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Potential Biological Control Agents of the Common Pistachio Psylla, *Agonoscena pistaciae*, a review

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Abstract

The common pistachio psylla, *Agonoscena pistaciae* BURCKHARDT & LAUTERER (Hemiptera: Psylloidea), is a significant pest of pistachio trees, *Pistacia vera* LINNAEUS, occurring in many countries along the southern borders of the old Soviet Union, and throughout most of the Middle East and Mediterranean region. Several laboratory and field studies have documented the biological parameters of *A. pistaciae* and its natural enemies. However, to-date surprisingly little effort has been expended to develop and implement an integrated pest management programme, despite the economic importance of pistachio and the effects of this pest in different growing seasons. The present review is believed to be the first on *A. pistaciae* natural enemies and provides information towards understanding the potential of its biocontrol in Iran. Further research will be needed to characterize the main factors responsible for changes in population dynamics and, in particular, the reason for outbreaks under natural conditions. There is a need: (a) for an accurate assessment of the impact of psyllid enemies under field condition, (b) to design an IPM programme and (c) to improve the sustainable management of *A. pistaciae*.

Keywords: Pistachio, Parasitoids, Predators, Psyllid, Biological control, Conservation.

Introduction

Pistachio is one of the most important economic crops in Iran, with about 420,000 ha of plantations, mostly in Kerman province in the southern part of the country (Ministry of Jahad-e-Agriculture, 2006). The annual earnings from pistachio was estimated at $1.3 billion US dollars in 2007 (ABDOLAHI-EZZATABADI, 2009). At present, Iran is ranked first in the world in terms of pistachio nut production, followed by the USA and Turkey. Although pistachio production has occurred recently in 13 provinces in Iran, the provinces of Kerman, Yazd and Khorasan are the largest with respect to yield, producing between them approximately 95% of the total value in 2007. Of these areas, Kerman has almost always been the most important in terms of both plantation area and total production in the last 10 years. The cultivated pistachio plantations are usually located in dry, desert regions of the country. These regions are characterized by an average annual rainfall of about 100 mm; cold winters (with minimum temperature of –15ºC), hot summers (with maximum temperatures of +45ºC), very low soil quality (mostly alkaline saline land) and salty water resources of low quality (supplied from very deep wells up to 350 meters deep) (HOSSEINIFARD et al., 2008). Production of pistachio nuts has been predominantly by owners of small orchards using traditional management methods. These particular water and soil conditions, along with the harsh climate in the desert areas, have resulted in a monoculture system with a relatively narrow vegetational diversity and this has created ideal conditions for pest problems (MEHRNEJAD, 2001).

Arthropod pests have been the main problem for Iranian pistachio growers for the last 65 years. Numerous phytophagous insects and mites attack the trees. The common pistachio psylla (CPP), *Agonoscena pistaciae* BURCKHARDT & LAUTERER, 1989 (Hemiptera: Psylloidea: Rhinocolinae) is an indigenous pest in Iran. It is now the most serious pest throughout the pistachio-producing regions of the country. Usually the psyllid population rapidly increases immediately after bud-break in early spring through to mid-autumn. The presence of large populations of psyllid nymphs and adults causes severe problems in kernel development, with subsequent bud drop and defoliation (MEHRNEJAD, 2001, 2002, 2003). This damage affects not only the yields in the current year but also in the two subsequent years (MEHRNEJAD, 2003), and it therefore causes heavy economic losses. For this reason, psyllid infestations have received particular attention from pistachio-growers, who insist on spraying to reduce the damage. Besides the several other disadvantages of using insecticides, the development of pesticide resistance has meant that chemical applications have failed more and more frequently. No biocontrol agents have been introduced into pistachio orchards to date, despite (i) the economic importance of the crop, (ii) the presence of several potential biological control agents against CPP, and (iii) the variability in the importance of this pest in different growing seasons. Several laboratory and field studies have documented the biological parameters of CPP and its natural enemies (MEHRNEJAD, 1998, 2002, 2008, MEHRNEJAD & JALALI, 2004, MEHRNEJAD & COPLAND, 2005, 2005a, 2006, EMAMI, 2001, JALALI, 2001, ARAB-HORMOZABADI, 2005, MEHRNEJAD et al., 2010). In general, apart from a few large producers, growers still have insufficient knowledge of the potential for biological control within their orchards. However, because of the wide range of possible biocontrol agents, there is a major opportunity for their artificial introduction and/or application to pistachio orchards, along with education of the growers. This review summarizes the major publications on parasitoids and predators of CPP over the past two decades, and considers the suitability of each for exploitation as biological control agents.

Pistachio plantation

Pistacia LINNAEUS (Anacardiaceae) is mainly a subtropical genus comprising some 11 species of wind pollinated deciduous and dioecious trees and shrubs. Geographically, the largest concentration of *Pistacia* species is found in West Asia and in the Mediterranean region (ZOHARY, 1995, TOUS & FERGUSON, 1996). The pistachio, *Pistacia vera* LINNAEUS, originated in Asia Minor, in the northern part of Afghanistan, but has largely spread throughout the Mediterranean and the Middle East (SHRESTHA, 1995). It is the only widely edible crop in the genus *Pistacia.* Other species like wild pistachios, which produce small, hard shell and un-split nuts are mainly consumed by some native tribes. The fruits are classified as drupes with edible seeds (TOUS & FERGUSON, 1996). In its native range, pistachio grows under extreme climatic conditions is characterized by long, hot, dry summers and moderately cool or cold winters. Pistachio is tolerant to salinity and alkalinity as well as drought, but needs well drained soils and adequate irrigation for economic production (JOLEY, 1979). It has a very long life-span and there are pistachio trees in Iran which are more than 300 years old (MEHRNEJAD, 1998, KASKA, 1995, FERGUSON, 1997). The crop matures in early autumn. The nuts are borne in clusters that can be harvested by hand, by knocking with a pole or by shaking. Mechanical harvesting and processing procedures have been well developed in California (TOUS & FERGUSON, 1996). Three *Pistacia* species occur naturally in Iran: *Pistacia atlantica* DESF., *Pistacia khinjuk* STOCKS and *P. vera* (SHEIBANI, 1995). Wild species are important in the development of pistachio varieties because they provide rootstocks that are resistant to biotic and abiotic stresses, and tolerant of drought and poor soil conditions. It is these characteristics that make this crop and its wild relatives suitable for planting in marginal lands (PADULOSI et al., 1995). The current major growing areas are the Middle East (Iran, Syria); the Mediterranean area including Turkey, Greece, Spain and Italy; S. W. North America (California and Arizona); and Australia (KASKA, 1995, FERGUSON, 1997, SHEIBANI, 1995).

