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Alexandra Schoeny, Antoine Lauvernay, Jérôme Lambion, Christophe Mazzia, Yvan Capowiez. The beauties and the bugs: A scenario for designing flower strips adapted to aphid management in melon crops. *Biological Control*, 2019, 136 (103986), pp.1-10. 10.1016/j.biocontrol.2019.05.005 . hal-02619746

HAL Id: hal-02619746

<https://hal.inrae.fr/hal-02619746>

Submitted on 25 May 2020

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The beauties and the bugs: a scenario for designing flower strips adapted to aphid management in melon crops

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Keywords

Conservation biological control, *Cucumis melo*, ecological engineering, field margins, habitat manipulation, natural enemies

Abstract

Flower strips appear to be a promising lever for promoting pest control but a careful selection of the plant species used is needed prior to implementation to avoid possible negative side effects. In the case of open field melon crops, the main pitfall would be to generate aphid and aphid-borne virus reservoirs near the crops. Combining biotests under controlled conditions and data from the literature, we assessed 18 candidate plant species, and ruled-out those posing a potential risk of hosting *Aphis gossypii* (melon pest and virus vector), *Myzus persicae* (virus vector) and/or viruses (*Cucurbit aphid-borne yellows virus* (CABYV), *Cucumber mosaic virus* (CMV), *Watermelon mosaic virus* (WMV) and *Zucchini yellow mosaic virus* (ZYMV)). Five plant species made it through the selection process: cornflower, grass pea, sainfoin, salad burnet and sweet marjoram. Flower strips sown with a mix of these five plant species were evaluated in a five-year field experiment. They displayed a flowering continuum likely to provide a food resource to natural enemies throughout the growing season. Their potential to host natural enemies was compared to those of grass strips and bare soil by monitoring generalist and specialist predators within the different field margins and melon crop. Flower margins supported significantly more of these natural enemies than grass margins and bare soil. All predator taxa analyzed responded positively to the floral resources displayed. Spiders were 3.2 times more abundant in pitfall traps placed in flower margins than in bare soil. Generalist predators and aphid specialist predators collected using a vacuum sampler were 5.5 and 9.1 times more abundant in flower margins than in bare soil, respectively. Interception traps set for weekly periods showed that coccinellid and syrphid fluxes were significantly enhanced near flower margins.

1. Introduction

Aphids and aphid-borne viruses can cause severe economic damage to open field vegetable crops. In conventional cropping systems, synthetic insecticides are often the first option for controlling aphids. However their efficiency is frequently challenged by the development of resistant clones (Bass et al., 2015) and their usage is increasingly questioned due to environmental and health risks. In addition, they are of little relevance to limit non-persistently transmitted viruses, where acquisition and inoculation occur in a matter of seconds (Perring et al., 1999). Cultural practices such as the use of plastic mulches or row covers may limit both aphid colonization and the transmission of aphid-borne viruses but only provide temporary protection and lead to plastic waste (Lecoq and Desbiez, 2012). Whenever available, resistant cultivars are the easiest, most efficient and environmentally friendly way to manage pests and diseases, but genetic resistance durability can be jeopardized by the emergence of adapted clones. A complementary way of reducing aphid and virus damage within an open field crop can be to take advantage of ecological services provided by the environment. For example, Losey and Vaughan (2006) estimated that the annual value of pest control by wild native insects is \$4.5 billion in the United States. Unfortunately, agricultural landscapes are rarely optimal environments for natural enemies. The excessive use of insecticides and the lack of alternative food resources generally limit the performance of natural enemies (Tscharntke et al., 2016). Thus increasing attention is being paid to conservation practices that enhance the survival, fecundity, longevity and behavior of natural enemies. In particular, habitat management seeks to alter the habitats within or around crops to improve the availability of the resources required for optimal performance by natural enemies (Gurr et al., 2017; Landis et al., 2000). To achieve pest control it is crucial to provide nectar, pollen, alternative hosts or prey, shelter, to parasitoid

65 and predator insects. Although flowering plants provide many of these food resources, habitat
66 manipulation should be more than “chocolate-box ecology” (Gurr et al., 2004). Floral displays
67 of plants picked at random can be at best ineffective, at worst detrimental by favoring pest
68 populations over beneficial organisms. Thus a rigorous evaluation of the candidate insectary
69 plants prior to flower strip implementation is needed to avoid these adverse effects.

