidae | Yes | ? | /No | ? |
| Conwentzia psicoliformis (Curtis, 1834) | Pred | Coniopterigidae | No | No | ? | /No | (Smaili 2009, 2013) |
| Aeolothrips sp. | Pred | Aeolothripidae | No | No | ? | /No | ? |
| Panklinothrips sp. | Pred | Aeolothripidae | No | No | ? | /No | Personal observation |

Para parasitoid; Pred. predator  
*Biological control only with C.bipustulatus var.iranensis
| Species                      | Origin                          | Nature | Family      | Date of first use by EPPO area | Release reported by EPPO for Morocco | Date of first report/use in Moroccan citrus groves | First references |
|------------------------------|---------------------------------|--------|-------------|--------------------------------|-------------------------------------|------------------------------------------|------------------|
| Aphytis lepidosaphes         | China                           | Par    | Aphelinidae | 1956                           | No                                  | 1965/No                                  | EPPO             |
| (Compere, 1955)              |                                 |        |             |                                |                                     |                                          |                  |
| Aphytis lingnanensis         | Est Asie-Chine (via Californie) | Par    | Aphelinidae | 1960                           | Yes                                 | 1965/No                                  | (Euverte 1967),  |
| (Compere, 1953)              |                                 |        |             |                                |                                     |                                          | (Benassy and     |
|                              |                                 |        |             |                                |                                     |                                          | Euverte 1967a,   |
| Aphytis melinus              | India-Pakistan                   | Par    | Aphelinidae | 1962 (probably 1961)           | Yes                                 | 1961/Yes                                  | (Euverte 1967),  |
| (DeBach, 1959)              |                                 |        |             |                                |                                     |                                          | (Benassy and     |
|                              |                                 |        |             |                                |                                     |                                          | Euverte 1967a,   |
| Cales novaci                | Chile                           | Par    | Aphelinidae | 1970                           | Yes                                 | 1970/Yes                                  | (Abbassi 1974,   |
| (Howard, 1907)              |                                 |        |             |                                |                                     |                                          | 1975b)           |
| Encarsia lahorensis         | India/Pakistan                   | Par    | Aphelinidae | 1973                           | No                                  | 1973/Yes                                  | (Orlinski and    |
| (Howard, 1911)              |                                 |        |             |                                |                                     |                                          | Bassova 1996)    |
| Eretmocerus debachi          | Japan- North America            | Par    | Aphelinidae | 1982                           | No                                  | 1992/Yes                                  | (Abbassi and     |
| (Rose and Rosen, 1992)      |                                 |        |             |                                |                                     |                                          | Lakhelifi 1994)  |
| Lysiphlebus testaceipes     | Cuba                            | Par    | Braconidae  | 1990                           | Yes                                 | 2002/No                                  | (EPPO 2002)      |
| (Cresson, 1880)             |                                 |        |             |                                |                                     |                                          |                  |
| Ageniospis citricola        | Thailand (Florida)              | Par    | Encyrtidae  | 1994                           | Yes                                 | 1995/Yes                                  | (FAO 1999)       |
| (Logvinovskaya, 1983)       |                                 |        |             |                                |                                     |                                          | (Abbassi et al. |
|                             |                                 |        |             |                                |                                     |                                          | 1997b)           |
| Comperiella bilisciata      | South China (via Californie)    | Par    | Encyrtidae  | 1924                           | Yes                                 | 1924/No                                  | (Abbassi 1990),  |
| (Howard, 1906)              |                                 |        |             |                                |                                     |                                          | (Noyes and Hayat |
|                             |                                 |        |             |                                |                                     |                                          | 1994)            |
| Leptomastix dactylopii      | Neotropique Brasil              | Par    | Encyrtidae  | 1992                           | Yes                                 | 1992/No                                  | (Noyes and Hayat |
| (Howard, 1885)              |                                 |        |             |                                |                                     |                                          | 1994), (Abdelkhelek |
|                             |                                 |        |             |                                |                                     |                                          | et al. 1998)     |
| Metaphycus flavus           | -                               | Par    | Encyrtidae  | 1999                           | No                                  | 2004/ ?                                  | (OILB 1971)      |
| (Howard, 1881)              |                                 |        |             |                                |                                     |                                          |                  |
| Metaphycus helvolus          | South Africa                    | Par    | Encyrtidae  | 1992                           | ?                                   | ?                                        | (Noyes and Hayat |
| (Compere, 1926)             |                                 |        |             |                                |                                     |                                          | 1994)            |
| Cirrospilus ingenues        | South East Asia (via Australie) | Par    | Eulophidae  | 1996                           | No                                  | 1996/Yes                                  | (FAO 1999),      |
| (Gahan, 1932)              |                                 |        |             |                                |                                     |                                          | (Rizqi et al. 2003) |
| Citrosciachi phyllocnistoides| South China (via Espagne)       | Par    | Eulophidae  | 1999                           | No                                  | 1999/Yes                                  | (Smalli et al.  |
| (Narayan, 1960)             |                                 |        |             |                                |                                     |                                          | 2001b), (Rizqi et al. 2003) |
| Quadrastichus citrella      | South Asia (via Espagne)        | Par    | Eulophidae  | 1997                           | Yes                                 | 1997/Yes                                  | (Smalli et al.  |
| (Reina and LaSalle 2004)    |                                 |        |             |                                |                                     |                                          | 2001b), (Rizqi et al. 2003), |
|                             |                                 |        |             |                                |                                     |                                          | (Reina and LaSalle 2004)               |
| Semielacher petiolatus      | Australia                       | Par    | Eulophidae  | 1996                           | Yes                                 | 1996/Yes                                  | (FAO 1999),      |
| (Girault, 1915)             |                                 |        |             |                                |                                     |                                          | (Rizqi et al. 1997a) |
| Amitus spiniferus           | Peru                            | Par    | Platygasteridae | 1971                           | No                                  | 1975/Yes                                  | Abbassi, Com. per. |
| (Brethes, 1914)             |                                 |        |             |                                |                                     |                                          | (Smalli et al. 2013) |
| Diachasmimorpha             | Spain                           | Par    | Braconidae  | 2016                           | No                                  | 2016/No                                  | (Mazih et al. 2016) |
|                             |                                 |        |             |                                |                                     |                                          |                  |
Table 2 Date of first use by EPPO area, reported by EPPO for Morocco, and date of first report and/or use in Moroccan citrus groves, related to introduced benefit species in citrus groves in Morocco (Continued)

