

Pear resistance to Psilla (*Cacopsylla pyri* L.). A review

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Abstract: Pear psylla, *Cacopsylla pyri* L., is one of the most important insect pests in European pear production areas. Control measures are directed specifically at controlling pear psylla and require accurate and timely information about insect densities in the orchard. Thus, there is a widespread interest in the search for suitable biological control agents and in breeding for resistance to pear psylla. Modes of host plant resistance to pear psylla damage have been studied extensively by several authors and the susceptibility of many European pear genotypes have been investigated in order to detect cultivars resistant or highly tolerant to this pest useful in breeding programs. This review presents an update of published results and knowledge on psylla life, host finding for feeding and oviposition, type of damages, monitoring and control strategies with renewed and improved efficacies, resistance characterization and breeding, with particular regard to the identified sources of resistance and the screening methods.

1. Introduction

Pear psylla is one of the most important pests affecting production of pears of *Pyrus communis* parentage. A sucking insect that causes severe wilting and defoliation, which reduces yields and weakens the trees. At least seven species of pear (*Pyrus*)-feeding psyllids in the genus *Cacopsylla* (formerly *Psylla*) are recognized, but there are three major species which occur primarily west of China: *C. pyricola* Foerster is the only species found in North America; *C. pyri* L. and *C. pyrisuga* Foerster are also endemic to Europe. *C. pyricola* probably originated in Western Eurasia in contact with wild *Pyrus* (Bell *et al.*, 1996).

All of the major cultivars of the European pear are susceptible to this Homopteran insect, varying only slightly in the degree of infestation and tolerance to feeding. Major cultivars of *P. pyrifolia* parentage are slightly less susceptible, while those of *P. x P. bretschneideri* or *P. ussuriensis* origin (e.g., Ya Li and Tzu Li) appear to be moderately resistant (Beutel, 1985).

2. Morphology and life of *Psylla*

C. pyri is characterized by a seasonal dimorphism, which is strong enough that the two morphotypes were at one time considered to be distinct species (Slingerland, 1892). The winter form is a large dark red overwinter-

ing adult with wide blackish longitudinal and traverses scratches, that is quite larger (2.6-2.9 mm) than the smaller and light-colored summerform adult (2.1-2.7 mm).

Pear psylla spends much of the winter in reproductive diapause, characterized by immature ovaries and a lack of mating. Dispersal of winterforms from the orchard in autumn begins in early September (Civolani and Pasqualini, 2003), and peaks during late-October and early-November, coinciding with leaf fall in pear. This winterform adults overwinter both alone or in small groups in bark crevices, branch intersections and at the base of shoots on the pear host plant (Priore, 1991) and away from the host plant, in the earth, or under rocks and clods which are exposed to sun irradiance (Nguyen, 1962). So, some individuals spend the entire winter on pears, others recolonize pear early in spring before bud break, long before any sign of green foliage, since they would feed on a plant other than pear but not complete develop (Fye, 1983). Cool, wet autumns result in a reduction in dispersal out of the orchard. As soon as the weather conditions become favourable, winterforms reach the apical twigs and pierce the plant by inflicting their stylets at the bud base. In Sicily overwintering nymphs from which adults flutter in February have been noticed as well (Nucifora, 1969; Tremblay, 1995).

The egg maturation is very slow in overwintering females and seems to be accelerated when psylla adults ceases to disperse among orchards (Rieux *et al.*, 1992; Lyoussoufi *et al.*, 1994). Generally diapause terminate in mid December, but in the more precocious females this event may occur starting from the end of November (Rieux *et al.*, 1990). At the end of January all females are mature

and inseminated, but for the beginning of egg-laying by overwintered winterforms a temperature over 10°C for 2 consecutive days (thermic quiescence) is required (Nguyen, 1975). In Italy egg-laying begins in late February in Campania (Priore, 1991), early March in Emilia-Romagna (Giunchi, 1959) or early April in Veneto (Terza and Pavan, 1988). Because of the absence of foliage at this time, the first eggs are deposited directly on wood, generally at the base of unopened buds (spurs), in a number of 300-400 per female. As foliage becomes available in mid- to late-March, oviposition shifts to occur primarily on expanding leaves and flowers: eggs are deposited along mid-veins and petioles of developing leaves and on stems and sepals of blossoms. First nymphal instars escape from winter eggs in concurrence with bud opening and leaves sprouting and infest the new vegetation. The first generation of summerform adults appears in April and fecundity of females appears to be quite higher compared to winterforms due to their major longevity (on average about 600 eggs per female) (Stratopoulou and Kapatos, 1995), although high temperatures can cause a substantial reduction in fecundity. Spring- and summer-deposited eggs require ca. 6-10 days to hatch, depending upon temperature (McMullen and Jong, 1977). There are 5 nymphal instars. Nymphs require 3-4 weeks to complete development at moderate (21-27°C) temperatures (Georgala, 1956; McMullen and Jong, 1977). Male and female progeny are produced in equivalent numbers (Burts and Fischer, 1967). Afterwards (May) feeding nymphs of second generation develop on growing shoots with an aggregate distribution on leaves and internodes (Deronzier and Atger, 1980; Pasqualini *et al.*, 1997) immersed in pools of honeydew, which they produce in extremely large amounts. Further generations overlap with all the ontogenetic stages and phases till autumn. In the warmer periods aestivation phenomena may occur (Stratopoulou and Kapatos, 1995). *C. pyri* develops 5-7 generation per year.

3. Host finding, probing and feeding behaviour

Host finding for feeding and oviposition contemplates a sequence of phases of hierarchic nature. The first, out of the three principal phases, consist of a host selection that the insect makes from distance using visual and olfactive impulses. The second phase occurs when the insect takes contact with the plant surface getting information about its physical structure. These impulses may strongly influence female egg-laying. The third phase regards the discrimination between host and non host plant through gustative impulses perceived during the survey of the internal tissues, the so called 'probing behaviour'.

Although most of the Homopteran insects have been reported to make little use of volatile compounds for the long and mid distance host finding and acceptance, the chemical characteristics are thought to be much more plant specific than the quality of the visual spectrum (Prokopy and Owens, 1983; Dethier, 1982). The role of olfactive and

gustative sensilli existing in the antennas and tarsi is not yet known, whereas that of gustative sensilli in the mouth apparatus is evident.

Psylla rarely initiates oviposition activities immediately upon leaf contact. Rather, oviposition activities tend to be preceded by settling-probing activity, as evidence that plant cues received on initial contact are insufficient to release oviposition activity but that plant cues received during settling-probing activity release oviposition activities. Thus plant cues received during oviposition activities ultimately affect whether the egg is deposited (Horton and Krysan, 1991). Deprivation or habituation may result in higher number of eggs oviposited on less suitable genotypes than in free-choice tests.