70 Melon, particularly the Charentais-type (*Cucumis melo* var. *cantalupensis*), is a very popular
71 fruit in France. It is cultivated between March (early tunnel plantings) and September (late open
72 field plantings) in three main production areas: South-East, South-West and Central-West.
73 Nearly 40% of the national production is in the South-East (286 000 t, 14000 ha in 2017,
74 www.agreste.agriculture.gouv.fr). Open field melon crops are regularly impacted by biotic
75 stresses, among which aphids and aphid-borne viruses. The melon aphid *Aphis gossypii* Glover
76 (Hemiptera: Aphididae) is the only aphid species colonizing melon crops in France, causing
77 leaf-curling, stunting and even plant death when colonization is intense. *Myzus persicae* Sulzer
78 (Hemiptera: Aphididae) has not yet been found to colonize melon crops in France, but it is the
79 most important aphid virus vector, able to transmit over 100 plant viruses (Blackman and
80 Eastop 2000). Both aphid species are efficient vectors for four viruses frequently observed on
81 melon crops in France: *Cucurbit aphid-borne yellows virus* (CABYV, Polerovirus,
82 Luteoviridae), *Cucumber mosaic virus* (CMV, Cucumovirus, Bromoviridae), *Watermelon*
83 *mosaic virus* (WMV, Potyvirus, Potyviridae) and *Zucchini yellow mosaic virus* (ZYMV,
84 Potyvirus, Potyviridae). WMV and ZYMV are the most harmful viruses, causing mosaic
85 symptoms on leaves, plant stunting and reduced fruit yield, but also, when infection is severe,
86 leaf deformation such as filiformism, mosaic on fruits, coupled with marbling and hardening
87 of the flesh for ZYMV (Lecoq and Desbiez, 2012).

88 In France as elsewhere in Europe, increasing importance is being granted to habitat
89 management, not only in organic farming systems, but also in conventional systems due to the

90 progressive reduction of pesticide usage imposed by changes in regulation. For melon
91 producers, flower strips could be a promising lever for controlling aphids. Several seed
92 companies sell blends which are supposed to boost biological control services. These advised
93 blends are identical regardless of crop and are not specific for melon crops. Yet pathogen
94 corteges differ a lot depending on the crops, so botanical composition should be crop-specific
95 to avoid negative side effects. In the case of open field melon crops, the main pitfall would be
96 to generate aphid and virus reservoirs near the crop by sowing plant species likely to host melon
97 aphids and viruses.

98 In this study, we focused on the selection and evaluation of flowering species appropriate for
99 melon crops. The first step was to screen a set of candidate plants under controlled conditions
100 to design a mix that minimizes the risk of hosting aphids (*A. gossypii* and *M. persicae*) and
101 viruses (CABYV, CMV, WMV and ZYMV). The second step was to evaluate, under field
102 conditions, the potential of the corresponding flower strips to enhance aphid predator
103 abundance within field margins and melon crop.

2. Materials and methods

2.1. Plant screening under controlled conditions

2.1.1. Plant species shortlist and plant rearing

Twenty plant species from 13 families were selected for the experiments (Table S1). Melon (*Cucumis melo* L.) and pepper (*Capsicum annuum* L.) were used as controls.

Virus-free plants were grown in an insect-proof greenhouse without pesticides. Seedlings were prepared in flats containing a peat/coco coir substrate (080 Klasmann-Deilmann France, Bourgoin Jallieu, France) and irrigated daily with bore water. Plantlets were transplanted individually to plastic pots (9 cm wide × 8 cm high) containing a peat/clay substrate (404 Klasmann-Deilmann France) and irrigated daily with bore water, the pH of which was adjusted to 5.8. Plants were used at the vegetative stage (3-8 week old depending on plant species, Table S1). During biotests, plants were irrigated daily with a nutrient solution (Soluveg Essentiel 16-5-25, Angibaud & Spécialités, La Rochelle, France).

2.1.2. Aphid rearing

Aphids were reared on virus-free plants in growth cabinets equipped with LED tube lights (4000K) under a photoperiod of 16:8 (L:D) h. *Aphis gossypii* (clone NM1, Thomas et al., 2012) was reared on 3-5 week old melon plants (cv. Védrantais) at 24/21±1°C day/night. *Myzus persicae* (clone Patho) was reared on 5-8 week old pepper plants (cv. Yolo Wonder) at 21±1°C day/night. Four weeks before experiments, mass rearing was shifted to synchronous rearing in order to manipulate 7 day-old apterous female cohorts.