| Species                  | Origin                     | Nature | Family      | Date of first use by EPPO area | Release reported by EPPO for Morocco | Date of first report/use in Moroccan citrus groves | First references                  |
|--------------------------|----------------------------|--------|-------------|--------------------------------|-------------------------------------|-----------------------------------------------|----------------------------------|
| Neoseiulus californicus (McGregor, 1954) | S No Amérique/California-Méditerranée | Pred | Phytoseiidae | 1985                           | No                                  | 2009(< 2007 in Morocco)/Yes               | (Kreiter et al. 2007), (Smaili et al. 2013) |
| Amblyseius swirskii (Athias-Henriot, 1962) | -                           | Pred   | Phytoseiidae | 2014 (< 2014 in Morocco) /Yes   |                                     |                                               | (Smaili 2017)                    |
| Cryptolaemus montrouzieri (Mulsant, 1853) | Australie                  | Pred   | Coccinellidae | 1908                           | Yes                                 | 1983/Yes                                    | (Smirnoff 1956)                  |
| Delphastus catalinae (Horn, 1895) | Nearctic/Neotropical (America) | Pred   | Coccinellidae | 1993                           | No                                  | 2011/No                                     | (Smaili et al. 2013)             |
| Exochomus nigropictus (Fairmaire, 1876) | -                           | Pred   | Coccinellidae | No                             | No                                  | 2010/No                                     | (Smaili et al. 2010a, Smaili et al. 2013) |
| Hyperaspis algirica (Crotch, 1874) | -                           | Pred   | Coccinellidae | No                             | No                                  | 2002/No                                     | (Smaili et al. 2010a, Smaili et al. 2013) |
| Hyperaspis pumila (Mulsant, 1887) | -                           | Pred   | Coccinellidae | No                             | No                                  | 2002/No                                     | (Smaili et al. 2006, Smaili et al. 2010a, Smaili et al. 2013) |
| Nephus peyerimhoffi (Sicard, 1923) | -                           | Pred   | Coccinellidae | No                             | No                                  | 2011/No                                     | (Smaili et al. 2013)             |
| Rodolia cardinalis (Mulsant, 1850) | Australia                  | Pred   | Coccinellidae | 1897                           | yes                                 | 1921/Yes                                    | (Smirnoff 1956)                  |
| Rhyzobius lophanthae (Blaisdell, 1892) | Australia                  | Pred   | Coccinellidae | 1980                           | yes                                 | 1944/Yes                                    | (Smirnoff 1956)                  |
| Episyrphus balteatus (DeGeer, 1776) | Europe                     | Pred   | Syrphidae    | 1995                           | yes                                 | ⊥/No                                        | (Diricx 1994), (Smaili et al. 2009) |

