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New mite invasions in citrus in the early years of the 21st century

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Abstract Several mite species commonly attack cultivated citrus around the world. Up to 104 phytophagous species have been reported causing damage to leaves, buds and fruits, but only a dozen can be considered major pests requiring control measures. In recent years, several species have expanded their geographical range primarily due to the great increase in trade and travel worldwide, representing a threat to agriculture in many countries. Three spider mite species (Acari: Tetranychidae) have recently invaded the citrus-growing areas in the Mediterranean region and Latin America. The Oriental red mite, *Eutetranychus orientalis* (Klein), presumably from the Near East, was detected in southern Spain in 2001. The Texas citrus mite, *Eutetranychus banksi* (McGregor), is widely distributed in North, Central and South America. It was first reported in Europe in 1999 on citrus in Portugal; afterwards the mite invaded the citrus orchards in southern Spain. In Latin America, the Hindustan citrus mite, *Schizotetranychus hindustanicus* (Hirst), previously known only from citrus and other host plants in India, was reported causing significant damage to citrus leaves and fruits in Zulia, northwest Venezuela, in the late 1990s. Later, this mite species spread to the southeast being detected on lemon trees in the state of Roraima in northern Brazil in 2008. Whereas damage levels, population dynamics and control measures are relatively well know in the case of Oriental red mite and Texas citrus mite, our knowledge of *S. hindustanicus* is noticeably scant. In the present paper, information on pest status, seasonal trends and natural enemies in invaded areas is provided for these species, together with morphological data useful for identification. Because invasive species may evolve

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during the invasion process, comparison of behavior, damage and management options between native and invaded areas for these species will be useful for understanding the invader's success and their ability to colonize new regions.

Keywords Invasive species · Citrus · *Eutetranychus orientalis* · *Eutetranychus banksi* · *Schizotetranychus hindustanicus* · Tetranychidae

Introduction

Injurious plant mites aroused our interest in the second half of the 20th century because of two important facts. First, several minor, non-economic phytophagous mite species have become key pests on many crops due to the wide use of broad-spectrum agrochemicals, mainly through their adverse effect on natural enemies (McMurtry et al. 1970) or by directly stimulating mite activity and fecundity under sublethal conditions (Luckey 1968). Second, plant mites are very small, ranging from 120 to 400 μm in length, and difficult to detect on or inside the plants that are transported throughout the world. They often become pests in their new environment. Trade and movement of plant material between countries have increased dramatically during the last decades. Many of the most important mite pests can nowadays be considered to be cosmopolitan species. In addition, these pests reveal some biological and behavioral traits that enhance their potential as invasive species and their economic impact (Navia et al. 2007).

Recent decades have seen an explosion of interest in bioinvasions, but only in the last few years have invasive or adventive mites been the target of research to determine their potential distribution and understand the intrinsic properties of these invaders and the relationship between the genetic structure of populations, geographic distribution and response to environmental factors, all of which are essential to developing appropriate and effective management strategies and policies. This has resulted in contributions concerning important pests, such as the cassava green mite, *Mononychellus progresivus* Doreste (Navajas et al. 1994), the coconut mite, *Aceria guerreronis* Keifer (Navia et al. 2005) and the tomato spider mite, *Tetranychus evansi* Baker & Pritchard (Boubou et al. 2011). So far, citrus mite pests have not received much attention from the perspective of invasive species, in spite of the fact that some of them, like the citrus red mite, *Panonychus citri* (McGregor), and the broad mite, *Polyphagotarsonemus latus* (Banks), cause important damage and losses to crops and have spread in the past, colonizing all the productive areas in the world.

Phytophagous citrus mites were reviewed recently by Gerson (2003) and in greater depth by Vacante (2010). The latter author lists a total of 104 phytophagous species causing different levels of damage to leaves, buds and fruits, although only a dozen can be considered as major pests that usually require control measures to be taken. Three of these species have spread in the last years, colonizing new geographical areas in the Mediterranean basin and South America, affecting important citrus-producing countries. In the present paper, we summarize published, new and unpublished information concerning the Oriental red mite (ORM), *Eutetranychus orientalis* (Klein), the Texas citrus mite (TCM), *Eutetranychus banksi* (McGregor), which invaded Spain and Portugal at the beginning of this century, and the Hindustan citrus mite, *Schizotetranychus hindustanicus* (Hirst), previously known from India, that has been reported to cause significant damage and is spreading through Venezuela, Brazil and Colombia. Because invasive species may evolve during the invasion process in response to selection pressures generated in the new environment, comparison of behavior, damage and management options between native and invaded areas for these species will be useful for understanding the invaders' success and their ability to colonize new regions and to generate population outbreaks.

An unexpected event: two *Eutetranychus* species invade Europe simultaneously

The genus *Eutetranychus* Banks contains 33 species distributed mainly through the Afrotropical and Oriental regions (Migeon and Dorkeld 2010). Most of them have a restricted geographical range with ORM (*E. orientalis*) and TCM (*E. banksi*) the most widespread in tropical, subtropical and Mediterranean areas. *E. orientalis* occurs in many countries in Africa and the Near, Middle and Far East below 40° N latitude. Although evidence on its geographic origin is absent, in the last decades the mite has spread from these regions reaching northeast Australia at the beginning of the 1960s (Walter et al. 1995) and the Western Mediterranean 10 years ago (García et al. 2003). *E. banksi* is an American species which occurs from the southern USA to northern Argentina and is reported from most countries in Latin America. Far from the supposed geographic origin in the Americas, TCM has been found in Egypt (Abdel-Shaheed et al. 1973) and more recently in Portugal (Carvalho et al. 1999) and Spain (García et al. 2003).