2.1.3. Plant-aphid interaction biotests

Each plant species was evaluated for its capacity to host two aphid species: *A. gossypii* and *M. persicae*. For each aphid species, no-choice settling tests were carried out on 10 plants per plant species, each plant tested constituted a replicate. Ten 7 day-old apterous females were deposited per plant. After 24h, settled females were counted and removed. The acceptance rate was calculated as the number of recovered females divided by 10. After six additional days, the offspring produced during the initial 24h period was counted. The reproductive rate was calculated as the number of offspring divided by the number of recovered females. Together, the acceptance rate and the reproductive rate were used to assess the capacity of the tested aphid species to accept the tested plant species as a suitable host. Results were compared to those obtained on plant species used for aphid rearing, which were considered as reference plant species (melon for *A. gossypii*, pepper for *M. persicae*).

2.1.4. Plant-virus interaction biotests

Each plant species was evaluated for its capacity to host the most frequently observed viruses in melon crops in France: CABYV, CMV, WMV and ZYMV. For CABYV and CMV, one isolate was used; for WMV and ZYMV, two isolates reflecting the recent changes in the genetic structure of these viruses in France were used (Table 2). For each viral isolate, biotests were conducted on eight plants per plant species, each plant tested constituted a replicate. Melon (cv. Védraçais) was used as positive control.

The persistently aphid-transmitted CABYV was tested through aphid transmission using *A. gossypii* as vector. Virus sources were infected melon plants (cv. Védraçais). Virus-free aphids reared as in Section 2.1.2. were collected with a fine-tip paint brush and transferred onto virus sources. After a 48h acquisition access period (AAP), groups of 10 aphids were gently transferred to virus-free test plants for a 48h inoculation access period (IAP). At the end of the

IAP, aphids were killed by spraying the plants with two systemic insecticides (0.5 ml/l NUPRID 200, Nufarm SAS) at 24h intervals. Plants were then placed in a dedicated greenhouse for 4-5 weeks of incubation.

The non-persistently aphid-transmitted CMV, WMV and ZYMV were tested through mechanical inoculation. Virus sources were infected zucchini plants (*Cucurbita pepo* L. cv. Diamant). Inoculum was prepared by grinding 2 g of young leaf tissue with a mortar and pestle in 8 ml of a solution containing 0.03M Na₂HPO₄ with 0.2% DIECA. Carborundum (75 mg/ml) and activated charcoal (75 mg/ml) were added before rub-inoculation of test plants. Plants were rinsed with tap water and placed in a dedicated greenhouse for 3-5 weeks of incubation. Viruses were detected using a double antibody sandwich enzyme-linked immunosorbent assay (DAS-ELISA) with specific polyclonal antisera produced in our laboratory. Plants were considered infected when the absorbance at 405 nm (Multiskan EX, Thermo Electron Corporation) was three times above the mean value of the healthy controls (Schoeny et al., 2017). The transmission rate was calculated as the number of infected plants to the total number of tested plants.

2.2. *In situ* evaluation of field margins

2.2.1. Experimental design

Five field trials were conducted between 2011 and 2015 at the INRA St Paul experimental station in Avignon (southeastern France, 43°54'53N, 4°52'59E) on a 1.3 ha plot edged north and south by 6 m-high cypress trees. The experimental design consisted of a melon crop with three modalities of field margin management: bare soil, flower strip and grass strip (Figure S1). Each modality consisted of two strips 25.5 m apart: one 'north strip' and one 'south strip'. Strips were 55 m long and 3 m wide. The spatial organization of the modalities was defined randomly

