sciendo

Hellenic Plant Protection Journal **18:** 50-68, 2025
DOI 10.2478/hppj-2025-0006

REVIEW ARTICLE

Eco-friendly alternatives to chemical pest control for sustainable citrus groves in Morocco

M.C. Smaili[1,*], N. Haddad[1], O. Chetto[1], H. Benyahia[1] and H. Benaouda[1]

Summary The citrus industry plays a significant socio-economic role in the Moroccan national economy. Seventy phytophagous insect, mite and snail species have been recorded from citrus orchards in Morocco. However, only a few are considered major or occasional pests and may cause economic damage warranting control. Using broad-spectrum pesticides to control insects and mites has resulted in several problems due to human, environmental and eco-toxicological concerns. This paper provides an overview of practical and preventative eco-friendly alternatives to chemical pest control for sustainable citrus groves in Morocco. The role of appropriate biological and cultural methods and safe chemical control in controlling citrus pests is discussed.

Additional keywords: alternative methods, citrus, insects, mites, Morocco, snails

Introduction

In Morocco, the citrus industry plays a significant socio-economic role in the national economy with a citrus area of about 91243 ha and an average annual production of 2 million tons, and it is a source of foreign revenue (Bennani-Smires, 2025). It also generates employment for 13000 families with 32 million workdays per year, including harvesting in orchards, packing and processing and many other related industries. About 70 phytophagous insects, mites and snail species have been recorded on citrus trees in Morocco (Smaili, 2020; Smaili *et al.*, 2022, 2024, 2025; Mrabti *et al.*, 2024; Haddad *et al.*, 2025). However, only a few of them are considered major pests exceeding the economic threshold and warranting reduction or elimination (Smaili, 2016; Garcia-Marí *et al.*, 2018). Some are occasional pests, below the economic threshold with the potential to become major pests, depending on the climate during the year and the citrus growing area and may thus cause economic loss. The California red scale, *Aonidiella aurantii* Maskell (Hemiptera: Diaspididae), is a major pest in most citrus growing areas throughout the country. It is found on leaves, twigs and fruit on all citrus cultivars. Sometimes, high populations and severe infestations may cause dieback of twigs and branches. Heavy feeding by this scale can reduce the quality of the fruit and the vigor of the citrus tree. Chaff scale *Parlatoria pergandii* Comstock (Hemiptera: Diaspididae) is another key citrus armored scale in northern Morocco (Sidi Kacem province). In many cases, the pest reached the economic injury level causing heavy infestation of fruit. Heavy feeding by this scale can reduce the quality of the fruit but severe infestation on twigs can also be recorded as damaging. This is also the case of the black parlatoria scales *Parlatoria ziziphi* Lucas (Hemiptera: Diaspididae), particularly in orange tree orchards where the pest occasionally reaches the economic injury level during autumn. A severe infestation can occur on leaves, twigs, branches and fruits. Occasional pests may include *Lepidosaphes beckii* Newman (Hemiptera: Diaspididae) found in the Gharb region (North-Western Morocco) and *Lepidosaphes gloverii* Packard (Hemiptera: Diaspididae) in Berkane (North-Estern Morocco). In some years, high infestations of these species are

[1] National Institute of Agricultural Research, Regional Center of Agricultural Research of Kenitra, 14000 Kenitra Morocco.
[*] Corresponding author: csmaili@yahoo.fr

recorded on leaves, twigs, branches and fruit.

The Mediterranean fruit fly, *Ceratitis capitata* Wiedemann (Diptera: Tephritidae) (medfly), causes considerable economic losses for citrus growers in Morocco. The presence of punctures, eggs or larvae in citrus fruit reduces their commercial value. Indeed, the occurrence of this pest in Mediterranean areas remains the main obstacle to the export of fresh citrus fruit to the major world markets (i.e. Japan). The apparent losses from the medfly in citrus orchards may be further exacerbated in fruit packing houses if fruits with eggs and young larvae remain unnoticed during the sorting process. Moreover, many thrips species are associated with citrus trees in Morocco, but few of them are key pests in citrus groves (Smaili *et al.*, 2018a; Smaili, 2019). Feeding by thrips larvae, i.e *Scirtothrips* sp. and *Pezothrips kellyanus* Bagnall (Thysanoptera: Thripidae), causes discolored rinds located under the calyces of the young citrus fruitlets and their expansion across the surface of the fruit lead to discolored damage zones during the fruit development process. While such feeding damage does not affect the physico-chemical characteristics of the fruit, it significantly reduces its market value due to consumer and export rejection of the affected fruit. The oriental red mite (Citrus brown mite) *Eutetranychus orientalis* Klein (Acari: Tetranychidae), the two spotted spider mite *Tetranychus urticae* Koch (Acari: Tetranychidae), and the citrus red mite *Panonychus citri* McGregor (Acarina: Tetranychidae) are the key pest mites in Moroccan citrus orchards. *Tetranychus urticae* is a highly polyphagous mite species but *E. orientalis* generally occurs, mainly in citrus trees despite being reported as a polyphagous species. These mite species can be found in citrus orchards between end of April and early January. Currently, *P. citri* population always remains below the economic threshold, while *T. urticae* and *E. orientalis* populations can reach high levels on leaves and fruit. The snail species *Theba pisana* O.F. Müller, *Eobania vermiculata* O.F. Müller, *Helix aspersa* aspersa Müller and *Helix aspersa* maxima Müller (Gastropoda, Helicidae) are all "major pests" in Moroccan citrus groves, mainly in the Gharb region (Smaili, 2013). Once present, the snails consume the fruit epicarp and cause significant damage, which seriously affects citrus productivity. The scars generated by scale feeding on the fruits also provide a means for fungal and bacterial introduction infection, resulting in fruit decomposition. When environmental conditions are favorable for scale activities (mainly wet conditions), snails may cause considerable economic losses for citrus growers. In addition, at packing stations, fruit bearing scars induced by snails are discarded.

In Morocco insect, mite and snail control in citrus orchards is based mainly on pesticides. Chemical control is primarily used for keeping the damage caused by the pests below the economic injury level. However, this strategy is not always effective in reducing damage to leaves, twigs, and fruit. In addition, management based on broad-spectrum insecticides and miticides may cause pesticide-resistance issues, the resurgence of occasional pests and several undesirable side-effects on beneficial insect and mite species. Many efforts have been made by companies, mainly those exporting fruit, to switch from chemical control to the integrated pest management (IPM) approach in citrus groves with and significant progress including surveys, release of natural enemies and efficient use of registered pesticides, with significant progress. In many cases, the exporting compagnies have certified their orchards according to the standards and requirements of importers of fresh citrus fruit with rigorous control requirements. Currently, several factors have greatly encouraged Moroccan citrus producers to search for sustainable alternative methods to chemicals pesticides: i) the limited number of registered insecticides and miticides after the ban of hazardous products (i.e. chlorpyrifos-methyl and spirodiclofen, respectively) from use in citrus groves in the country; ii) new requirements for importers and local market, related to quality of citrus fruit; iii) a decline in bees associated with chemical pesticides use; iv) climate change and mainly variable temperatures inducing occurrence and increased abundance of some insects and mite pests, and v) a noticeable increasing interest in new alternative methods to chemicals, including biological control and organic methods. Here, we discuss the practical and preventative eco-friendly and alternative methods to chemicals pesticides available for the control of key pests in the frame of sustainable citrus grove management in Morocco.

Materials and Methods

The presented and discussed practical, sustainable, preventative and alternative methods to chemicals pesticides against key pests (i.e. armored scales, thrips, medfly and mites) in Moroccan citrus groves considered i) the authors' experience in applied research and extension services conducting field trials over many years, and ii) published peer-reviewed articles. The review reflects the authors' views on the availability, validity and practical use of the plant protection methods in the citrus groves under Moroccan conditions.

Results and Discussion

In Morocco, chemical pesticides and other alternative methods have been explored in experiments to control many pest species in citrus groves (Abbassi, 1990; Benziane, 2003; Smaili, 2016; Smaili *et al*., 2014, 2016). Here we review and propose several practical and preventative eco-friendly and alternative methods to chemical control of key pests in citrus groves in Morocco. The higher the farmers' acceptance of alternative control methods, the healthier the ecosystem, including the biodiversity of natural enemies of pests (Göldel *et al.,* 2020).

Implementation of biological control

Augmentative biological control

Smaili *et al.* (2020) listed the species richness of parasitoids and predators, including those imported for classical biological control, in citrus orchards in Morocco and how to facilitate near future investigations on their potential use as biocontrol agents. The same authors discussed the effects of these beneficial insect communities on citrus pests and concluded that none of the reported taxa are harmful to crops (based on knowledge to date).