Surprisingly, both *Eutetranychus* species arrived almost at the same time to the Iberian Peninsula, in southwestern Europe, around the turn of the century. In 1999, Carvalho et al. (1999) reported the presence of TCM on citrus in Portugal. Heavy mite infestations resulted in important damage to citrus in the Algarve region, in south Portugal, where the mite is currently considered a key pest of citrus (Carvalho et al. 1999; Gonçalves et al. 2002). In 2001, Spanish citrus orchards were invaded by ORM and TCM (García et al. 2003). The first specimens of *E. orientalis* were collected and identified from citrus located near Malaga in the midsouth, whereas *E. banksi* was reported from Ayamonte (Huelva province) in citrus orchards in the southwest, near the Portuguese border. The two areas are separated by ca. 300 km. Although there is no evidence of the pathways followed by these mites, it has been suggested that TCM was disseminated via fruit containers which are frequently exchanged between Portuguese and Spanish farmers (García et al. 2003). There is no information explaining how ORM has spread internationally and how it has arrived to Spain, but the movement or trade of mite-infested plant material, most probably from East Mediterranean countries, could explain its arrival.

It seems likely that the first record of the occurrence of ORM and TCM in Spain and Portugal took place soon after their invasion, because citrus growers and technicians quickly realized the presence of the new spider mites on the trees. Species in the genus *Eutetranychus* have distinct characteristics and can be easily separated from other spider mites found on citrus in the Mediterranean region, such as the two-spotted spider mite, *Tetranychus urticae* Koch, and the citrus red mite, *P. citri*. When resting, both females and males have the first two pairs of legs oriented straight forward and the third and fourth pairs straight backward. Females are broadly oval and somewhat flattened, green, orange or brown and with irregular dark green spots dorsally, near the lateral margins (Figs. 1, 2); males are slender, triangular in shape, with noticeable long legs and they are very active on the leaves (Figs. 1, 2). In contrast to *T. urticae*, *Eutetranychus* spp. produce little webbing and usually feed on the upper surface of the leaf. As in the case of *P. citri*, feeding symptoms of *Eutetranychus* consist of discolorations of leaves and fruits. However, morphologically they are distinctly different: *Eutetranychus* spp. lack the dorsal strong tubercles which characterize the dorsal surface in *P. citri*, the mobile forms are brown, orange or green and the eggs are pale or green, flat and disk-shaped; eggs of *P. citri*, are almost spherical, somewhat flattened and with a straight and tapering filament emerging from the top, and the adults and all immature stages are reddish or purple.

Oriental red mite and TCM are very similar morphologically and it is not possible to distinguish them with the naked eye, or by using a hand lense in the field or a stereoscopic microscope in the laboratory. Once the specimens are processed and slide mounted, the two species can be distinguished easily using a compound microscopic. Intraspecific variability in some characteristics, such as the length of dorsal setae, has been reported in both species, and morphological variability depending on the host plant has been

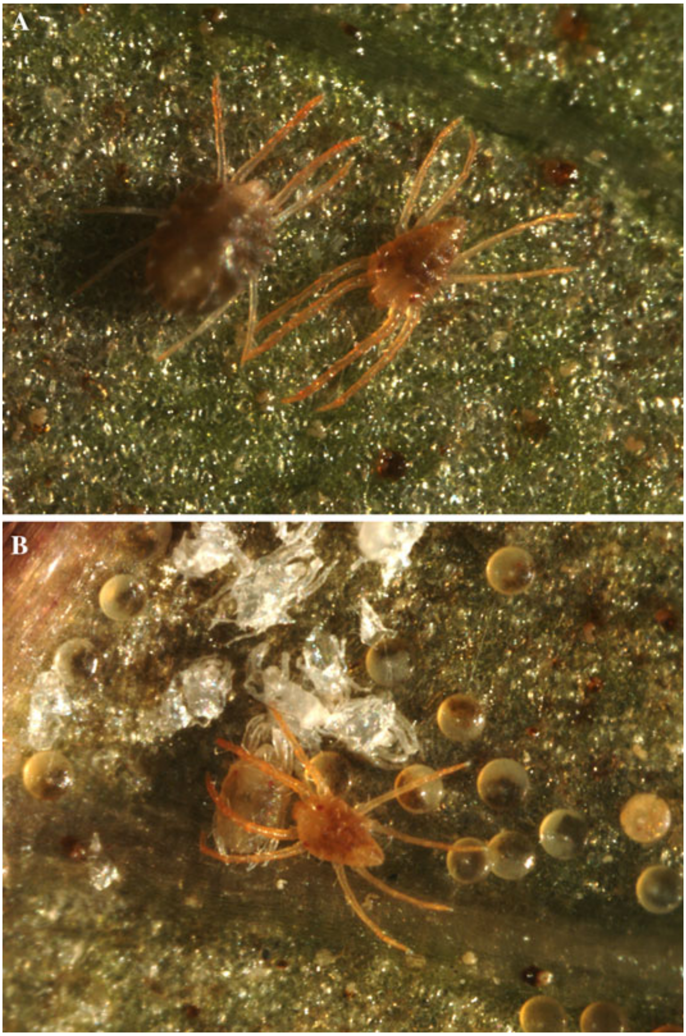

Fig. 1 **a** Female (*left*) and male (*right*) of *Eutetranychus orientalis*. **b** Precopulatory behavior: guarding male on a female teleiochrysalis

Fig. 2 *Eutetranychus banksi*. **a** Females, immature, eggs and exuvia next to the midrib. **b** Male and eggs

demonstrated in *E. banksi* (Mattos and Feres 2009). Reliable characters for species identification include the pattern formed by the setae *e1* and *f1* on the dorsal surface and the number of ventral setae on the coxa of leg II. In *E. orientalis*, the distance between the insertions of the *f1* pair of setae is similar to the distance between the bases of the *e1* pair of setae, the four bases forming a square pattern (Fig. 3a). In *E. banksi*, the *f1* setae are separated by a distance greater than the *e1* setae, the four bases forming a trapezoid pattern (Fig. 3b). In addition, coxa II has only one ventral seta in *E. orientalis*, but two setae in *E. banksi* (Fig. 4); *E. orientalis* has six setae on tibia III and seven on tibia IV, whereas in *E. banksi* tibia III bears 4–5 setae and tibia IV 5–6 setae (Smith-Meyer 1987; Mattos and Feres 2009). Fortunately, these differences can be observed in female specimens, making it unnecessary that males to be present, processed and slide mounted.