178 each year. Flower strips were sown with a mix of five plant species selected after the above
 179 mentioned biotests: sainfoin (*Onobrychis viciifolia*, 22 kg/ha, 40%) grass pea (*Lathyrus sativus*,
 180 16.5 kg/ha, 30%), salad burnet (*Sanguisorba minor*, 11 kg/ha, 20%), cornflower (*Centaurea*
 181 *cyanus*, 2.75 kg/ha, 5%) and sweet marjoram (*Origanum majorana*, 2.75 kg/ha, 5%). The
 182 proportions of each plant species in the mix were defined with the expertise of a seed seller.
 183 Grass strips were sown with ryegrass (*Lolium perenne*, 50 kg/ha). Flower and grass strips were
 184 sown during the second half of March (18-30 March) approximately two months before melon
 185 planting (24-31 May). Special attention was given to soil preparation and weed control to foster
 186 the establishment and growth of the field margins. Two tillage operations (disc harrowing
 187 before or after ploughing) were implemented in late autumn/winter. Just before sowing, a rotary
 188 harrow completed soil preparation to create a perfect seedbed. Flower and grass strips were
 189 sown with a portable spreader (421-S, Solo®). For the flower strips, to optimize seed
 190 germination and considering the difference in seed size of the five plant species selected, large
 191 seeds (sainfoin, grass pea, salad burnet) were sown in a first passage, followed by a comb
 192 harrow, the small seeds (cornflower, sweet marjoram) were sown in a second passage,
 193 completed by a roller. Flower and grass strips were irrigated with sprinklers (up to 63 mm per
 194 week depending on weather conditions) and hand-weeded when needed. The bare soil modality
 195 was maintained using mechanical weeding.
 196 Melon crops were set up between the north and south strips after soil preparation with a rotary
 197 harrow. Charentais-type melon seedlings at the 1-3 leaf stage were planted in 16 rows (1.5 m
 198 row spacing) parallel to the strips on dark brown plastic mulch with drip irrigation (Figure S1).
 199 Basal PK fertilization (0-25-25) was applied during winter/early spring (250-300 kg/ha),
 200 complemented with ammonium nitrate (33-0-0) during spring in 2011 and 2012 (130 kg/ha). A
 201 monoammonium phosphate (12-61-0) fertigation was applied just after planting (100 kg/ha) to
 202 boost melon growth. No insecticides were applied during trials.

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2.2.2. Plant development monitoring

The development of sown strips was monitored 2-3 times before melon planting with the quadrat technique. A 1-m² wooden frame was randomly placed in the north and south strips and the percentage of plant cover was visually estimated.

The flowering of flower strips was monitored 4-6 times after melon planting. Ten randomly chosen plants per species were examined in one quadrat per strip in 2011 and 2012, in five quadrats per strip in 2013, 2014 and 2015. Plants were considered at flowering stage when displaying at least one open flower. Specific flowering rates were calculated as the number of flowering plants divided by the number of examined plants.

2.2.3. Arthropod monitoring

To assess the biocontrol potential of the different field margins, we surveyed both generalist (able to feed on various prey) and specialist (mainly aphidophagous) predators. Three complementary trapping methods were used: pitfall traps to assess epigeal spiders moving on the soil surface, vacuum sampling to assess arthropods active in the vegetation, and interception traps to assess arthropods flying or moving from the margins to the crop (Figure S1).

Pitfall trapping was used at two dates in 2013 (27/06, 19/07) and 2014 (23/06, 23/07) when the vegetation was fully developed. Traps were placed within each field margin strip (north and south) and within the melon crop at two different positions (inter-rows 3 and 15) and left in place for one week of monitoring. The experimental design comprised two and three replicates per strip or position in 2013 and 2014, respectively. The data of 120 traps were analyzed.

Vacuum sampling was used at two dates in 2012 (21/06, 03/07), 2013 (20/06, 01/07) and 2014 (20/06, 10/07). At each date and for each modality, four samplings were made in the morning in the melon crop (inter-rows 6 and 12) and field margins (for flower and grass strips: two in

north strips and two in south strips; for bare soil: four in the spontaneous vegetation of the pathway between the north cypress hedge and the trial, to avoid sampling dusty dry soil). For each sample, the pipe of the vacuum device (441, Solo®) equipped with a collection bag was placed 5 x 1s within the canopy.

Interception trapping was used in 2014 (13/06-18/07) and 2015 (29/05-10/07). Lightweight tent traps (BT2003, Bugdorm, MegaView Science Co., Taiwan) made of black polyester fabric (96x26 mesh/square inch, mesh aperture: 680 µm) were used (Figure 1a). They are 60 cm wide, 60 cm long and 60 cm high, with a dome-shaped window (45 cm wide and 27 cm high) in one panel. Insects entering the trap tend to fly upwards until they fall into the collecting bottle (500 ml) half-filled with a 30% ethanol solution with 5 µl/l detergent (Teepol 610 S, ref 86350, Sigma-Aldrich) to kill and preserve the catch. Four tent traps were set up (two facing the bare soil and two facing the flower strips) for 5-6 weeks of monitoring. Collecting bottles were changed weekly.