Indeed, *C. pyricola* adult has been found to be more selective in oviposition activities than in its settling-probing activities, i.e. probing is not likely to be an indicator of a variety's acceptability, since *C. pyricola* is able to colonize and feed nonhosts like *Pyrus calleriana* and *Malus* spp., but without laying eggs (Horton and Krysan, 1990). As for plant cues that mediate host acceptance it has been reported that pear psylla readily settled on nonhosts to an extent that initially unacceptable species eventually receive eggs, thus suggesting either that plant cues that release settling activity differ from those that release abdomen bend activity and oviposition, or that thresholds for these activities differ. Yet, there is evidence that settling is partially mediated by leaf surface characteristics for winterform psylla. First, settling-probing activity differs between upper and lower leaf surfaces, suggesting that cues received at the leaf surface affect activity. Second, at leaf contact, pear psylla scrape the leaf surface with their tarsi (Ullman and McLean, 1988; Horton and Krysan, 1990). Finally, despite the tendency to settle readily on apple, the amount of time between initial leaf contact and onset of settling-probing was smaller for psylla encountering Bartlett pear than for those encountering apple, suggesting that leaf surface cues affected behaviour.

Psylla adults ingest more frequently xylematic tissue, while nymphs prefer phloematic tissue or at least that of vascular fascies. A good knowledge on the different *C. pyri* feeding phases by means of EPG may allow to discriminate between susceptible and resistant selections and to locate the mechanisms of resistance within plant tissues (Civolani *et al.*, 2010). Up to know only little differences have been found in the feeding behavior of psylla adults on the susceptible William and the resistant NY10353 pears. However, lasting of the first and second non-probing is longer on William compared to NY10353, and *C. pyri* needs less time to reach the phloematic fascies in the susceptible plant, in accordance with the assumption of Horton and Krysan (1990, 1991).

4. Types of damage

Pear psylla causes three primary types of damage: fruit russet, psylla shock, and pear decline (Burts, 1970; Westi-

gard *et al.*, 1979; Beers *et al.*, 1993). Fruit russet is caused by the feeding activities of nymphs and is of most concern to growers, and control programs are generally directed at preventing this injury, since it can be caused by relatively low population densities (Burts, 1988).

As in other Homoptera, pear psylla ingests excessive quantities of plant juices and other plant products that must be eliminated (as honeydew) during the digestive process. In fact, lymph in the phloematic tissue is rich of carbohydrates and poor of nitrogenous substances, due to this deficiency the insect has to absorb a great quantity of lymph that it afterwards excretes through his digestive apparatus producing honeydew. Adult psylla excrete these waste products as small, waxy pellets that cause no harm to the plant or fruit. Conversely, the immature form of the insect secretes copious quantities of honeydew, a sugary, sticky substance. If nymphal-produced honeydew is in contact with fruit for a significant period of time it causes dark blotches or streaks on the surface of the fruit (russetting), which in turn results in downgrading of the fruit at harvest (Burts, 1970). Honeydew allows a black, sooty mold fungus (*Antennaria*, *Aureobasidium*, *Capnodium*, *Ceratocarpia*, *Cladosporium*, *Torula*, *Ulocladium*) to grow on both fruit and leaves, not only reducing the quality of the fruit, but also blocking sunlight from the leaves and decreasing photosynthesis.

A second type of injury, also caused by the sucking nymphs at high densities, is of a more indirect nature than that previously mentioned. Infected leaves turn brown and often fall and the fruits drop prematurely or are small and of poor quality, thus suppressing root growth and reducing tree vigor and yield. (Westigard and Zwick, 1972). These symptoms have collectively been termed psylla shock, and are caused by a toxin in the saliva of feeding nymphs (Beers *et al.*, 1993). Symptoms of the injury can be similar in appearance to those associated with pear decline disease. Psylla shock can be particularly damaging because the effects are not always restricted to the year of infestation, but symptoms may carry-over into a second year even if densities are not high the second year (Beers *et al.*, 1993). Cultivars that are less preferred by psylla, such as some red pears or pears of Asian origin, tend less likely to experience this type of damage.

Finally, adult pear psylla vector the mycoplasma-like organism (Hibino and Schneider, 1970) that is the causal agent of pear decline disease especially during vegetative growth (Carraro *et al.*, 1998; Davies *et al.*, 1998; Guerini *et al.*, 2000). The feed and phytoplasma are assumed together from a diseased plant and transmitted to a healthy plant during the salivation of phloematic feedings (Carraro *et al.*, 1998). The way of transmission is persistent-dispersive, as pear decline phytoplasma propagate in the insect body. Disease acquisition and inoculation require at least 1-2 hours of phloematic feeding; thereafter the vector undergoes to a period of latency (about 1-2 weeks) during which the phytoplasma circulates and propagate within its body till he reaches the slave glands. Both winterform and

summerform pear psylla can be important in the transmission of pear decline (Blomquist and Kirkpatrick, 2002).

This pathogen causes sieve-tube necrosis at or below the graft union (Batjer and Schneider, 1960; Westigard *et al.*, 1979), preventing tree-synthesized nutrients from reaching the roots and resulting in starvation of the roots (Wilde and McIntosh, 1964). Symptoms of the disease include a slow to abrupt decline or collapse in growth and vigor, causing a reduction in yield and (often) death of the tree. Certain affected pear trees may recover if psylla densities are kept low or during winter quiescence thanks to the degeneration of epigeous phloematic tubes (Giunchedi and Refatti, 1997; Davies *et al.*, 1998). Severity of the disease depends upon psylla density and type of rootstock (Beers *et al.*, 1993). Cultivars that have been grafted onto *P. communis* rootstock are less susceptible than those grafted onto *P. pyrifolia* or *P. ussuriensis* rootstock. Quince (*Cydonia oblongata*) rootstocks possess a limited aptitude to allow phytoplasma survival between one vegetative cycle and another. Resistant rootstock has largely remedied this problem in various pear growing regions.

5. Monitoring and control tactics

The psyllid *C. pyri*, along with its natural enemies, needs to be carefully monitored for correct integrate pest management and biological pest control decision making. Moreover, timing of spray application against *C. pyri* is crucial because recommended insecticides are only efficient at certain stages. Monitoring should provide starting from spring density of eggs, nymphs, adults and presence of the principal antagonist. A simple method for estimating densities of pear psylla is desirable. Monitoring pear psylla is made difficult by the uneven distribution of insects (eggs and nymphs) on the trees, a distribution that may in fact change seasonally. Densities of psylla may also vary with height in the tree canopy (and sex) both for *C. pyricola* (Brunner, 1984; Horton, 1994) and *C. pyri* (Stratopoulou and Kapatatos, 1995).

Currently, sampling of the adult population is necessary to determine the onset of reentry in late winter or the population density, and sampling of fruit spurs for eggs is often the easiest way to determine the beginning of egg-laying.