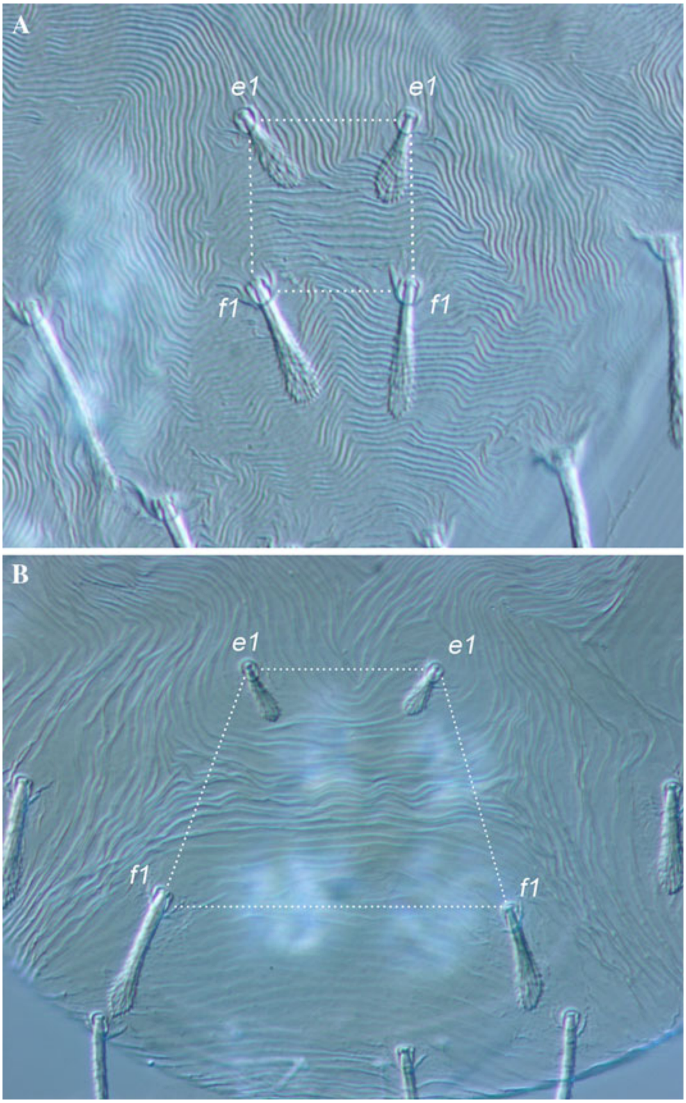

Fig. 3 Pattern formed by the third and fourth pair of dorsocentral hysterosomal setae. **a** *Eutetranychus orientalis* forming a *square*. **b** *Eutetranychus banksi* forming a *trapezoid*

What limits the geographic range of ORM and TCM in invaded regions?

Once established in Spain, both *Eutetranychus* species have undergone a rapid expansion, particularly evident in the case of ORM. Even though TCM spread through the citrus area in the first 2 years, its current distribution seems to be restricted to the Huelva province (Alvarado, personal communication). On the other hand, ORM has expanded its range into the provinces of Cordoba, Seville and Cadiz, and has spread north along the east coast, reaching the southern citrus crops of the Comunidad Valenciana, the main productive citrus region in Spain. There is no evidence of overlap between both geographical ranges.

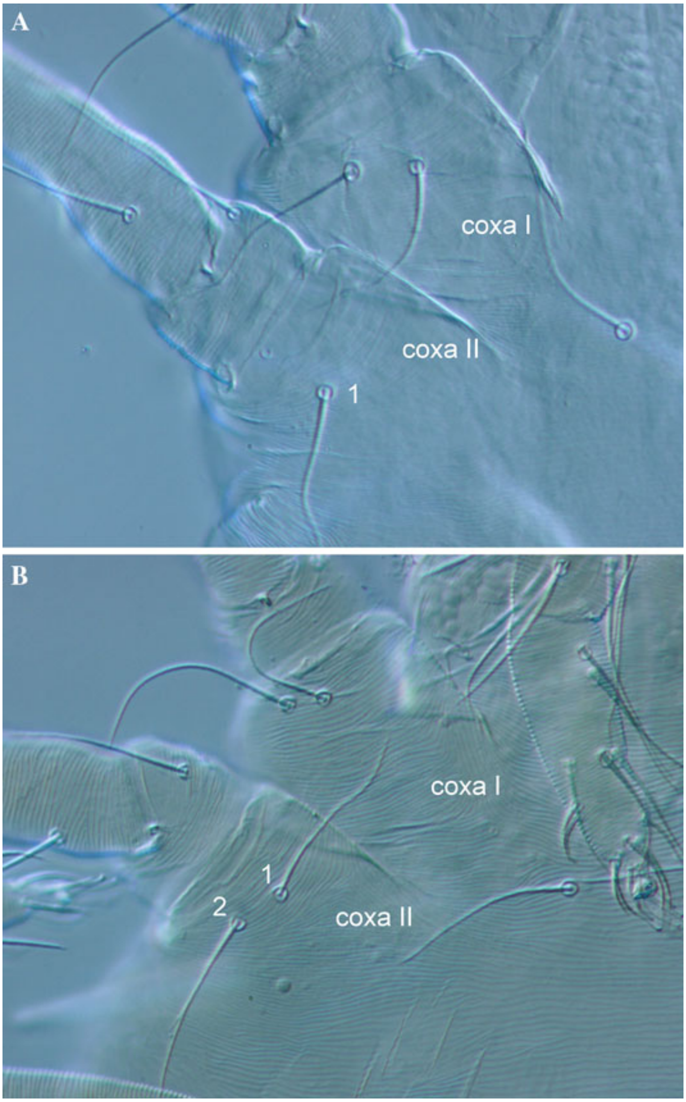

Fig. 4 Number of setae in coxa II. **a** *Eutetranychus orientalis*. **b** *Eutetranychus banksi*

Because ORM and TCM can easily be confused in the field, actually there is an uncertainty about the limits of both distributions.