Pistachio arthropod pests

Pistachio trees are hosts to relatively extensive arthropod faunas. The phytophagous species are usually specific to pistachios, although the beneficial arthropod fauna mostly act as non specific enemies of pistachio pests. As long-term perennial plants in desert climate condition, pistachio provides stable ecological habitats. Application of broad-spectrum insecticides, such as organochlorine, organophosphorus, carbamate or pyrethroid compounds, has a profound impact on the range and relative abundance of arthropods on pistachio trees, especially if applications are frequent. Most species are highly sensitive to insecticides and are virtually eliminated by a single application. However, others like CPP may develop insecticide-resistant strains and as a result continue to thrive as important pests. Treatment with broad-spectrum insecticides gives short term control but usually eliminates or greatly reduces the numbers of their enemies, so making subsequent outbreaks more severe. The most important key pests are the CPP, the pistachio twig borer moth, *Kermania pistaciella* AMSEL (Lepidoptera: Tineidae), and the stink and sucking bugs including six species *Acrosternum heegeri* FIEBER, *Acrosternum millieri* (MULSANT & REY), *Apodiphus amygdali* (GERMAR), *Brachynema germari* KOLENATI, *Brachynema segetum* JAH. (all Hemiptera: Pentatomidae) and *Lygaeus pandurus* (SCOPOLI) (Hemiptera: Lygaeidae). They frequently cause economic damage to flowers, fruits, leaves and twigs directly and their natural enemies are insufficiently effective in commercial orchards currently to regulate their numbers below damaging levels. The most important secondary pests are scale insects including

Pistaciaspis pistaciae (ARCHANGELSKAYA), the pistachio trunk and branch scale *Melanaspis inopinata* LEONARDI (both Hemiptera: Diaspididae), the pistachio bark beetle *Hylesinus* (=*Chaetoptelius*) *vestitus* MULSANT & REY (Coleoptera: Scolytidae), the pistachio leaf hopper *Sulamicerus* (*Idiocerus*) *stali* (FIEBER) (Hemiptera: Cicadellidae), the pistachio fruit moth *Recurvaria pistaciicolla* DANILEVSKY (Lepidoptera: Gelechidae), the pistachio fruit hull borer *Arimania komaroffi* RAGONOT (Lepidoptera: Pyralidae), the pistachio weevil *Polydrusus davatchii* HOFFMANN (Coleoptera, Curculionidae), the pistachio leaf borer *Ocneria terebinthina* STGR. (Lepidoptera: Lymantriidae), and the common pistachio mite *Tenuipalpus granati* SAYED (Acari: Tenuipalpidae), all of these considered as mostly localized key pests. Some of these can be very damaging when allowed to increase over a number of seasons but they are controlled readily with insecticides. In addition, there are large numbers of less important and minor pests which are either of sporadic or local occurrence, or cause limited damage in general (MEHRNEJAD, 1993, 2001, 2002, 2003, FARIVAR-MEHIN, 2002, MEHRNEJAD & UECKERMANN, 2001, 2002, VAN ACHTERBERG & MEHRNEJAD, 2002, SAMET, 1985).

Pistachio psyllids

Among phytophagous Hemiptera, jumping plant-lice or psyllids (Psylloidea) are particularly interesting for their highly specialized host requirements. Individual psyllid species can usually complete their development on only one or a few closely related host species. In addition to this, related psyllids are often associated with closely related plant taxa (BURCKHARDT & BASSET, 2000). The approximately 3000 described species (HODKINSON, 2009) represent probably much less than half the number of globally existing species (MIFSUD & BURCKHARDT, 2002). They occur throughout nearly all the world’s major climatic regions where suitable host plants are found (HODKINSON, 2009). The great majorities of psyllid species is narrowly host-specific and are predominantly associated with perennial dicotyledon angiosperms, while a few species develop on monocots (HODKINSON, 1988, HODKINSON, 2009, HODKINSON & WHITE, 1981). The psyllid life cycle typically comprises of an egg stage, five nymphal instars and a sexually reproducing adult stage, with males and females usually showing only moderate deviation from a 1:1 sex ratio at emergence. Parthenogenetic reproduction, in which only females are found in the population, is rare (HODKINSON, 1983, HODKINSON & BIRD, 2006, MOORE, 1983). The psyllids, like aphids have considerable importance as pests of cultivated crops and ornamental trees and also they are vectors of plant diseases (HODKINSON, 1974, BURCKHARDT & LAUTERER, 1989). In addition, the effects of salivary injection can be very severe, causing growth abnormalities in the plant. They generally hibernate as diapausing adults with undeveloped ovaries. However, there are no records of the common pistachio psylla as a vector of plant diseases.

The literature indicates that six psyllid species in the genera *Agonoscena* and *Megagonoscena* develop on *Pistacia*. In a systematic study BURCKHARDT & LAUTERER (1989, 1993) indicated that the genus *Agonoscena* is restricted to Mediterranean biotopes of the Palaearctic, Afrotropical and Oriental regions. Four species of *Agonoscena* on *Pistacia* have been found as follows: (1) *Agonoscena targionii* (LICHTENSTEIN) develops on *Pistacia lentiscus* LINNAEUS and is recorded from the Azores, Portugal, Spain, France, Greece, Italy, Yugoslavia, Syria and Turkey; (2) *Agonoscena bimaculata* MATHUR develops on *P. khinjuk* and *Pistacia mutica*, and is recorded from Pakistan and

Iran; (3) *Agonoscena cisti* (PUTON) develops on *Pistacia lentiscus* and *Pistacia palaestina* BOISSIER, the species being widely distributed in the Mediterranean region, and recorded from the Canary Islands, Greece, Iraq and Turkey; (4) *Agonoscena pistaciae* develops on *P. atlantica*, *P. mutica*, *P. palaestina*, *P. terebinthus* and *P. vera*, recorded from Armenia, Tadzhik, Turkey, Greece and Iran. The genus *Megagonoscena* comprises two Western Palaearctic species on *Pistacia*: (a) *Megagonoscena gallicola* BURCKHARDT & LAUTERER, gall forming on *P. palaestina*, *P. terebinthus* and *P. vera*, and recorded from Bulgaria, Cyprus, Jordan and Yugoslavia; (b) *Megagonoscena viridis* (BAEVA) developing on *P. vera*, *P. mutica*, *P. palaestina* and *P. terebinthus*, and recorded from Jordan, Bulgaria, Tadzhik, Turkey, Azerbaijan and Iran (BURCKHARDT & LAUTERER, 1989, 1993, LABABIDI & ZEBITS, 1995, LAUTERER et al., 1998).