Scales: In Moroccan IPM certified citrus orchards, armored scale control is based mainly on monitoring, threshold and efficient insecticide spraying (Smaili *et al*., 2017, 2022). For biological control of the California red scale, *A. aurantii*, the release of the parasitoids, *Aphytis melinus* DeBach (Hymenoptera Aphelinidae) and *Comperiella bifasciata* Howard (Hymenoptera: Encyrtidae), is of crucial importance (Table 1). In Moroccan citrus groves, *A. melinus* is most effective during the spring and autumn season while *C. bifasciata* complements during the summer and winter season (Abbassi, 1990; Benziane, 2003; Smaili, 2009, 2016). When the total parasitism reaches an appropriate percentage (i.e. >40%), the scale could be kept below the threshold. *Aphytis. melinus* is commercially mass produced in Morocco. Optimization of this parasitoid's mass rearing facilities should be a priority at a large scale under current conditions, while *C. bifasciata* mass rearing facilities, require a small scale in each citrus producing area. Moreover, there are records of very efficient biological control of *A. aurantii* using the parasitoid *A. melinus* during the fruit growing period in Moroccan citrus growing areas (Abbassi, 1990; Benziane, 2003; Smaili, 2009). In citrus groves where *A. melinus* was released at a high number, significantly higher parasitism rates of *A. aurantii* (64%) were recorded and compared to parasitism rates in control citrus groves (<5%) (Smaili *et al*., unpublished data). This level of parasitism cannot be reached in many Moroccan citrus regions considering the effect of chemical use, where shifting to IPM may increase parasitism of *A. aurantii* using *A. melinus* releases.

Table 1. Suggested doses, number and periods of release of appropriate biological control agents to control main pests in citrus orchards in Morocco.

Species	Targeted main pests	Relased number	Frequency	Periods
Aphytis melinus	*Aonidiella aurantii*	80000 - 120000/ha	1-2	April-May and October
Comperiella bifasciata	*Aonidiella aurantii*	80000 - 100000/ha	1-2	April-June/ September-November
Aphytis hispanicus	*Parlatoria pergandii*	40000 - 80000/ha	1-2	April-May and October
Aphytis lepidosaphis	*Lepidosaphes beckii*	40000 - 80000/ha	1-2	April-May and October
Orius laevigatus	*Scirtothrips* sp., *Pezothrips kellyanus*	80000 - 100000/ha (10 - 20/m^2 infested trees)	1-2	March-June/ September-October
Amblyseius swirskii	*Scirtothrips* sp., *Pezothrips kellyanus*	100000 - 200000/ha (10 - 40/m^2 infested trees)	1-2	March-June/ September-October
	Panonychus citri, *Tetranychus urticae*, *Eutetranychus orientalis*	100000 - 200000/ha	1-2	April-June/ September-October
Phytoseiulus persimilis	*Panonychus citri*, *Tetranychus urticae*, *Eutetranychus orientalis*	80000 - 200000/ha	1-2	April-June/ September-October
Neoseiulus californicus	*Panonychus citri*, *Tetranychus urticae*, *Eutetranychus orientalis*	80000 - 200000/ha	1-2	April-June/ September-October
Stethorus punctillum	*Panonychus citri*, *Tetranychus urticae*, *Eutetranychus orientalis*	10 - 40 /m^2 infested trees	1-2	April-June/ September-October
Chrysoperla carnea	*Panonychus citri*, *Tetranychus urticae*, *Eutetranychus orientalis*	60000 - 80000/ha 100 larvae/small area	1-2	April-June/ September-October

Concerning the chaff scale *P. pergandii* and the purple scale *L. beckii* release of the main parasitoids *Aphytis hispanicus* Mercet (Hymenoptera: Aphelinidae) and *Aphytis lepidosaphes* Compere (Hymenoptera: Aphelinidae), respectively, play an important role in reducing their populations (Smaili, 2016; FAO, 2024). Currently, these two parasitoids, acting alone, are not effective in controlling these scales. In Morocco, *A. swirskii* release, may be used to control crawlers of the armored scales, *A. aurantii* and *P. pergandii*, in April–May and May-June, respectively, to avoid the settling in of crawlers on new fruit; thus, offering the possibility of reducing fruit infestation during the growing stage.

Mites and thrips: Citrus mites are mainly controlled by predatory mite and insect species, such as phytoseiid mites, lacewings and coccinellids (Smaili, 2020), while thrips are controlled by predatory mites that can easily occupy, the calyx of citrus fruit during fruit development (zones that are preferred by thrips). In this respect, many species can be released in the Moroccan citrus groves to control mites (Smaili *et al.*, 2022). In addition, for mites, the use of a *Beauveria bassiana* (Balsamo) Vuillemin - based product is proposed as foliar treatment when the mite densities are still low (personal research results). This was also the case, after a sudden heavy infestation of fruit by mites (i.e. clementine), just before harvest (mid-October and November).

Neoseiulus californicus McGregor (Mesostigmata: Phytoseiidae), a specialized predator of spider mites and effective predator against phytophagous mites (Pascua *et al.*, 2020) is promoted for biological control against mites in Morocco (Smaili *et al.*, 2020). Abad-Moyano *et al.* (2010a) reported that this phytoseiid mite may be able to persist in the crop when spider mite prey is scarce and addition of pollen could improve *T. urticae* biological control by this beneficial species. However, a study by Abad-Moyano *et al.* (2010b) reports the intraguild effect after the release of *Phytoseiulus persimilis* Athias-Henriot (Acarina: Phytoseiidae) and *N. californicus* and their interaction with *E. stipulatus* due to the occurrence of the spider mite webbing, in Valencia (Spain), a region similar to many Moroccan citrus area productions. In Morocco, release of *N. californicus*, to control mites, especially *T. urticae*, would be recommended, when *E. stipulatus* abundance is low, to avoid the lethal effect of intraguild predation.

Amblyseius swirskii Athias-Henriot (Acari: Phytoseiidae), a generalist predator, is effective against several species of pests, including mites, i.e. *E. orientalis* (Yalçin *et al.*, 2023) and thrips (Arthurs *et al.*, 2009). In Spain, the augmentative release of *A. swirskii* has been reported as an efficient biological control approach against the Asian citrus psyllid, *Diaphorina citri* Kuwayama (Hemiptera: Liviidae) in citrus (Juan-Blasco *et al.*, 2012).

Phytoseiulus persimilis is a specialized predator of *Tetranychus* species (McMurtry and Croft, 1997) which has been proved highly effective in reducing the damage level caused by mites on citrus plants (Abad-Moyano *et al.*, 2010a; Fadamiro *et al.*, 2013). However, in Morocco, the abundance of this predator is very low in citrus orchards and its resident populations could not maintain *E. orientalis* and *T. urticae* population at acceptable levels (Smaili, 2009; Smaili *et al.*, 2020, 2022). It has been suggested that, when *E. stipulatus* abundance is scarce, at least one release of this predator is required per year to enhance its abundance and confrontation with the mite prey.

In practice, releases of predator species with known positive biocontrol value (Table 1) are preferable, such as *Stethorus punctillum* Weise (Coleoptera: Coccinellidae), both larvae and adult, against spider mites, on the first located infested trees before mite populations reach the threshold, might be useful (Smaili *et al.*, 2022); *Chrysoperla carnea* Stephens (Neuroptera: Chrysopidae) against spider mites during April-June and September October; *Orius laevigatus* Fieber (Hemiptera: Anthocoridae) against thrips; the generalist *C. carnea* and the specialist *S. punctillum* might provide additional effects to reduce the abundance of the spider mites.

Mediterranean fruit fly: In Morocco, medfly control is based mainly on insecticides (i.e. bait application technique and cover spraying) and mass trapping. Inundative biological control of the medfly using entomopathogenic nematodes (Gazit *et al.*, 2000), has not been sufficiently assessed in the citrus orchards in Morocco to date. However, in Greece, field trials of four species of entomopathogenic nematodes, *Heterorhabditis bacteriophora* Poinar, *H. downesi* Stock (Rhabditida: Heterorhabditidae), *Steinernema carpocapsae* Weiser and *S. feltiae* (Rhabditida: Steinernematidae), used at different doses on medfly (Kapranas *et al.*, 2023) have shown that during the early and late season, a single application of *S. feltiae* on soil at a rate 2.5×10^6 *S. feltiae*/m^2, can result in best pest control with 65 % adult medfly suppression. The pathogenicity of the entomopathogenic fungi, *B. bassiana* and *Metarhi-*

zium anisopliae (Metschnikoff) Sorokin to medfly was studied in Morocco (Imoulan *et al.*, 2011). Foliar treatments with entomopathogenic fungi during one or two months before harvest might be a suitable method with added value to control medfly in addition to mass trapping.

Spinosad has been successfully used against a large number of insects worldwide, mainly to control medfly (Chueca *et al.*, 2007; Smaili *et al.*, 2016; Abdel-Razek and Abd-Elgawad, 2021). In Morocco, spinosad is registered and applied to control a wide variety of species in citrus, including thrips species and medfly. Although a bioinsecticide, spinosad can have side effects on natural enemies (D'Ávila *et al.*, 2018). Therefore, we suggest using it mainly for medfly control and only during the two weeks before harvest when i.e., using mass trapping techniques may be not sufficient to control medfly in large scale citrus groves. However, regarding medfly control, using a selected mass trapping method via integrating mainly fruit resistance and spinosad-based bait appat technique seem to enhance medfly control (Smaili *et al.*, 2016, 2018b).