Counts have been obtained in USA using frapping, sticky traps, beat trays and open-ended organandy bags, the last one providing direct estimates of psylla numbers per leaf but being extremely time consuming (Horton, 1994; Horton and Lewis, 1997). Effectiveness of yellow sticky-board traps have been examined by several authors and seasonality of the catch and flight activity of pear psylla (*C. pyricola*) according to weather conditions have been reported (Krysan and Horton, 1991; Horton, 1994; Civolani and Pasqualini, 2003; Erler, 2004), as well as diurnal difference (Horton, 1993) and intraorchard changes in distribution associated with leaf fall (Horton *et al.*, 1993). Laboratory study have shown that males of both the sum-

merform and winterform morphotypes in *C. pyricola* are attracted to volatiles given off by females, whereas in the field male has shown a clear preference for sticky traps that have been baited with live females compared with traps baited with live males or left unbaited (Brown *et al.*, 2009). Limb beating or limb jarring to collect arthropod specimens from trees has been known for a long time and in several variations: frapping or beating tray (two-dimensional) and beating umbrella (three-dimensional). The first of this procedure has been applied by several authors and has been reported by Jenser *et al.* (2010) to depend considerably on weather condition, while the second one to be much less temperature and wind-sensitive, due to its vertical extension, and much more suitable for collecting fast moving or flying beneficial organisms than the two-dimensional method. In contrast with the hypothesis that any data collected for the adults using a beating umbrella would be influenced more by weather conditions than those gathered using funnels, Sanchez and Ortìn-Angulo (2011) have found a higher efficacy of the net in relation to the funnel. The same authors also have stated a low efficacy of the beating techniques for sampling nymphs that may be due to the fact that they hold tight to the substrate and are not easily removed by the act of beating.

Both the application of the sticky board traps and beating tray provide accurate information about the changes of pear psylla population density (Jenser *et al.*, 2010). In particular the capture of adults using either the funnel or the net may be used to estimate the absolute number of *C. pyri* nymphs on trees, thanks to the high correlation found by Sanchez and Ortìn-Angulo (2011) between nymphs counted on shoots and the capture of adults using either of the beating techniques. Several authors have reported the same relationship for other psyllid species (Horton, 1994; Jenser *et al.*, 2010).

The beating techniques also have the advantage of being less time-consuming than the sampling of leaves and, for beating over a net or tray, samples may be processed directly in the field, although the amount of collected insects using beating umbrella some times makes necessary the laboratory process.

In Europe the dynamic of *C. pyri* populations have been studied using frapping by various authors (Deronzier, 1984; Rieux *et al.*, 1992). According to Civolani and Pasqualini (2005) frapping is the sampling method which best represents the dynamics of populations of psylla and its predators (Antocoridis, Coccinellids, lacewings). Predators overwintering in bark crevices may be estimated by using corrugated cardboard traps (Bogya *et al.*, 1999; Horton *et al.*, 2002; Civolani and Pasqualini, 2003; Jenser *et al.*, 2010).

Alternatively the psylla eggs have been counted on the shoots and leaves using a binocular dissecting microscope by several authors (Jenser *et al.*, 2010) and a few of the authors investigated and counted both the eggs and larvae. This method provides real data, but it's time consuming; the sample must be taken into the laboratory and the counting completed within a short time. Berlese funnel is

a widespread technique for extracting arthropods mainly from soil and litter samples (Stäubli *et al.*, 1992). Moreover the mite brushing machine or leaf brushing machine developed by Henderson and McBurney (1943) is a technology that can reduce the time required to obtain either absolute counts or estimates of arthropods on leaves from samples. Recently developed, the wash-down method described by Jenser *et al.* (2010) offers the advantages of the independence of the weather conditions (temperature, wind, rain) and the daily rhythm of the examined psylla stages. Since practically every larvae developing on the flowers and shoots are extracted, it provides suitable data about the pear psylla population density and its changes, as well as about the effectiveness of the insecticides. This method has been suggested to provide also significant data to judge the susceptibility or tolerance of the pear cultivars to pear psylla species.

Since observing the population development of pear psylla is time-consuming and prone to error, phenological models could assist growers in the timing of monitoring and control measures, as they simulate and predict, by means of driving variables (usually temperature), the timing of natural events. There have been modest attempts to develop degree-day models that predict onset of egg-laying and appearance of first generation nymphs (Westgard and Zwick, 1972; Brunner, 1984; Beránková and Kouček, 1994) and timing of reentry (Horton *et al.*, 1992), with aims toward improving timing of the dormant spray. Morgan and Solomon (1993) have provided a phenological model for *C. pyricola* which have been integrated into a multi-pest forecasting system. Further on, a phenological model for *C. pyri* based on biological mechanisms, in particular the emergence of juvenile instars of the second generation, has been developed by Schaub *et al.* (2005).

In Italy the defence against *C. pyri* is mainly based on integrated pest management (IPM), supported by natural control aimed to equilibrate the complex biological relationships of the field community (Civolani, 2012). Among the basic strategies there are the 'good agricultural practice' (GAP) techniques that reduce tree suitability for growth and reproduction of pear psylla by avoiding overuse of fertilizers, incorrect or over pruning, and reducing excessive plant vigor (Beers *et al.*, 1993; Civolani, 2012). Suckers or water sprouts should be removed from scaffold limbs (Beers *et al.* 1993), because these are a source of rapidly growing and highly nutritious foliage. Also the strategies to control other pest species, such as the technique of mating disruption and the use of granulosis virus (CpGV) employed to control codling moth (*Cydia pomonella*), may influence psylla and assist in chemical control.

However, in the last decade commercial pear growers have relied primarily on the use of synthetic products to control pear psylla, and the advantages and disadvantages of the main strategies performed in the last 20 years in integrated and conventional farms have been described by Civolani (2012).

Unfortunately, these methods are not always entirely effective, as their efficiency depends both on the active in-

gradients employed and the weather conditions at the time of treatment and moreover pear psylla has developed resistance to several classes of commonly used insecticides (Riedl *et al.*, 1981; Follett *et al.*, 1985; Burts *et al.*, 1989; Croft *et al.*, 1989).

Current control recommendations emphasize destruction of the overwintered generation, or offspring of the overwintered generation with insecticides. A typical control program for overwintered adults is performed at leaf fall, commonly in France on *C. pyri* and in North America on *C. pyricola*, with the application of pesticides belonging to the pyrethroid family (with or without mineral oil added), repeated as necessary in late winter (at bud swelling stage or bud break) to break down the population of females emerging from winter shelters and about to lay eggs.

These pyrethroids are completely non-selective but broad spectrum and therefore dangerous for the beneficial insects. For this reason the treatment must be performed only at complete leaf fall (late November or early December), when *A. nemoralis* populations have already found shelter in bark crevices while *C. pyri* adult winter forms are still active on plants. Efficiency of treatments may vary considerably upon seasonal conditions. For example most psylla adults take shelter early and survive to the late autumn treatments when an early frost occurs at the beginning of autumn. Similarly the efficiency of chemicals is reduced after frost waves at the end of winter which interrupt and delay the emergence of adults, while activity of pesticides is best after a mild winter when almost all adults leave their shelters at the time of treatment (Civolani, 2000; Civolani and Pasqualini, 2003).

In Italy the dormant sprays are discouraged since the pest population, after an initial sharp decline, soon recovers in spring because the natural control by its predator *A. nemoralis* is limited, then increases again in May, reaching the economic threshold for spring-summer treatments (Civolani, 2012).