Although systematic records show a wide distribution for different species of *Agonoscena* and *Megagonoscena* on wild and cultivated *Pistacia* trees throughout the Middle East, Mediterranean region and former Soviet Union countries, there is very limited information on the biology and economic position of these insects. In Turkey, MART *et al*. (1995) reported that *A. pistaciae* has become a major pest in pistachio orchards since the late 1980s due to intensive pesticide application against the pistachio leaf hopper, *S. stali* disturbing the natural balance. In Syria, an investigation on the ecological aspects of *A. targionii* showed a heavy infestation by this insect in all four pistachio-growing regions (LABABIDI & ZEBITS, 1995). In Greece, it was reported that *A. pistaciae* attacks the leaves causing severe heavy honeydew secretion and premature defoliation (LAUTERER et al., 1998, MOURIKIS et al., 1997). In Iran, as the major pistachio pest, *A. pistaciae* is distributed throughout the country in both pistachio producing regions and wild pistachio growing areas (MEHRNEJAD, 1998, 2002, 2003, 2006). In addition to *A. pistaciae*, two other psyllid species including khinjuk psyllid, *A. bimaculata* and pistachio leaf-rolling psylla, *M. viridis*, occur in Iran. *A. bimaculata* was found on *P. khinjuk* and *P. atlantica* subsp. *mutica* but M. *viridis* attacks all three pistachio species (*P. atlantica* subsp. *mutica*, *P. khinjuk* and *P. vera*) that grow in Iran (BURCKHARDT & LAUTERER, 1993, MEHRNEJAD, 2003, 2006). However, these later two psyllid species are considered economically unimportant now (MEHRNEJAD, 2003).

The common pistachio psylla, *Agonoscena pistaciae*, is known as the most important key pest in pistachio plantation areas of Iran. In general, more than 65% of dollars (about 145 US $ per hectare annually) spent to control arthropod pests in commercial pistachio orchards are directed specifically at controlling this species. Although control measures require accurate and timely information about dispersal, onset of egg-laying in spring, densities in July and August as the critical period for the trees' sensitivity, control means are widely applied by growers at random and no Integrated Pest Management programme is available yet.

Historical aspects of the CPP in Iran

The presence of the CPP was first reported in Iran in 1946 by KIRIUKHIN (1946) and considered to be a minor pest of cultivated pistachio trees. The same report suggested that the numbers of a psyllid species are limited by an encyrtid parasitoid of the genus *Prionomitus*, but he added that a cicadellid *S. stali* is the most injurious pest in all the pistachio-growing regions of Iran, where the crop loss was sometimes estimated at 70-90

%. Later, DAVATCHI (1958) indicated that control of *S. stali* by chemicals was followed by a change in the pest status and occurrence of the pistachio psyllid *A. targionii*. However, further research on the Iranian psyllid fauna based on extensive collections by BURCKHARDT & LAUTERER (1989) indicated that the species referred to as *A. targionii* is in fact *A. pistaciae* which they described as a new species. During the last 50 years *A. pistaciae* has emerged as the most serious insect pest of cultivated pistachio trees (MEHRNEJAD, 1998, 2001, 2003). Similar problems have been reported in Turkey and Greece (MART et al., 1995, SOULIOTIS et al., 2002). The control of this pest relies almost exclusively on pesticides; however, the tendency of *A. pistaciae* to develop resistance against insecticides has been clearly observed since the early 1950s, few years after DDT was used against this insect (MEHRNEJAD, 2001, 2003). From then at least 5 insecticides have been removed from chemical application programmes due to the appearance of resistance in CPP (MEHRNEJAD, 2003).

Insects and mites associated with the CPP in Iran

Although the CPP has been a very well known pistachio pest through the last 50 years, surprisingly its natural enemies have received poor attention (MEHRNEJAD, 1998, 2002, 2003, 2008, MEHRNEJAD & JALALI, 2004). In fact, the diversity and role of psyllid natural enemies remained unclear until the early 1990s. At least 18 beneficial insects have now been associated with CPP in Iran. The majority are Coccinellidae (ARAB-HORMOZABADI, 2005, HASSANI et al., 2009, JALALI, 2001, MEHRNEJAD, 2003, MEHRNEJAD & JALALI, 2004, MEHRNEJAD et al., 2010), however, predatory bugs belonging to the Anthocoridae and Miridae (MEHRNEJAD, 2003, 2007), predatory mites including Phytoseidae, Anystidae and Erythraeidae (MEHRNEJAD, 2003, MEHRNEJAD & UECKERMANN, 2001, 2002), Chrysopidae and Encyrtidae (EBRAHIMI et al., 1999, MEHRNEJAD, 1998, 2003, YAZDANI & MEHRNEJAD, 1993) were all found to be active in pistachio plantation areas. No pathogen has been isolated from *A. pistaciae*; however, a little information is available on the effect of entomophagous fungi on CPP. HAGHDEL et al. (2009) evaluated the pathogenicity and virulence of two fungi e.g., *Beauveria bassiana* (BALSAMO) and *Lecanicillium muscarium* (PETCH) Zare and Gams, on the CPP under controlled conditions. In another laboratory tests, 7 isolates of *B. bassiana* were examined on CPP too (ALIZADEH et al., 2007). Furthermore, LABABIDI (2002) reported the positive influence of *B. bassiana* against 1st and 2nd nymphal instars of *A. targionii* under field condition in early growing season in Syria. Most beneficial insects are recorded as polyphagous, i.e. feeding on CPP, aphids, scale insects and others. However, a few species are recorded to be strictly monophagous, i.e. only feeding and developing on the CPP.

Parasitoids

Any organism that feeds on another organism is a natural enemy. In biological control, natural enemies are referred to as parasitoids, predators or pathogens. Effective biological control may be achieved through utilisation of any of these groups, but parasitoids have been the most important to date, with predators ranking second in importance (DEBACH & ROSEN, 1991). Both parasitoids and predators are animals that feed on other animals, but a parasitoid completes its development on a single host, whereas a predator consumes several prey individuals during its development.

The term 'parasitoid' was first used by REUTER (1913) to describe a group of insects that develop as larvae on the tissues of other arthropods. A parasitoid is defined by the feeding habit of its larva. The larva feeds exclusively on the body of another arthropod, its host, and eventually kills it, whereas the adult parasitoids are free-living (GODFRAY, 1994). Adult female parasitoids forage actively for hosts, depositing eggs through an ovipositor either in, on or near their hosts. After attacking a host, the female parasitoid does not attempt to move the host to a protected site or nest (distinguishing parasitoids from certain solitary wasps which have an otherwise similar life history) (CROSS et al., 1999). Upon hatching the larvae locate and begin feeding on host tissues and pass through several developmental stages either inside the host, as endoparasitoids, or on the host, as ectoparasitoids (GODFRAY, 1994, WAAGE & HASSELL, 1982). Most adult parasitoids require food such as honeydew, nectar, or pollen and many feed on their host's body fluids (DEBACH & ROSEN, 1991, JERVIS & KIDD, 1986). Insect parasitoids show a variety of life styles (MILLS, 1992, 1994). At oviposition, the host is either killed or permanently paralysed (idiobiont parasitoids), or is not or only temporarily paralysed (koinobiont parasitoids) (ASKEW & SHAW, 1986). The hosts of koinobiont parasitoids recover and continue feeding whilst the parasitoid remains quiescent as an egg or a first instar larva. Thus, koinobionts can attack the host while it is still too small to support full larval development. Parasitoids are also categorized by the life stage of the host attacked e.g., egg, larval, pupal or adult parasitoids (ASKEW & SHAW, 1986, VAN ALPHEN & VET, 1986, VINSON, 1976). They can also be classed as solitary (one parasitoid develops per host) or gregarious (two or more develop per host), and as ectoparasitoids (feed externally with their mouth-parts embedded in the host) or as endoparasitoids (feed internally). Polyembryonic species, in which the female lays one or a few eggs that divide asexually to produce a large clutch, are one special category of gregarious parasitoids (GODFRAY, 1994, QUICKE, 1997).