Arthropods collected by the three trapping methods were stored in 70% ethanol until taxonomic identification under a stereomicroscope. Generalist predators (Aeolothripidae (Thysanoptera), Anthocoridae, Lygaeoidae, Miridae and Nabidae (Hemiptera), Carabidae and Staphylinidae (Coleoptera), Dermaptera, Arachnids (spiders)) and specialist predators (Coccinellidae (Coleoptera), Neuroptera, Syrphidae (Diptera)) were identified to the taxonomic level required to know their feeding behavior and counted.

2.3. Data analysis

2.3.1. Biotests under controlled conditions

No-choice settling tests were performed to evaluate the capacity of 18 candidate plant species to host two aphid species (*Aphis gossypii* and *Myzus persicae*). For each aphid species, a Chi-

square test was conducted to determine if the plant species affected the acceptance rate (proportion of aphids recovered 24h after deposition). When the null hypothesis of equality was rejected, the Marascuilo procedure for pairwise multiple comparisons was applied. The effect of the plant species on the reproductive rate (number of offspring per recovered aphid) was investigated through nonparametric Kruskal-Wallis tests. When the null hypothesis of equality was rejected, Dunn's pairwise multiple comparisons were performed using the Bonferroni correction.

Transmission tests were performed to evaluate the capacity of the candidate plant species to host four viruses (CABYV, CMV, WMV and ZYMV). For each virus, a Chi-square test was conducted to determine if the plant species affected the transmission rate. When the null hypothesis of equality was rejected, the Marascuilo procedure for pairwise multiple comparisons was applied.

All statistical analyses were performed using XLSTAT (version 2015.4.01, Addinsoft, Paris).

2.3.2. Field experiments

Depending on the trapping method used to monitor aphid predators and thus the main taxa caught, statistical analyses were conducted on different categories: spiders for pitfall traps; generalist predators and specialist predators for vacuum sampling and flight interception traps. For this latter trapping method, the abundance of specialist predators was further separated into Coccinellidae, Neuroptera and Syrphidae.

For pitfall trapping and vacuum sampling, we first tested the independence of catches between dates and years using a Spearman's correlation test (for each kind of field margin separately).

As no significant correlation was found, we considered each strip (north and south) and each sampling date as independent values and computed mean values accordingly. We then tested the effect of the management type (flower strip/grass strip and bare soil) and sampling zone

278 (margin/crop) on abundances using two-way ANOVA (no heteroscedasticity was detected)
279 followed by post hoc multiple comparisons (Tukey HSD). For interception trapping, the effect
280 of the management type (flower strip/bare soil) was investigated through a nonparametric
281 Wilcoxon signed-rank test performed between paired values (n=22). All computations were
282 carried out using R software.

3. Results

3.1. Plant screening under controlled conditions

3.1.1. Evaluation of the risk of aphid infestation

For *A. gossypii*, the mean percentage of aphids recovered after 24h (acceptance rate) ranged from 1 to 95% and the mean number of offspring per recovered aphid (reproductive rate) ranged from 0 to 18.4 (Table 1). The acceptance rates obtained for basil, bullwort and French marigold were not significantly different from that obtained for melon ($\chi^2 = 1729$, $df = 18$, $p\text{-value} < 0.0001$). The reproductive rates for borage, bullwort, lacy phacelia were not significantly different from that obtained for melon (Kruskal-Wallis test: $K = 293$, $df = 18$, $p\text{-value} < 0.0001$).

For *M. persicae*, the mean acceptance rate ranged from 0 to 97% and the mean reproductive rate ranged from 0 to 6.0 (Table 1). The acceptance rates obtained for borage, bullwort, corn marigold, dill, field marigold were not significantly different from that obtained for pepper ($\chi^2 = 1832$, $df = 19$, $p\text{-value} < 0.0001$). The reproductive rates for borage, corn marigold, dill, field marigold, lacy phacelia were not significantly different from that obtained for pepper ($K = 293$, $df = 19$, $p\text{-value} < 0.0001$). A plant species was considered as a suitable host for an aphid species when its acceptance rate and/or reproductive rate were not significantly different from the reference rates obtained on plant species used for aphid rearing (melon for *A. gossypii* and pepper for *M. persicae*). Thus, in the case of *A. gossypii*, five species were accepted as hosts: basil, borage, bullwort, French marigold and lacy phacelia (Table 1). *M. persicae* was able to use six species as hosts: borage, bullwort, corn marigold, dill, field marigold and lacy phacelia (Table 1). Considering the potential impact they could have on *A. gossypii* and/or *M. persicae* populations and subsequently on virus transmission, eight plant species were considered high

risk for melon crops: basil, borage, bullwort, corn marigold, dill, field marigold, French marigold and lacy phacelia.