Mass rearing of biocontrol agents for inoculative biological control

Setting up small or larger scale mass rearing facilities of the key natural enemies to provide/purchase to growers for release in citrus groves may assist in inoculative control but this might be difficult in a of low or middle-income country such as Morocco. Thus, very few beneficial species are mass produced in mass rearing facilities as reported by Smaili *et al*. (2013, 2020; Table 1). In this context, we consider that the inoculative biological control approach may be possible at two levels in the citrus groves of the country:

Small-scale mass rearing of known efficient beneficial species: Smaili *et al.* (2013, 2020) report information on the beneficial species under artificial mass-rearing and release in commercial citrus orchards in Morocco. In practice, it is better to focus on the predator species with known positive biocontrol impact in the citrus groves.

Collect and release natural enemies: Collecting the natural enemies from spontaneously growing weeds and releasing them (with or without small-scale mass rearing) is a common approach used in several citrus groves in Morocco. This is the case with *S. punctillum*, which can be manipulated by collecting its population from spontaneous herbaceous growth areas and easily moved and released on known mite infested citrus plots. This is also the case with several beneficial species, i.e. *Citrostichus phyllocnistoides* Narayanan (Hymenoptera: Eulophidae); *Adalia decempunctata* L. *Coccinella septempunctata* L.; *Rodolia cardinalis* Mulsant (Coleoptera: Coccinellidae); (Smaili *et al.*, 1999a, 2014; Rizqi *et al.*, 2003; Nia *et al.*, 2008; Nafide *et al.*, 2010). This method might be useful in controlling citrus pests in small citrus production areas.

Conservation biological control

The conservation approach could be achieved by managing habitat and food for natural enemies and adjacent shelters/refuges near to citrus groves as well as selective use of pesticides. Smaili *et al.* (2010, 2020) report 105 species of natural enemies in citrus in Morocco and discuss their potential to enhance biocontrol services in citrus groves. Their conservation is important. For instance, to contribute to the reduction of armored scale populations in citrus orchards, conservation practices are encouraged for *A. melinus*, *C. bifasciata, A. hispanicus, Cybocephalus* spp. and *C. bipustulatus* (for armored scales). For mites, conservation should target to *P. persimilis, E. stipulatus*, *Typhlodromus phialatus* Athias-Henriot, *Euseius rubinia* (Acarida: Phytoseiidae), *S. punctillum, C. carnea, Nephus* sp., *Scymnus* sp. (Smaili *et al.*, 2013, 2020). Predator species that attack *T. urticae* and *P. citri* mite populations may also be potential predators against *E. orientalis*. For instance, *E. stipulatus* is the most common and abundant phytoseiid and widespread species in most Moroccan citrus orchards, especially clementine orchards, where the use of chemicals is minimal (Smaili *et al.*, 2013, 2020). Its prey is limited to certain spider mite species, in particular *P. citri* (also *T. urticae* and *E. orientalis*) in Morocco (Smaili *et al.*, 2020, 2022). Compared to other phytoseiid mites, *E. stipulatus* is the species most tolerant to pesticides.

Conservation of potential natural enemies against thrips could include the predators: *O. laevigatus*, *Orius* sp., *Franklinothrips* sp., *Aeolothrips* sp., *Haplothrips* sp., phytoseiids, the lacewings *C. carnea*, *Contwenzia psociformis* Curt (Neuroptera: Coniopterygidae). However, despite the presence of these predators (i.e. *Aeolothrips* sp. and *Haplothrips* sp.) in high abundance in citrus trees, they do not seem to play an important role in limiting thrips populations (Smaili *et al.*, 2018a; Smaili, 2019).

Management of groundcover vegetation to conserve natural enemies

Habitat management involving the manipulation of farmland vegetation can exert direct suppressive effects on pests and promote natural enemies. Indeed, tillage between rows in the groves may affect abundance and diversity of insects, mites, snails, and natural enemies (Gurr *et al.*, 2017). The occurrence and diversity of spontaneous herbaceous plant growth play an important role in conserving beneficial species (Beaumelle *et al.*, 2021). Their inter-row presence constitutes an important source of food and a favorable habitat for their continuous activities during the year. Pollen, nectar, alternative prey, and shelter are the major resources provided by plants to natural enemies (Gurr *et al.*, 2017). On the other hand, mowing and tillage of the grass between citrus rows might have major side effects, i.e. increase of mite and snail abundance in tree canopies. Aguilar-Fenollosa *et al.* (2011a, b) discuss how a conservation approach by means of groundcover offers an interesting alternative to chemical control of the two-spotted spider mite, a key pest of clementine mandarins in Spain. The occurrence of mite populations in spontaneous herbaceous plant growth is considered a primary source of infestation of many pests and may be a source of significant continuous re-infestation of citrus trees throughout the year. If no appropriate measures are taken, their population will move to the trees from the groundcover and their abundance will increase in the canopy, thus exceeding the economic threshold.

Knowledge of the nature of the spontaneous herbaceous plant growth is the first step to an appropriate control of mites (i.e. *T. urticae* and *P. citri*). To not affect citrus trees development, the cutting of spontaneous plant growth under the tree is recommended. However, groundcover-based spontaneous plant growth at 20 cm in height between the citrus rows is preferable as it will provide a conservation habitat, food and shelter for natural enemies. In some cases (i.e. absence of the main predators) the weeds between the citrus rows seem not to contribute to reducing *E. orientalis* populations on the trees (Smaili *et al.*, 2017, 2022). However, these trials carried out mainly in the Gharb area, showed that *T. urtica* abundance on citrus trees is lower in groves with Poaceae as cover vegetation than a mixture of dicotyledonous and monocotyledonous weeds. Several studies have shown that phytoseiid abundance and diversity are strongly influenced by the management of the spontaneous herbaceous plant growth located between the citrus rows in comparison to the bare soil (Aguilar-Fenollosa *et al.*, 2011a). Suitable groundcover management is among the most important cultural practices to regulate the abundance level and movement mainly of thrips and mite species in citrus orchards (Aguilar-Fenollosa *et al.*, 2011a,b; Aguilar-Fenollosa and Jacas, 2013).

Preservation of Poaceae: In Morocco, cultural practices deliberately encouraging and preserving *Poaceae* host plants between rows seems to be a promising solution for reducing the abundance of *T. urticae* and *P. citri* mites on citrus trees. This practice might also increase phytoseiid abundance in the citrus groves.

Deliberate sowing of tall fescue: *Festuca* *arundinacea* Schreber (Poaceae) is widely distributed as a native grass in temperate and cool climates throughout Europe, North Africa, and West and Central Asia (Gibson and Newman, 2001). In Spain, Aguilar-Fenollosa *et al.* (2011b) provide evidence that both bottom-up and top-down regulation processes related to the nature of the ground cover affected the tetranychid mite populations in citrus orchards. The authors concluded that best results were obtained with the ground cover of *F. arundinacea*, which offered a better regulation of both *P. citri* and *T. urticae* than either bare soil or the resident wild cover. In Morocco, planting strips (length; 10-60 m; width: 0.2-1 m) of *F. arundinacea* between the rows of citrus trees might be a new technique to reduce abundance of mites and other insects such as thrips.

The "Predator in First" approach as a preventative biological control technique

The 'predator in first' approach is a new promising approach to control thrips (Kumar *et al.,* 2020; Pasquier *et al.*, 2021). It is a prophylactic control strategy that aims to establish predators before the appearance of pests in an agro-ecosystem (Kumar *et al.,* 2015). This method involves the release of specific predators on un-infested seedlings before transplanting in the field (Kumar *et al.,* 2020; Pasquier *et al.*, 2021). In Morocco, use of host plants, which are already recognized as being attractive to thrips (i.e. peppers, tomatoes, etc.) and which were previously infested at the nursery by an effective predator (i.e. *A. swirskii* or *O. laevigatus*), is preferable. These plants should be planted along the edges of citrus orchards where the predator may become established before the onset of the citrus flowering. This offers the possibility of limiting adult thrips abundance in these plants which will be responsible for the production of the two main first generations of this pest.

'Farming with alternative pollinators' approach as preventative biological control

The 'farming with alternative pollinators' approach (FAP) uses the habitat enhancement zone in fields to attract pollinators and natural enemies i.e., by marketable habitat enhancement plants (MHEPs), so the land serves simultaneously ecological purposes and the interest of farmers to gain income from their entire land. This is one of the advantages of FAP in comparison to wildflower strips, which cause opportunity costs and are not scalable in low- and middle-income countries (Christmann, 2020). FAP measures impacts of habitat enhancement on diversity and abundance of flower visitors, natural enemies, and pests, and net income. In smallholder FAP fields, the main crop is planted in the central area (75%) and 4-12 MHEP cover together 25% of the field area (Christmann and Aw-Hassan, 2012). The mix of MHEP with different colors of petals and different flower types (i.e. oil seeds, spices, food crops, medicinal plants) prolong the flowering period significantly and substantially (Christmann *et al.*, 2021). The 25%-zone hosts also low-cost materials for nesting- and water support. Farmers using FAP approach noticed higher income, an increase in pollinator diversity and abundance, lower pest abundance, and also the impact on the quality of many crops (Christmann *et al.*, 2021, 2022). In FAP plots, predators and parasitoids diversity and abundance were increased (Christmann *et al.*, 2021, 2025). Pollen as food source might help to sustain a population of several beneficial species, i.e. Phytoseiidae mites (Pascua *et al.*, 2020). Combining FAP and augmentative biological control using natural enemies might be another alternative method with additive effects. Such management offers the possibility of increasing both parasitism and predation levels, mainly for armored scale populations during the settling process of crawlers during the fruit growing period.

