A review of novel and alternative approaches to aphid control on soft fruit

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Background

Soft-fruit growers are finding it increasingly difficult to gain control of aphids. Losses of effective spray control products in recent years, combined with further pending revocations, make it increasingly difficult to gain control, particularly close to harvest. Novel and alternative approaches will be required in future. AHDB has already funded several projects to identify and investigate some such methods, but this desk study aims to identify additional ideas.

Summary of main findings

- Alternative chemical control strategies
    - Aphid alarm pheromone could be used in future control strategies and studies are needed to assess the effects on aphid behaviour in field conditions
    - Sex pheromones can attract aphid parasitoids and may be useful for manipulating parasitoid populations to improve their success as a control strategy
    - Insect growth regulators can inhibit aphid growth and reduce fecundity
    - Mineral oils might be useful in combination with insecticides or plant-derived antifeedants to maximise aphid control
- Biological controls
    - A mix of six parasitoid species gives best control of strawberry aphid (*Chaetosiphon fragaefolii*) and this is now commercially available for use by growers
    - Augmented release of multiple parasitoid species can be compatible with the use of certain biopesticides for suppression of aphid populations
    - Among aphid predators, the larvae of some lacewing species have shown most promise for aphid suppression
    - Entomopathogenic fungi can increase aphid susceptibility to insecticide products, allowing reduction in spray application rates
- Crop management
    - Pest abundance tends to be reduced in landscapes with a high proportion of semi-natural habitat, and biological control by natural enemies tends to be more effective in these landscapes
    - Reflective mulches can deter aphid settling and commercial netting products provide a physical barrier to reduce numbers of aphids and other pests in tunnels

Approach

This desk study was commissioned to fill a knowledge gap in novel and alternative strategies to gain better control of aphid species noted as being problematic for soft-fruit growers. It aims to identify potential products for assessment in SCEPTREplus and provide, where possible, information about product application timing and likely success of the strategy. The aphid species attacking soft fruit are listed in Table 1, with brief information about host range and damage caused to the crop. More detailed information about the biology of these aphid species is provided in Appendix 1.

The study was undertaken by performing literature searches of Web of Science, Google Scholar and the websites of grower organisations globally (e.g. Bioforsk, CSIR, as well as AHDB), using the aphid species names (common and Latin names) as search terms, along with integrated pest management, aphid control, semiochemicals, biological control and crop management. The study summarises information gathered from these literature searches regarding alternative and novel chemical and biological control strategies that have been tested on aphids and have potential to be used on the target aphid species (Table 1). Note that for control of several aphid species, there was limited or no information available in the literature. Specific attention was given to control strategies that show promise in controlling the two main aphid species of concern to AHDB: melon and cotton aphid (*Aphis gossypii*) and potato aphid (*Macrosiphum euphorbiae*) on soft-fruit crops and other crops. Finally, the study summarises additional crop management strategies that could be used to aid aphid pest control as part of an integrated pest management approach.

Chemical control strategies

Strategies are available to replace or reduce reliance on conventional fungicides and insecticides. These include using semiochemicals to monitor pest populations or to modify pest behaviour, or as an attractant in lure traps used to monitor or kill the target pest. It also includes application of biologically derived bioprotectants, such as insect growth regulators and essential oils, and also mineral oils.

Semiochemicals

Semiochemicals have been identified and developed for control of many insect pest species, but there has been limited research in aphids. Semiochemicals include: (a) alarm pheromones, (b) sex pheromones, or (c) plant volatiles that can be used as a monitoring method, to lure and kill the pest, for mating disruption or for attracting natural enemies.

(a) Alarm pheromones. In response to attack, aphids release alarm pheromones, which cause neighbouring aphids to stop feeding, move away or drop from the plant. The sesquiterpene (*E*)-(*β*)-farnesene (EBF) is the primary component of the alarm pheromone of several economically important aphid pests (Vandermoten et al., 2012). Although EBF has been shown to reduce aphid populations in some cases, it does not always lead to predictable effects on aphid behaviour, due to chemical instability or aphid habituation to the pheromone signal. Field studies are needed to assess EBF effects on aphid behaviour in soft fruit, as it might have potential to improve the efficacy of natural enemy control, both as a natural enemy attractant and by reducing aphid responsiveness to aphid-derived alarm signals (summarised in Vandermoten et al., 2012).

