Chapter 9

Aphid management

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1. Generalities about aphids

Belonging to the superfamily Aphidoidea, aphids are Hemiptera insects, many of the species causing economic damage to most cultivated plants. This occurs directly, when they suck the sap and weaken the plants, or indirectly through the transmission of several plant diseases, especially of a viral nature.

Aphids cause this plant damage using their biter-sucker mouth, as all the Hemiptera (MIYAZAKI, 1987b). The labium has been modified, taking the shape of a wide canal mouth (rostrum or proboscis) that encloses four thin stylets, which are developed from the two maxillae and the two mandibles, forming an elongated filament, which contains two ducts. The insect, after piercing the plant with its stylets, will inject the saliva through one of the ducts (the salivary canal) in order to dissolve the sap, while the other duct (the food canal) is used for absorbing the sap once it has been dissolved. This feeding system explains the Hemiptera capacity (and particularly, the aphid capacity) to transmit viruses or other type of pathogens: when they suck the fluids of a sick plant, the insects acquire the virus and later, when they inject the sap into a healthy plant, they infect it with the virus acquired.

Among the Hemiptera, the aphids form a group with very particular morphological and biological characteristics. Figure 1 shows a sketch of an adult aphid (an alate parthenogenetic female, without left wings in order to see some details), and displays the main characteristics of aphids. The presence of siphunculi or cornicles (S) is exclusive of aphids,

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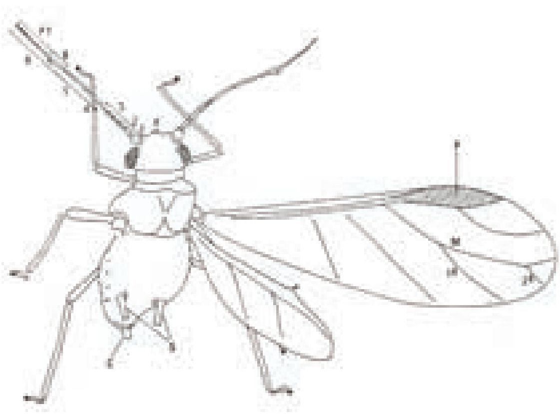

Figure 1. Alate parthenogenetic female of aphid (without left wings)

and although not all the aphid species have them the majority do; they have very different shapes and colours (although constant for each species) and with different functions, among others, the defensive one, because through them, the hemolymph, rich in aphid waxy substances, can be discharged directly outside, and when it is solidified, can glue a predator's mandibles. The cauda (C), situated at the end of the abdomen and with morphological characteristics peculiar for each species, is very typical of aphids, as is the spot or pterostigma (P) of the fore-wing in the alate aphids and the number of bifurcations (1st, 2nd) of the media vein (M) of this wing. Finally, it is useful to classify the aphids the shape of the frons (F) and the number, colour, proportions and characteristics of the antennal segments (1 to 6), especially the last one, which is divided into a base (B) and a processus terminalis (PT).

With respect to the biology of aphids, they show a curious alternation between amphigonic generations (females and males) and parthenogenetic ones (only females), with different apterous (apterae) and winged (alate) adult forms, in addition to the different nymphal instars necessary to produce adults (MIYAZAKI, 1987a). The typical complete cycle of the Aphididae family starts with the winter egg, from which a nymph hatches in spring, and after several molts it will give birth to an apterous female, the fundatrix. It reproduces by parthenogenesis (without male intervention) and by viviparity (it does not lay eggs, but gives birth to nymphs), producing several generations of apterous females (also parthenogenetic and viviparous) until a generation of alate females appears (but always parthenogenetic and viviparous), which migrate to other plants of the same species (if the cycle is monoecious) or to plants of different species (if the cycle is dioecious, then the primary host refers to the vegetal species of origin and secondary host refers to the destination species). Females continue reproducing by parthenogenesis and viviparity on the plants to which they have migrated, giving birth to several generations of apterous females (which remain on each plant) and alate (which infest other plants) during good weather. In autumn, females appear, called sexuparae because they give birth to females and males, generally alate ones, which return to the primary host, when they mate and females lay the winter eggs.