3.1.2. Evaluation of the risk of virus infection

A plant species was considered a virus host when its transmission rate was not significantly different to the reference rate obtained on melon (Table 2). Dill was the only host for CABYV ($\chi^2 = 58$, df = 18, p-value < 0.0001). Eleven plant species were infected with CMV: basil, borage, buckwheat, corn marigold, cornflower, French marigold, lacy phacelia, marigold, nigella, sweet marjoram and white campion ($\chi^2 = 139$, df = 18, p-value < 0.0001). Six plant species were infected with both WMV isolates: buckwheat, bullwort, dill, field marigold, lacy phacelia and nigella (LL1A: $\chi^2 = 152$, df = 18, p-value < 0.0001; LL2B3: $\chi^2 = 153$, df = 18, p-value < 0.0001). Three plant species were infected with both ZYMV isolates: bullwort, dill and nigella (E9 and 124L11: $\chi^2 = 155$, df = 18, p-value < 0.0001). Taking into account the relative harmfulness of the four viruses, plant species capable of hosting WMV and/or ZYMV were considered a high risk for melon crops. These were buckwheat, bullwort, dill, field marigold, lacy phacelia and nigella.

3.1.3. Combining risks of aphid infestation and virus infection to select plant species

Ten plant species, which showed a high risk for both aphid infestation and virus infection according to biotests, were discarded from the selection: basil, borage, buckwheat, bullwort, corn marigold, dill, field marigold, French marigold, lacy phacelia and nigella. Three additional plant species previously reported to be aphid hosts (Table S1) were also discarded: marigold, ryegrass and white campion.

The remaining five species (cornflower, grass pea, sainfoin, salad burnet and sweet marjoram) were selected and combined in a seed mix with the expertise of a seed seller and tested *in situ*.

3.2. *In situ* evaluation of the flowering capacity of the seed mix

Over the course of our five-year experiment, cornflower, grass pea, sainfoin, salad burnet established first and constituted the higher vegetation strata; sweet marjoram generally appeared later, constituting the low stratum. At melon planting, nearly all strips had 100% plant cover. Flowering spanned the entire melon cropping period (Table 3). Grass pea was generally the only flowering plant species at melon planting. It started to flower around mid-May and was abundant until the end of June. The flowering of cornflower generally started shortly after melon planting and lasted until the end of July with a peak at mid-crop. Sainfoin and salad burnet flowered between mid-June and the end of July. Sweet majoram had a short flowering period centered around mid-July. Thus, the five-species mix allowed a flowering continuum likely to provide a food resource continuum conducive to the development of natural enemies.

3.3. *In situ* evaluation of aphid predator abundance in field margins and melon crop

3.3.1. Pitfall trapping

Both the management type and the sampling location (field margin vs crop) had a significant effect on spider abundance (p-value = 0.0018 and p-value = 0.0020, respectively). Within the field margins, the mean number ($\pm$ SEM) of spiders trapped per week was significantly higher in the flower strip (36.1 ± 2.7) than in bare soil (11.3 ± 2.3) which corresponds to an average increase of 219% (Figure 2). Spider abundance was intermediate in grass strip (22.6 ± 1.6)

(Figure 2). Within the melon crop, no difference was observed between the field margin management modalities. The mean numbers of spiders trapped per week ranged from 10.0 ± 1.0 to 15.7 ± 4.0 , i.e. similar to that assessed in bare soil (Figure 2).

3.3.2. Vacuum sampling

The abundance of generalist predators was significantly affected by both the management type (p-value = 0.026) and the sampling location (p-value < 0.001). There was also a significant management type*sampling location interaction (p-value = 0.037) indicating that the effect of management type changed according to sampling location. Within the field margins, the mean number of generalist predators trapped per suction was significantly higher in the flower strip (18.3 ± 5.4) than in bare soil (3.3 ± 0.6) which corresponds to an average increase of 455% (Figure 3a). The abundance of generalist predators was intermediate in grass strip (13.1 ± 4.1) (Figure 3a). Within the melon crop, in contrast, the effect of management type was not significant with abundances ranging from 3.2 ± 0.7 to 4.1 ± 0.8 individuals trapped per suction (Figure 3a).