The main side effect of the use of pyrethroids in late winter is that they sharply reduce the psylla first generation and therefore could starve the anthocorids, interfering with their settlement during early plant growth in spring. Various alternative biorational solutions to synthetic pesticides have been tested against the overwintering generations, and among them kaolin and some oily compounds. Kaolin, a white, non-abrasive, fine-grained aluminosilicate mineral that is purified and sized so that it can be easily dispersed in water, creates a mineral barrier on plants that prevents oviposition and insect feeding (Puterka *et al.*, 2000). Treatment with kaolin has been reported to hinder egg anchorage on the leaf surface and inhibiting host-plant acceptance. Moreover, some insects have been found to be less mobile and unable to reach the laying site (host location) on plants, as their body and wings have become soiled (Pasqualini *et al.*, 2003; Daniel and Wyss, 2006).

Further on, Puterka *et al.* (2005) investigated the effects of particle film type (hydrophobic versus hydrophilic) and formulation determining that there are a number of bio-

logical effects particle films have on pear psylla beyond the deterrence of adult settling and oviposition.

Alternatively, mineral oils and oily compounds could also be used to interfere with egg deposition by psylla adults. A good reduction of the number of eggs laid has been obtained in Northern Italy with pure mineral oil alone ('dormant oil') (Pasqualini *et al.*, 2003) and in Turkey with fish-liver oil and summer oil (Erler, 2004).

Some growth regulators have proved to possess a good activity against eggs and nymphs of first and second generation by interfering on the cuticle transport and deposition during larvae development (Erler and Cetin, 2005).

At the beginning of the second generation growers can assess the risk to their orchard and still target specific stages. Therefore, treatments target mostly eggs and/or young larvae of the second generation. The treatments against summer generations can be performed towards eggs or nymphs.

Chitin inhibitors, usually employed against *C. pomonella*, have shown a secondary effect on second generation eggs, usually laid in the first decade of May, especially when they are applied on newly laid eggs (white eggs) or on eggs laid in a short time after the treatment.

However, control strategies against juvenile stages are of most relevance, and were performed in the past with generic organophosphorates, whereas are based in present times on specific synthetic active ingredients, often acaricides. Among these, abamectin (produced by the soil bacterium *Streptomyces avermitilis*) is the basic chemical employed today against young nymphs of second generation (usually in May) and included in the Italian Disciplinary of Integrated Management. The best results are obtained when yellow eggs are mostly present and when the hatching peak has not yet achieved (Pasqualini and Civolani, 2006). Abamectin is allowed only once in a year or twice in case of young orchards; since it's not systemic, the addition of mineral oil may improve its penetration within 24 hour time. A new broad spectrum acaricides, namely spirodiclofen (BAJ2740, trade name: Envidor®), belonging to the new chemical class of tetrionic acid derivatives, has been discovered by Bayer CropScience during the 1990s and is commercially available since 2007. Spirodiclofen has a new original mode of action (interference with lipid biosynthesis) and shows no cross-resistance to any resistant mite or whitefly field population, representing an invaluable new tool to manage insecticide resistance in rotation with abamectin. It's efficiency is best on yellow eggs some days before the hatching of first instar nymphs and is improved by addition of mineral oil, although often lower than that of abamectin (Pasqualini and Civolani, 2007; Bosselli and Cristiani, 2008; Marčić *et al.*, 2009).

Besides summer mineral oils, whose main action is that of dissolving honeydew, sodium dioctyl sulphosuccinate or other vegetal free fatty acids may be used for washing the trees (Briolini *et al.*, 1989). Recently some other novel compounds have been used, similar to liquid glue and capable of controlling almost all juvenile instars of *C. pyri*. These products are synthetic sugar esters (sucrose oc-

tanoate) and represent a relatively new class of insecticidal compounds that are produced by the reaction of sugars with fatty acids, valuable in crop integrated pest management programs (Puterka *et al.*, 2003).

It's important to keep in mind that summer psylla infestation depend on the antagonists development in spring, first of all the most important one, *A. nemoralis*, which has to be protected. For first instar nymphs control threshold is given by the ratio between number of infested shoots and number of shoots with the antagonist Antocoride, which have to be ≥ 5 (Marani and Reggidori, 2007).

Also the relevant effect of weather conditions on pest populations should not be underestimated. In fact, the development of psylla is strongly reduced by high summer temperatures that cause the death of eggs and the slow-down of juvenile growth. On the other hand, cold and rainy periods during blossoming and petal fall encourage nymph spreading on plants, often clustering in flower calyxes, sometimes causing russet blotches or young fruit drop (Civolani, 2012). Climate conditions, such as wind, have been demonstrated to have an impact on the clustering of psyllids, whereas spatial factors, such as distance from a mixed hedge have been found to be related to beneficial arthropod community (Debras *et al.*, 2008).

Localized resistance cases to organophosphorates insecticides, pyrethroids and carbamates pesticide families and chitin inhibitors family have been developed and have been largely documented, especially for *C. pyricola* in North America since 1960 (Harries and Burts, 1965). Resistance rates among the active ingredients has been reported to be very variable in laboratory tests and probably there are different mechanisms involved in the resistance to different pesticide families, as reported by Civolani (2012).

In Italy, cases of loss of efficiency of abamectin have been noticed in some orchards in Emilia-Romagna region, indicating that there is a high risk of selection for resistance to abamectin, especially if the number of treatments per year is high. Up to now, the tests data indicate that no apparent resistance to abamectin has been developed in *C. pyri* populations of that region, but may rather be related to incorrect pest defence management (Civolani *et al.*, 2007).

Control strategies should be based on a limited use of pesticides, possibly selective ones, in order to foster the development of *A. nemoralis* populations, which become a relevant factor to control the pest, preying on both eggs and nymphs of psylla. In Emilia-Romagna *A. nemoralis* generally shows three generations and may feed also on other insects, for example aphids and the pear sawfly *Hoplocampa brevis*. Laboratory tests have shown an average predation of about 300 psylla nymphs during the entire life of an adult, which lasts about 60 days (Civolani, 2012).

One problem is that the populations of this anthocorid grow rapidly in spring only if there is psylla of first generation in the orchard for feeding, therefore in May-June some amounts of the pest have to be tolerated. A further weakening of the wild *A. nemoralis* populations may be caused by the large amount of active ingredients used

against other pests, having significant toxic effects on *A. nemoralis*. Among these, thiacloprid, the most frequently pesticide used against the codling moth, *C. pomonella*, as well as the neonicotinoids, not employed in Italy and Europe as specific psyllicides, but against aphids and the pear sawfly *H. brevis*.

The artificial introduction of the antagonist Antocoride at the end of March - beginning of April is a very useful mean for controlling eggs and young nymphs of the first generation. The flow is made with about thousand individuals per hectare fractioned in 3 times at weekly intervals. Resettlement is much more feasible much wider the cultivated area is (minimum 1 hectare).