However, this complete cycle only takes place in the holocyclic aphid species, because in the anholocyclic species the amphigonic generation of the cycle is not produced, and they reproduce parthenogenetically during the whole year. Consequently, the only adults that appear are parthenogenetic females, apterae as well as alate. Furthermore, there are holocyclic species that under specific circumstances (for example, in warm climates) can reproduce continuously as anholocyclic, without amphigonic stage. In any case, although this amphigonic stage takes place, it lasts a short time in the year and with fewer individuals. Therefore, in the holocyclic species, as undoubtedly in the anholocyclic species, the parthenogenetic females are usually observed.

With respect to the differences between adults and nymphs, they are evident when the last ones are going to give birth to alate individuals, because the small wings can be distinguished perfectly. However, when the nymphs are going to give birth to apterous adults, it can be difficult to differentiate the last nymphal stages from the adults. For this purpose, characteristics such as the nymph's cauda being less developed than adults' must be considered. Furthermore, we must bear in mind that the morphological characteristics of apterous adults can be different from the alate adults, which could lead to the error of considering different forms of the same aphid species as being from a different species.

2. Aphids on protected crops

The following crops have been considered as main protected crops: within Cucurbitaceae, melon (*Cucumis melo*), watermelon (*Citrullus vulgaris*) and zucchini (*Cucurbita pepo*, v. *oblonga*); within Solanaceae, pepper (*Capsicum annuum*), tomato (*Lycopersicon esculentum*) and eggplant (*Solanum melongena*); and within Papilionaceae, bean (*Phaseolus vulgaris*). These plants are attacked by different species of aphids, the most significant of them being shown in Table 1 (BLACKMAN and EAS-

TOP, 1985, modified). As can be observed, the most widespread aphids are *Aphis gossypii* and *Myzus persicae*, which feed on all the crops reported, and then we can find *Aphis fabae* and *Macrosiphum euphorbiae*, which attack five of them, and *Aulacorthum solani* (three of them). Below, we will study each of these species in depth (HOLMAN, 1974; NIETO *et al*.,1984 y 2005; BLACKMAN y EASTOP, 1985; BELLIURE *et al*., 2009).

Aphis fabae Scopoli

This is a cosmopolite and polyphagous aphid which lives on a great number of plants, cultivated or not, and in principle it behaves as a dioecious holocyclic although it can live as an anholocyclic. The apterous parthenogenetic female (photo 1) has a mat dark colour (intense black or blackish brown, but sometimes with waxy whitish spots), with black siphunculi and cauda of the same colour and with many setae.

Photo 1. Apterous parthenogenetic female of *Aphis fabae*

Besides the crops mentioned in Table 1, it attacks many plants of agricultural interest: avocado, cherimoya, celery, turnip, cabbage, carrot, fennel, parsley, artichoke, lettuce, borage, radish, hemp, hop, chickpea, lentil, lucerne, pea, broad bean, onion, leek, cotton, fig, barley, maize, beet, spinach, strawberry, apple, cherry, plum, pear, pomegranate, orange, sour orange, lemon, mandarin, tobacco, potato and vine.

In addition to the direct damage caused in these plants, it can also cause damage due to its capacity for transmitting more than thirty different viruses, some of them with more harmful effects than physical damage.

Table 1. Most important aphids that attack the main protected crops

Aphid	Melon	Watermelon	Zucchini	Pepper	Tomato	Eggplant	Bean
Aphis fabae			X	X	X	X	X
Aphis gossypii	X	X	X	X	X	X	X
Myzus persicae	X	X	X	X	X	X	X
Aulacorthum solani				X	X	X	
Macrosiphum euphorbiae			X	X	X	X	X

Aphis gossypii Glover

This is also a polyphagous and cosmopolite species, and is particularly harmful in greenhouses. It usually reproduces in the anholocyclic manner although on some occasions has displayed holocyclic behaviour. The colour of apterous parthenogenetic females is very diverse, from almost white to almost black, with a wide range of intermediate colours (pale yellow, brown, light or dark green) (Photo 2), which can make their identification difficult, although the siphunculi are always dark and the cauda has the colour of the body (cauda clear in pale specimens and black in the darker ones), and with a reduced number of setae (seven at the most) in the cauda.