Why would TCM maintain a restricted distribution while ORM has increased its range in the invaded areas and what factors are limiting their respective geographic ranges? As far as we know, no studies have been done to predict the potential geographic range of these species based on distribution data from the native range and the invaded areas. Several studies have evaluated the influence of temperature on developmental and reproductive biology of these spider mites. The first to provide data on the biology of *E. orientalis* was Bodenheimer (1951). According to this author, mites were able to develop on citrus trees in Israel at 11 °C and reach the adult stage at temperatures ranging between 18 and 30 °C and between 35 and 72 % RH; however, Imani and Shishehbor (2009) found that development occurred at the considerably lower temperature of 8.9 and 6.4 °C for females and males, respectively. The effect of temperature on *E. banksi* was studied on grapefruit (*Citrus* × *paradisi* Macfadyen) leaves in Florida, USA (Childers et al. 1991) and on sweet orange (*Citrus sinensis* [L.] Osbeck) leaves in Mexico (Badii et al. 2003). The mite was able to develop at temperatures ranging from 15 to 35 °C, although immatures did not reach the adult stage at 35 °C in Florida populations. The optimal temperature for development was considered to be about 32 °C. At that temperature the developmental period from egg to adult and the intrinsic rate of increase were quite similar in both studies, ranging from 8.5 to 9.6 days on grapefruit and orange, respectively, and reaching an intrinsic rate of increase of 0.190 females/female/day. All these results suggest that both species can survive, develop and reproduce over a wide range of temperatures, which is in accordance with their vast geographical distribution.

The citrus production area in Spain covers 315.000 ha (MARM 2010) and it extends along the Mediterranean coast from the mouth of river Ebro (about 40° 30′N latitude) to the Portuguese border on the Atlantic coast. Citrus are also cultivated in the Canary Islands, mainly on Tenerife and Gran Canaria, around 28° N latitude. Climatic conditions prevailing over all of this area are of the Mediterranean type, with relatively mild winters and warm summers; similar conditions can be found in southern Portugal. Thus, there are no significant climate differences between these regions and the small range of temperatures between winter and summer permits the maintenance of populations year round.

Information on population dynamics of ORM is very inconclusive, but the mite has been reported to show one or two populational peaks, depending on the country or region of study. Seasonal trends in India, China and Africa reveal the presence of two periods of higher numbers, in May and September, after the rainy season (OEPP/EPPO 1997). Under Mediterranean conditions, the ORM population usually peaks in late summer and fall. This is also the case, for example, in Jordan Valley, where Tanigoshi et al. (1990) reported high mite densities on lemon leaves from midsummer to December, and in South Africa, where infestations appear between February and April, associated with dry weather conditions (Smith-Meyer 1998). In southern Spain, the mite population increases at the end of summer and no differences were observed in populational trends on orange, lemon and clementine trees (Ledesma et al. 2011). We do not know why in some cases population peaks are absent in spring, when other environmental conditions seem to be ideal for development and reproduction. Predatory mites and insects may play an important role at that time in controlling the pest as it has already been demonstrated with other spider mites in citrus (see below). Also, alternative foods for phytoseiids could enhance their efficacy as biocontrol agents by increasing their abundance. It is now accepted that pollen availability improves the performance of some generalist predatory mites (Nomikou et al. 2002; Weintraub et al. 2009), for example, *Euseius* species which are the predominant predatory mites on citrus in the Mediterranean (McMurtry 1977).

Infestations of TCM may occur at any time of the year in Florida, Arizona and California (USA), but usually populations peak twice a year in spring and late fall and sometimes in winter when humidity conditions are low (Childers 1992, 1994). Populations of TCM decline in Florida in summer due to heavier rains and high humidity, whereas in Arizona, very high temperatures in that season seem to be responsible for the low densities (Anonymous 2011). Observations on seasonal trends of TCM in southern Spain and Portugal suggest that the pest reaches its peak densities in late summer and fall, similar to those of ORM and *P. citri*. However, detailed monitoring of this pest has not yet been conducted in these areas.

Another factor that could limit the geographical range of these species in the invaded areas is the availability of appropriate host plants. Both, ORM and TCM, are among the most polyphagous species of spider mites. *E. orientalis* has been reported on 216 plant species belonging to 66 plant families, but most frequently colonizes plants of the family Fabaceae (Leguminosae) (31 spp.) and Rutaceae (13 spp.). *E. banksi* has been found on 101 hosts belonging to 31 plant families, and likewise prefers Fabaceae (18 spp.) and Rutaceae (10 spp.) (Migeon and Dorkeld 2010). However, caution must be taken in analyzing these data, because authors usually have considered a report of the occurrence of a species on a plant as sufficient evidence that the plant is a host of the mite; however, its presence on the plant does not necessarily imply a feeding relationship and/or the ability to complete its development.

There is no detailed information on the host plant range of ORM and TCM in Spain and Portugal. However, their occurrence seems to be more restricted in comparison with that given in the literature, especially in the case of *E. banksi*. In southern Spain, the presence of TCM has only been confirmed on *Citrus* spp., *Ricinus communis* L. (Euphorbiaceae) and *Psoralea bituminosa* L. (Fabaceae) (García et al. 2003; Alvarado, personal communication). ORM occurs in invaded regions on a wide host range which includes not only cultivated citrus, but also other fruits such as figs, pears, peaches, papayas, grapes, avocados, mangos, almonds, guavas and olives, field crops such as cotton, and ornamental plants in gardens and green areas such as *Melia* spp. (Meliaceae) and *Cercis siliquastrum* L. (Fabaceae) (García et al. 2003). In any case, everything appears to indicate that the current limits of the host range of either of these species cannot be attributed to a lack of feeding resources.