Some authors however retain that 500 individuals would be sufficient for each introduction (Beninato and Morella, 2000). Good natural equilibrium have been obtained in Veneto with the introduction of 500-600 psylla adults per ha in a sole time in May (Mori and Sancassani, 1984). In France the introduction of *A. nemoralis* has been performed by the distribution of *Pelargonium* stems containing 2.940 eggs of the psylla antagonist (Fauvel *et al.*, 1994; Rieux *et al.*, 1994).

Some authors indicated that the efficacy of this predator is not strongly mediated by plant quality, at least at tree scale, thus, for systems where pest population growth is strongly tied to plant vigor or quality, the reduction of fertilizers to the minimum level required for proper fruit set is likely to improve the success of pest biocontrol (Daugherty *et al.*, 2007).

6. New pesticides and strategies for Integrated Pest Management

In the last years new pesticides have been developed with generally low toxicity towards beneficial insects. AkseBio2 is a mixture of various aromatic plant essential oils, edible plant extracts and a bacterium TR 2000 which decreases oviposition and immature stages of the pest (Erler *et al.*, 2007).

Spirotetramat (Movento®) is a new, fully systemic and ambimobile active ingredient particularly effective against a broad range of sucking pests, similar to the tetroneic acid derivative spiroadiclofen. Its singularity depends upon its unique translocation property, which allows the protection of new shoots or leaves appearing after foliar application, in fact after foliar uptake the insecticidal activity is translocated within the entire vascular system (Nauen *et al.*, 2008). Due to the lack of any cross-resistance to existing chemical classes of insecticides, spirotetramat is a very interesting alternative to be used in rotation schedules.

Natural plant compounds, fungal pathogens and different orchard ground cover all seem promising controls. Among nontoxic plant compounds, sugar-ester extracted from wild tobacco has proved to be most successful in psylla control (USA), killing most nymphs within 2 hours. Even nymphs that hatched 3 to 5 days after spraying die as soon as they walk on leaves (Stanley, 1993). Rapeseed

oil and petroleum oil as well have showed a total efficacy against eggs laid by winterforms females of *C. pyri* (Marčić *et al.*, 2008, 2009). Several naturally occurring fungal pathogens (spores of *Beauveria*, *Verticillium*, and *Paecilomyces* mixed with either oil or water) have given 100-percent control as well within 5 days. The advantage is that fungi can last indefinitely compared to the sugar ester that may persist on the plant for about a week. They are host-specific, completing their life cycle on infected insects on the plant, and therefore nontoxic to humans, animals and beneficial insects. After killing their host, the fungi release hundreds of spores, each capable of infecting another pear psylla. Since pear psylla also have several predators (Table 1), planting ground covers with perennial crops between tree rows to attract them could provide a measure of control (Stanley, 1993).

New strategies for integrated pest management of psylla may be offered in the future by the optimization of the recently identified sex attractant pheromone, the 13-methylheptacosane, for *C. pyricola* winterforms males (Guédot *et al.*, 2009).

7. Resistance to pear psylla

All of the main cultivars of the European pear grown commercially (Abate Fétel, William, Conference, Doyenne de Comice, Kaiser, etc.) (Bellini and Nin, 2002) are susceptible to this arthropod pest and biological controls are becoming of limited effectiveness since resistance to insecticides has developed rapidly. Host plant resistance would therefore be a valuable control strategy.

Resistance to the pear psylla has been demonstrated in the East Asian pear species, *P. betulifolia* Bunge, *P. calleryana* Decne., *P. fauriei* Schneid., *P. ussuriensis* Maxim., and *P. x bretschneideri* Redh. (Westigard *et al.*, 1970; Quamme, 1984; Moore and Ballington, 1991). Hybrids of *P. ussuriensis* x *P. communis* have been found to be resistant to *C. pyricola* (Harris, 1973; Harris and Lamb, 1973; Quamme, 1984) as well as to *C. pyri* (Robert *et al.*, 2004). Different interspecific hybrids between *P. communis* and *P. longipes* or *P. pyrifolia* have shown high levels of resistance to *C. pyri*, too (Robert *et al.*, 2004). Resistance has been reported also for a few genotypes of *P. nivalis* Jacq. and *Sorbopyrus* (Westigard *et al.*, 1970; Bell, 1992). Small fruit size of the pure species and gritty or coarse texture of both the pure species and interspecific hybrids may limit the utility of some of this germplasm for rapid transfer of resistance into cultivars with *P. communis* type fruit. Within *P. communis*, moderate resistance has been demonstrated in the old Italian cultivar Spina Carpi (Quarta and Puggioni, 1985), and in eleven 'primitive' cultivars from Yugoslavia and Hungary (Bell and Stuart, 1990; Bell, 1992). All of these genotypes have relatively poor fruit quality but are important sources of resistance within the primary gene pool available for improvement of *P. communis* cultivars.

In many countries *ex situ* pear collections have been established in some important pear growing areas with a great diversity of national, local and foreign cultivars, mainly for evaluation of resistance to major disease and insects, to be used as potential parents in breeding (Quarta and Puggioni, 1985; Braniste *et al.*, 1994; Braniste and Militaru, 2008; Benedek *et al.*, 2010). More than 200 pear cultivars of Tuscan, national and international origin, in-

Table 1 - Natural enemies associated with pear psylla in Europe

| Natural enemy | Taxonomic group | Species | |
|---------------------------|---------------------------|--|---|
| Predators | Arachnida, Araneae | Unidentified spiders | |
| | Dermoptera | <i>Forficula auricularia</i> Linnaeus | |
| | Heteroptera, Anthocoridae | | <i>Anthocoris nemoralis</i> (Fabricius) |
| | | | <i>Orius</i> spp. |
| | | | <i>Nabis</i> spp. |
| | Heteroptera, Nabidae | Several species | |
| | Heteroptera, Miridae | Several species | |
| | Heteroptera, Lygaeidae | | <i>Chrysoperla carnea</i> (Stephens) |
| | | | <i>Chrysopa formosa</i> Brauer |
| | | | <i>Chrysopa septempunctata</i> Wesmael |
| | | <i>Anisochrysa prasina</i> (Burmeister) | |
| | | Several species belonging to different genus | |
| Coleoptera, Coccinellidae | | <i>Episyrphus balteatus</i> (De Geer) | |
| | | <i>Epistrophe</i> spp. | |
| Parasitoids | Hymenoptera, Encyrtidae | <i>Trechnites psyllae</i> (Ruschka) | |
| | | <i>Prionomitus mitratus</i> (Dalman) | |
| Entomopathogenic fungi | Hymenoptera, Pteromalidae | <i>Syrphophagus mamitus</i> (Walker) | |
| | | <i>Entomophthora sphaerosperma</i> | |

From: Armand *et al.*, 1991; Tremblay, 1995; Civolani and Pasqualini, 2003; Erler, 2004.

cluding also 25 Afghan accessions, are presently being evaluated in *ex situ* and *in situ* collections for psylla resistance at the Department of Plant, Soil and Environmental Science of the Florence University (DiPSA-UNIFI) within the AGER project 'INNOVAPERO: Management and crop innovations for high-quality pear production'. Moreover, evaluation of insect preference in tunnel is being in progress on 26 local cultivars showing good pomological traits.