Use of host plants as traps to reduce thrips population

Commercial host plants of thrips may be used as traps in citrus groves to reduce or to control, i.e., thrips. This strategy can be used at two levels for thrips control.

Host plants deliberately planted as trap

crops: Host plants are planted on the edges of orchards (and not inside the groves as strips) before the onset of the flowering period of citrus trees. Once abundance of thrips becomes significantly higher in trap plants, their suppression via effective and registered products will prevent their moving towards fruits of the citrus canopy. While the trap plant approach might not provide sufficient control to targeted pests, this technique may have positive effects when combined with other techniques.

Spontaneous plant growth managed as host plants: The nature of the spontaneous herbaceous plants around the citrus groves must be known. In our experience, at the edges of citrus orchards, white or yellow flowers of wild plants that precede the blooming phase of citrus trees should be eliminated to prevent thrips populations from moving from those plants to citrus trees. Generally, flowers located in the groundcover are attractive to pests and act as trap crops, mainly for thrips populations. However, during the flowering phase of the spontaneous plants, it is suggested to apply foliar application with an efficient and safe product to reduce their population abundance before they move to the citrus tree (Smaili *et al.*, 2025).

Implementation of cultural practices

Cultivars with host fruit resistance to reduce medfly infestation

Physico-chemical parameters of citrus fruit such as acidity, maturity index, and firmness may determine the level of fruit punctures by medfly, mainly for clementine cultivars (Aluja and Mangan, 2008; Papachristos and Papadopoulos, 2009). Trails conducted in the Gharb region revealed a significant correlation between clementine cultivars and medfly fruit punctures (Smaili *et al.*, 2016, 2017, 2018b), concluding that the main factors affecting the punctures were fruit firmness and maturity index. In Morocco, this use of physico-chemical characteristics of fruit during fruit infestation susceptibility (i.e. two months before harvesting clementine varieties) could contribute to decreasing the number of insecticide applications for the control of this key pest.

Cultural practices improving health and productivity of trees

Water stress combined with heavy infestation by *T. urticae* in citrus trees can result in leaf drop (Aucejo-Romero *et al.*, 2004). Proper irrigation of citrus trees is therefore important.

To achieve an appropriate fruit size, thinning during fruit set is an important cultural practice, mainly for clementine, *Citrus reticulata* var. Bruno, reducing the burden of the tree by eliminating fruits with small size. This practice may also be used to reduce fruit infested with thrips populations. During this phase, it is recommended to target small fruits that can be: i) sensitive to subsequent attacks by thrips, ii) susceptible to host thrips larvae, iii/ close to symptomatic fruits that are visible or not (Smaili *et al.*, 2018a).

Schöneberg *et al.* (2020) reported that pruning small fruit crop canopies alters the microclimate, which in turn may influence insect pest activity. Tree pruning also enables ventilation of the interior and the creation of several openings, so-called external windows. This practice not only enables penetration of bright solar rays to the most shaded places of the tree, but also ventilation of the different external parts of the foliage thus creating an unfavorable environment for different stages of pests, mainly armored scales and mites, hindering their activity in the leaves.

Behavior manipulation for pest control

Behavioral manipulation of a pest includes methods that interfere with their natural behavior and activity (Foster and Harris, 1997). This behavior can be influenced by cues for perception, such as visual, chemical, tactile stimuli, acoustic and vibration waves (Greenfeld, 2016).

Pest monitoring based on growing degree days

Citrus pest activities may vary from one year to another and also within the same year, depending on weather, mainly temperature variation. For citrus trees grown in large areas, monitoring of insects, mainly scale diaspines and thrips species, by collection of samples (leaves, twigs, and fruits) and the beating method (flowers, fruit-set, and fruits, shoots), can be very laborious, time consuming and cost intensive. Using growing degree days between male flights may be a tool to predict the suitable time for application of chemical sprays or the release of natural enemies to control *A. aurantii* (Campos-Rivela *et al.*, 2012). In northern Spain, the same authors, working with Valencia *Citrus sinensis* Osbeck trees, found a thermal constant (615 degree days) across the different development instars of *A. aurantii*, using the lower developmental threshold (11.7°C). Citrus producers can use this technique to identify the male peak flights or the maximum crawler abundance peaks in citrus orchards.

Mating disruption

The mating disruption technique, using synthetically produced chemicals in the orchards to confuse males and limit their ability to perceive calling females, may be effective in controlling *A. aurantii* (Vacas *et al.*, 2009; Leonard, 2019). In Spain, mating disruption techniques using pheromone dispensers reduced the number of downgraded fruits by 60% to 70% (Vacas *et al.*, 2010). In Morocco, the mating disruption technique is a biotechnical method that uses diffusers installed in a citrus orchard at approximately 250 to 300 diffusers/ha. This method is very specific and has no adverse effect on beneficial species and the environment. Such a method can be valid only for isolated orchards, i.e. mandarin Afourer plots. A combination of the mating disruption technique and augmentative biological control using a parasitoid (i.e. *A. melinus*) may be efficient at reducing the occurrence of crawlers on the fruit during the citrus fruit set and can be used to control armored scale between April and June (depending to the zone in the country).

Enhanced mass trapping technology to control medfly and thrips

Mass trapping technology (MTT) can be used to control many citrus pests. In Spain, a combined approach of mass trapping and other methods is used to control mainly populations of medfly (Martinez-Ferrer *et al.*, 2012). In Morocco, producing high fruit quality requires the combination of selected control methods against the targeted pests, mainly medfly and thrips (i.e. *Scirtothrips* sp.). To avoid or to reduce broad-spectrum insecticides, including organophosphate, use of MTT to control *C. capitata* (since 2014) (Smaili *et al.*, 2016) and thrips (since 2021) has increased in Morocco as a new suitable alternative control method to chemical methods. However, during some years, mainly during autumn, despite the use of the MTT, *C. capitata* control method fails to consistently provide sufficient control, particularly in years with high adult medfly abundance in citrus groves. While MTT use in Moroccan orchards is currently efficient, this method could be considerably improved (profitability/cost) in terms of the chosen attractant and the density, maneuverability and location of the traps used. This might depend on the orchard, the prevailing climate conditions of the year and the destination of the production. A study by Smaili *et al.* (2017, 2018b) showed that high medfly population may require addition of complementary methods to mass trapping to control medfly. The authors concluded that BAT (bait appat technique) based on bioinsecticide and fruit resistance seems to improve medfly control using an efficient mass trapping method. Indeed, a current study by Ben-Yazid *et al.* (2020) confirms this funding. MTT combined with another complementary method (i.e. entomopathogen-based biopesticide) as a support might provide additional effects in controlling such dipteral by reducing punctures on fruits.

First attract and kill approach-based mass trapping for thrips species, showed little or non-lasting success coupled with high costs (Smaili, 2019, 2020). However, field trials conducted in lemon citrus, during 2024 (spring and autumnal) and 2025 (spring), showed that installation of 1–2 yellow sticky traps (baited with or without pheromone)/4 trees, proved effective in mass trapping of *Scirtothrips* sp. by reducing fruit infestation under large scale field conditions (Smaili *et al.*, 2025). Therefore, set up of yellow sticky traps-based MTT at suggested rate are recommended for management of this thrips in citrus orchards.

Sterile insect technique to reduce medfly infestation

The sterile insect technique (SIT) is an environmentally friendly pest control method that involves sterilizing male insects using radiation, and their release in target areas, resulting in lower or no fruit infestation. The SIT can be applied in integration with other control methods against the medfly. Indeed, Morocco recently completed the construction of a new mass-rearing facility to apply the SIT to protect citrus produce (IAEA, 2025). The facility will eventually be capable of producing 130 million sterile medfly per week. which will allow releases to cover approximately 55,000 hectares of citrus growing area (Souss and Oriental areas) (Zouhry *et al.*, 2025). The first releases of sterile males were conducted in September 2024 in 7,000 ha in Ouled Aissa area, Taroudante province.

Alternative substances to chemical pesticides

Water and potassium-soap foliar applications: A strong jet of water can remove insects like aphids and spider mites of plant leaves and stems (Adhikari, 2022). Foliar spraying with high pressure of water can reduce the abundance of mite populations by mechanical effect, disrupting their activities and making the environment unsuitable for them, especially on the exposed fruit and leaf surface (Smaili *et al.*, 2022). It applies to all spider mites, especially for *E. orientalis*, that try to settle on the exposed leaves and fruit surface; a single application is sufficient to increase the time between at least two peaks of abundance on leaves and fruit. Aqueous solution of potassium soap might provide additional impact in reducing mite population (Smaili *et al.*, 2022).

Kaolin: Smaili *et al.* (2014, 2016) studied the effects of foliar application with kaolin Under Moroccan conditions and reported that kaolin (99.9 %) protects citrus shoots and fruits against aphids and medfly, suggesting its integration in the IPM approach against citrus pests. Recently, Salerno *et al.* (2020) studied the mechanism of action of kaolin particle film and how this natural product can contribute to developing future physical control barriers against pest insects. We propose kaolin-based foliar application throughout the year and just before the fruit harvesting period to avoid any pesticide residues remaining after foliar application.