(b) Sex pheromones. Sex pheromones are released by the females of holocyclic aphids. For potato aphid (*Macrosiphum euphorbiae*) control (Goldansaz, 2004), sex pheromones were tested for use in an IPM system, but although they had success in the wind tunnel, three years of field trials in Canada did not capture many males. The study suggested that the aphid population size was too low to capture many males, or the pheromone blend was not optimised, or the trap placement wasn't optimised for catching males. Sex pheromones have also been shown to attract parasitoids and may be useful for manipulating parasitoid populations in the field to improve their success as a control strategy (Powell et al., 1998).

(c) Plant volatiles. Plant-derived volatile organic compounds (VOCs) can act as a direct defence mechanism (e.g. release of deterrent volatile chemicals that repel pests). For example, raspberry aphids will respond to release by *R. idaeus* of the green leaf volatile (*Z*)-3-hexenyl acetate

(McMenemy et al., 2012), suggesting that volatile composition could be exploited to deter aphid settling. Plant volatiles can also act as indirect plant defences by increasing the recruitment of natural enemies (e.g. herbivore-induced plant volatiles that attract parasitoids or predators of arthropod pests: Stenberg, 2015). For example, plant semiochemicals have been identified in cotton that modified the behaviour of the melon and cotton aphid (*Aphis gossypii*) and one of its natural enemies, the predatory lacewing *Chrysoperla lucasina* (Hegde et al., 2011). Alate aphids were shown to spend significantly more time in areas with odour from uninfested cotton seedlings compared with areas with odour from aphid-infested seedlings, indicating preference for uninfested plants. Aphid-infested cotton

Table 1. Aphid species attacking soft fruit (* indicates no information was available)

Aphid species	**Primary host**	**Secondary host**	**Damage**	**Virus vector**
Strawberry aphid (*Chaetosiphon fragaefolii*)	strawberry		fungal growth on excreted honeydew	yes
Shallot aphid (*Myzus ascalonicus*)	strawberry (winter)	potatoes, shallots and sugar beet	malformed leaves, stunted growth and shortened and distorted flower stalks	no
Potato aphid (*Macrosiphum euphorbiae*)	polyphagous, including strawberry and bush fruit		causes little damage	no
Melon and cotton aphid (*Aphis gossypii*)	polyphagous, including strawberry and bush fruit		yellowing and distortion in the leaves and fungal growth on excreted honeydew	no
Glasshouse and potato aphid (*Aulacorthum solani*)	highly polyphagous aphid with hosts including strawberry		deformation and discolouration of the leaves	yes
Large raspberry aphid (*Amphorophora idaei*)	raspberry		no or little damage	yes
Small raspberry aphid (*Aphis idaei*)*	raspberry and loganberry		leaf curl	yes
Currant-lettuce aphid (*Nasonovia ribisnigri*)	blackcurrant, redcurrant and gooseberry	Asteraceae, including lettuce	leaf curl and shoot stunting	yes
Currant-sowthistle aphid (*Hyperomyzus lactucae*)	blackcurrant, redcurrant and white currant	*Sonchus*	downward curling of the leaves and stunting of the young growth	no
Gooseberry aphid (*Aphis grossulariae*)*	gooseberry	*Epilobium*	deformation and clumping of young leaves which can lead to stunting of growth	yes
Peach-potato aphid (*Myzus persicae*)	peach if present	polyphagous, including bush fruit	tightly curled leaves	yes
Permanent currant aphid (*Aphis schneideri*)*	*Ribes spp.*		striated and stunted shoots, bunching and leaf curl	no
Redcurrant blister aphid (*Cryptomyzus ribis*)*	*Ribes spp.*	*Stachys spp.*	blisters cause discolouration and distortion of leaves, fungal growth on excreted honeydew	no
Currant stem aphid (*Rhopalosiphoninus ribesinus*)	*Ribes spp.*		causes little damage	no
Blackcurrant aphid (*Cryptomyzus galeopsidis*)*	*Ribes spp.*	labiate hosts (e.g. *Galeopsis spp.*)	leaf crinkling and discolouration, tips of infested shoots become brown and die	no
Gooseberry-sowthistle aphid (*Hyperomyzus pallidus*)*	gooseberry	*Sonchus arvensis*	stunting and leaf curl	no
Currant root aphid (*Eriosoma ulmi*)*	*Ulmus*	*Ribes spp.*	nursery stock and young plants are weakened	no
Gooseberry root aphid (*Eriosoma grossulariae*)*	*Ulmus*	gooseberry	nursery stock and young plants are stunted or killed	no