Most parasitoids that have been used in biological control are in the orders Hymenoptera, and to a lesser degree Diptera (VAN DRIESCHE & BELLOWS, 1996). EGGLETON & BELSHAW (1992) outlined that approximately 87,000 species of insect parasitoid have been described; they also suggested that roughly one quarter of insect parasitoids are non-hymenopteran (20,000 species). However, GODFRAY (1994) proposed that parasitoids constitute 20% - 25% of the 8 million species of insects on earth. Parasitoids are found in all major holometabolous orders of insects including Hymenoptera, Diptera, Coleoptera, Lepidoptera and Neuroptera (EGGLETON & BELSHAW, 1992), but it is in the Hymenoptera that they reach their greatest diversity, abundance and importance.

Literature records that a wide range of parasitoids and predators attack different psyllid species, moreover HODKINSON (1974) suggested that the primary parasitoid species are almost exclusively specific parasitoids on psyllids. BURCKHARDT & LAUTERER (1989) stated that the CPP are parasitized by two encyrtid wasps *Psyllaephagus* sp. and *Metaphycus* sp. MOHAMMED & SHEET (1989) reported that 4^{th} and 5^{th} instar nymphs of pistachio psyllid *A. targionii* were attacked by an endoparasitoid belonging to the family Ceratopogonidae (Diptera) in Iraq. A similar report from Syria by LABABIDI & ZEBITZ (1995) indicated that a dipteran endoparasitoid (Ceratopogonidae) parasitized the older psyllid nymphs. MART *et al*. (1995) reported an encyrtid wasp *Psyllaephagus* sp. as a biocontrol agent of the pistachio psyllid *A. pistaciae* in Turkey. Through a survey on pistachio trees' pests, KIRIUKHIN (1946) stated that a parasitoid wasp of the genus *Prionomitus* attacks a psyllid in the southern part of Iran. In this regard, it was also reported by DEZYANIAN (1998) that, apart from *P. pistaciae*, a parasitoid he called *Prionomitus* emerges from CPP mummies in pistachio orchards of Damghan, in the northern part of the country. However, *Prionomitus* species have not yet been collected in major pistachio plantation areas of Kerman province (EMAMI, 2001, EMAMI & MEHRNEJAD, 2006, MEHRNEJAD, 2008, MEHRNEJAD & EMAMI, 2005). It is believed that either *Prionomitus* does not occur in the major pistachio plantation areas of the country, or its population is rather low or it may occur only in a particular narrow period of the growing season. More attention is definitely needed to clarify the activity of this wasp on CPP.

Psyllaephagus pistaciae

The first report on this species (FERRIÈRE, 1961), described it as a member of the Encyrtidae (Chalcidoidea), from studies on samples collected on pistachio trees from Iran, Iraq and Turkey. Many years later, YAZDANI & MEHRNEJAD (1993) recorded that this species is an important hymenopterous parasitoid of the common pistachio psylla *A. pistaciae* in Iran. However, little information is available on this parasitoid in the other pistachio-growing regions of the world. It is a specific, solitary, koinobiont endoparasitoid of CPP nymphs and is the only primary parasitoid of CPP (MEHRNEJAD, 1998, 2002, 2003, 2008, MEHRNEJAD & EMAMI, 2005). The parasitoid is present in all pistachio orchards, even those that have heavy chemical spray programmes (MEHRNEJAD, 2003). It lives up to 42 days under controlled conditions in the laboratory (27.5°C, 55±5 RH, 16 h. light) (MEHRNEJAD, 1998). All five nymphal instars of CPP are susceptible to parasitism and suitable for development of the immature parasitoids, even though the female prefers to lay eggs in the third and fourth instars (MEHRNEJAD & COPLAND, 2006a). She can lay more than 400 eggs during her life span, and has been shown to destroy up to 8 fourth-instar psyllid nymphs daily through host feeding (MEHRNEJAD & COPLAND, 2006, 2006a). Feeding upon host haemolymph was reported as a common behaviour of *P. pistaciae* in the sequence of foraging behaviour and occurs throughout the adult life span of this parasitoid (MEHRNEJAD & COPLAND, 2006a). All instars of the psyllid nymphs were accepted for destructive non-concurrent host feeding, and therefore female *P. pistaciae* causes host mortality by feeding other than by parasitism (MEHRNEJAD & COPLAND, 2006a). However, no data are available on its longevity and reproductive capacity during its long seasonal presence, around 8 months, in orchards.

Monitoring of the behavioral responses of *P. pistaciae* to volatiles emanating from its host plant and host honeydew showed that infested pistachio leaves were the most favored source of the volatile attracting the parasitoids. It was found that psyllid honeydew acts as both a contact and a volatile kairomone, and that it significantly affects parasitoid host-searching behavior. Furthermore, psyllid honeydew acts as a host-searching stimulant; that is, it emitted a host recognition kairomone for *P. pistaciae* (MEHRNEJAD & COPLAND, 2006b). Psyllid honeydew is a very good and long lasting food source for *P. pistaciae* but in the presence of a psyllid nymph, the wasp prefers to kill and feed upon host haemolymph (MEHRNEJAD & COPLAND, 2006a).

MEHRNEJAD & COPLAND (2007) reported that female *P. pistaciae* is able to recognize already parasitized psyllids, although this depended on the time since the previous oviposition, and it allows some super-parasitism. This aspect of discrimination by *P. pistaciae* is weak feature of its biology, although VAN ALPHEN & NELL (1982) and BAKKER *et al*. (1985) have proposed that host discrimination by parasitoids is never absolute. However, in all cases only one adult wasp emerges from each superparasitized psyllid nymph (MEHRNEJAD & COPLAND, 2007). It was also found that females of *P. pistaciae* respond to changes in host quality associated with the parasitoid's larval development four days after the initial parasitization, clearly indicating that the second female could detect the presence of the larvae and adjust her host-selection decision (MEHRNEJAD & COPLAND, 2007).