On these host plants, both *Eutetranychus* species prefer the upper surface of the leaves, especially the area near the mid-rib of the leaf. In general, their feeding symptoms are similar to those of the citrus red mite, *P. citri* (Jeppson et al. 1975) and confusion may arise from diagnosis of the causal agent based on symptoms only. In Spain, ORM infestations have been reported on oranges, clementines and lemon. Heaviest infestations were reported on lemon, mainly in young plantations (García et al. 2003). Changes in the color of the fruit develop abnormally and with a noticeable delay in comparison with that of non-affected fruits. Trees that have been severely attacked show less vigor and produce smaller fruit (García et al. 2003). Furthermore, trees located on the periphery of the groves, near the roads, are heavily infested. As has been shown in species of phytophagous mites, deposits of dust on the surface of leaves enhance the abundance of mites and the intensity of damage they cause. It has also been observed that most mites are located in the outer canopy, preferably on the side more exposed to the sun.

Finally, there is evidence that competition between closely related species sharing the same habitat may limit their geographic range. Competition among TCM and *P. citri* in Florida citrus has been reported by Childers (1992) and others, where TCM has become the dominant species in the orchards since 1955, displacing the citrus red mite. Even though both spider mite species have been observed in southern Spain to coexist on the same leaf, no conclusions can be drawn on interspecific interactions and possible competitive displacement.

Pest status and management in invaded regions

Chemical control is commonly used to maintain populations of ORM and TCM below economic threshold levels. In Spain, the same acaricides applied on citrus to combat *T. urticae* (always) and *P. citri* (only if necessary) are also recommended against these pests. Márquez et al. (2006) tested the efficacy of several acaricides against ORM on Fine lemon and Valencia-Late orange trees. All the chemicals significantly reduced mite populations, although some differences in efficacy were observed. Dicofol and fenpiroximate were the most effective and persistent ones, propargite showed a good initial impact but its efficacy decreased three weeks later, whereas hexythiazox and etoxazol only reached a good level of efficacy after three weeks. In case of heavy infestations of ORM, plant protection authorities recommend mineral oil, clofentezine, etoxazole, fenazaquin, fenbutatin oxide, fenpiroximate, hexythiazox, propargite, spirodiclofen and tebufenpyrad. In Portugal, treatments with dicofol, fenpyroximate or hexythiazox are recommended against TCM when the mite density exceeds an average of 5–10 mites per leaf (Gonçalves et al. 2002). When treatments are necessary, trees can be sprayed with a combination of an ovicide (hexythiazox) and an adulticide (dicofol). So far, no records of pesticide resistance in any *Eutetranychus* species have been included in the Arthropod Pesticide Resistance Database (APDR 2011).

At this point two problems should be considered. The use of chemical pesticides to control agricultural pests in Europe is changing and is expected to change even more in the near future. After the application of the European Directive 91/414/EEC regulating plant protection product registration and the subsequent revisions, it remains clear that many acaricides that have shown to be effective against spider mites will not be available in the coming years. For instance, hexythiazox, fenbutatin oxide, propargite, amitraz and dicofol most likely will be removed from the market. Furthermore, from an integrated pest management (IPM) perspective the side-effects of these acaricides on predatory mites need to be taken into account. Some of the chemicals, such as hexythiazox and fenbutatin oxide that are considered to be harmless for phytoseiid mites, will be eliminated by the directive 91/414, whereas some of the permitted acaricides such as abamectin, fenpyroximate and tebufenpyrad have detrimental effects on phytoseiids (Ferragut, unpublished data).

Spain is the sixth largest producer of citrus and the largest exporter of seedless tangerines (clementines and mandarins) and lemons (FAO 2008) in the world with most of production going primarily to the fresh market. For this reason, pests that cause cosmetic damage and affect the external appearance of fruits are of great concern because of the considerable influence they have on the final market price. The two *Eutetranychus* species differ in the way they have spread since their arrival, and also in their pest status. While TCM is considered to be a secondary pest and currently no specific program has been implemented to monitor its population, ORM is considered to be a primary pest that needs to be controlled when heavy mite infestations coupled with moisture-stressed trees and hot winds occur. Plant protection organizations are more concerned about the potential spread and economic impact of ORM. For example, the EPPO (European and Mediterranean Plant Protection Organization) includes this species on its A2 List of pests recommended for regulation as quarantine pests because it may present a phytosanitary risk for the EPPO region and ORM is considered a quarantine pest in the USA (OEPP/EPPO 2010).

Are native predators effective against these invasive pests?

The arrival and establishment of an exotic, phytophagous species in a new country or region of the world begs the question whether or not the native predatory mites and insects will be able to feed on and significantly reduce the pest's population. Both *E. orientalis* and *E. banksi* have been found associated with several predatory insects and mites in their native geographical range. Vacante (2010) listed a total of eight predatory insects and 45 predatory mites associated with ORM, including 32 phytoseiid mite species, although none of them have demonstrated the ability to reduce pest populations below the economic threshold under field conditions and chemical control is usually applied. Laboratory studies to assess the efficacy of predatory mites have been conducted mainly in the Near and Middle East countries. In these regions *Euseius scutalis* (Athias-Henriot), a phytoseiid mite well adapted to warm and dry climatic conditions, is one of the dominant species on trees and shrubs. In Israel, Swirski et al. (1967, 1970) evaluated the performance of *E. scutalis* (reported as *Amblyseius rubini* Swirski & Amitai) and *E. hibisci* (Chant) (a predator from the Americas) as predators of ORM to release them in the arid areas of the country where ORM is abundant on citrus. In Egypt, Momen and El-Borolossy (1999) studied the performance of nine phytoseiid species that feed on ORM. Only *Neoseiulus barkeri* Hughes, *Euseius olivi* (Nasr & Abou-Awad) and *Typhlodromus athiasae* Porath & Swirski were able to develop and lay eggs using ORM as their food source. Natural enemies, other than arthropods, have also been associated with ORM. The most reported is the entomopathogenic fungus, *Hirsutella thompsonii* Fisher, a pathogen commonly associated with mites which produces natural epizootics under favorable micro-climate conditions, with high humidity (McCoy and Selhime 1974; Gerson et al. 1979; Dhooria and Butani 1984).