Taking earlier and present results into account almost 60 European pear cultivars being resistant or highly tolerant to pear psylla infestation and damage can actually be listed (Table 2). Some of these ancient or local cultivars may be exploited both in organic farming or in breeding, but further investigations are needed to estimate their yield capacity and fruit quality (Benedek *et al.*, 2010; Szabó *et al.*, 2010). Moreover, some varieties considered resistant in field have shown to be susceptible, if isolated

and artificially infested by adults (Westgard *et al.*, 1970; Harris, 1975).

Methods of evaluating host resistance are sufficiently developed and rapid nymphal feeding bioassays have been developed to screen pear germplasm for antibiosis-based resistance by Harris (1973, 1975) and Butt *et al.* (1989) for the evaluation of pear germplasm introduced in North America from Eastern Europe, and then modified by different Authors (Table 3). The results of tests can vary, depending on the type of assay and host phenological stage, which affects ovipositional preference (Bell and Puterka, 2003).

Genetic psylla resistance do not follow a general rule and is supposed to be often polygenically inherited (Harris and Lamb, 1973). Lespinasse *et al.* (2008) found that psylla resistance was not well transmitted from the *P. ussuriensis* x *P. communis* hybrid NY10355 to its progenies, assuming that genetic resistance in NY10355 may result

Table 2 - Pear cultivars showing some degree of resistance to psylla as reported by different authors

| Cultivar | Tolerant | Resistant | Moderately resistant | Low susceptible | Country | Reference |
|----------------------|----------|-----------|----------------------|-----------------|---------|--|
| 20th Century | | | x | | Serbia | Stamenkovic <i>et al.</i> , 1993 |
| Bartjarka | | x | | | USA | Bell, 1992 |
| Bókoló Körte | | x | | | Hungary | Benedek <i>et al.</i> , 2010; Szabó <i>et al.</i> , 2010 |
| Bötermő Kálmán | | x | | | Hungary | Benedek <i>et al.</i> , 2010; Szabó <i>et al.</i> , 2010 |
| Bulgaresti | | x | | | Romania | Braniste <i>et al.</i> , 1994 |
| Cantalupesti | | x | | | Romania | Braniste <i>et al.</i> , 1994 |
| Cantari | | | | x | Romania | Sestras <i>et al.</i> , 2009 |
| Cj16-9-13 | | x | | | Romania | Straulea <i>et al.</i> , 1992 |
| Craiesc | | x | | | Romania | Braniste <i>et al.</i> , 1994 |
| Cure | | | | x | Romania | Straulea <i>et al.</i> , 1992 |
| Cure-6 | x | | | | Hungary | Benedek <i>et al.</i> , 2010 |
| D'Aout Lamer | | x | | | France | Robert and Raimbault, 2005 |
| Daoyenné de Poitiers | | x | | | France | Robert and Raimbault, 2005 |
| Erabasma | | x | | | USA | Bell and Stuart, 1990 |
| Ewerd | | x | | | Romania | Braniste <i>et al.</i> , 1994 |
| Füge Alakú | | x | | | Hungary | Benedek <i>et al.</i> , 2010 |
| General Osmanwill | | x | | | Romania | Braniste <i>et al.</i> , 1994 |
| Haydeea | | x | | | Romania | Sestras <i>et al.</i> , 2009 |
| Honeysweet | | x | | | USA | Quamme, 1984 |
| Imperiale | | x | | | Romania | Braniste <i>et al.</i> , 1994 |
| Imperiale | | | | x | Romania | Sestras <i>et al.</i> , 2009 |
| Jerisbasma | | x | | | USA | Bell, 2003 |
| Kajzerka | | x | | | USA | Bell, 1992 |
| Karamanka | | x | | | USA | Bell, 2003 |
| Karamanka | | | x | | Serbia | Stamenkovic <i>et al.</i> , 1993 |
| Karamanlika | | x | | | USA | Bell and Stuart, 1990 |
| Katman | | x | | | USA | Bell and Stuart, 1990 |
| Katman | | x | | | France | Robert and Raimbault, 2005 |
| Kései Kálmán | x | | | | Hungary | Benedek <i>et al.</i> , 2010 |
| Kieffer seedling | | x | | | Romania | Braniste <i>et al.</i> , 1994 |

| Cultivar | Tolerant | Resistant | Moderately resistant | Low susceptible | Country | Reference |
|---------------------------|----------|-----------|----------------------|-----------------|---------|--|
| Kieffer | x | | | | Hungary | Benedek <i>et al.</i> , 2010 |
| Kieffer Éd | x | | | | Hungary | Benedek <i>et al.</i> , 2010 |
| Krupen Burnusus | | x | | | USA | Bell and Stuart, 1990 |
| Krupen Burnusus | | x | | | USA | Puterka, 1997 |
| Lorencz Kovacs | | | | x | Romania | Sestras <i>et al.</i> , 2009 |
| Lorenz | | x | | | Romania | Braniste <i>et al.</i> , 1994 |
| Lucele | | x | | | USA | Bell, 1992 |
| Magness | | x | | | Romania | Braniste <i>et al.</i> , 1994 |
| Magness | | | x | | Serbia | Stamenkovic <i>et al.</i> , 1993 |
| Mednik | | x | | | USA | Bell and Stuart, 1990 |
| Mednik | | x | | | USA | Puterka, 1997 |
| Monglow | | | | x | Italy | Quarta and Puggioni, 1985 |
| Nagyasszony Körte | | x | | | Hungary | Benedek <i>et al.</i> , 2010 |
| Nyári Kálmán | | x | | | Hungary | Benedek <i>et al.</i> , 2010 |
| Obican Vodenac | | x | | | USA | Bell and Stuart, 1990 |
| Obican Vodenac | | x | | | USA | Puterka, 1997 |
| Pinguoli | | | x | | Serbia | Stamenkovic <i>et al.</i> , 1993 |
| Rocha Portugheza | | x | | | Romania | Braniste <i>et al.</i> , 1994 |
| Rozs Nyári Körte | | x | | | Hungary | Benedek <i>et al.</i> , 2010 |
| Severinka | | | | x | Romania | Sestras <i>et al.</i> , 2009 |
| Sierra | | x | | | USA | Quamme, 1984 |
| Sirrine | x | | | | USA | Quamme, 1984 |
| Sirrine | | | | x | Italy | Quarta and Puggioni, 1985 |
| Smokvarka | | x | | | USA | Bell and Stuart, 1990 |
| Spadona | | x | | | Romania | Braniste <i>et al.</i> , 1994 |
| Spina Carpi | | | | x | Italy | Quarta and Puggioni, 1985 |
| Spina Carpi | | | | x | France | Robert and Raimbault, 2005 |
| Steiner | x | | | | Hungary | Benedek <i>et al.</i> , 2010 |
| Téli Kálmán | x | | | | Hungary | Benedek <i>et al.</i> , 2010 |
| Tomnatice | | x | | | Romania | Braniste <i>et al.</i> , 1994 |
| Topka | | x | | | USA | Bell and Stuart, 1990 |
| Triomphe de Joidogne | | x | | | Romania | Braniste <i>et al.</i> , 1994 |
| Triomphe de Joidogne | | | | x | Romania | Sestras <i>et al.</i> , 2009 |
| Vidovaca | | | x | | Serbia | Stamenkovic <i>et al.</i> , 1993 |
| Viki Körte | | x | | | Hungary | Benedek <i>et al.</i> , 2010; Szabó <i>et al.</i> , 2010 |
| William Precoce Morettini | | x | | | Romania | Braniste <i>et al.</i> , 1994 |
| Zelinka | | x | | | USA | Bell and Stuart, 1990 |
| Zelinka | | x | | | USA | Puterka, 1997 |