The diapause strategies of the parasitoid have been described (MEHRNEJAD & COPLAND, 2005). *P. pistaciae* has a facultative diapause and it is the parasitoid pupae that are responsive. Moreover, both diapause induction and termination are determined by environmental cues (MEHRNEJAD & COPLAND, 2005). The psyllid *A. pistaciae* also responds to environmental cues, producing adult winter-forms and then undergoing a pre-oviposition phase. Therefore, there is a good synchronisation between parasitoid and psyllid for both initiation and termination of diapause (MEHRNEJAD & COPLAND, 2005, 2005a).

The population growth characteristics of the parasitoid, *P. pistaciae*, and its host, the CPP were determined under controlled conditions (MEHRNEJAD & COPLAND, 2006). Although these results cannot be directly related to orchard conditions, they provide a guide for interpretation of field observations on the bionomics of these two insect species. The parasitoid usually developed faster than its host particularly at temperatures ranging from 27.5 to 35°C. In comparison with its host, the shorter generation time of the parasitoid may be considered an advantageous characteristic for utilising the parasitoid as a biological control agent. The intrinsic rate of increase (r_m) of the parasitoid (0.20) is close to that of the psyllid (0.22) under similar conditions. Although the r_m of *P. pistaciae* is slightly less than the r_m of the CPP, the large psyllid mortality caused by parasitoid host feeding (MEHRNEJAD & COPLAND, 2006a) may increase the efficiency of the parasitoid, particularly at high psyllid densities. The predicted lower threshold for development of the parasitoid was a little higher than its psyllid host; however, the difference was less than 1°C which is a small value. Moreover, it could be considered as a favourable biological factor, as the higher developmental threshold in parasitoids will result in their spring emergence being delayed until hosts are available (CAMPBELL et al., 1974, COHEN & MACKAUER, 1987).

In a field survey MEHRNEJAD (2008) showed that parasitized psyllid nymphs developed on the leaves and mummified at their feeding site, stuck onto the pistachio leaves whereupon the parasitoid larvae pupated. The parasitoids entered diapause in late October in their pupal stage within psyllid mummies and were carried with the falling leaves when the latter senesced. They fell to the ground and were then dispersed in pistachio orchards in late autumn. The parasitoid *P. pistaciae* and its host, the CPP, were active throughout the pistachio growing season, from early April to almost the end of November (MEHRNEJAD, 2002, 2003, 2008). The appearance of the first adult parasitoid in the field tended to coincide with the first psyllid nymphs emerging on the leaves (MEHRNEJAD, 2003, 2008). Thereafter, the parasitoid normally has no difficulty in finding its host, as all psyllid nymphal instars are available throughout the growing season.

The parasitism rate of CPP was reported low throughout spring, summer and early autumn, ranging from 1 to 5%, rising to about 11% in November in orchards where chemical sprays were applied for pest control as usual each year (MEHRNEJAD, 2008). However, MEHRNEJAD & EMAMI (2005) found that, where no chemical was used for several years in a pistachio orchard, the parasitism rate is also low from May through to September but increased to 65% in November. The reason for low parasitism in early spring is that most *P. pistaciae* fail to overwinter successfully due to poor overwintering sites (MEHRNEJAD, 2008, MEHRNEJAD & EMAMI, 2005). As a result, the majority of the diapausing immature wasps may be lost during the winter, through predators, agricultural practices or even, perhaps to grazing by animals on the soil surface. These factors could be very harmful to the size of the wasp population the following spring. It might be argued that *P. pistaciae* is inefficient since it does not appear to reproduce quickly enough to keep pace with psyllid populations. However, it is assumed that this parasitoid can play an important role in the natural control of the CPP because the rate of parasitism can reach 65% (MEHRNEJAD & EMAMI, 2005) in the late growing season in non-sprayed orchards. HUFFAKER & MESSENGER (1964) and MURDOCH et al. (1985) stated that parasitoids considered desirable as biological control agents are generally thought to operate in a density dependent manner, but no evidence of density dependence was found for *P. pistaciae*, although this needs further research. In Greece, SOULIOTIS et al. (2002) reported that *P. pistaciae* was not observed at all in the period between April and June, whereas it appears in great numbers after the second week of July and peaks at the end of September or beginning of October, when the parasitism rates on pistachio trees reach 50%. The same researchers concluded that this parasitoid plays a significant role in reducing the populations of CPP that are on the point of hibernating.

The presence of shared hyperparasitoids attacking both CPP and weed-infesting aphids in pistachio orchards have been reported (MEHRNEJAD, 2003, MEHRNEJAD & EMAMI, 2005). An investigation in Rafsanjan's pistachio orchards, the main pistachio producing area of Iran, showed that, of wasps emerging from mummified psyllids, 46% were the primary parasitoid *P. pistaciae*, and the remaining 54% represented six species of hymenopterous hyperparasitoids, *Chartocerus kurdjumovi* (NIKOL'SKAJA), *Marietta picta* (ANDRÉ), *Pachyneuron aphidis* (BOUCHÉ), *Pachyneuron muscarum* (LINNAEUS), *Psyllaphycus diaphorinae* (HAYAT) and *Syrphophagus aphidivorus* (MAYR). *Lysiphlebus fabarum* MARSHALL, the parasitoid of *Aphis gossypii* GLOVER and *Aphis craccivora* KOCH present on weeds was found to be an alternative host for three major hyperparasitoids of CPP (EMAMI & MEHRNEJAD, 2006, MEHRNEJAD & EMAMI, 2005). The most abundant hyperparasitoid was *S. aphidivorus*, appearing during the growing season on psyllids and aphids in pistachio orchards (MEHRNEJAD & EMAMI, 2005). The weed-infesting aphids, along with their primary parasitoid, can act as a reservoir of CPP secondary parasitoids. Therefore, parasitized aphids allow populations of secondary parasitoids to increase and consequently to apply higher pressure on P. pistaciae. Based on this information, the hyperparasitoid complex is an important factor affecting primary parasitoid efficiency and the resulting population dynamics of CPP. Several investigations in various systems have indicated that secondary parasitoids, which are usually abundant in the field, can influence the density, population dynamics and community structure of primary parasitoids (MORRIS et al., 2001, MÜLLER et al., 1999, VAN NOUHUYS & HANSKI, 2000, VAN VEEN et al., 2001) with possibly regulating effects.

In conclusion, *P. pistaciae* is potentially an important natural enemy of CPP in pistachio plantations, though acting alone it is unlikely to be sufficiently effective to prevent the development of large pest populations. While *P. pistaciae* might be sufficiently equipped to regulate host density in theory, various factors are thought to decrease its impact, e.g. hyperparasitism, low survival rate through overwintering difficulties and the side effects of pesticide applications throughout the growing season, April to November. Mass-rearing techniques and inundative release of this wasp have not been developed yet, however it is expected that production of *P. pistaciae* might be difficult and costly, because both the wasp and psyllid are specialized for *Agonoscena* and *Pistacia* respectively. Undoubtedly research is also needed to identify new primary parasitoid species either inside the country, or to consider introducing a parasitoid of a closely related psyllid from another region, and in any case to develop methods to protect and augment what currently exists.