There is little information available on field efficacy of predators on TCM in its native geographical area. In Florida, the phytoseiids *Euseius mesembrinus* (Dean), *Iphiseiodes quadripilis* (Banks) and *Galendromus helveolus* (Chant) are common species on citrus, and were tested in the laboratory with TCM as a food source. The intrinsic rate of natural increase (r_m) of *E. mesembrinus* reared as immatures on *Malephora crocea* (Jacq.) (Aizoaceae) pollen and reared as adults on a mixture of developmental stages of *E. banksi* was 0.191 day^{-1} at 26 °C, similar to the value obtained with *P. citri* as prey (Abou-Setta and Childers 1989). The oviposition rate of *G. helveolus* was 1.96 eggs/day/female (Caceres and Childers 1991) and the developmental period of *I. quadripilis* was 8.5 days at 28 °C (Villanueva and Childers 2007); the oviposition was not followed in the females of the latter species.

In a revision on bionomics and control of spider mites on citrus worldwide, McMurtry (1985) suggested that predators that attack *P. citri* may also be effective against *Eutetranychus* spp. because both species are phytophagous and have a similar colonization pattern on the leaves and produce small amounts of webbing. However, the first results on the efficacy of native phytoseiids on the two *Eutetranychus* species in Spain do not support this hypothesis. *Euseius stipulatus* is the predominant phytoseiid on citrus in Spain and is a useful biocontrol agent of the citrus red mite (Ferragut et al. 1983, 1987, 1988). This predator was studied under constant laboratory conditions to verify its predatory potential on *E. orientalis*, and its developmental time, survivorship and ovipositional rate (Garzón-Hidalgo and Ferragut, unpublished data). The predatory mite was able to complete its life cycle when feeding on *E. orientalis*, but mortality was high, the reproductive parameters were very low and almost no eggs were produced, indicating that this prey is not a suitable food source. During the trials, the presence of a white coloration in the opisthosoma of many of the immature stages and adults was observed, caused by large amounts of guanine crystals inside the excretory system which could affect the mite's performance. In addition, some *E. stipulatus* females retained the egg inside their body allowing for the complete development of the larva before oviposition. According to some authors, these symptoms are related to a deficient diet (Sanderson and McMurtry 1984; Schütte et al. 1995; Di Palma 1996; Van der Geest et al. 2000). Similar experiments are being conducted with invasive populations of *E. banksi* as prey of *E. stipulatus* (Ferragut et al., unpublished data). Preliminary results indicate that most immatures of *E. stipulatus* reached the adult stage, however, egg production was very low and pathological symptoms were also observed in some of the individuals tested.

These initial results on the suitability of ORM and TCM as prey for *E. stipulatus* in the laboratory do not support the idea that this biocontrol agent will be a realistic tool against these new pests in the Western Mediterranean region. Given that *E. stipulatus* represents about 80–90 % of the phytoseiids on citrus and the feasibility of augmentative releases of other phytoseiid species to control spider mites is still in an experimental stage, outbreaks of both *Eutetranychus* species would force the application of acaricides, disrupting the implementation of IPM programs.

A great leap: the Hindustan citrus mite arrives in the Americas

Reconstructing the routes followed by invasive species to disperse around the world is not an easy task. In some occasions the invader moves forward slowly spreading out from the previous geographic range; in other cases a long-distance dispersal occurs and the species suddenly bursts into new and remote areas far from the native range. *S. hindustanicus* was originally described on citrus from Coimbatore (southern India) by Hirst in 1924. For almost 80 years, it was found only in India, supposedly the area where the species originated. But in 2002, it was reported from South America, infesting citrus in Zulia, in northwestern Venezuela (Quirós and Geraud-Pouey 2002). Soon afterwards, in 2008 it was identified in the state of Roraima, in the northern tip of Brazil, bordering Venezuela (Navia and Marsaro 2010) and in 2010 it was detected in Colombia, in the Department of La Guajira, in the north on the border with Venezuela, and in the Department of Magdalena, also in the north (Mesa-Cobo, personal communication). So far, no further records of this species have been published in other countries or continents. After its arrival, HCM seems to have spread over areas where citrus are cultivated in Venezuela. The mite has been observed in the extreme west (Zulia), in the east (Sucre), in the northern central areas (Aragua), as well as in the southern areas (Nienstaedt-Arreaza 2007; Quirós, personal communication). In Brazil, its distribution is still restricted, being found only in three northeastern municipalities in Roraima, namely Boa Vista, Canta and Bonfim (Fantine et al. 2010). Quarantine measures have been applied to avoid wider dissemination of HCM in the country, especially to the main Brazilian citrus production areas.

A peculiar nest weaver

Schizotetranychus hindustanicus has also been called the 'nest-webbing mite' after the peculiar nests made of web that females produce and under which they lay the eggs and the colony develops. This peculiar weaving behavior has been classified by Saitô (1985) as 'web nest type' and is considered to be the most specialized of the Tetranychidae.

This nest weaving behavior has two important practical consequences. First, the small and homogenous nests covering leaves and fruits facilitate the pest identification visually in the field or after harvest. The size of these nests usually ranges from 1 to 3 mm in diameter (Quirós and Geraud-Pouey 2002; Navia and Marsaro 2010). Under the stereomicroscope, the mites can be observed in greater detail. Emerging larvae and nymphs feed off and defecate on the cells and tissue protected by the web, whereas the adults exit or remain under the nest-web for feeding (Quirós and Geraud-Pouey 2002; Nienstaedt-Arreaza 2007). Adults actively move on the leaves and fruits, while immature stages prefer to settle under the web that was spun by the female, although they are highly active and move quickly when disturbed. Second, the densely woven nest provides not only refuge and better microclimatic conditions for the phytophagous mites, but also serves as protection against predatory mites. Although data on the efficacy of natural enemies under field conditions is still lacking, it seems evident that some phytoseiids have difficulty entering the nests and are unable to catch the prey. This was demonstrated in the case of the Persea mite, *Oligonychus perseae* Tuttle, Baker & Abbatiello on avocado trees (Montserrat et al. 2008), a spider mite with a similar weaving behavior. Likewise for *Schizotetranychus nanjingensis* Ma & Yuan (=*Stigmaeopsis nanjingensis*) with tight nests on bamboo leaves, there have been reports on well-known biocontrol agents such as *Neoseiulus cucumeris* (Oudemans) being unable to invade intact web nests of *S. nanjingensis* (Zhang et al. 2000).