This aphid has been reported on many crops in addition to the crops studied here: avocado, cherimoya, asparagus, carrot, endive, hemp, hop, cucumber, pumpkin, cotton, maize, pomegranate, beet, loquat, strawberry, apple, plum, almond, pear, orange, sour orange , mandarin, lemon, grapefruit , satsuma, clementine, tobacco, potato and vine.

Photo 2. Apterous parthenogenetic females of *Aphis gossypii*

This species transmits more than fifty plant viruses, not only of horticultural crops but also of woody plants: the big epidemic of the citrus tristeza virus which eliminated a large extent of the Spanish citrus plantations from 1957 was basically spread by this aphid. In addition, this species developed resistance to some insecticides around 1985 (MELIÀ and BLASCO, 1990), which made its control difficult and reactivated its presence on the crops, causing, among other things, new epidemics of viral diseases.

Myzus persicae (Sulzer)

As with previously mentioned species, this aphid is also cosmopolite and polyphagous, and it behaves generally in a dioecious holocyclic manner. Several plants of the *Prunus* genus (mainly peach tree) serve as primary hosts, where it spends the winter in egg stage, and many other plants, some of them cultivated, serve as secondary hosts. However, if there are not peach trees or in warm climates, it can reproduce parthenogenetically and continuously as anholocyclic.

The apterous parthenogenetic females are usually yellow or green (Photo 3), although they can also be pink or reddish. They have a very deep groove in the frons, with converging sides, and their siphunculi are a little more elongated than those of the previously mentioned *Aphis* species. They can be differentiated too from those *Aphis* species because the siphunculi of *M. persicae* have a light colour and usually are swollen towards the end, while the cauda also has a clear colour.

Photo 3. Apterous parthenogenetic female of *Myzus persicae*

In addition to the cultivated plants that have been considered in Table 1, it also attacks the following: turnip, cabbage, pawpaw, artichoke, carrot, sweet potato, lettuce, radish, potato, onion, celery, beet, orange, sour orange, mandarin, lemon, satsuma, pumpkin, loquat, strawberry, apple, tobacco, pea, apricot, cherry, plum, almond, peach, pear, wheat, broad bean and maize.

This species is considered as being the most significant species amongst the virus vectors of plants, because it transmits more than 100 viral diseases that affect a high number of crops. Furthermore, as in the case of *A. gossypii*, it is resistant to several insecticides.

Aulacorthum solani (Kaltenbach)

Photo 4. Colony of *Aulacorthum solani*

This is a species of European origin, although currently its spread is almost cosmopolite, and it is quite polyphagous (Photo 4). It can reproduce in both a holocyclic and anholocyclic manner. The apterous parthenogenic female can show a yellowish, greenish or brownish colour, and as occurs with *M. persicae*, it has a groove in the frons, but with sides parallel, nonconverging; this female is a little bigger than the preceding species, and its siphunculi and cauda are longer and have a light colour.

In addition to the crops mentioned at the beginning of this section, *A. solani* can appear on other crops such as lettuce, potato, cucumber and strawberry, and can transmit around 40 viral diseases.

Macrosiphum euphorbiae (Thomas)

Although it is a native aphid of North America, it is spread almost worldwide, and it is very polyphagous. In the United States it behaves as a dioecious holocyclic, with plants of the genus *Rosa* as primary hosts, while in Europe it is mostly anholocyclic (although, occasionally, sexed individuals are observed).

The apterous parthenogenetic females are very big, the biggest ones of all the species mentioned here. In general, they are green, but sometimes are yellowish or pink (Photo 5), with the groove of the frons with diverging sides, and the cauda and the siphunculi also being longer than the other species and of the same light colour as the body. Furthermore, this species can be distinguished from the others because the siphunculi of *M. euphorbiae* adults show reticulated distal parts.