Botanical products: Botanical extracts have emerged as another safe alternative to chemical pesticides as biodegradable and with little side effects on natural enemies. Guleria and Tiku (2009) and Ngegba *et al.* (2022) studied the effect of derived plant-based pesticides extracted from many plants, such as neem (from *Azadirachta indica* A. Juss), *Capsicum frutescens* L., pyrethrin (from flower *Chrysanthemum cinerariaefolium);* pyrethrum (from *Tanacetum cinerariifolium*), tobacco (from *Nicotiana tabacum* L.), rotenone (from *Derris* spp., *Lonchocarpus* spp. and *Tephrosia* spp.), sabadilla (from *Schoenocaulon* spp. (*S. officinale*)), thyme essential oil (from *Thymus vulgaris L., Thymus* spp.) and other products. Guleria and Tiku (2009) reported the efficiency of these botanical products and concluded that since botanical insecticides are fast acting and degrade rapidly in sunlight and moisture, frequent foliar applications during precise timing might be necessary. To date, only neem is the main botanical product used for pest control in practice in Morocco. A review of Isman (2020) showed that insecticides based on pyrethrum and neem (azadirachtin) are high performing botanical products, due to the introduction of new jurisdictions. Nevertheless, it must be noted that some botanical components, i.e. essential oils, may have a harmful effect on natural enemies. In our opinion, botanical insecticides need to be carefully selected in relation to possible adverse effects on beneficial species and pollinators, but they must be used more frequently as alternative pest control methods to chemicals in the near future.

Control of snails

In Morocco, methaldehyde-based formulation, a chemical molluscicide, is typically applied to control snails in citrus orchards, mainly *T. pisana*. Indeed, *T. pisana* is the only snail species with known biological cycle in citrus groves in the country: spawning periods, the structure of the populations as well as the movements of this snail between citrus trees and the groundcover. Using this biological data, an appropriate control method could be used to block adults from laying their eggs (i.e. collection of adults or using safe chemical control) during fall and when snail adults located in the tree canopy try to reach ground cover. This measure may decrease the snail population abundance during the following spring.

Physical – cultural control

Hand collection is an important method that enables collecting a high number of snails located on groundcover between the rows of citrus trees (Smaili, 2013; Smaili *et al.*, 2017). The snail collection may continue throughout the year, focusing on snails with large diameter (shell width) and the young stages. In practice, snail collection should be a permanent activity and not limited to occasional collectors who only collect snail species with commercial interest (i.e. *E. vermiculata* and not *T. pisana*). We suggest keeping spontaneous herbaceous plants, when available, between rows as groundcover (not under canopy as this will drive a high snail population to move to the citrus trees) for a long period, during autumn and spring, the seasons with high humidity (and frequent rains, in some years). During autumn, especially for *T. pisana*, when the population becomes active with a high risk of infesting citrus fruit, collecting on canopy is possible only for medium-sized trees as well as for young plantations. Unfortunately, this technique cannot be used in trees with large canopy which would induce high costs and difficult operation during collection.

New trap

The Regional Center of Agricultural Research of Kenitra, Morocco (National Institute of Agricultural Research) developed a new trap for keeping snails out of citrus orchards in 2011 for the first time in the country (Smaili, 2013). The potential use of this trap for keeping snails out (i.e. *T. pisana*) has been recognized as a promising new technology and snail control method in many citrus orchards in the country, mainly in the Gharb region (Smaili, 2017). These traps, settled in the trunk (at least 40-60 cm from soil), catch the snails trying to climb up the tree during their movement from the soil to the tree canopy. Especially for young plantations and small trees, trap use is suggested during February and May (early June in some years). The traps may be improved by using nets with enamel instead of plastic. When the citrus growing area is very large, this method combined with other techniques such as continuous survey and physical control, cover ground management, and biological control, might have an additional positive effect on snails.

Biological control

Duck have been used as a non-chemical control method against the golden apple snail *Pomacea canaliculata* Lamarck (Architaenioglossa: Ampullariidae) in wetland rice ecosystems in China (Liang *et al.*, 2013). Currently, duck production is a common activity in rural Moroccan households to enhance farmers' income as well as food security. Ducks can be used as preventative pest control in the context of natural biological control approaches to reduce snail abundance in citrus orchards. A group made up of 10-20 individuals placed early in the morning in an infested area when snails are active, can provide an appropriate method to reduce snail populations. However, when the citrus area production is very large, a consistent survey of the ducks is necessary to prevent their disappearance.

Integrated Pest Management

Efficient use of selective, appropriate, safe and effective chemical products are major components of the IPM approach which provides an alternative to conventional chemical control. The Economic threshold and the Economic injury level are the basis for pest control decision making, mainly for pesticide applications in IPM citrus groves, while reflecting economic considerations (Pascual-Ruiz *et al.*, 2014). In addition, two key aspects for the success of chemical spraying to control scales are the developmental stages that predominate in the population and the time of invasion by crawlers of the citrus fruitlets (Rodrigo *et al.*, 2004).

In Moroccan citrus groves, the economic threshold may depend on many parameters, mainly biology and population dynamics of the targeted key pest, parameters used for monitoring and the nature of market access and safe product exports. To avoid the settling of a maximum of new crawlers of armored scales (i.e. California red scale), under Moroccan conditions, Smaili *et al.* (2017) discussed various technologies of pest control of armored scales in citrus trees and concluded that many parameters need to be assessed. According to the authors during the process of invading fruit between fruitlets and the fruit growing period, these parameters include i) monitoring of male flight numbers in pheromone-based sticky traps and ii) moving of first crawlers, percentage of highly susceptible armored scales (mainly crawlers, first, second stage and female first instar), iii) percentage of newly infested fruit by crawler during fruitlets period. For each region, the economic threshold must be established before any decision is taken regarding pesticide application. Also, small trials should be performed to ensure and implement the economic threshold. For instance, *E. orientalis* causes discolouration of leaves and fruit where it feeds, while *T. urticae* displays chlorotic spots on the leaves and scars on the fruit. In Morocco, noticeable damage is observed on leaves and later on fruit when the mite abundance increases and reaches 10% of infested leaves (i.e. 10-16 moving nymphs or 4 females of *E. orientalis*/leaf; 3 moving *T. urticae*/leaf) (Smaili *et al.*, 2022). In Spain, chemical control measures are recommended once population of *Eutetranychus* spp. reach the economic injury level of 20% of leaves infested during August to October (Monzó *et al.*, 2016).

Conservation of beneficial species through judicious chemical control

Efficient use of safe pesticides is one of the major components of the IPM approach as well as the knowledge of the effects of pesticides on biological control agents (Bozhgani *et al.*, 2018). Some insecticides and miticides, including insect growth regulators, are toxic and harmful (direct and indirect impact) for one category of beneficial species but safe and selective for another. Biondi *et al.* (2012) discussed the acute and sublethal toxicity of 14 pesticides on the adults of the generalist predator *O. laevigatus* under laboratory conditions and concluded that these pesticides greatly differed in their toxicity, both in terms of lethal and sub-lethal effects, as well as in their persistence. Broad-spectrum insecticides have direct and indirect effects on spider mites that can promote mite outbreaks (Rebek *et al.*, 2012). This is the case in Morocco with, i.e. control of *Phyllocnistis citrella* Stainton (Lepidoptera: Gracillariidae) and medfly with pyrethroid insecticides that can cause a resurgence of mites (Smaili *et al.*, 1999b). Similar cases were reported with neonicotinoids that are applied as foliar application to control several pests in the citrus orchards leading to a resurgence of cottony cushion scale *Icerya purchasi* Maskel (Hemiptera: Monophlebidae) (Smaili, personal observations).

According to a study by Torres and Bueno (2018), choosing a selective insecticide or selectively applying one is an important decision for conserving natural enemies. Basically, reducing pesticide interventions means applying an IPM approach, with appropriate application of chemicals only when needed via efficient monitoring of pest population thresholds and efficient product use. Efficient pesticide use intends to avoid broad-spectrum application with persistent compounds and to consider priority and selection of pesticides with high direct and indirect toxicity on pests but without any side effects on natural enemies. Several research studies have provided evidence that the use of many products, including hazardous pesticides, may have side effects on a range of non-target insects, including natural enemies, pollinators, and soil-beneficial insects (Biondi *et al*., 2012; Goulson, 2013; Serrão *et al*., 2022). In Morocco, in the context of good phytosanitary practices, safe pesticides are selected and carefully applied only when needed in commercial citrus orchards certified for Good Agricultural Practices (Smaili *et al*., 2017, 2018b).

Conclusion

In view of the non-target effects of chemical pest control methods and their costs, new approaches are required for sustainable citrus production Morocco. More appropriate solutions using cultural and biological control methods to reduce chemical control could contribute to this direction as well as suitable alternative substances to chemical pesticides. However, in citrus orchards, these alternative pest control approaches may have low direct control effects in the short term compared to conventional chemicals pesticides, due to the need for technical support for application, additional inputs and their variable efficacy.

Conflict of interest
The authors declare no conflict of interest.