seedlings were shown to produce larger quantities of VOCs, including (*Z*)-3-hexenyl acetate, (*E*)-4,8-dimethyl-1,3,7-nonatriene (DMNT), methyl salicylate, and (*E,E*)-4,8,12-trimethyl-1,3,7,11-tridecatetraene (TMTT), and these were shown to be repellent to aphids. Adult lacewings showed an antennal response to the VOCs emitted by infested cotton seedlings, although the consequences for lacewing attraction were not quantified. The authors suggested that 'smart' resistant cotton varieties could be bred to produce these deterrent compounds in anticipation of aphid attack. The effects of these VOCs, individually or in blends, on aphid control in field conditions have yet to be tested.

(d) Insect growth regulators*.* Insect growth regulators can adversely affect insects by regulating or inhibiting specific biochemical pathways or processes required for growth and development. They can be derived from synthetic or natural sources (Tunaz, 2004). Transgenic plants with snowdrop lectin (*Galanthus nivalis* agglutinin, GNA) was tested against glasshouse and potato aphid (*Aulacorthum solani*) and was shown to inhibit aphid growth and decrease fecundity (Down et al., 1996). Another growth regulator, chlormequat chloride, was tested in a UK field trial and was successful in reducing numbers of currant-sowthistle aphid (*Hyperomyzus lactucae*), which correlated with an increase in crop yield the following year (Singer, 1976). In the potato aphid (*Macrosiphum euphorbiae*), Benskin and Perron (1973) tested an insect growth regulator, Altozar IGR; ZR 512, which affected juvenile hormone activity; the study showed that the third instar was most sensitive, and treatment led to reduced fecundity by inhibiting normal adult development.

Essential and mineral oils

Essential oils are derived from aromatic plants and contain volatile, low-molecular-weight terpenes and phenolics. Causing neurotoxic effects, they are successfully used to control pre- and post-harvest phytophagous insects (Regnault-Roger et al, 2012). Essential oils that are both repellent and toxic are likely to be the most useful for control by killing aphids that have already colonised the plant and repelling newly colonising aphids (Munneke et al., 2004). There are many trials testing essential oils, several of which show a repellent or mortality effect. Examples include hemp oil used against *Aulacorthum solani*, (Gorski et al., 2016); three essential oils, identified as Denka A, Denka B and Denka C, used against *Macrosiphum euphorbiae*, (Munneke et al., 2004); rosemary oil and ginger oil used against *M. euphorbiae,* (Hori, 1999); garlic, soybean and eucalyptus essential oil mix used against *Aphis gossypii*, *Myzus persicae* and *M. euphorbiae* in Argentina (Castresan et al, 2013); three essential oils (from *Azadirachta indica*, *Eucalyptus camaldulensis* and *Laurus nobilis*) used against *Aphis gossypii* (Ebrahimi, 2013); sugar apple oil (*Annona squamosa*) (Lin et al., 2009); a plant-derived neem extract and a terpenoid blend used against *Amphorophora ideai* and *Macrosiphum euphorbiae* (O'Neill et al., 2014); and neem oil used against *Chaetosiphon fragaefolii* (Lowery and Isman, 1993).

Mineral oils are derived from petroleum and have been used to control aphids and reduce the spread of non-persistent viruses. A laboratory study showed that the mineral oil Finavestan EMA can induce either probiotic effects or toxic effects in *M. euphorbiae*, depending on the mode of application (topical contact, inhalation or ingestion) and the concentration tested (Martoub et al., 2011). The authors noted that as other studies have shown mineral oil to be effective at controlling the spread of non-persistent viruses by aphids, it would be useful to test the mineral oil in combination with an insecticide or plant-derived antifeedants to maximise aphid control and counter any probiotic effects on aphids via oil inhalation (Martoub et al., 2011).