Photo 5. Apterous parthenogenetic female and nymphs of *Macrosiphum euphorbiae*

In addition to the crops that have been mentioned in Table 1, this species attacks the following ones: chickpea, cherimoya, beet, cabbage, orange, sour orange, mandarin, lemon, satsuma, pumpkin, artichoke, lettuce, lentil, apple, loquat, tobacco, pea, pear, radish, potato and maize.

Also it is significant as a vector of viral diseases, because it is responsible for the transmission of more than 40 diseases of this type.

3. Biological control of aphids on protected crops

All these aphid species are controlled, either in a spontaneous way or artificially, by a wide range of natural enemies: parasitoids, predators or even pathogenic agents. Belliure *et al*. (2009) have reported the relationships between enemies and aphids found in Spain, considering a series of bibliographical references, among which the following ones are highlighted: Baixeras and Michelena (1983); González and Michelena (1987); Michelena and González (1987); Michelena and Oltra (1987); Rossmann and Fortmann (1989); Llorens (1990); Bennison (1992); Ben Halima-Kamel and Ben Hamouda (1993); Laubscher and Von Wechmar (1993); Kazda (1994); Marcos-García And Rojo (1994); Michelena *et al*. (1994 and 2004); Alomar *et al*. (1997); Alvarado *et al*. (1997); Castañé *et al*. (1997); Ehler *et al*. (1997); Michelena and Sanchis (1997); Orlandini and Martellucci (1997); Asin and Pons (1998); Völkl and Stechmann (1998); Winiarska (1998); Askary *et al*. (1999); Wojciechowicz-Zytko (1999); El-Arnaouty *et al*. (2000); Hunter *et al*. (2001); Alvis *et al*. (2002); Belliure (2002); García-Marí and Ferragut (2002); Soler *et al*. (2003); Bird *et al*. (2004); Kavallieratos *et al*. (2004); Snyder *et al*. (2004); Deligeorgidis *et al*. (2005); Jansen (2005); Nebreda *et al*. (2005); Van Munster *et al*. (2005);

Pascual-Villalobos *et al*. (2006); Kim *et al*. (2007); Sastre-Vega (2007); ZARPAS *et al*. (2007); Hermoso De Mendoza *et al*. (2008a and 2008b); Pineda and Marcos-García (2008b); Roditakis *et al*. (2008).

3.1. Parasitoids

Table 2 shows all the parasitoids described in Spain on each of the aphid species mentioned before. All of them are Hymenoptera and, although there is a species of the Aphelinidae family, most of them belong to the Aphidiinae subfamily of the Braconidae family. Females lay an egg inside each aphid, from which a larva emerges and feeds on the internal tissues of the aphid, until this one has only the external cover, referred to as the mummy. Finally, the parasitoid carries out pupation in a cocoon that can be internal to the aphid mummy (as it occurs in the genera *Aphidius*, *Diaeretiella*, *Lysiphlebus* or *Trioxys*), or external (as in the genus *Praon*, Photo 6). The colour of these mummies can characterize each genus: in *Ephedrus* they are black (Photo 7), while in *Aphidius*, *Diaeretiella* or *Trioxys* they are brown. Finally, the parasitoid adult emerges from the aphid mummy (Photo 8), after having pierced the cuticle with its mandibles, forming a circle in it.

Photo 6. Mummy of aphid parasitized by *Praon volucre*

Photo 7. Aphid parasitized by *Ephedrus* sp.

Photo 8. Adult of *Trioxys angelicae*

Table 2. Parasitoids (Hymenoptera) mentioned in Spain on the main aphids of protected crops

Parasitoids	*Aphis fabae*	*Aphis gossypii*	*Myzus persicae*	*Aulacorthum solani*	*Macrosiphum euphorbiae*
Aphelinidae					
Aphelinus abdominalis			X		X
Braconidae Aphidiinae					
Aphidius colemani		X	X		
Aphidius ervi			X	X	X
Aphidius matricariae	X	X	X	X	X
Diaeretiella rapae		X	X		X
Ephedrus persicae			X		
Lysiphlebus confusus	X	X			
Lysiphlebus fabarum	X	X			
Lysiphlebus testaceipes	X	X			
Praon volucre	X	X	X		X
Trioxys acalephae	X	X			
Trioxys angelicae	X	X	X		

Among these parasitoids, *Lysiphlebus testaceipes* (Cresson) stands out (Photo 9); probably, it is native of North and Central America and was introduced in Europe during the sixties and in Spain during the seventies, its acclimatization being confirmed during the eighties. Since then, it has been widely spread in the Mediterranean basin, so that nowadays it is one of the most abundant parasitoids on several species of aphids.