No funding was received for conducting this study. We use the support provided by the Regional Center of Agricultural Research of Kenitra (INRA-Morocco). The authors wish to express their gratitude to Qureshi J.A. (University of Florida/IFAS, Florida, USA) for their helpful critiques and suggestions on the manuscript. We also thank reviewers for helpful comments and suggestions on the manuscript.

Literature Cited

Abad-Moyano, R., Pina, T., Perez-Panades, J., Carbonell, E.A. and Urbaneja, A. 2010a. Efficacy of *Neoseiulus californicus* and *Phytoseiulus persimilis* in suppression of *Tetranychus urticae* in young clementine plants. *Experimental and Applied Acarology,* 50: 317–328.

Abad-Moyano, R., Urbaneja, A. and Schausberger, P. 2010b. Intraguild interactions between *Euseius stipulatus* and the candidate biocontrol agents of *Tetranychus urticae* in Spanish clementine orchards: *Phytoseiulus persimilis* and *Neoseiulus californicus. Experimental and Applied Acarology,* 50: 23–34.

Abbassi, M. 1990. *Contribution à la lutte biologique contre les homoptères, ravageurs des citrus au Maroc*: Faculté Sciences Agronomique Gembloux, Gembloux (BL), 191 pp. PhD Thesis.

Abdel-Razek, A.S. and Abd-Elgawad, M.M.M. 2021. Spinosad combined with entomopathogenic nematode for biocontrol of the Mediterranean fruit fly (*Ceratitis capitata* [Wiedemann]) on citrus. *Egyptian Journal of Biological Pest Control,* 31: 112.

Adhikari, U. 2022. Insect pest management: Mechanical and physical techniques. *Reviews in Food & Agriculture,* 3: 48–53.

Aguilar-Fenollosa, E. and Jacas, J.A. 2013. Effect of ground cover management on Thysanoptera (thrips) in clementine mandarin orchards. *Journal of Pest Science,* 86: 469–481.

Aguilar-Fenollosa, E., Pascual-Ruiz, S., Hurtado, M.A. and Jacas, J.A. 2011a. Efficacy and economics of ground cover management as a conservation biological control strategy against *Tetranychus urticae* in clementine mandarin orchards. *Crop Protection,* 30: 1328–1333.

Aguilar-Fenollosa, E., Ibáñez-Gual, M.V., Pascual-Ruiz, S., Hurtado, M.A. and Jacas, J.A. 2011b. Effect of ground-cover management on spider mites and their phytoseiid natural enemies in clementine mandarin orchards (I): Bottom-up regulation mechanisms. *Biological Control,* 59: 158–170.

Aluja, M. and Mangan, R.L. 2008. Fruit Fly (Diptera: Tephritidae) host status determination: critical conceptual, methodological and regulatory considerations. *Annual Review of Entomology,* 53: 473–502.

Arthurs, S., McKenzie, C.L., Chen, J., Dogramaci, M., Brennan, M., Houben, K. and Osborne, L. 2009. Evaluation of *Neoseiulus cucumeris* and *Amblyseius swirskii* (Acari: Phytoseiidae) as biological control agents of chilli thrips, *Scirtothrips dorsalis* (Thysanoptera: Thripidae) on pepper. *Biological Control,* 49: 91–96.

Aucejo-Romero, S., Gómez-Cadenas, A. and Jacas-Miret, J.A. 2004. Effects of NaCl-stressed citrus plants on life-history parameters of *Tetranychus urticae* (Acari: Tetranychidae). *Experimental and Applied Acarology*, 33: 55–68.

Beaumelle, L., Auriol, A., Grasset, M., Pavy, A., Thiéry, D. and Rusch, A. 2021. Benefits of increased cover crop diversity for predators and biological pest control depend on the landscape context. *Ecological Solutions and Evidence,* 2: e12086.

Bennani-Smires, K. 2025. Mise à jour des données du patrimoine agrumicole national. In: MarocCitrus (ed.). Recueil des résumes des présentations. *Congrès national des agrumes,* 1ére édition, 13-15 Mai 2025, Marrakech, Maroc. p: 8. (In French).

Ben-Yazid, J., Chafik, Z., Bousamid, A., Bibi, I. and Kharmach, E. 2020. Field efficacy of IPM with mass trapping technique to control the Medfly "*Ceratitis capitata*" (Diptera: Tephritidae) in citrus orchards of Moulouya perimeter in North-East of Morocco. *Journal of Entomology and Zoology Studies,* 8: 626–631.

Benziane, T. 2003. De la lutte dirigée à la lutte intégrée contre les principaux ravageurs en vergers d agrumes au Maroc : cas de la région du Gharb. Thèse de Doctorat Es-Sciences, Université Moulay Ismail, Meknes, Maroc, 206 pp.

Biondi, A., Desneux, N., Siscaro, G. and Zappalà, L. 2012. Using organic-certified rather than synthetic pesticides may not be safer for biological control agents: Selectivity and side effects of 14 pesticides on the predator *Orius laevigatus*. Chemosphere, 87: 803–812.

Bozhgani, N.S.S., Kheradmand, K. and Talebi, A.A. 2018. The effects of spirotetramat on the demographic parameters of *Neoseiulus californicus* (Phytoseiidae). *Systematic and Applied Acarology,* 23: 1952–1964.

Campos-Rivela, J.M., Martínez-Ferrer., M.T. and Fibla-Queralt, J .M. 2012. Population dynamics and seasonal trend of California red scale (*Aonidiella aurantii* Maskell) in citrus in Northern Spain. *Spanish Journal of Agricultural Research,* 10: 198–208.

Chueca, P., Montón, H., Ripollés, J.L., Castañera, P., Moltó, E. and Urbaneja, A. 2007. Spinosad bait treatments as alternative to malathion to control the Mediterranean fruit fly *Ceratitis capitata* (Diptera: Tephritidae) in the Mediterranean Basin*, Journal of Pest Science,* 32: 407–411.

Christmann, S. 2020. Pollinator protection strategies must be feasible for all nations. *Nature Ecology & Evolution,* 4: 896–897.

Christmann, S. and Aw-Hassan A.A. 2012. Farming with alternative pollinators (FAP)-An overlooked win-win-strategy for climate change adaptation. *Agriculture, Ecosystems and Environment,* 161: 161–164.

Christman, S., Bencharki, Y., Anougmar, S., Rasmont, P., Smaili, M.C., Tsivelikas, A. and Aw-Hassan, A. 2021. Farming with Alternative Pollinators benefits pollinators, natural enemies, and yields, and offers transformative change to agriculture. *Scientific Reports,* 11: 18206.

Christmann, S., Aw-Hassan, A., Güler, A.Y., Sarisu, H.C., Bernard, M., Smaili, M.C. and Tsivelikas, A. 2022. Two enabling factors for farmer-driven pollinator protection in low- and middle-income countries. *International Journal of Agricultural Sustainability,* 20: 54–67.

Christmann, S., Bencharki, Y., Sentil, A., Smaili, M. C., Ssymank, A., Tsivelikas, A., and Aw-Hassan, A. (2025). Advantages of marketable habitat enhancement plants for pollinator protection notably in low-and middle-income countries. *Journal of Environmental Management*, 389, 126088.

D'Ávila, V.A., Barbosa, W.F., Guedes, R.N.C. and Cutler, G.C. 2018. Effects of spinosad, imidacloprid, and lambda-cyhalothrin on survival, parasitism, and reproduction of the aphid parasitoid *Aphidius colemani*. *Journal of Economic Entomology,* 111: 1096–1103.

Fadamiro, H.Y., Akotsen-Mensah, C., Xiao, Y and Anikwe, J. 2013. Field evaluation of predacious mites (Acari: Phytoseiidae) for biological control of citrus red mite, *Panonychus citri* (Trombidiformes: Tetranychidae). *Florida Entomologist,* 96: 80–91.

FAO, 2024. Guide de bonnes pratiques de gestion des principaux ravageurs et maladies des agrumes au Maroc. Rabat, Maroc. pp 44.

Foster, S.P and Harris, M.O. 1997. Behavioral manipulation methods for insect pest-management. *Annual Review of Entomology,* 42: 123–46.

Garcia-Marí, F., Ammad, F., Forti, A.J., Aroun, M.E.F., Belguendouz, R., Benfekih, L., Bounaceur, F., Chermiti, B., Conti, F., Fernandes, JE, Carlos-Franco, J, Giannakou, I, Kapaxidi, E, Kormpi, M, Markellou, E, Ramdani, B, Razi, S, Satar, S, Siscaro, G, Smaili, M.C., Soares, C., Tzortzakakis, E and Varikou, K. 2018. Questionnaire on Current situation of Citrus Pests and Diseases in the Mediterranean basin. *IOBC Bull*. 132: 2–5.

Gazit, Y., Rossler, Y. and Glazer, I. 2000. Evaluation of entomopathogenic nematodes for the control of Mediterranean fruit fly (Diptera: Tephritidae). *Biocontrol Science and Technology,* 10: 157–164.

Gibson, D.G. and Newman, J.A. 2001. *Festuca arundinacea* Schreber (*F. elatior* L. ssp. *arundinacea* (Schreber) Hackel). *Journal of Ecology,* 89: 304–324.