Table 2. Summary of potential alternative chemical control strategies for soft-fruit aphids

Strategy	Product	Aphid species	Application rate/timing	Reference
Semiochemical	(Z)-3-hexenyl acetate, DMNT, methyl salicylate, TMTT	*Aphis gossypii*	lab assay – 200 ml/min flow rate	Hegde et al., 2011
Insect growth regulator	chlormequat chloride	*Hyperomyzus lactucae*	UK field trial – one spray 2200 ppm	Singer and Smith, 1976
	Altozar IGR	*Macrosiphum euphorbiae*	lab assay – applied when aphids are third instar	Benskin and Perron, 1973
Essential and mineral oils	hemp oil	*Aulacorthum solani*	lab assay – 0.1% aqueous emulsion solutions	Gorski et al., 2016
	Denka A, Denka B and Denka C	*Macrosiphum euphorbiae*	lab assay – application equivalent to 284 l/hectare	Munneke et al., 2004
	sugar apple	*Aphis gossypii*	lab assay – leaf discs sprayed 0.05% w/v applied until run-off	Lin et al., 2009

Biological control strategies

The first use of biological control predates the modern pesticide era. There are advantages and disadvantages to using biological control. The advantage is that control organisms tend to be quite specific and the pest organism does not build up resistance, so the control method can be repeated on multiple occasions. The disadvantage is that the control organism population can take time to build up to levels capable of controlling the pest and can be quite costly to produce. For biological control to be successful, research effort is required to understand the biology and ecology of both the pest and control organisms and the influence of environmental factors on biocontrol efficacy (Bale et al, 2008).

Parasitoids

The use of parasitoids in biological control has been well documented and with mixed results. They can be tested individually or as part of a mixture of parasitoid species. A good level of control of glasshouse and potato aphid (*Aulacorthum solani*) was achieved using parasitoids (Silva et al, 2009), but tests on the shallot aphid (*Myzus ascalonicus*) (Enkegaard, 2013) showed that the aphids all died after parasitism so that a second generation of parasitoids was not produced. Three parasitoid species, *Aphidius colemani, Aphelinus abdominalis* and *Aphidius ervi*, were tested on the large raspberry aphid (*Amphorophora idaei*) (Mitchell, 2007), with all three parasitoid species showing a low level of parasitism success, which could be due to the presence of protective facultative bacterial endosymbionts (Frew, 2014). *Aphidius ervi* was shown to be more successful at parasitising aphids on a susceptible raspberry variety compared with a variety with some aphid resistance (Mitchell et al., 2010). Using a mixture of parasitoid species allows for variation in aphid population size and species between years and between locations. Different mixtures of parasitoid species were tested over several years in greenhouses. A mixture of six parasitoid species was shown to give the best control of the strawberry aphid (*Chaetosiphon fragaefolii*) (de Menten, 2011). This product is now commercially available. Augmented release of multiple parasitoid species was shown to be compatible with the use of certain biopesticides for suppression of aphid infestations (O'Neill et al., 2014). Understanding the reasons why parasitoids fail to suppress pest populations is vital if they are to continue to be an important part of IPM strategies. One reason for their failure which has been given some attention is the presence of inter- and intra-species variation in aphid susceptibility to parasitoid attack (Henter and Via, 1995; Asplen et al., 2014). Facultative bacterial endosymbionts such as *Hamiltonella defensa* and *Regiella insecticola* have been shown to be present in many aphid species and differ in their effects on aphid resistance depending on host aphid species identity (Moran et al., 2005). In *M. euphorbiae,* resistance to the common parasitoid *Aphidius ervi* is encoded within the aphid genome rather than the facultative endosymbiont *H. defensa* (Clarke et al., 2017). In this case, parasitism resistance led to lack of larval development in attacked aphids. Aphids of the resistant genotype showed a high level of fitness, suggesting that biological control of *M. euphorbiae* using *A. ervi* could aggravate pest problems by selecting for the fittest parasitism-resistant genotypes.

Other arthropod natural enemies

Using predators which are either naturally present or introduced into the area has proved, on the whole, not to be as successful as parasitoids at controlling aphid populations, as they tend to be less effective at searching for aphids when the aphid population size is small. In this situation, predators tend to move away from the target area (i.e. the crop). Despite this, predators should still be considered for their use as part of an IPM strategy. The natural enemies investigated for their ability to control aphid populations include:

- Beetles, such as the Coccinellidae, including the two-spotted ladybird (*Adalia bipunctata*), seven-spotted ladybird (*Coccinella septempunctata*), and ten-spotted ladybird (*Adalia decempunctata*)
- True bugs, such as the anthocorids or pirate bugs of the genera *Orius* and *Anthocoris*
- Neuropterans, such as green lacewings of the genera *Chrysopa* and *Chrysoperla*
- Hoverflies, such as *Syrphus*, *Scaeva, Episyrphus*
- Gall midges, such as *Aphidoletes*

Lacewing species have shown the most promise as aphid predators. In studies using shallot aphid (*Myzus ascalonicus*) and currant-lettuce aphid (*Nasonovia ribisnigri*), lacewing larvae reduced aphid numbers, although both studies were conducted at a small scale (Shrestha et al., 2013). Laboratory experiments using carabids collected from apple orchards and strawberry plantations showed that the carabids were very mobile and able to move about the plant structure and reduce strawberry aphid (*Chaetosiphon fragaefolii*) numbers (Fitzgerald and Solomon, 2001).