The abundance of specialist predators was significantly affected by both the management type (p-value < 0.001) and the sampling location (p-value = 0.0045). There was also a significant management type*sampling location interaction (p-value = 0.035). Within the field margins, the mean number of specialist predators trapped per suction was significantly higher in the flower strip (5.8 ± 1.0) than in the grass strip (2.0 ± 1.1) or bare soil (0.6 ± 0.3) which corresponds to an average increase of 813% in flower strip compared to bare soil (Figure 3b). Within the melon crop, the effect of management type was not significant with abundances ranging from 0.5 ± 0.2 to 2.0 ± 0.8 individuals trapped per suction (Figure 3b). Specialist

predators collected by vacuum sampling were mostly coccinellids (91%), rarely lacewings (8%) and syrphids (1%) (data not shown).

3.3.3. Interception trapping

Tent traps facing flower strips intercepted significantly more aphid predators than those facing bare soil: +95% for generalist predators (Wilcoxon signed-rank test: $V = 191$, $p\text{-value} = 0.009$), +174% for specialist predators ($V = 166$, $p\text{-value} = 0.005$) (Figure 4). Specialist predators (coccinellids, lacewings, syrphids) represented 20-27% of total predators. The impact of the field margin management type varied depending on the taxa: the mean numbers of coccinellids and syrphids trapped per week were significantly enhanced near flower strips compared to bare soil ($V = 162$, $p\text{-value} = 0.034$ and $V = 133.5$, $p\text{-value} = 0.001$, respectively), whereas the effect on lacewings was not significant ($V = 42$, $p\text{-value} = 0.15$).

4. Discussion

In this study, we implemented a multi-step plant selection process to design flower strips adapted to melon crops. In a first step, we evaluated the capacity of 18 candidate plant species to host *A. gossypii* and/or *M. persicae*. Host plants could harbor and increase the populations of these aphid species, thus generating pest and vector reservoirs near the crop. Based on our results under controlled conditions, eight plant species were considered a high risk for aphid infestation for melon crops and ruled out: borage, bullwort, corn marigold, dill, field marigold, French marigold and lacy phacelia. These are new host descriptions for *A. gossypii* (bullwort, lacy phacelia) and *M. persicae* (borage) compared to previous reports (Blackman and Eastop, 2006; Kavallieratos et al., 2007). In a second step, we evaluated the capacity of the same 18

401 candidate plant species to host the most frequently observed viruses in melon crops in France:
 402 CABYV, CMV, WMV and ZYMV. Under controlled conditions, 15 plant species showed
 403 systemic infection by at least one virus. These are new host descriptions for CABYV (dill),
 404 CMV (nigella, sweet marjoram), WMV (buckwheat, dill, field marigold and nigella) and
 405 ZYMV (dill, nigella) compared to the literature (Desbiez and Lecoq, 1997; Edwardson and
 406 Christie 1991; Edwardson and Christie, 1997; Lecoq et al., 1992). For CMV, this extends the
 407 already tremendous host list reporting 1287 species in 518 genera of 100 families (Edwardson
 408 and Christie, 1997). Taking into account the relative harmfulness of the four viruses (Lecoq and
 409 Desbiez, 2012), plant species capable of hosting WMV and/or ZYMV were ruled-out as a
 410 priority: buckwheat, bullwort, dill, field marigold, lacy phacelia and nigella. Morales et al.
 411 (2006) adopted a similar precautionary principle to select insectary plants suitable for growing
 412 in tomato crops and discarded plant species likely to be a reservoir for Potato virus Y and CMV.
 413 In a third step, we combined biotest results and literature to take into account potential aphid
 414 and virus infection risks not revealed in our study.
 415 Like in a “guess who?” game, plant species presenting a risk regarding *A. gossypii* (melon pest
 416 and virus vector) and *M. persicae* (virus vector), and a risk regarding the most harmful viruses
 417 (WMV and ZYMV) were in turn removed from the candidate list. The remaining five species
 418 (cornflower, grass pea, sainfoin, salad burnet and sweet marjoram) were selected and combined
 419 in a seed mix to be further tested *in situ*. It is noteworthy that outsiders made it through the
 420 selection while plant species frequently cited in habitat management literature were ruled-out
 421 during the process. Such was the case for buckwheat and lacy phacelia which have been given
 422 much attention since the 1990s due to the large quantities of nectar and pollen they produce
 423 (Fiedler et al., 2008; Laubertie et al., 2012; Robinson et al., 2008; White et al., 1995). The same
 424 applies for bullwort and dill, plants of the Apiaceae family considered some of the best nectar
 425 sources. Indeed, due to their small open flowers accessible to short-tongued insects, they attract