Hindustan citrus mite adults and immature stages are yellowish or yellowish green with dark internal spots on the sides of the idiosoma. The female body is oval, somewhat flattened, about 430 μm long and with stubby legs. The male is pear-shaped, with remarkably long legs (especially the first pair), paler and smaller than the female and measuring less than 350 μm (Hirst 1924; Quirós and Geraud-Pouey 2002; Nienstaedt-Arreaza 2007). Eggs are spherical and slightly flattened, with a translucent to light yellow coloration. Just before the larvae hatch, they become yellowish green and show two small red spots which represent the future eyes in active stages. Larvae have a globular shape and are yellowish bright green after hatching, gradually becoming oval and darker by feeding. During the deutonymphal stage, it is already possible to observe small differences between the males and females, the deutonymph male being smaller and with a slightly sharper opisthosoma. The quiescent stages can be recognized by the opaque appearance and leg positioning where the anterior ones are placed forwards and the posterior ones backwards.

Accurate identification of spider mites requires the examination of females and males under a compound microscope. However, the taxonomic status of HCM is somewhat confused. The species was described by Hirst in 1924 based on a single male; thus, no females were included in the original description and, although the figures are clear and informative, the text is incomplete and lacks sufficient details on many of the taxonomic characteristics currently used in spider mite taxonomy. In spite of the fact that several records have been published afterwards in India (Gupta and Gupta 1994), there is no information on the external morphology, chaetotaxy and other taxonomic characters of females. Two other closely related species, *Schizotetranychus spiculus* Baker & Pritchard and *S. baltazari* Rimando, have been collected on citrus in Kenya, India and Taiwan (Jeppson et al. 1975; Migeon and Dorkeld 2010). Curiously, *S. spiculus* is known only from the female and the original description does not include morphological details of the male. According to the literature, the three species could overlap in their geographical range, because all of them have been reported from India (Karuppuchamy and Mohanasundaram 1987; Gupta and Gupta 1994). The dorsocentral setae on the hysterosoma in all three species are broad at their bases and narrow distally, setae *f1*are more widely spaced than the other dorsocentral hysterosomal setae and the aedeagus (not known in *S. spiculus*) has the distal portion forming a sigmoid curve. Although differences in setal lengths, patterns of dorsal striae and details of the knob or distal portion of aedeagus have been used to characterize them (Jeppson et al. 1975), it seems evident that this species complex is in need of a thorough revision. Information on damage and symptoms caused by these species on citrus is still scarce or simply does not exist; thus, this argument cannot be used to distinguish between them.

Host preferences and damage in invaded regions

Prior to the arrival of HCM to the Americas the mite had been reported in India on the host plants *Citrus* sp. (Rutaceae), coconut palms (*Cocos nucifera* L.) (Arecaceae), *Acacia* sp. (Mimosaceae), neem (*Azadirachta indica* A. Juss) (Meliaceae), Persian lilac (*Melia azedarach* L.) (Meliaceae) and sorghum (*Sorghum vulgare* Pers.) (Poaceae) (Cherian 1931; Gupta and Gupta 1994; Bolland et al. 1998). As far as we know, invasive populations in South America have infested exclusively citrus plants, although experimental colonies have been developed and maintained for some generations in the laboratory on neem plants (Fantine 2011).

In South America, colonies of HCM can develop on different citrus species and varieties. In Venezuela, the mite has been reported infesting Tahiti lime, *Citrus latifolia* (Tanaka ex Yu.Tanaka) (Quirós and Dorado 2005), Key lime, *Citrus aurantiifolia* (Chistm) Swingle, mandarin, *Citrus reticulata* Blanco, lemon, *Citrus limon* (L.), and sweet orange, *C. sinensis* (L.) Osbeck (Nienstaedt-Arreaza 2007). When HCM was reported in Brazil in 2008, colonies were found infesting leaves and fruits of Tahiti lime and lemon plants (Navia and Marsaro 2010). Soon afterwards, surveys were conducted in gardens and commercial orchards in Boa Vista (Roraima), in an effort to determine other citrus host plants for HCM in Brazil. Several citrus species/varieties showing typical feeding symptoms were sampled and the presence of HCM was also confirmed on Rangpur lime, *Citrus limonia* Osbeck, Poncan mandarin, Valencia sweet-orange and Tangor Murcott *C. reticulata* Blanco × *C. sinensis* (L.) Osbeck (Marsaro et al. 2010).

However, detailed information on host preference and biology is still scarce and only preliminary results have been obtained in Venezuela. After its invasion, Nienstaedt-Arreaza (2007) studied for the first time the biology and population trends on three citrus species, Key lime, sweet orange and lemon. Trials conducted under laboratory conditions at 25 ± 2 °C on the development and reproduction showed that the period from egg to adult takes 14–15 days and the oviposition period lasted about 9 days, during which each female produced an average of 11 eggs on lemon and 13 on lime. These biological studies were conducted under laboratory conditions and did not reveal differences in the mite's development among citrus species.