Entomopathogenic fungi

Entomopathogenic fungi occur naturally in the environment and attack many arthropods, including aphids. Research into the use of entomopathogenic fungi has involved either identifying which species are already present in the pest population or using laboratory-reared or commercially available fungal species. In a glasshouse study testing twelve species of entomopathogenic fungi on *A. gossypii* and *M. persicae*, temperature and humidity were shown to play an important role in mycelium development. For good control, the fungi must be able to work over the range of temperatures and humidities experienced in glasshouses and polytunnels. *Lecanicillium lecanii* strain 41185 was shown to be the most virulent of the fungal strains tested over a range of temperatures (20–30^{o}C) and relative humidities (45%–90% RH) which covered the range of conditions occurring in the glasshouse (Vu et al., 2007). The entomopathogenic fungus *Beauveria bassiana* was shown to increase aphid mortality in glasshouse and potato aphid (*Aulacorthum solani*) (Kim et al, 2007) and UK large raspberry aphid (*Amphorophora idaei*) (Dickson, 1979) and also reduced fecundity in the currant-lettuce aphid (*Nasonovia ribisnigri*) in Denmark (Shrestha et al., 2015).

Co-application of entomopathogenic fungi with a suitable sublethal concentration of selective insecticide has been successfully employed against various insect pests, including aphids, to reduce the selection pressure using insecticides alone. General insecticide resistance mechanisms involve elevated activities of detoxification enzymes, such as monooxygenases and esterases (Ambethgar, 2009). Entomopathogenic fungi can increase aphid susceptibility to insecticides by suppressing these enzyme activities (Kanost et al., 1990).

Densoviruses

Densoviruses are invertebrate-specific parvoviruses that are highly pathogenic and usually fatal. They have been identified in many insect orders, including Lepidoptera, Diptera, Homoptera, Orthoptera and Hemiptera. Research into their use for pest control is limited, although densoviruses have proven successful for the control of the mosquito *Aedes aegypti*. The disadvantage of these viruses is that they can take between 2 and 20 days to kill the host, which means that the pest can still cause crop damage after becoming infected with the virus. Modification of the virus genome can successfully reduce the time required for infection to be fatal (Jiang et al., 2007). In the peach-potato aphid (*Myzus persicae*), a densovirus has been reported to infect the anterior portion of the digestive tract of the aphid, with infection causing reduced aphid size, delayed development and decreased fecundity (van Munster et al., 2003).

Table 3. Summary of potential biological control strategies for soft-fruit aphids

Strategy	Species name and/or product name	Aphid species	Application rate/timing	Reference
Parasitoid	*Praon volucre*	*Aulacorthum solani*	lab assay – one parasitoid allowed to parasitise 20 nymphs for one hour at 22°C	Silva et al., 2009
	Six-species mixture/ FresaProtect	*Macrosiphum euphorbiae, Aphis gossypii* and other strawberry aphids	Available from Viridaxis – one tube covers 200 m^2	de Menten, 2011
Entomopathogenic Fungi	*L. lecanii* 41185	*Aphis gossypii, Myzus persicae*	lab assay – range of temp 20–30°C; 20 ml of 1×107/ml conidia suspension spread on each leaf	Vu et al., 2007
	Lecanicillium longisporum (Vertalec®), *Lecanicillium attenuatum* (CS625)	*Aulacorthum solani, Myzus persicae* and *Macrosiphum euphorbiae*	lab assay – leaf discs sprayed with 1 ml conidia suspension (108 conidia/ml) at room temperature	Kim et al., 2007
	Beauveria bassiana strain GHA/ BotaniGard	*Nasonovia ribisnigri*	semi field assay – knapsack spray with a fine nozzle used to spray 35 ml of 1.44 × 107 conidia/ml	Shrestha et al., 2015