Göldel, B., Lemic, D. and Bažok, R. 2020. Alternatives to synthetic insecticides in the control of the colorado potato beetle (*Leptinotarsa decemlineata* Say) and their environmental benefits. *Agriculture*, 10: 6.

Goulson, D. 2013. An overview of the environmental risks posed by neonicotinoid insecticides. *Journal of Applied Ecology,* 50: 977–987.

Greenfeld, M.D. 2016. Evolution of acoustic communication in insects. In insect hearing- Handbook of Auditory Research (eds. Pollack G S, Mason A C, Popper A N and Fay R R), Springer, Berlin, Springer, Cham., 17–47.

Guleria, S. and Tiku, A. 2009. Botanicals in Pest Management: Current Status and Future Perspectives. In: Peshin, R., Dhawan, A.K. (eds) *Integrated Pest Management: Innovation-Development Process* Volume 1: 317–329.

Gurr, G.M., Wratten, S.D., Landis, D.A. and You, M. 2017. Habitat management to suppress pest populations: progress and prospects. *Annual Review of Entomology,* 62: 91–109.

Haddad, N., Ait-Baddou, S., Benkirane, R. and Smaili, M.C. 2025. The citrus leafhopper *Penthimiola bella* (Stål) (Hemiptera: Cicadellidae), infesting avocado and citrus trees in Morocco. *EPPO Bulletin*, 55(1): 13093.

IAEA (2025) International day of plant health: Suppressing fruit flies in Africa. Available at https://www.iaea.org/newscenter/news.

Imoulan, A., Alaoui, A. and El Meziane, A. 2011. Natural occurrence of soil-borne entomopathogenic fungi in the Moroccan endemic forest of *Argania spinosa* and their pathogenicity to *Ceratitis capitata*. *World Journal of Microbiology and Biotechnology,* 27: 2619–2628.

Isman, M.B. 2020. Botanical insecticides in the twenty-first century-Fulfilling their promise?. *Annual Review of Entomology,* 65: 233–249.

Juan-Blasco, M.J.A., Qureshi, A., Urbaneja, A. and Stansly, P.A. 2012. Predatory Mite, *Amblyseius swirskii* (Acari: Phytoseiidae), for biological control of Asian citrus psyllid, *Diaphorina citri* (Hemiptera: Psyllidae). *Florida Entomologist,* 95: 543–551.

Kapranas. A., Chronopoulou, A., Peters, A., Antonatos, S., Lytra, I., Milonas, P. and Papachristos, D. 2023. Early and off-season biological control of medfly with entomopathogenic nematodes: from laboratory experiments to successful field trials. *Biological Control,* 179: 105173.

Kumar, V., Xiao, Y., McKenzie, C.L. and Osborne, L.S. 2015. Early establishment of the phytoseiid mite *Amblyseius swirskii* (Acari: Phytoseiidae) on pepper seedlings in a Predator-in-First approach. *Experimental and Applied Acarology,* 65: 465–81.

Kumar, V., Mehra, L., McKenzie, C.L. and Osborne, L.S. 2020. "Predator-In-First": A preemptive biological control strategy for sustainable management of pepper pests in Florida. *Sustainability,* 12: 7816.

Leonard, J.T. 2019. Evaluation of pheromone mating disruption for California red scale control in commercial California citrus. Thesis, December 2019, Faculty of California Polytechnic State University, San Luis Obispo, USA. pp 98.

Liang, K., Zhang, J.E., Fang, L., Zhao, B., Luoa, M., Parajulic, P. and Ouyang, Y. 2013. The biological control of *Pomacea canaliculata* population by rice-duck mutualism in paddy fields. *Biocontrol Science and Technology,* 23: 674–690.

Martinez-Ferrer, M.T., Campos, J.M. and Fibla, J.M. 2012. Field efficacy of *Ceratitis capitata* (Diptera: Tephritidae) mass trapping technique on clementine groves in Spain. *Journal of Applied Entomology,* 136: 181–190.

McMurtry, J.A and Croft, B.A 1997. Life-styles of phytoseiid mites and their roles in biological control. *Annual Review of Entomology,* 42: 291–321.

Monzó, C.C., Bouvet Juan, P.R., Alonso, M. and Urbaneja, A. 2016. Control químico del ácaro de Texas, *Eutetranychus banksi*, en cítricos. *Levante Agrícola,* 431: 126–134.

Mrabti, I., Haddad, N., Watson, G.W., Brhadda, N., Ziri, R. and Smaili, M.C. 2024. Pyriform scale, *Protopulvinaria pyriformis* (Cockerell, 1894) (Hemiptera: Coccidae), infesting citrus trees in Morocco. *EPPO Bulletin,* 54: 95–103.

Nafide, M., Boutaleb-Joutei, A., Mazih, A. and Rizqi, A. 2010. Research of substitute products for the control of cottony cushion scale *Icerya purchasi* Maskell (1878) (Hemiptera : Margarodidae) on citrus in Morocco and role of vedalia beetle *Rodolia cardinalis* Mulsant (Coleoptera: Coccinellidae). In: *Abstracts of the meeting working group "Integrated Control in Citrus Fruit Crops*, Agadir (Morocco), 1-3 March.

Ngegba, P.M., Cui, G., Khalid, M.Z. and Zhong, G. 2022. Use of botanical pesticides in agriculture as an alternative to synthetic pesticides. *Agriculture*, 12: 600.

Nia, M., Bouchakour, M. and Hanich, M. 2008. Utilisation de la coccinelle *Stethorus* spp. (Coleoptera Coccinellidae) comme moyen de contrôle de *Panonychus citri* (Acarina: Tetranychidae). Paper presented at the symposium *"Symposium Méditérranée sur la Protection Phytosanitaire des Agrumes"*, Rabat (Maroc), 911 Juin.

Papachristos, D.P. and Papadopoulos, N. 2009. Are citrus species favorable hosts for the Mediterranean fruit fly? A demographic perspective. *Entomologia Experimentalis et Applicata,* 132: 1–12.

Pascua, M.S., Rocca, M., Greco, N. and De Clercq, P. 2020. *Typha angustifolia* L. pollen as an alternative food for the predatory mite *Neoseiulus californicus* (McGregor) (Acari: Phytoseiidae). *Systematic and Applied Acarology,* 25: 51–62.

Pasquier, A., Monticelli, L.S., Moreau, A., Kaltenbach, B., Chabot, C., Andrieux, T., Ferrero, M. and Vercken, E. 2021. A promising "Predator-In-First

Strategy" to control Western corn rootworm population in maize fields. *Agronomy*, 11: 1984.

Pascual-Ruiz, S., Aguilar-Fenollosa, E., Ibanez-Gual, V., Hurtado-Ruiz, M.A., Martınez-Ferrer, M.T. and Jacas, J.A. 2014. Economic threshold for *Tetranychus urticae* (Acari: Tetranychidae) in clementine mandarins *Citrus clementina*. *Experimental & applied acarology,* 62: 337-362.

Rebek, E.J., Frank, S.D., Royer, T.A. and Bogran, C.E. 2012. Alternatives to chemical control of insect pests'. In: Soloneski S. and Larramendy M. eds. Insecticides-basic and other applications. pp. 171-196. InTech, 2012. 282 pp.

Rizqi, A., Nia, M., Abbassi, M. and Rochd, A. 2003. Establishment of exotic parasitoides of citrus leafminer *Phyllocnistis citrella* in citrus groves in Morocco. *IOBC Bulletins,* 26: 1–6.

Rodrigo, M.E., Garcia-Mari, F., Rodriguez-Reina, J.M. and Olmeda, T. 2004. Colonization of growing fruit by the armored scales *Lepidosaphes beckii, Parlatoria pergandii* and *Aonidiella aurantii* (Hom.: Diaspididae). *Journal of Applied Entomology,* 128: 569–575.

Salerno, G., Rebora, M., Kovalev, A., Gorb E. and Gorb, S. 2020. Kaolin nano-powder effect on insect attachment ability. *Journal of Pest Science,* 93: 315–327.

Schöneberg, T., Arsenault-Benoit, A., Taylor, C.M., Butler, B.R., Dalton, D.T., Walton, V.M., Petran, A., Rogers, M.A., Diepenbrock, L. M., Burrack, H. J., Leach, H., Van Timmeren, S., Fanning, P.D., Isaacs, R., Gress, B.E., Bolda, M.P., Zalom, F.G., Roubos, C.R., Evans, R.K., Sial, A.K. and Hamby, K.A. 2020. Pruning of small fruit crops can affect habitat suitability for *Drosophila suzukii*. *Agriculture, Ecosystems & Environment,* 294: 106860.

Serrão, J.E., Plata-Rueda, A., Martínez, L.C. and Zanuncio, J.C. 2022. Side-effects of pesticides on non-target insects in agriculture: a mini-review. *The Science of Nature*, 109 (17).

Smaili, M.C. 2020. Integrated pest management approach and other alternative pest control methods to chemical control of citrus pests in Morocco. *Citrus Integrated Pest Management Conference* , ENA April 2020, Meknes Morocco. pp 122. (In French).

Smaili, M.C. 2019. Les thrips sur agrumes au Maroc. In Journée organisée par Morocco Foodex 23 Décembre 2019, Morocco-Foodex Agadir, Agadir Morocco. pp 60. (In French).