either from the combination of several small-effect resistance genes, according to Pasqualini *et al.* (2006), or from a combination of dominance or epistatic effects or from both. A genetic mapping approach should help researchers to understand the genetic mechanism of psylla resistance. The molecular interaction between pear tree and the piercing/sucking psylla has been investigated through the construction and characterization of cDNA subtracted libraries. Genes expressed upon insect infestation were identified in a susceptible and a resistant pear genotype. The two expression profiles were found to be different: in the resistant plant more genes involved in the response

to biotic and abiotic stress were activated than in the susceptible one. The further characterization of the identified genes could lead to the development of molecular markers associated with tolerance/resistance to psylla (Salvianti *et al.*, 2006). The quantitative resistance to pear psylla has been analyzed recently in a progeny of the European pear Angelys crossed with the resistant genotype NY10355, and by screening parents/seedlings with microsatellite markers a QTL (Quantitative Trait Loci) that explained 15% of the phenotypic variability has been determined and mapped on the linkage group 17 (Bouvier *et al.*, 2011).

Table 3 - Pear resistance to psylla: assay methods adopted in controlled conditions

| Reference | Number of insects used for artificial infestation | Site of infestation | Replications per cultivar/selection | Observations (hours or days after infestation) |
|---------------------------------|--|--|-------------------------------------|--|
| Harris, 1975 | 100 adults | plant | 1 | 4 days: removal of adults, growth and development of the resultant progeny |
| Butt <i>et al.</i> , 1988 | 1 nymph | lower midrib of 10 fully expanded detached-leaves | 3-10 | 2 h, 4 h, 6 h, 24 h: position of nymph and presence of honeydew |
| Butt <i>et al.</i> , 1988 | 1 nymph | lower midrib of 10 fully expanded leaves of potted trees | 2 | 2 h, 4 h, 6 h, 24 h: position of nymph and presence of honeydew |
| Butt <i>et al.</i> , 1988 | 10 first instars | lower midrib of the 2 youngest fully expanded leaves of potted trees | 2 | 24 h: position of nymph and presence of honeydew |
| Butt <i>et al.</i> , 1989 | 25 first-instar nymphs | 2 youngest and fully expanded leaves of a shoot | 4 | each day: feeding determined by excretion of honeydew |
| Puterka <i>et al.</i> , 1993 | 2-6 females | excised twig collected at different stages of bud development | 8 | 24 h after infestation at stages of dormant bud, green tip, fully expanded leaf: adults per twig 48 h: adults per twig 72 h: eggs per twig |
| Berrada <i>et al.</i> , 1995 | 15 pairs of sexually mature adults | 10-16 leaves (≈ 300 cm ²) | 4 | 24 h: removal of adults and egg count each day: survival of eggs and larvae until they developed into adults |
| Baldassari <i>et al.</i> , 1996 | 6-10 third-fourth instar nymphs | 2 younger and more expanded leaves of a shoot | 2-3 | 5 days: vitality of nymphs, amounts of produced honeydew, possible development of sooty moulds 15 days: number of deaths |
| Baldassari <i>et al.</i> , 1996 | 10 first instar nymphs | 2 younger and more expanded leaves of a shoot | 3 | Every day: number and age of dead nymphs, days needed for possible development of adults |
| Puterka <i>et al.</i> , 1997 | 5 nymphs | 4 fully expanded terminal leaves | 5 | 4 days: nymphal survival and development alternating 3 rd and 4 th day up to day 29: nymphal survival and development |
| Robert <i>et al.</i> , 1999 | 1 female | plant | 1 | 2-7 days: female removal after 50 eggs on average per plant had been laid Each week: larval mortality and count of different instars |
| Bell, 2003 | 10 second or third instar nymphs | underside of the top 2 youngest fully expanded leaves of | 5 | 48 h: number of surviving and actively feeding nymphs |
| Robert and Raimbault, 2005 | 4 females and 1-2 males in two times at 8 day-interval | plant | 7-8 | 15 days: number of eggs on the 8 upper leaves of shoots 36, 63 and 98 days: number of nymphs 134 days: shoot and leaf state |
| Pasqualini <i>et al.</i> , 2006 | 300-400 males and females | plant | 5-16 | 10 -25-50 days: number of adults per plant 10-25 days: number of eggs per plant 25-50 days: number of nymphs producing honeydew per plant |
| Pasqualini <i>et al.</i> , 2006 | 1 female | upper surface of a leaf in a clip-cage | 3-11 | 48-72 h: number of laid eggs per female |
| Bouvier <i>et al.</i> , 2011 | 8 insects | plant | 7 | presence of honeydew on the first, second and last third of the plant. The quantity of larvae present on the whole plant |

8. Resistance characterization

Resistance is characterized by both ovipositional non-preference (antixenosis = settling and oviposition) and feeding inhibition, delayed development and increased nymphal mortality (antibiosis) (Bell and Stuart, 1990). While antixenosis influences the size of the ini-

tial nymphal population, antibiosis probably exerts the greatest effect on population levels over a season. So, feeding rejection is a major component of resistance and leads directly to a precocious nymphal mortality; the mechanism for feeding acceptance or rejection is probably internal to the leaf as reported by Butt *et al.* (1988).

Volatile substances emitted by the leaves of different varieties are not substantially dissimilar and therefore do not probably play a basilar role in the affinity and repulsion of psylla adults (Miller *et al.*, 1989), but bioassays on this topic are still lacking. Resistance of genotypes is not directly proportional to leaf cuticle thickness, the resistant genotype NY10355 for instance has a lower content of cutin compared to the susceptible William variety (Gérard *et al.*, 1993). Pubescence is not a major factor in feeding deterrence according to Bell and Stuart (1990). However, antixenosis is influenced by both the physiological status (Bigre and Lefeuvre, 1982) and bud phenological phase (Stuart *et al.*, 1989; Puterka *et al.*, 1993) of pear tree. Thus differences in leaf morphology may influence psylla oviposition, bearing in mind that the insect prefers to lay the eggs on prominent structures such as leaf vein or crevices at the base of fruiting spurs.