Crop management

Plant traits

Plant traits, both physical and chemical, can play a role in control against many insect pests, including aphids. These plant traits either provide a physical barrier against movement or feeding, chemical deterrence of pest settling and feeding, or reduced plant palatability (Mitchell et al., 2016). Glandular trichomes, which secrete metabolites, are the plant trait mechanism which has been given most attention in aphid control. Sugar esters produced by glandular trichomes was linked to reduced abundance of *Macrosiphum euphorbiae* on tomato plants (Goffreda et al, 1990). Plant surface waxes and allelochemicals have been proposed as desirable traits for repelling or deterring aphids (Smith and Chuang, 2013). Aphid-resistance genes in raspberry are thought to lead to a chemical deterrence at the leaf surface (e.g. Shepherd et al., 1999) and reduced phloem nutritional quality (Lightle et al., 2012).

Increasing plant biodiversity

Increased plant biodiversity can enhance pest control by increasing natural enemy abundance, biodiversity and activity, which can translate into a decrease in pest numbers. Increasing plant biodiversity can be achieved in several ways, including introducing non-crop components (e.g. floral mixtures) as an undersowing of the main crop, in the field margins, or in floral strips within the crop, or by intercropping the main crop with a companion crop species. Using floral strips to provide food for adult hoverflies was shown to increase predator numbers in lettuce fields and reduce the abundance of the currant-lettuce aphid (*Nasonovia ribisnigri*) in the USA (Gillespie et al., 2011). Undersowing grass in a UK potato field was shown to reduce *Macrosiphum euphorbiae* abundance and the grass did not compete with the crop to affect yield (McKinlay, 1985).

Intercropping might be an attractive option for improved aphid control in *Rubus* plantations by growing susceptible genotypes alongside one or more resistant genotypes. In other crop systems, the presence of resistant plants can mask the presence of susceptible genotypes and dilute the presence of infective or infesting colonies, limiting the overall pest and disease load (Tooker and Frank, 2012). Such an approach might also slow the evolution of resistance-breaking pest and disease variants and enhance the durability of crop resistance (Tooker and Frank, 2012). At a larger scale, pest abundance tends to be reduced in landscapes with a high proportion of semi-natural habitat, and biological control by natural enemies tends to be more effective in these landscapes (Veres et al., 2013).

Plant priming using defence elicitors

Plant defence can be 'primed' to stimulate plant defence pathways without triggering a full plant defence response; this can enhance plant resistance by allowing rapid induction of a strong and potentially more sustained response when the plant is attacked by pests (e.g. Stenberg et al., 2015; Martinez-Medina et al., 2016). 'Elicitors' of plant defence pathways include plant signal compounds such as jasmonates, and synthetic and plant-derived products (Aranega-Bou et al., 2014). Elicitors might offer an additional category of bioprotectant products in the future, although they have yet to be tested rigorously for effects on soft-fruit-crop susceptibility to aphids. In raspberry, raspberry aphids colonising plants infected with black raspberry necrosis virus and raspberry leaf mottle virus showed slower development than aphids on uninfected plants (McMenemy et al., 2012), which might indicate that activation of defensive pathways (by virus infection) primes raspberry plant defences against aphids, although the biochemical pathways involved in this response have yet to be identified.

Protective coverings

UV-blocking materials, such as polythene sheets and netting, have been developed as a tool to reduce pest numbers. These materials block out UV light (wavelengths in the 240–400 nm range), which impairs insect vision and affects their ability to locate and colonise plants. Reflective mulches are used to deter insects, with different colours being more effective against specific insect pests. Netting and covers are used as a barrier to prevent insects from landing on the crop (Diaz and Fereres, 2007). In Mexico, clear mulches were shown to reduce aphid numbers to the greatest extent (compared with bare soil) in watermelon crops, but black and white mulches also reduced aphid abundance (Farias-Larios and Orozco-Santos, 2010). In Israel, seven net products (P-Optinet, P-AntiInsect net, T-AntiInsect net, BioNet white, BioNet transparent, Antivirus 50 mesh and Spidernet Plus) were tested in pepper crops in polytunnels: all seven net types were shown to reduce numbers of aphids and other pests (Legarrea et al., 2010).