Smaili, M.C. 2017. Current pest status and the integrated pest management strategy in the citrus groves in Morocco. Oral presentation. In: Garcia M.F. ed. *Citrus working group meeting on citrus pests, diseases and weeds*, 25-27 September 2017, Valencia, Spain. Available from https://iobc-wprs.org/product/iobc-wprsbulletin-vol-132-2018/ [accessed 30 June 2024].

Smaili, M.C. 2016. *Développement de nouvelles méthodes de luttes alternatives pour une agrumiculture durable dans la région du Gh*arb. Université Moulay Ismail, Faculté des sciences Meknes, Maroc. 210 p. PhD Thesis.

Smaili, M.C. 2013. Snails: Importance, damage and alternative control methods in citrus groves. Meeting organized by the Association of Citrus Producers in Morocco (ASPAM). March 20, 2013 at the Citrus Technical Center, Belksiri, Morocco. 52 pp. (In French).

Smaili, M.C. 2009. Développement de nouvelles stratégies de lutte contre les principaux ravageurs des agrumes dans la région du Gharb : Impact sur la lutte intégrée. Mémoire de Recherche. National Institute of Agricultural Research, Rabat (Morocco). 62 pp.

Smaili, M.C., Benzahra, H., Haddad, N. and Benyahia, H. 2025. Identification des thrips associés aux vergers d'agrumes au Maroc et évaluation des méthodes de luttes alternatives à la lutte chimique sur leurs abondances. In: MarocCitrus (ed.). Recueil des résumes des présentations. *Congrès national des agrumes*, 1ére édition, 13-15 Mai 2025, Marrakech, Maroc. p: 30. (In Frensh).

Smaili, M.C., Mrabti, I., Grijja, H., Watson, G.W., Moghaddam, M. and Ziri, R. 2024. Florida red scale, *Chrysomphalus aonidum* (Linnaeus, 1758) (Hemiptera: Diaspididae) in Morocco, infesting citrus orchards and an avocado tree. *EPPO Bulletin*, 54(2): 204–211.

Smaili, M.C., Rouaissi, M., Haddad, N., Afechtal, M., Benyahia, H. and Benaouda, H. 2022. Seasonal trends of *Eutetranychus orientalis* (klein) in Moroccan citrus groves: does cultural practices can enhance IPM package service for controlling this tetranychid mite. In: ICC and ISHS eds. *Reframing citriculture: Better connections for future,* Book of abstract, 6-11 November 2022, Mersin, Turkey: 182 pp.

Smaili, M.C., Boutaleb, J.A. and Blenzar, A. 2020. Beneficial insect community of Moroccan citrus groves: assessment of their potential to enhance biocontrol services. *Egyptian Journal of Biological Pest Control*, 30:47.

Smaili, M.C., Benyahia, H. and Kabbage, T. 2018a. Invasion des populations du thrips *Pezothrips kellyanus* (Thysanoptera : Thripidae) sur différentes variétés d'agrumes dans la région du Souss-Massa. *Agriculture du Maghreb*, 114: 82–85.

Smaili, M.C., Rouissi, M., Bakri, A., El Kraa, L. and Fadli, M. 2018b. Host Susceptibility of Citrus to *Ceratitis capitata* (Diptera: Tephritidae): Does physicochemical characteristics of the fruit influence the IPM strategy in the citrus groves in Morocco. In: INIA ed. The *IV International Symposium on Citrus biotechnology*, book abstract, 1^{6th} - 1^{8th} April 2018, Montevideo Uruguay. 86 pp.

Smaili, M.C., Rouissi, M., Bakri, A., Blenzar, A. and Fadli, M. 2017. Role of fruit physical and chemical characteristics in the resistance of four Clementine varieties groves to Mediterranean fruit fly punctures in the Gharb area, Morocco: A field trial. In: Garcia-Marí F. ed. *Citrus Working Group Meeting on Citrus pests, Diseases and Weeds*, Book abstract, 25-27 September 2017 Valencia, Spain. 235 pp.

Smaili, M.C., Bakri, A., Gaboune, F., Bouharroud, R. and Blenzar, A. 2016. Compararison of the effect of spinosad, kaolin and protein bait spray on *Ceratitis capitata* (Diptera: Tephritidae) in citrus orchards in the Gharb (Morocco). *International Research Journal of Agricultural Science,* 3: 197–205.

Smaili, M.C., El Ghadraoui, L., Gaboun, F., Benkirane, R. and Blenzar, A. 2014. Impact of some alternative methods to chemical control in controlling aphids (Hemiptera: Sternorrhyncha) and their side effects on natural enemies on young citrus Moroccan groves. *Phytoparasitica,* 42: 421–436.

Smaili, M.C., Abbassi, M., Boutaleb-Joutei, A. and Blenzar, A. 2013. Richesse spécifique des ennemis naturels associés aux vergers d'agrumes au Maroc: Intérêt et implication pour la lutte biologique. *EPPO Bulletin,* 43: 155–166.

Smaili, M.C., Blenzar, A. and Fursch, H. 2010. First record of new species and phenotypes of ladybird (Coleoptera: Coccinellidae) in citrus orchards in Morocco. *Entomologie Faunistique,* 62: 103–107.

Smaili, M.C., Afellah, M., Aarab, A. and Zrida, L. 1999a. Biology and ecology of leafminer and evaluation of parasitoids in Clementine in the Gharb area (Morocco). *Med Fac . Landbouww.*, 64/3a: 121–131.

Smaili, M.C., Afellah, M., Zrida, L. and Aarab, A. 1999b. Trapping and evaluation of the bait spray to control Medfly in citrus in Gharb area (Morocco). *Med Fac. Landboww.*, 64/3a: 69–175.

Torres, J.B. and Bueno, A.D.F. 2018. Conservation biological control using selective insecticides – A valuable tool for IPM. *Biological Control,* 126: 53–64.

Vacas, S., Alfaro, C., Navarro-Llopis, V. and Primo, J. 2009. The first account of the mating disruption technique for the control of California red scale, *Aonidiella aurantii* Maskell (Homoptera: Diaspididae) using new biodegradable dispensers. *Bulletin of Entomological Research,* 99: 415.

Vacas, S., Alfaro, C., Navarro-Llopis, V. and Primo, J. 2010. Mating disruption of California red scale, *Aonidiella aurantii* Maskell (Homoptera: Diaspididae), using biodegradable mesoporous pheromone dispensers. *Pest Management Science,* 66: 745–751.

Yalçin, K., Döker, I. and Kazak, C. 2023. Foraging behaviors of *Amblyseius swirskii* Athias-Henriot and *Euseius scutalis* (Athias-Henriot) (Acari: Phytoseiidae) feed on the invasive pest, *Eutetranychus orientalis* (Klein) (Acari: Tetranychidae). *Egyptian Journal of Biological Pest Control,* 33:18.

Zouhry, H., Zim J., Leghlid, A., Machal, Y. and Adnasse, R. (2025) Projet de lutte contre la cératite par la technique des insectes stériles (TIS). In: MarocCitrus (ed.). Recueil des résumes des présentations. *Congrès national des agrumes*, 1ére édition, 13-15 Mai 2025, Marrakech, Maroc. p: 34. (In French).

Received: 25 November 2024; Accepted: 10 July 2025

ΑΡΘΡΟ ΑΝΑΣΚΟΠΗΣΗΣ

Οικολογικές εναλλακτικές μέθοδοι φυτοπροστασίας στη χημική καταπολέμηση για βιώσιμους οπωρώνες εσπεριδοειδών στο Μαρόκο

M.C. Smaili, N. Haddad, O. Chetto, H. Benyahia και H. Benaouda

Περίληψη Η βιομηχανία των εσπεριδοειδών διαδραματίζει σημαντικό κοινωνικοοικονομικό ρόλο στην εθνική οικονομία του Μαρόκου. Εβδομήντα είδη φυτοφάγων εντόμων, ακάρεων και σαλιγκαριών έχουν καταγραφεί σε εσπεριδοειδώνες στο Μαρόκο. Ωστόσο, μόνο λίγα από αυτά θεωρούνται σοβαροί ή περιστασιακοί εχθροί και ενδέχεται να προκαλέσουν οικονομική ζημία οπότε απαιτούν αντιμετώπιση. Η χρήση ευρέως φάσματος χημικών εντομοκτόνων και ακαρεοκτόνων για την καταπολέμηση εντόμων και ακάρεων έχει δημιουργήσει αρκετά προβλήματα που σχετίζονται με ζητήματα για την ανθρώπινη υγεία, το περιβάλλον και την οικοτοξικότητα. Η παρούσα εργασία παρέχει μια επισκόπηση πρακτικών και προληπτικών, φιλικών προς το περιβάλλον εναλλακτικών λύσεων έναντι της χημικής φυτοπροστασίας, για τη βιώσιμη καλλιέργεια των εσπεριδοειδών στο Μαρόκο. Συζητείται ο ρόλος κατάλληλων βιολογικών και καλλιεργητικών μεθόδων, καθώς και της ασφαλούς χημικής καταπολέμησης, στην αντιμετώπιση των εχθρών των εσπεριδοειδών.

Hellenic Plant Protection Journal **18:** 50-68, 2025