Photo 9. Adult of *Lysiphlebus testaceipes* parasitizing aphids

Several of the parasitoids mentioned are commercialised for the control of aphids in greenhouses. As such, *Aphelinus abdominalis* (Dalman), *Aphidius colemani* Viereck and *Aphidius ervi* Haliday are used against aphids such as *Myzus persicae* or *Aphis gossypii*, spread in crops through the use of reservoir plants, usually wheat or barley infested by the aphids *Rhopalosiphum padi* (L.) or *Sitobion avenae* (Fabricius) which are parasitized by the hymenopteran in question so that, when hatching, it will attack the aphids found on the greenhouse crops.

3.2. Predators

In tables 3, 4 and a part of table 5 there appear the main predators reported in Spain on the most significant aphids of protected crops. Table 3 shows the Diptera, table 4 shows the other insects and table 5 shows the mites.

Table 3. Predators mentioned in Spain on the main aphid of protected crops. I: Diptera

Predatory Diptera	*Aphis fabae*	*Aphis gossypii*	*Myzus persicae*	*Aulacorthum solani*	*Macrosiphum euphorbiae*
Cecidomyiidae					
Aphidoletes aphidimyza	X	X	X		X
Syrphidae					
Episyrphus balteatus	X	X	X	X	X
Epistrophe eligans	X				
Eupeodes corollae	X	X	X	X	X
Eupeodes flaviceps	X		X		
Eupeodes lucasi	X				
Eupeodes luniger	X				
Meliscaeva auricollis	X				
Paragus haemorrhous	X	X	X		X
Paragus tibialis	X				
Platycheirus scutatus	X				
Scaeva albomaculata	X				
Scaeva pyrastri	X		X		X
Sphaerophoria rueppellii	X	X	X	X	X
Sphaerophoria scripta	X		X		X
Syrphus ribesii	X		X		X
Syrphus vitripennis			X		X

Table 4. Predators mentioned in Spain on the main aphids of protected crops. II: Other insects

Predators	*Aphis fabae*	*Aphis gossypii*	*Myzus persicae*	*Aulacorthum solani*	*Macrosiphum euphorbiae*
Coleoptera Coccinellidae					
Adalia bipunctata			X		
Coccinella septempunctata	X	X	X		X
Harmonia axyridis		X			X
Hippodamia convergens	X	X			
Propylea quatuordecimpunctata			X		
Scymnus spp.		X			
Neuroptera Chrysopidae					
Chrysoperla carnea	X	X	X	X	
Hemiptera Anthocoridae					
Orius laevigatus		X			X
Orius majusculus		X			X
Hemiptera Miridae					
Dicyphus tamaninii		X			X
Macrolophus caliginosus		X			X
Dermaptera					
Forficula auricularia				X	

Table 5. Mites and pathogenic agents mentioned in Spain on the main aphids of protected crops

Predators	*Aphis fabae*	*Aphis gossypii*	*Myzus persicae*	*Aulacorthum solani*	*Macrosiphum euphorbiae*
Mites					
Erythraeidae	X				
Fungi					
Lecanicillium attenuatum			X		X
Lecanicillium longisporum			X		X
Lecanicillium lecanii	X	X	X		X
Viruses					
Parvovirus			X		

Photo 10. Adult of *Aphidoletes aphidimyza*

Among the Diptera, we can find two families, the Cecidomyiidae and the Syrphidae. Among the Cecidomyiidae we can find *Aphidoletes aphidimyza* Rondani (Photo 10), whose larvae feed on aphids by sucking their internal fluids and are abundant naturally in some crops. Their use is also popular commercially in pepper and tomato greenhouses.