Hindustan citrus mite symptoms observed in citrus plants in Brazil (Navia and Marsaro 2010) are similar to those described in Venezuela (Quirós and Geraud-Pouey 2002). Chlorotic spots caused by HCM feeding first appear on the upper surface of the leaf, along the midrib, and later extend to the entire leaf blade (Fig. 5). On fruit, the females spun webs over the cavities or depressions on the rind and attacked fruit became uniformly silvered and hard in the case of high infestations. In that situation, HCM symptoms can be observed over the entire canopy giving the citrus tree a peculiar appearance. There is no information on symptoms produced by this mite on non-citrus plants.

Seasonal trends and the influence of climatic conditions have only been observed in Maracay, Venezuela, suggesting that higher populations occur during the dry season, or in months with low precipitation. Precipitation is considered a key factor that causes the major fluctuations in population size; during the rainy months, populations decreased abruptly (Nienstaedt-Arreaza 2007).

Economic impact, regulatory and control options in South America

Currently, there is no information on economic losses due to HCM infestations throughout areas of occurrence in India and South America. However, severe damage on citrus leaves

Fig. 5 Symptoms due to *Schizotetranychus hindustanicus* on citrus leave

and fruits in backyard and commercial orchards has been observed in the invaded areas in Venezuela and Brazil. Nevertheless, there is no doubt that damage can reduce the commercial value of fresh fruits due to depreciation in its aesthetic quality caused by the conspicuous symptoms associated with high infestations. There is also a possibility of loss in the nutritional quality of fruits affected by high HCM populations and this aspect should be evaluated.

Information on chemical control is still scarce. In Venezuela, the efficacy of the acaricide Peropal, liquid soap and mineral oil in controlling HCM in Tahiti lime was evaluated by Quirós and Dorado (2005). Results showed no significant differences between the efficacy of Peropal and soap treatments, both being around 90 % of mortality. The least effective treatment was mineral oil averaging about 42 % of mite mortality. Because it represents no danger to the beneficial fauna and environment, and due to its biodegradable properties, authors have recommended the use of liquid soap to control HCM. In Brazil, dimethoate and spirodiclofen showed to be efficient in the field to HCM control, however these pesticides are not yet registered in citrus in the country (Marsaro, personal communication).

Data concerning the presence and potential of predatory mites and insects on this pest are noticeably scarce. So far, surveys to identify the natural enemies associated to HCM have only been conducted in Brazil. Predatory mites belonging to three families were observed in association with HCM in citrus orchards from Boa Vista (Roraima), in March 2009, including three Phytoseiidae, *Galendromus annectens* (De Leon), *Euseius concordis* (Chant) and *Iphiseiodes zuluagai* Denmark & Muma, one Stigmaeidae of the genus *Agistemus*, and one Bdellidae of the genus *Bdella* (Marsaro et al. 2009). The potential and suitability of these predators as biocontrol agents of the should be evaluated.

An important impact caused by the introduction and dissemination of HCM in South America is the implementation of sanitary barriers in the international or domestic trade of fresh citrus fruits and plant material, or in the exchange of genetic material of host plants. This impact represents a threat mainly to Brazil, one of the largest citrus producers in the world. Most Brazilian citrus exportation consists of concentrated orange juice, a commodity that does not represent a gateway for the mite. However, fresh fruit exportation has increased significantly, especially lemon, which represents more than 60,000 tons/year (Abanorte 2008). Thus, the potential dispersal of HCM to the main citrus production areas in Brazil could have a high economic impact and/or lead to restrictions in the exportation of commercial citrus due to sanitary barriers. In Brazil, a post-harvest procedure for citrus fruits was evaluated by researchers of Embrapa Roraima and Instituto Biologico de Campinas and approved by the Ministry of Agriculture. This procedure has become a requirement in domestic transportation of fresh fruits from infested to non-infested States (MAPA 2009). This official requirement aims to prevent HCM from expanding beyond Roraima, the only infested state in the country, and moving to other states.

What can we expect in the short term?

Obviously, it is difficult to foresee how these invasive spider mites may develop in the coming years in terms of their geographical distribution and economic impact. However, we can take a look at the behavior and dispersal displayed by other related invasive mites in the past. The Persea mite *O. perseae*, one of the most damaging pest of avocados, originated in Mexico and spread through the Mediterranean region in the last decade, arriving in southern Spain in 2004 (Alcázar et al. 2005); later, it was reported for the first time from Madeira Island in 2005 and the Canary Islands in 2006 (Hernández-Suárez et al. 2007). Apparently, the pest was introduced with cultivated avocados, colonizing all productive areas in that region. Movement of mite-infested plant material is the responsible factor for rapid intra-continental spread and establishment of this mite on the Atlantic islands. As mentioned before, ORM is able to develop and reproduce at a wide range of temperatures. Therefore, the prevailing climatic conditions in the Mediterranean and the Macaronesian Region would be suitable for establishment of this mite. Recent information seems to indicate that ORM is presently causing damage on citrus crops in Morocco (Pekas, personal communication), a country with a growing citrus industry. Because of their proximity, the Canary Islands and southern Italy would also be threatened by this pest.

Although TCM is currently restricted to southern Portugal and Huelva province in Spain, it could extend its range in the near future. Furthermore, the pest status may change with time. Some spider mite species have been present for years in agricultural areas without causing noticeable damage before reaching pest status. *Oligonychus afrasiaticus* (McGregor), a serious pest of dates in North Africa and the Middle East, was first reported in Israel in 1980 on weeds growing in palm orchards but commercial damage to palms was only observed in 1996 (Palevsky et al. 2003). In addition, changes in the mite's susceptibility to acaricides or resistance development could enhance the economic impact of these mites.

In the case of ORM and TCM many observations concerning their biology, population dynamics, damage and control measures have been reported in the past; however, our knowledge of HCM is still scarce and fragmentary and nothing is known about its potential distribution and future economic impact. *S. hindustanicus* is now present in northern Brazil, one of the main citrus producing countries, and the potential spread of this pest to citrus-growing areas in the south of the country would have a considerable impact on production. Phytosanitary authorities have adopted emergency security measures to avoid the spread of the pest but further studies concerning its biology, behavior and control are necessary to generate sufficient knowledge to develop sustainable strategies for its control.

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