Para parasitoid; Pred. predator
(20.68%), Encyrtidae (17.24%), Eulophidae (13.79%), Braconidae (6.89%), Coccinellidae (27.58%), Phytoseiidae (6.89%), Syrphidae (3.44%), and Platygasteridae (3.44%). The introduced species have been used deliberately to control main target pests in classical biological control reached (68.96%), mainly for Aphelinidae, Encyrtidae, Eulophidae, Coccinellidae, and Phytoseiidae. The other introduced species have been found accidentally at the citrus trees representing 31.03%. The major voluntarily introduced beneficial species to Morocco came from different origins, especially Spain, South East Asia (via INRA Antibes, France and Florida or California), and Australia. For those introduced accidentally, ladybeetle species are the most noted. In Europe, the majority of beneficial species have been introduced by accident, while a third of the species were intentionally introduced for biological control (Roy et al. 2011). In Morocco, during the period of 1921 to 1944, 3 voluntary introductions of coccinellids were made (Smirnoff 1956; EPPO 2011). Indeed, already in the year 1921, R. cardinalis remained the first and the main beneficial insect introduced to the Moroccan citrus orchards to control I. purchasi. Twelve years later, the ladybeetle C. montrouzieri was also introduced for biological control of the meal bugs. Then in 1944, there was a third new introduction of R. lophanthae to combat the armored scale on citrus, particularly A. aurantii (Smirnoff 1956). During the period of 1961 and 1970, 4 major voluntary introductions were made (Bénassy and Evverte 1968a; Bénassy and Evverte 1968b; Abbassi 1974; Abbassi and Evverte 1974). Three species to control armored scale, A. aurantii and another species Aphelinid species C. noacki, to reduce the whitefly A. floccosus. These species were very abundant and important during this period. Since then until the 90s, very few new introductions were made. This is in case of the parasitoid, A. spiniferus, introduced to control A. floccosus in 1975 (Abbassi 2010). This could be explained by the growing trade, the emergence, the availability, and the efficiency of synthetic chemicals. This is also true for the adoption at this time of the classical chemical control, as an effective control solution. It is important to consider that the new major introductions of parasitoids and/or predator species have been made since the nineties, especially for the purpose of a classical biological control. This is the case of introduced species against citrus leafminer P. citrella, as a new pest...
emerging in 1994 in Morocco (Belarbi and Abir 1995). These introductions were later coincided with the implementation of integrated pest management program and also the organic agriculture protection in several agricultural sectors in Morocco.

The introduction of the certification procedure and the elimination of several active ingredients from commercial markets in Morocco encouraged more citrus producers to improve their integrated pest management strategy and use the natural enemies in their pest control management. Except the new introduction in citrus orchards, like the predators Neoseiulus californicus (Mc Gregor) (Acari: Phytoseiidae) and Amblyseius swirskii (Athias-Henriot) (Acari: Phytoseiidae) against the oriental mite E. orientalis, no new deliberate introduction after the 2000s has been done to our knowledge (Smaili et al. 2013; Smaili 2017). However, more A. melinus and many other parasitoids and predators were released in citrus groves in the context of the IPM. This is the case for S. puntillum to control spider citrus mite (Nia et al. 2008), R. cadinalis to control I. purchasi (Nafide et al. 2010), and C. decempunctata to control aphids (Smaili et al. 2014). The introduced parasitoid A. melinus remains the beneficial insect released widely in classical biological control in the main Moroccan citrus area (Abbassi 1990, 2010). Other species were newly introduced in the year 2011 but in an accidental way. This is the case of the ladybeetle D. catalinae (Smaili et al. 2013), which is recognized as a potential predators and very effective against whiteflies (Simmons and Legaspi 2004). The efficacy of this predator is currently considered as unknown in Morocco, because the low infestation of citrus whiteflies located alongside the coastal regions in the northwest part of Morocco, except some citrus groves located at Larache, Tazi, and Belkseri area with high infestations of A. floccosus during the 3 last years.