Photo 11. Adult male of *Paragus tibialis*

Amongst the Syrphidae there is a long list of predators of aphids. These dipterans show three larval instars, which feed on aphids by piercing the aphid body surface with their mandibles and lifting them from the plant surface while sucking their fluids out. Adults (Photo 11 and 12) feed on nectar and pollen (Photo 13); females lay the eggs close to the incipient colonies of aphids and, after eggs hatch, larvae begin to feed on aphids until they pupate. Due to the need for nectar and pollen of adult syrphids, the access to flowering plants in the crops or near to them is an important factor in the effectiveness of these dipterans as biological control agents of aphids: the flowers of some specific plants increase the attraction of syrphids

Photo 12. Adult male of *Scaeva albomaculata*

Photo 13. Adult of *Episyrphus balteatus*

Photo 14. Adult of *Adalia bipunctata*

Photo 15. Adult of *Coccinella septempunctata*

in different types of crops, outdoors as well as in greenhouses. On the other hand, the condition of semi-opening, typical of the greenhouses used in the Mediterranean area, is very favourable for the entry of syrphids that are present naturally outside the greenhouses (Pineda and Marcos-García, 2008). With respect to commercialised species, *Episyrphus balteatus* De Geer is available as pupae to be released against aphids.

With respect to Coleoptera, the Coccinellidae (or ladybirds) are the best known predators of aphids, and furthermore, in their two stages: adults as well as larvae of many coccinellid species eat aphids. As in the case of other predators, they lay the eggs next to aphid colonies which are not yet very advanced. Among the most abundant species, found naturally, we can find *Adalia bipunctata* (L.) (Photo 14), *Coccinella septempunctata* L. (Photo 15), *Hippodamia convergens* Guérin-Méneville (Photo 16), *Propylea quatuordecimpunctata* (L.) (Photo 17) and *Scymnus* spp. (Photo 18). Among the species commercialised against aphids we can find *A. bipunctata* and

Photo 16. Adult of *Hippodamia convergens*

Photo 17. Adult of *Propylea quatuordecimpunctata*

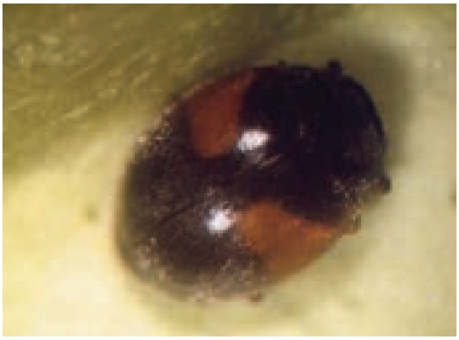

Photo 18. Adult of *Scymnus* sp.

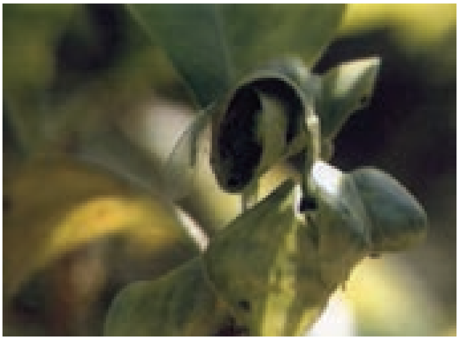

Photo 19. Adult of *Chrysoperla carnea* next to a colony of aphids

Harmonia axyridis Pallas, this last one having been introduced.

Amongst the Neuroptera Chrysopidae, *Chrysoperla carnea* (Stephens) (Photo 19) stands out, whose larvae feed actively on aphids and other arthropods. Its egg laying is very characteristic, with each egg appearing on the tip of a long filament and, generally, grouped close to the aphid colonies. This species is also commercialised for the biological control in greenhouses.

Among the Hemiptera, we can find the Anthocoridae, mainly of the *Orius* genus (Photo 20), which are very polyphagous because they feed not only on aphids, but also on thrips, lepidopteran eggs and larvae, mites and others. Besides, as they can also feed on plants or pollen, they are easy to maintain in crops with low plant density. *Orius laevigatus* (Fieber) and *O. majusculus* (Reuter) are commercialised to be released in greenhouses.