Conclusions

Although the range of studies examining novel or alternative control options for the target aphid species in Table 1 is limited, potential control strategies have emerged from these studies and from research on other aphid species. Among chemical controls, insect growth regulators, essential and mineral oils and some semiochemicals have been identified that could be suitable for testing in soft fruit. Among biological protectants, parasitoids and certain other natural enemies can be effective, although, often, biological products do not make it beyond small-scale trials in controlled conditions, perhaps due to the challenges of conducting controlled large-scale field trials. Entomopathogenic fungi can be applied on a larger scale and some species and strains are effective over a range of temperatures and relative humidities, which would make this strategy suited to polytunnel conditions. Combining biological and chemical controls might increase efficacy, as highlighted by the potentially synergistic effects of entomopathogenic fungi and insecticides for aphid control.

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Appendix 1 – Biology of the target aphids

Strawberry aphid (*Chaetosiphon fragaefolii*)

Chaetosiphon fragaefolii is one of the most serious pests in strawberry crops. They tend to be found feeding on new shoots, crowns and close to veins on the underside of leaves. Direct damage caused by aphid feeding includes fungal growth on the excreted honeydew, which leads to reduced fruit yield and quality. The aphid is a principle vector of six plant viruses, with strawberry crinkle virus and strawberry mild yellow edge virus being the most pathogenic viruses affecting strawberry. This aphid reproduces parthenogenetically all year round and therefore overwinters as adults. In outside strawberry production, alates are produced in May and June and then again in October to December.

Shallot aphid (*Myzus ascalonicus*)

Myzus ascalonicus is a polyphagous aphid with hosts including strawberry, onion, brassicas and garden ornamentals. It reproduces parthenogenetically and does not require host plant alternation during its life cycle. The aphid is cold hardy and can overwinter in glasshouses and in sheltered places. Overwinter hosts include several weed species, such as speedwell and chickweed. *M. ascalonicus* can reproduce even at low temperatures, and as temperatures increase in spring, alate aphids are produced, which migrate to other host plants. Damage caused by this aphid species includes malformed leaves, stunted growth and shortened and distorted flower stalks.

Potato aphid (*Macrosiphum euphorbiae*)

This is a highly polyphagous aphid with over 200 host plant species, including strawberry and bush fruit. In the US, the primary host is *Rosa* spp., where it overwinters and reproduces sexually, but in Europe the aphid is thought to reproduce parthenogenetically all year round. Alate forms are produced in spring and autumn and migrate to alternative hosts. Direct feeding damage results in chlorotic misshapen leaves, which causes a reduction in quality and yield, and the aphid is also known to transmit potyviruses. Insecticide resistance and natural enemy (parasitoid) resistance have been documented in this species, which increases the need to find alternative control methods.

Melon and cotton aphid (*Aphis gossypii*)

This is a highly polyphagous pest with a worldwide distribution. Host plants include strawberry and bush fruit, with many reported biotypes/clones, which are thought to be host-plant specific (Liu, 2002). In the cooler climate of the UK, the life cycle is heteroecious, with migration to a winter host to lay eggs and parthenogenetic reproduction on the summer host. Direct feeding damage includes yellowing and distortion in the leaves, which causes a reduction in the quality and yield. It is known to transmit viruses.

Glasshouse and potato aphid (*Aulacorthum solani*)

Aulacorthum solani is a highly polyphagous aphid with hosts including strawberry. The species has very toxic saliva, which causes deformation and discolouration of the leaves.

Large raspberry aphid (*Amphorophora idaei*)

Amphorophora idaei is only found on raspberry. It causes direct feeding damage, but more importantly it transmits four plant viruses: black raspberry necrosis virus; raspberry leaf mottle virus; raspberry leaf spot virus; and Rubus yellow net virus. There are thought to be four different biotypes of this species that have overcome resistance genes introduced through raspberry breeding. Eggs overwinter and adults start appearing by March. This species goes through two parthenogenetic cycles in summer before alates are produced which migrate to new plants. The sexual cycle starts in October and eggs are laid at the base of plants.

Small raspberry aphid (*Aphis idaei*)

Aphis idaei is a major pest of raspberry and feeds on raspberry and loganberry, causing leaves to curl. The eggs are found on the upper half of the current year's cane, either at the junction of the petiole with the cane or between the axillary bud and the cane. During the asexual part of the life cycle, aphids congregate around the base of stalks of the clusters of buds. Sexual forms appear in October. This aphid species vectors raspberry leaf mottle virus, raspberry leaf spot virus, black raspberry necrosis virus and *Rubus* yellow net virus.