Predators

In perennial tree crops, such as apple and pear, there are many opportunities for exploiting the biocontrol potential of long term or permanent populations of naturally occurring predators of pests (SOLOMON et al., 2000). Many of the predator species occurring in orchards are polyphagous, and may contribute in a general way to the reduction of several pest species. However, some predators are more specialized feeders, and they are more likely to be exploitable as major biocontrol agents against a particular pest species. Predators form the largest and the most diverse natural enemies of the CPP. They offer some promise as biological control agents against pistachio pests, especially CPP, although they are mostly general predators. SYMONDSON et al. (2002) reviewed the importance of generalist predators in biological control and stated that these predators significantly reduced pest density in annual crops in about 78% of the cases.

Coccinellids

Predaceous ladybirds have largely fascinated ecologists the world over, because of their biocontrol potential against aphids, diaspidids, coccids, aleyrodids and other soft-bodied insects and mites (OMKAR, PERVEZ, 2005). Most of the coccinellid species found in orchards are principally predators of aphids, although aphidophagous species take other prey when aphids are scarce (SOLOMON et al., 2000). Eight coccinellid species were reported in pistachio orchards of Greece (SOULIOTIS et al., 2002), and 22 ladybird species were also collected on pistachio trees in Turkey (BOLU et al., 2007). In Rafsanjan, the main pistachio growing areas of Iran, Eleven predacious ladybird species are found in planted pistachio orchards and 17 species are present on wild pistachio trees in mountainous areas. Out of which eight species were recognized as being psyllophagous in both planted and wild pistachio plantations in Iran namely: *Adalia bipunctata* (LINNAEUS), *Coccinula elegantula* WEISE, *Coccinella septempunctata* (LINNAEUS), *Coccinella undecimpunctata aegyptica* (REICHE), *Exochomus nigripennis* (ERICHSON), *Hippodamia variegata* (GOEZE), *Menochilus sexmaculatus* (FABRICIUS) and *Oenopia conglobata contaminata* (MENETRIES) (JALALI, 2001, MEHRNEJAD, 2003, MEHRNEJAD &

JALALI, 2004, MEHRNEJAD et al., 2010). These coccinellids frequently attack CPP nymphs and can reproduce and complete development using this insect as a prey. In pistachio orchards, adult coccinellids may therefore be important early in the growing season due to their abundance and diversity.

Among these psyllophagous coccinellids, *A. bipunctata* and *O. conglobata contaminata* are considered as the most abundant predatory beetles in the pistachio orchards in Kerman province. These ladybirds are highly active in spring and autumn on pistachio trees, but are very scarce during July, August and early September. There is evidence that, when adequate food (i.e., psyllids) are present on pistachio trees, *A. bipunctata* and *O. conglobata contaminata* tend to feed and, in particular, to lay their eggs on pistachio trees, even though herbaceous plants contaminated with *A. gossypii* and *A. craccivora* were available in the orchards at the same time. It might be suggested that, because of the preference of *O. conglobata contaminata* to attack psyllid nymphs and because this ladybird prefers taller vegetation, it might remain in the pistachio trees contaminated with psyllids (JALALI, 2001, MEHRNEJAD & JALALI, 2004, MEHRNEJAD et al., 2010). However, HODEK (1967) considered that the best criterion for considering a species typical for a particular habitat is that the species breeds there. Two morphs of *O. conglobata contaminata* live in pistachio plantations. The form with a cream background on the elytra is widely distributed in pistachio orchards, while the second form, with a light pink background, is only found on wild pistachio trees in the mountainous area (HASSANI et al., 2009, MEHRNEJAD et al., 2010). Both morphs of *O. conglobata contaminata* attacks CPP nymphs and destroys a large number of psyllid nymphs (a total of 620 4th instar nymphs) throughout its larval period and also many during the adult stage as well (a mean of 191 4th instar nymphs daily). The intrinsic rate of natural increase (r_m) at 27.5°C was 0.19 (MEHRNEJAD & JALALI, 2004).

A. bipunctata occurs as several different forms. MAJERUS et al. (1982) reported that *A. bipunctata* occurred in many forms ranging from red to black in color, and HODEK & HONĚK (1996) stated that *A. bipunctata* is a polymorphous species with a Palaearctic and Nearctic distribution. On pistachio trees, three forms exist, e.g., *A. bipunctata "revelierei"* a form with many black spots on a light red background, and a form with a light red background with two black spots called f. *typica*, and another with a black background with a few red spots on the elytra, known as the melanic form. *A. bipunctata* is known to be a generalist aphidophagous ladybird, feeding on a wide range of aphid prey (BANKS, 1955, OMKAR, PERVEZ, 2005). BLACKMAN (1967) showed that adult *A. bipunctata* preferred to oviposit at the shrub level (about 4 ft), while *C. septempunctata* preferred plants near ground level. In this regard, in a field experiment, ARAB-HORMOZABADI (2005) showed that *A. bipunctata* preferred to oviposit at a height of 150 cm on pistachio trees. This ladybird consumed a mean of 338 4th instar psyllid nymphs during its larval period and a mean of 186 4th instar psyllid nymphs daily during its adult stage. The intrinsic rate of increase (r_m) at 27.5°C was 0.18 (JALALI, 2001). Although both *A. bipunctata* and *O. conglobata contaminata* destroy large number of CPP nymphs, the r_m values of both are less than their prey under similar conditions.

Adults and larvae of *C. septempunctata* feed readily on CPP nymphs and develop quickly, with relatively low mortality, during the pre-imaginal developmental period. This beetle consumes a total of about 1500 4th instar psyllid nymphs during its larval stage while the adult female destroys a mean 400 4th instar psyllid nymphs daily. Adult

C. septempunctata were frequently collected in psyllid colonies in both planted and wild pistachio trees in the spring and autumn (MEHRNEJAD et al., 2010). *C. septempunctata* in particular is a member of a group of ladybirds that can feed on many kinds of prey but appears to specialize on aphids (DIXON, 2000, HODEK & HONĚK, 1996). The high voracity of both the larvae and adults of this ladybird, the presence of this predator on the trees throughout spring and autumn and its wide distribution in the lowlands and mountainous areas of central and southern Iran are the major criteria for conserving this predator in pistachio orchards. More research is clearly needed to clarify the reproduction requirements of this predator so as to improve its efficiency in pistachio orchards.

Of the other ladybird species, *E. nigripennis* was found only on planted pistachio trees feeding on scale insects and CPP but *H. variegata* and *C. undecimpunctata aegyptica* are found in both planted and wild pistachio plantations. The r_m values of these latter two coccinellid beetles is almost equal to that of the CPP under controlled conditions, which is important when considering these ladybirds for use as biocontrol agents against CPP (JALALI, 2001, MEHRNEJAD et al., 2010). In general, conservation of the coccinellid population, e.g., by providing pollen sources and by avoiding the use of wide spectrum insecticides, might contribute to a reduction in CPP populations.