Other hemipteran family with species which prey on aphids is Miridae, among which the genera *Dicyphus* and *Macrolophus* stand out (Photo 21),

Photo 20. Adult of *Orius* sp.

Photo 21. Nymph of *Macrolophus* sp.

Photo 22. Trombidiid mite attacking an aphid

also used commercially against other horticultural pests outdoors and in greenhouses.

Among the Dermaptera, *Forficula auricularia* L. feeds on aphids, amongst other types of prey, and it controls them mainly on the soil.

Finally, within the mites there are several families of the Prostigmata order, such as the Erythraeidae and the Trombidiidae (Photo 22), which attack aphids in a different manner depending on their stage of development: they act as parasites of the aphids in the nymphal stages of the mites, and act as free-living predators in the adult stages.

3.3. Pathogenic agents

There are different species of entomopathogenic fungi of the Entomophthoraceae family which fight against aphids (Photo 23), belonging to the genus *Lecanicillium*, as Table 5 shows.

Some of these fungi, such as *L. longisporum*, are carried by ants from one aphid to the other, transmitting the infection in this manner. There are others, for example *L. lecanii*, which are commercialised to be used in crops, taking into account that the different isolates of this fungus can show different specificity according to the aphid species involved (for example, if it is *Aphis fabae* or *Aphis gossypii*).

Photo 23. Aphid attacked by fungi

With respect to the entomopathogenic viruses, some of these aphids are attacked by Parvovirus (Table 5), with the special feature that the plants invaded by aphids infected by the virus, can transport it through the phloem, infecting other aphids without needing to be in contact with the sick aphids. That is to say, the plant can act as entomopathogenic virus vector using it to defend itself.

4. Integrated control of aphids on protected crops: economic injury level

The integrated control of pests, considering the habitat and the population dynamics of the phytophagous, uses different methods of fight (particularly the biological one), avoiding the excessive use of chemicals to combat it. Therefore, the key point of this system is to find out the economic injury level (EIL), that is to say, the level of the pest over which treatments have to be applied if we do not want to have economic losses, (or, in other words, the amount of pest in which the losses caused are equal to the treatment expenses).

In the case of the crops and the aphids considered here, the formula of the economic injury level for peppers has been obtained in two aphid species: *Aulacorthum solani* (HERMOSO DE MENDOZA *et al*., 2006) and *Myzus persicae* (LA SPINA *et al*., 2008). These formulae are:

EIL (*A. solani*):

$$\frac{88{,}98 \cdot VP_o K + 3750{,}36 \cdot C}{58{,}16 \cdot VP_o K - 100 \cdot C}$$

EIL (*M. persicae*):

$$\frac{1{,}05 \cdot VP_o K + 359{,}79 \cdot C}{21{,}05 \cdot VP_o K - 100 \cdot C}$$

In both formulae the economic injury level (EIL) is expressed in number of aphids per leaf, and the parameters that intervene in them are:

V: price of the fruit (euros/kg).

P_o: crop yield with the minimum level of pest (kg/ha).

K: efficacy of the insecticide, lying between 0 and 1 (if it is 100 %, K=1).

C: total cost of the insecticide (product + application) (euros/ha).

Under the current economic conditions of the pepper crop in greenhouse, its profitability (as a consequence of the high price and yield of pepper) is so high compared with the treatment cost, that the economic injury level resulting is very low for these two aphid species, so that treatment would have to be applied when the aphid was detected. However, if the profitability circumstances of the pepper crop change, also the economic injury level of both species would change, although it would be calculated in the same manner because the formulae mentioned are valid for each type of economic conditions; it would be enough to apply the parameters (V, K, C and P_o) corresponding to each situation.

On the other hand, these formulae for the calculation of the economic injury level are applicable to all types of insecticides, not only chemical but also biological, that is to say, they are also valid when aphids are controlled by parasitoids or predators. In this last case, the K value should be previously found out (in other words, the efficacy of the natural enemy in question against the aphid involved), as well as its cost (C).

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