Except new introduction of Diachasmimorpha longicaudata (Ashmead) (Hymenoptera: Braconidae) against the Mediterranean fruit fly Ceratitis capitata (Diptera: Tephritidae), an important pest for Moroccan citrus growers (Smaili et al. 1999a, 2016; Mazih 2015; Mazih et al. 2016; Smaili 2017). It is also true in terms of citrus thrips which has a new economic importance on some citrus groves located in the south part of Morocco (Smaili et al. 2018).

The newly introduced species are significant in terms of their positive impact on the economy or the environment, particularly those introduced for biological control objective (Roy et al. 2011; Van Lenteren et al. 2018). The authors reported that a number of recent successes showed how biological control can save agricultural production when pesticides fail or are not available. According to the authors, in some cases, the new introduction may also have a negative impact, because of the interference of this exogenous species with the indigenous. In Morocco, among the all introduced species, no species has been reported to be harmful to this date. In many countries, the introduction of ladybird Harmonia axyridis Pallas (Coleoptera: Coccinellidae), originated from China, known as aphidophagous species that was imported for a biological control against aphids, but recently it has become a harmful insect for native aphidophagous species (Osawa 2011).

**Establishment**

Among the introduced species, a high proportion of parasitoids and predator species was established. A part of 79.31% of all introduced species has been well established after their introduction (and/or released) in citrus groves under the Moroccan conditions. Percentage of establishment of the introduced species grouped in the families are given in Fig. 4. The Encyrtidae, Eulophidae, and Platygasteridae families included few species that have not been established after their releases (less than 4%). The Eulophidae, Coccinellidae, and Braconidae families remained the only families that include introduced species with unknown level of establishment (3.44%).

![Fig. 3 Percentage of presence (%) of introduced species according to their targeted pests in Moroccan citrus orchard (N = 29)](image-url)
Probably, ecological factors can limit their establishment, a new agro-ecosystem after their introduction. This is the case of *A. citricola* that did not perform well and failed to reduce leafminer population, after many release in several area of Morocco (Smaili et al. 2001b and Rizqi et al. 2003). Cold winter, and not arid or hot summer, seems to be the main reasons of the failure of this encyrtid in Mediterranean areas (Garcia-Mari et al. 2004). The same authors reported that in Spain, *A. citricola* was recovered in summer in many release points, reaching nearly 50% of parasitism and dispersing more than 300 m, but it was not able to overwinter.

**Efficacy**

Presence percentage of parasitoids and/or predators species according to their efficacy in controlling main citrus pests is presented in Fig. 5. Among all identified parasitoids and predators species, only few species are effective or partially effective. Among all parasitoids and predators species, 3.80% is represented as effective species (0 and 3.80% for the native and introduced species, respectively). The percentage of presence of the partially effective species is about 15.23% (5.71 and 9.52%, respectively). The species that have low efficacy or failed in controlling their target pests represent 50.47 and 27.61%, respectively. It is important to note that 21.90% (native species), and only 5.71% (introduced species) are represented by the species which failed to control their targeted pests. Species which efficacy is unknown represent only 2.85%.

For native species, the majority of species is not effective and does not control their target pest. Among the only native species (*N* = 76), the species characterized with low efficacy or failed to control their targeted pests, represent a higher percentage (61.84 and 30.26%, respectively). Conventionally, the native natural enemies are always known by very limited effectiveness against the main pests. Advances will hinge on improved holistic understanding of the ecological roles of this species, particularly coccinellids and their ability to complement other beneficial species (Michaud 2012). This is because conservation biological control should focus on
enhancing benefic species arthropod habitats by increasing the natural resources required for survival and reproduction (Botha et al., 2017). The same authors reported that this requires knowledge about the specific requirements of these benefic species, which can only be acquired from species-level data.

Considering all introduced species, few species were represented as effective (< 14%) or partially effective (the third). Among the all introduced species (for intentionally introduced and unknown), 13.79 and 34.48% were considered as effective and partially effective, respectively (Fig. 6). Aphelinidae, Encyrtidae, Eulophidae, Coccinellidae, and Phytoseiidae families, include effective species and partially effective. The families like Encyrtidae (3.44%), Eulophidae (3.44%), Platygasteridae (3.44%), and Coccinellidae (10.34%) present some introduced species that failed to control their targeted pests. This is the case of the S. petiolatus and C. phylocnistoides, major parasitoids Eulophidae of P. citrella (Abbassi et al., 1999; Smaili et al. 1999b, 2001; Rizqi et al. 2003 and Abbassi 2010). Species that have failed to control target pests are important. This is the case of A. citricola and Q. citrella. 2 introduced parasitoids species of P. citrella (Abbassi et al. 1997; Smaili et al. 2001; Rizqi et al. 2003; Reina and LaSalle 2004). Encyrtidae, Braconidae, and Coccinellidae presented some introduced species that are to control their target pests are considered as unknown (< 4%).