Predatory bugs

Anthocoris minki pistaciae WAGNER (Hemiptera: Anthocoridae), *Farsiana pistaciae* LINNAVUORI (Hemiptera: Miridae), and *Pseudoloxopis* sp. (Hemiptera: Miridae) are the most abundant predatory bugs of the CPP in Iran (MEHRNEJAD, unpublished). Mirids and anthocorids are generalist predators and have one or two generations a year. Mirids overwinter as eggs that, in most cases, are inserted into the bark of trees; whereas anthocorids overwinter as adults (LATTIN, 1999). Most known species of Anthocoridae are predatory and occur in a variety of habitats, although a few are plant feeders, at least in part, chiefly on pollen (PERICART, 1972). Their prey is usually small insects, e.g. thrips, scales, aphids, psyllids, bark beetles, small caterpillars, mites and the eggs of various insects (CARAYON, 1972, LATTIN, 1993, 1999), although aphids seem to be the most common prey (LATTIN, 1999). Many species of *Anthocoris* occur especially on deciduous shrubs and more particularly trees (ANDERSON, 1962, LATTIN, 1999) such as *Salix*, *Populus*, *Malus*, *Pyrus* and *Fraxinus* (KELTON, 1978, PERICART, 1972). Anthocorids such as *A. nemoralis*, *A. nemorum* (LINNAEUS), *Orius majusculus* REUTER, *O. minutus* (LINNAEUS) and *O. vicinus* (RIBAUT) have been recognized as significant members of the predator complex in pear orchards for many years (ANDERSON, 1962, BOOIJ, 1990, DRUKKER et al., 1995, HODGSON & MUSTAFA, 1984, PERICART, 1972, SOLOMON et al., 1989), principally against species of pear psyllids such as *C. pyri*. No information is available on their distribution nor on the variety of other hemipterous predatory bugs in pistachio plantations of Iran and neighboring countries but *Anthocoris nemoralis* (FABRICIUS) has been reported as a biocontrol agent of CPP in Greece (SOULIOTIS et al., 2002), but the presence and activity of this species in pistachio plantations in Iran remains unclear.

Anthocoris minki pistaciae appears on pistachio trees in mid April as soon as the CPP population builds up in early spring. The females insert their eggs into leaf tissues under the epidermis, particulaly around to the midrib. The newly emerged nymphs are able to attack all instars of psyllid nymphs, even 5th instars, even though these nymphs have an active defensive behaviour. *A. minki pistaciae* was found to be an abundant CPP predator on wild pistachio trees in mountainous areas. Its population increases with the increasing CPP nymphal population through late April to early June and then sharply declines in mid June due to a major drop in the prey population (MEHRNEJAD, 2007). Again, when the CPP population increases again in early autumn just prior to the appearance of the winter-form adult psyllids, various stages of *A minki pistaciae* appear on the wild pistachio trees. However, *A. minki pistaciae* has only a small population in pistachio orchards, probably mainly due to the large amounts of chemicals applied, particularly in the early spring (MEHRNEJAD, unpublished). WYSS (1995) found greater numbers of anthocorids and mirids in orchard strips that had been undersown with flowering plants. Unfortunately, flowering plants are scarce in pistachio plantations because of the salty soil conditions and the general lack of irrigation.

A. minki pistaciae produces two generations a year and hibernates as the adult under the bark and in deep crevices in the stems and branches of the trees in pistachio plantation areas of Iran. Under controlled conditions (27.5±0.5°C, 55±0.5 rh and 16h light) successful development and reproduction of *A. minki pistaciae* occurs on CPP nymphs, indicating that CPP is a suitable prey for this predatory bug, although the immature mortality rate of bug is high (about 55%). During this development, the bug attacks and destroys a mean of about 130 4th instar nymphs during the larval period, and a mean of 40 4th instar psyllid nymphs daily during its adult stage. Under the above controlled conditions, the r_m value for this species was 0.14, much lower than the r_m of its prey (reported to be 0.22 under the same conditions). The fecundity of this anthocorid was about 250 eggs when fed on CPP 4th instar nymphs. It is not clear what its alternative prey is in pistachio orchards, as rearing of this predator on such aphids species as *A. gossypii* and *A. craccivora* was unsuccessful. Cannibalism was observed, particularly at low host densities (Mehrnejad, unpublished). Although the bio-ecological parameters of this predator, e.g. the voracity of the larvae and adult, the number of generations a year and the r_m value, are not comparable to the other CPP predators such as coccinellids, this bug could be a useful addition to the biocontrol complex for this psyllid in an IPM programme.

The mirid bugs *Farsiana pistaciae* and *Pseudoloxopis* sp. both attack CPP nymphs and developed successfully when the psyllid is used as prey. Both bugs appear in CPP colonies from late April, particularly on wild pistachio trees. However, these populations in the wild drastically decrease from early summer and only adults are found in a very low density on pistachio trees thereafter (Mehrnejad, unpublished). Only limited information is available on the status of these bugs in pistachio plantations and little is known about them as predators of CPP.

The mirid *Campylomma diversicornis* REUTER is also a very active bug with a large population in both planted and wild pistachio trees. Although it has been reported as a predator of the whitefly *Bemisia tabaci* (GENNADIUS) (KAPADIA & PURI, 1991, GENCSOYLU & YALCIN, 2004), it also appears to be phytophagous on pistachio trees and so further investigations are needed to clarify its diet regimes.

Lacewings

Three chrysopid species have so far been recorded from pistachio in Iran, *Chrysoperla carnea* (STEPHENS), *Suarius nanus* (MCLACHLAN) and *Italochrysa italica* (ROSSI) (Neuroptera: Chrysopidae). *C. carnea* is a cosmopolitan generalist predator found in a broad range of temperate habitats and is considered to be the most important of these three chrysopids in terms of population size and its distribution within pistachio plantations (JAFARI-NODOSHAN, 1998). *C. carnea* is among the most-frequently detected species in surveys of natural enemies of orchard pests but there are few confirmed reports of regulatory effects on pest populations without artificial manipulation (SOLOMON et al., 2000). *C. carnea* has also been reported as a natural enemy of the CPP in Greece (SOULIOTIS et al., 2002) and also of pear psyllids in Europe (SOLOMON et al., 2000). Chrysopids are mostly generalist feeders, principally taking aphids (PRINCIPI & CANARD, 1974), but will feed on almost any other soft-bodied arthropods, including siblings and other beneficial insects (CANARD et al., 1984). Their biology and ecology has been reviewed extensively (BAY et al., 1993, CANARD et al., 1968).