Resistant genotypes express antibiosis with the production of a limited amount of honeydew and a strong nymphal mortality (Butt *et al.*, 1988, 1989). However, the quantity of produced honeydew has not been denotive of the infection intensity on selections obtained by induced mutagenesis (Baldassari *et al.*, 1996). Ingestion of substances belonging to the group of polyphenols (for example tannins) has been suggested to be the cause of this mortality (Bell, 1984). Challice and Williams (1968) underlined the presence of the group of active components flavone glycosides in the Asiatic *Pyrus ussuriensis*, which is lacking in *Pyrus communis*. Braniste *et al.* (1994) evidenced a lower total isoperoxidase activity in resistant pear cultivar compared to susceptible ones. Also sugar content in leaves differed between resistant and susceptible genotypes, an increase of sugar content due to a reduced level of starch synthesis and also its rapid degradation was noticed in susceptible cultivars.

Fiori and Lamb (1982) found the presence of secretory cells to be much more extensive in the phloem of leaf midveins of pear genotypes with resistance against *P. pyricola* and suggested that average percentage of the phloem area occupied by secretory cells in May-June may provide a valid method for determining the resistance of pear trees to *P. pyricola*.

Antibiosis towards preimaginal stages is accompanied by a reduction of feeding frequency, which may be linked to the presence of nutritional inhibitors (Butt *et al.*, 1989) or to an insufficient plant alimental appetizer (Chang and Philogène, 1975). Later on, the *ex novo* induction of a phenolic compound (3-O-trans-p-cumaroyltormentic acid) has been demonstrated after 12 hours from the phytophaga attack with a pick after 30 days from infection (Scutareanu *et al.*, 1999). This induction has been recently shown to be local (Conference) or systemic (William and NY10355), but there are no evidence on whether this induction can modify *C. pyri* behavior or not (Scutareanu *et al.*, 1999). A different effect has been attributed to other volatile substances still originating during the wounding process of the mouth apparatus. Some of these essences released from infected pear leaves, i.e. the monoterpene

(E,E)- α -farnesene and the phenolic compound methyl salicylate, are primarily responsible of the attraction of the main psylla predators, namely *Anthocoris nemoralis* and *Anthocoris nemorum* (Scutareanu *et al.*, 1997, 1999, 2001). The capacity of some plant species to emit mixture of volatile compounds, dominated by terpenes, to attract carnivorous arthropods that prey on or parasitise herbivorous insects or mites, has been well documented as plant defence strategy (Degenhardt *et al.*, 2003).

Finally, antixenosis and antibiosis are often associated in resistant genotypes, but are supposed to be independent from a genetic point of view, since only one of this two mechanisms of resistance exist in some genotypes (Puterka *et al.*, 1993).

9. Breeding

Fortunately, pear species vary considerably in their resistance to pear psylla and breeding for resistance is possible. For breeding, the use of the larger fruited species (*P. ussuriensis* and *P. x bretschneideri*) should prove to be more efficient for combining resistance with European-type fruit quality.

In Italy, the Experimental Institute for Fruit Crops, Rome, Forlì section (ISF-FO) has been studying genetic improvement of pear for about 35 years, looking with particular regard for fire blight and pear psylla resistant cultivars. The breeding activity for the transfer of pear psylla resistance lists 22 crossing combinations, about 8,200 seedlings and 13 advanced selections, 3 of which are rather tolerant to pear psylla (Baldassarri *et al.*, 1996). Praiseworthy is the selection ISF.68-14-44-11, which is rather tolerant to pear psylla, although the fruit does not have sufficient eating quality (Rivalta and Dradi, 1998). Transfer of resistance traits have been reported more recently in crosses with different NY selections (ISF 94-1/174-267, ISF 94-4/103-267, ISF 94-5/-51-268) and selections of *P. pyrifolia* (ISF 98-5-70-150, ISF 90-12/110-149) (Pasqualini *et al.*, 2006).

The Department for Tree Crops, Bologna University (DCA-UBO), has been implementing a programme of both intervarietal and interspecific cross breeding, which began about 30 years ago, in order to develop diversified pears for quality and ripening calendar, without disregarding the evaluation of fire blight and psylla resistance (Sansavini and Rosati, 1986; Sansavini, 1999). NY10353 and NY10355 have been used as male parents, while Max Red Bartlett and Doyenne de Comice as female parents, and eight seedlings have been selected and are under evaluation. Among these, DCA 92052105-119 (NY10353 x Doyenne de Comice) has shown a great degree of psylla resistance in controlled growth chamber and is actually under evaluation in open field (Musacchi *et al.*, 2005; Pasqualini *et al.*, 2006). Moreover, a number of 90 AFLP primer combination has allowed to indentify, through a Bulk Segregant Analysis, a first step of molecular markers linked to psylla (Sansavini, pers. com.).

In France, a close collaboration between INRA and the National Institute of Horticulture (INH), Angers, has been recently started for the definition of precocious tests for evaluation of pear psylla resistance as well as potential parents to be used in the breeding project. Now, some 10,000 resistant hybrids and 60 selections are under study using artificial inoculation tests (Le Lezéc, 1991; Le Lezéc, pers. com.).

Of great importance is also the breeding programme which is undergoing at the Fruit Research Stations of Pitesti-Maracineni, Cluj-Napoca and Voinesti, Romania, whose goals have been focused since many years on resistance improvement to fire blight, pear psylla and scab by means of intra and interspecific hybridization followed by backcross. The initial sources concerning psylla resistance were represented by biotypes derived from *P. serotina* and subsequent F₁ and F₂ interspecific selections. Some foreign and native *P. communis* cultivars were used as parents (Napoca, Butirra Precoce Morettini, Butirra Hardy, Butirra Six, Doyenné d'Hiver, etc.) and the psylla resistant or tolerant cultivars Haydeea, Euras, Getica and Ina Estival have been promoted and named (Andreis, pers. com.; Braniste, pers. com.; Sestras *et al.*, 2009).

In North America the breeding programmes initiated in the 1920's and 1930's developed in the 1960's into two impressive programmes for disease and insect resistance at Harrow in Canada and at Kearneysville (USDA) in the United States, based on hybridisation with cultivars and selections from *P. ussuriensis* and *P. pyrifolia* (characterised by a higher resistance, probably of monogenic type), with fruit characteristics of *P. communis* being recovered by backcrossing to selected *P. communis* cultivars (Bellini and Nin, 1997). Resistance to pear psylla represent an additional breeding objective of the pear programme at Harrow (Brunner, 1997; Hunter, 1994; Hunter, pers. com.), while has been added as specific primary objective of the United States Department of Agriculture (USDA) breeding programme. Selection methods have been developed from detailed studies of the modes of resistance (a 24-hour nymphal feeding bioassay plus choice and non choice oviposition assays for further resistance characterization), almost 4,400 seedlings have been evaluated and RAPD markers associated with resistance to nymphal feeding antixenosis are in progress. Among the most recent cultivars coming from United States are Elliot, Gourmet, Potomac and Blacke's Pride (Bell and van der Zwet, 1992; Bell *et al.*, 1996).

Often, parallel studies are carried on in order to support and speed up the attainment of the pursued goals. Generally, the future direction of such programs will include a biotechnology component, with the objective of identifying and transferring genes for resistance to fire blight and pear psylla (Bellini and Nin, 1997; Bellini *et al.*, 2000).

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