Considering introduced species used in the term of classical biological control only, 20 and 40% of the species are considered as very effective or partially effective, respectively; versus the species with low efficacy (15%) or failed to control their target pests (15%) (Fig. 7). It is important to note that when the beneficial species are specific, the effectiveness in controlling targeted pests is always very high. In Moroccan conditions, this is true (after repeated release) in the case of parasitoid A. melinus against A. aurantii (El Kaoutari et al. 2004; Jebbor et al. 2008; Smaili 2009; Abbassi 2010); for R. cardinalis against I. purchasi (Nafid et al., 2010) and for the parasitoids S. petiolatus and C. phylocnistoides against P. citrella (Rizqi et al. 2003). The importance of this specificity becomes more apparent at every new introduction of the citrus whitefly. This is the case of C. noacki against A. floccosus; E. debachi against P. myricae and finally E. lohrensis against D. citri (Abbassi 2010). This specificity has been reported in several countries (Orlinski and Bassova 1996; Argov et al. 1999; Fadamiro et al. 2008). The good plant protection practices consist of the use of specific beneficial insects to control a target pest, based mainly on the phylogenetic knowledge of the parasitoid and its host (Malausa et al. 2008).

**Parasitoids and/or predators in Morocco in relation with EPPO database**

Further information on parasitoids and/or predators species in relation to the EPPO database, like date reported; date reported in Morocco; and first references to Morocco are shown in Tables 1 and 2. Some of these introduced parasitoids and/or predators and their uses in biological control were not mentioned by many international scientist web-database. This is the case of E. nigropictus identified during 2010 or N. peyerimhoffi and D. catalinae mentioned in 2011 (Smaili et al. 2013). It is the same for database of EPPO, particularly for old introductions of natural enemies (e.g., A. spiniferus and Q. citrella) and new introduction (e.g., N. californicus and A. swirskii) (Smaili 2017). This could probably be explained by the scarcity of their population and their low impact on the target pests (low importance), and maybe also the absence of international publications mentioning their impact on main citrus pests in Morocco.

**Conclusion**

Among the beneficial insects (parasitoids and/or predators) identified in citrus groves of Morocco, only a small fraction of the introduced species found, attack armored scale and aphids. Considering only introduced species used in classical biological control context, many species

![Fig. 6 Percentage of presence (%) of introduced species according to their efficacy in Moroccan citrus orchard (N = 29)](image-url)
are considered effective or partially effective. This review article may facilitate future investigations on parasitoids and predators species to increase their potential in citrus orchards and to enhance the role of biological control agent (e.g., augmentative biological control) and the integrated pest management services, particularly for citrus in the Mediterranean regions.

Abbreviations
Ha: Hectare; ASPAM: Moroccan Association of Citrus producers;
IPM: Integrated pest management; USA: United States of America;
INRA: National Agricultural Research Institute; e.g.: Example; N: Total number;
Para.: Parasitoid; Pred.: Predator

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Authors’ contributions
SMC: Conceptualization, data curation, monitoring-compilation-investigation, methodology, interpretation of data; writing-original draft, writing-review-editing, supervision, and critical revision of the manuscript for important intellectual content. BJA: Methodology, interpretation of data; investigation, writing-review-editing, and critical revision of the manuscript for important intellectual content. BA: Methodology, interpretation of data, supervision, and critical revision of the manuscript for important intellectual content. All authors read and approved the final manuscript.

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Availability of data and materials
The data and material of this manuscript are available on reasonable request.

Ethics approval and consent to participate
We agree to all concerned regulations. This article does not contain any studies with human participants or animals or human tissue.

Consent for publication
We agree to publish this scientific paper at the EJBPC. The manuscript has not been published in completely or in part elsewhere.

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Authors’ contributions
SMC: Conceptualization, data curation, monitoring-compilation-investigation, methodology, interpretation of data; writing-original draft, writing-review-editing, supervision, and critical revision of the manuscript for important intellectual content. BJA: Methodology, interpretation of data; investigation, writing-review-editing, and critical revision of the manuscript for important intellectual content. BA: Methodology, interpretation of data, supervision, and critical revision of the manuscript for important intellectual content. All authors read and approved the final manuscript.

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