Currant-lettuce aphid (*Nasonovia ribisnigri*)

The primary hosts of the *N. ribisnigri* are blackcurrant and gooseberry and secondary hosts are members of the Asteraceae, including lettuce. Eggs are laid at the base of buds and alates migrate to the secondary hosts in May and return to primary hosts in the autumn. Dense colonies form on the shoot tips and cause leaf curl and shoot stunting. Vector of gooseberry vein banding virus.

Currant-sowthistle aphid (*Hyperomyzus lactucae*)

Hyperomyzus lactucae feeds on its primary hosts, blackcurrant, redcurrant and whitecurrant, in early spring, causing a downward curling of the leaves and the stunting of the young growth. It migrates to its secondary host in May and returns to currant again in the autumn.

Gooseberry aphid (*Aphis grossulariae*)

Aphis grossulariae can spend all year on its primary host, gooseberry, but can also migrate to its secondary host, willowherb. It overwinters as eggs and emerges at bud burst. Dense colonies of aphids at the growing tips of gooseberry can cause deformation and clumping of young leaves, which can lead to stunting of growth.

Peach-potato aphid (*Myzus persicae*)

Myzus persicae is a polyphagous species which has hundreds of secondary hosts, including bush fruit. In the absence of peach – the primary host – this species overwinters as adults hiding in sheltered places and reproduces parthenogenetically all year round. It causes direct feeding damage and transmits viruses. There are many genotypes of *M. persicae*, thought to be introduced to the UK each year by human action. Some of these genotypes persist while others die out. There are many genotypes that show insecticide resistance, with several different resistance mechanisms detected.

Permanent currant aphid (*Aphis schneideri*)

Aphis schneideri is only found on blackcurrant and other *Ribes* species. It overwinters as eggs on the shoots and, in spring, apterous aphids invade the flower trusses. In the summer, it forms dense colonies on young shoots and under leaves, which can cause bunching and leaf curl. Alates are produced in summer and these adults migrate to new *Ribes* hosts. Sexual forms are produced again in autumn.

Redcurrant blister aphid (*Cryptomyzus ribis*)

Cryptomyzus ribis overwinters as eggs on *Ribes* spp. and adults appear at bud burst. They migrate to *Stachys* species in early July and return to *Ribes* spp. in the autumn. In *Ribes*, aphid feeding causes galls on the leaves. These galls are raised patches of thickened upper leaf surface, which often make the leaf curl downwards.

Currant stem aphid (*Rhopalosiphoninus ribesinus*)

Rhopalosiphoninus ribesinus is found only on *Ribes* species and prefers shady areas. It overwinters as eggs and emerging aphids initially colonise the old wood of lower stems, then can move onto on the young shoots and leaves.

Blackcurrant aphid (*Cryptomyzus galeopsidis*)

Cryptomyzus galeopsidis overwinters on *Ribes* spp., most often blackcurrant but occasionally gooseberry and redcurrant. On *Ribes*, it lives on the underside of young leaves until summer when it can migrate to secondary labiate hosts, migrating back to *Ribes* in autumn. Aphid feeding on the young leaves causes leaf crinkling and discolouration and later the tips of infested shoots may become brown and die.

Gooseberry-sowthistle aphid (*Hyperomyzus pallidus*)

Hyperomyzus pallidus overwinters as eggs on gooseberry. In spring, colonies of aphids develop on the underside of leaves and at the tips of young shoots. Aphid feeding causes stunting and leaf curl, with a characteristic yellow vein banding of the leaves. In late spring, alates migrate to *Sonchus arvensis,* where breeding continues until migration back to gooseberry in late autumn.

Currant root aphid (*Eriosoma ulmi*)

Eriosoma ulmi overwinters as eggs on its primary host *Ulmus,* which in spring inhabits tightly curled and galled leaves. In early summer, alates migrate to *Ribes*. On *Ribes,* apterous aphids develop on the roots, often among masses of blue or white wax. Infested *Ribes* bushes can become stunted and yield is reduced.

Gooseberry root aphid (*Eriosoma grossulariae*)

Eriosoma grossulariae overwinters as eggs on *Ulmus*. Colonies develop in spring and can be observed amongst curled leaves, protected by masses of flocculent wax. Alates migrate to gooseberry in summer, where nymphs are deposited in the soil. The nymphs then feed on the underground parts of stems and roots. Colonies develop and a visible waxy bloom is observed. In autumn, alates migrate back to *Ulmus*, where sexual reproduction takes place. This aphid is particularly harmful to nursery and young plants.