In pistachio orchards, larvae of *C. carnea* prey mostly on weed-feeding aphids and CPP. However, it is thought to attack small lepidopterous caterpillars, such as those of *Arimania komaroffi* RAGONOT (Lepidoptera: Pyrallidae) and *Recurvaria pistaciicolla* DANIL. (Lepidoptera: Gelechidae), that frequently occur on pistachio trees. *C. carnea* is present in both planted and wild pistachio trees throughout of the growing season from mid April to October but is most abundant in early July and in October. In addition, a positive relationship has been found between its abundance and that of herbal weeds in pistachio orchards. Greater adult lacewing populations are present in pistachio orchards covered in weeds than in those from which these herbs have been removed (personal communication: F. KAZEMI, 2009).

Under controlled conditions the lacewing larvae attack both the eggs and nymphs of CPP, killing a mean of 1020 4^{th} stage psyllid nymphs at 30ºC and 1800 at 32.5ºC during the larval period. However, the larval mortality was relatively high while feeding on CPP, the developmental period lasted significantly longer than its prey in the temperature range 15-35ºC, and the r_m value was only 0.11, half that of the CPP (0.22). It develops faster between 30-32.5ºC while feeding CPP nymphs, but the females lacewing lay very few eggs at these temperatures (personal communication: M. HASSANI-SADI, 2009). Although *C. carnea* might be considered an unsuitable candidate for augmentative release against CPP, it is a biocontrol agent that plays a natural role in reducing psyllid populations and so should be included as an element within an IPM programme.

Mites

No information is available on the importance of predatory mites in the control of CPP, although several species are present on pistachio trees and it is assumed that beneficial mites do play a role in CPP control. The population density, distribution, prey-range preferences and biological parameters of these tiny, very active predators remain unclear. Here the identified predatory mites are introduced but more research is needed to clarify their status.

Anystis baccarum (LINNAEUS) (Anystidae) is a large (1-1.5 mm long) mite, broadly oval in shape, reddish, soft-bodied and fast running. This is a non-specialist predator that may occur everywhere, but is difficult to rear as it is cannibalistic. *A. baccarum* has been encountered in CPP colonies throughout the growing season, particularly in spring and from late summer to early autumn in both planted and wild pistachio growing areas (MEHRNEJAD, 2003, MEHRNEJAD & UECKERMANN, 2001, 2002).

Abrolophus sp. (Acari: Erythraeidae) is an elongate reddish-purple mite, 1.5-2 mm long, covered in fine setae and is extremely fast moving when disturbed. This species has been found actively feeding on CPP nymphs on wild pistachio trees, *P. atlantica* subsp. *mutica* (MEHRNEJAD, 2003, MEHRNEJAD & UECKERMANN, 2001, 2002). It is widely distributed in wild pistachio in mountainous areas but it is found rarely in pistachio orchards. It overwinters as an adult in crevices in the bark and appears on aerial parts of trees from late April when CPP eggs and nymphs first appear on pistachio leaves. *Abrolophus* sp. attacks eggs and all nymphal instars of CPP. This mite transfer between tress by clinging to the back (neck and notum) of adult CPP, this phoresy was seen frequently. In addition, this mite has been seen feeding on the nymphs of the predatory bug, *F. pistaciae*. Its abundance is very much reduced from early June onwards when the numbers of CPP decline sharply on wild pistachio trees. However, *Abrolophus* rebuilds its population from late September in CPP colonies [MEHRNEJAD, unpublished].

Paraseiulus porosus KOLODOCHKA and *Phytoseius corniger* WAINSTEIN (Acari: Phytoseiidae) are found on the aerial parts of pistachio trees, close to psyllid colonies. *P. porosus* is widely distributed in the pistachio growing areas on both *P. atlantica* subsp. *mutica* and *P. vera* (MEHRNEJAD, 2003, MEHRNEJAD & UECKERMANN, 2001, 2002). The biology and status of these phytoseiids and of the other predatory mites remains unknown and should be further investigated.

Ants and Spiders

These two predatory arthropod groups are usually abundant on pistachio trees throughout the growing season. However, their interactions with CPP remain unclear. Because ants feed on the honeydew and both nymphal and adult CPP produce large amounts of honeydew, ants definitely try to protect the colonies. This is particularly obvious on wild pistachio trees, *P. khinjuk*, in the mountainous areas where no chemicals have been used, and where colonies of the khinjuk psyllid, *A. bimaculata* almost always have several ants in attendance, but few psyllids' natural enemy species with very low density lives, it seems that the ants keep the natural enemies away the CPP colonies. The predatory behaviour of ants and spiders has been proved against other pistachio pests such as the pistachio twig borer moth, *Kermania pistaciella* Amsel (Lepidoptera: Tineidae: Hieroxestinae) (MEHRNEJAD & BASIRAT, 2009).

Conclusions and future research

Several factors regarding psitachio production and the difficulties of controlling this psyllid are worth consideration: (1) pistachio plantations are widely developed as a large-scale monoculture, where almost no other crop is produced, mainly due to the shortage of water resources and because of the alkaline soil; (2) refugia for beneficial insects, including alternative plants for food such as pollen and nectar, are limited; (3) chemical application is considered by most growers to be the main pest control method**.** It is possible that, because the sprays are reasonably effective against CPP, there is a population density effect and there is simply not enough food for the predators/parasitoids to remain, i.e., they manage to survive the sprays but there are easier pickings elsewhere; (4) the sensitivity of pistachio trees to the psyllid varies between cultivars and also during the growing season (from the end of March to late November); and (5) other pests, that also need additional management, might be present. The CPP is well adapted to the dry desert conditions of pistachio-growing areas in Iran, with the cold winters, long hot summers and poor vegetation. These characteristics of the environment and the psyllid make control using natural enemies difficult (MEHRNEJAD, 2003). For CPP, the most striking characteristic is its high reproductive rate. This has been found to exceed 1000 eggs/female for the winter form and 900 eggs/female for the summer-form respectively (MEHRNEJAD & COPLAND, 2005a). This high rate of reproduction and the other adaptations to this harsh environment mean that CPP is well adapted to exploit the pistachio plantations, particularly the winter-forms, as they allow the establishment of very large colonies in early spring or even from late winter (MEHRNEJAD, 1998). It is important to look for natural enemies that depress the CPP population in the pistachio plantations. All three methods of natural enemy exploitation, e.g., introduction, augmentation and conservation, should be developed. However, conservation should assume a central role in biological control strategies for this pest. Although progress has been made, our present knowledge of CPP's natural enemies, their value as biological control agents and the methods for their conservation are incomplete. It is suggested that future emphasis should on the identification and evaluation of natural enemies to determine the most promising agents.

Many natural enemies of the CPP are listed in this review. It is hoped it will encourage scientists and policy makers to turn this neglected and important field into an active branch of research and develop it as an integrated psyllid management. However, few experimental data exist on the impact of psyllid enemies under field condition at the present time. Further investigations are essential for the development of an effective CPP biocontrol programme, particularly to characterize the main factors responsible for changes in population dynamics and in particular the causes of pest outbreaks under natural condition. Finally there is a need for research on host-plant resistance as part of an IPM program.

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