a guild of beneficial insects, including syrphids, small parasitic wasps but also lacewings and coccinellids (Fiedler et al., 2008; Laubertie et al., 2012). These plant species, however, appeared clearly unsuitable for melon crops. In addition to being a host for *A. gossypii* and *M. persicae*, buckwheat and lacy phacelia combined risks to CMV and WMV, bullwort combined risks to CMV, WMV and ZYMV, and dill exhibited the maximal virus risk, as a suitable host for CABYV, CMV, WMV and ZYMV.

Under our pedoclimatic conditions, the five-species mix sown two months before melon planting was effective for establishing field margins with a dense heterogenous plant cover and a flowering continuum spanning the whole crop. As recently reviewed by Gontijo (2019), structurally complex habitats can improve predator survival by providing shelter with a suitable microclimate during summer (cooler temperature and higher humidity) and reduced intraguild predation (either by reducing the chances of direct encounters or by sheltering multiple alternative prey). In addition, the flowering continuum is likely to provide a food resource continuum (nectar, pollen) for natural enemies although the quality and quantity of each constitutive component might be different. In our case, cornflower appeared particularly interesting. First, its abundant flowering spanned the entire melon cropping period. Second, in addition to floral nectar and pollen, it has extrafloral nectaries (Weber et al., 2015) accessible to insects such as syrphids and lacewings (Gilbert, 1981; Limburg and Rosenheim, 2001). Moreover, it hosts a specific aphid *Uroleucon jaceae*, which is harmless to melon crops. Large colonies of this aphid developed during the vegetative growth of the cornflower and attracted numerous specialist predators such as coccinellids (Figure 1b). Such alternative preys and/or their honeydew allow predator populations to build up prior to melon planting thus enhancing the chances of success for biological regulation (Gontijo, 2019).

Three complementary trapping methods were used to monitor generalist and specialist predators: pitfall traps and vacuum sampling to assess the attractiveness of the different field

451 margins and the melon crop itself, and interception traps to assess the movement of predators
 452 from the margins to the crop. The abundance of spiders assessed by pitfall trapping was highly
 453 dependent on the vegetation type. There were respectively 1.6 and 3.2 times more spiders
 454 caught in grass and flower margins than in bare soil. Other authors previously observed that
 455 bare soil hosted fewer spiders than grassy zones in olive groves (Paredes et al., 2013) and
 456 vineyards (Costello and Daane, 1998) and that flower strip implementation resulted in even
 457 higher abundances than grass margins (Fernandez et al., 2008; Marko and Keresztes, 2014;
 458 Samu, 2003). Within the melon crop, on the contrary, the effect of field margin management
 459 was not significant. Spiders concentrated within the flower and grass strips and did not seem to
 460 spread much within the melon crop. These results are in agreement with those of Ditner et al.
 461 (2013) who observed that, despite high spider abundance in flower margins, their abundance
 462 was low in cabbage fields at two distances from the flower margins. This low dispersion of
 463 spiders from the field margins towards the crop may be due to both a low attractiveness of the
 464 crop or a high attractiveness of the field margins. The vegetative strata within the flower strips
 465 may be more suitable (shelter and microclimatic effects) and/or contain more potential prey
 466 (Gontijo, 2019). This high attractiveness of the field margins was also obvious for other
 467 generalist predators and specialist predators caught by vacuuming. Generalist predators
 468 (including spiders) and aphid specialist predators were respectively 5.5 and 9.1 times more
 469 abundant in flower margins than in bare soil. Canopy structure and composition, especially the
 470 presence of flowers, appear to be the main drivers of generalist and specialist predator
 471 populations as observed in other agro-ecological contexts (Gontijo et al., 2013; Mansion-
 472 Vaquié et al., 2017). For syrphids, flowers are complementary food resources which, in addition
 473 to aphid prey, are necessary to complete their life-cycle: larvae are aphidophagous but adults
 474 feed on pollen and nectar (Gilbert, 1981). Nectar sugars are fuel for flight and pollen proteins
 475 are necessary for egg maturation. For omnivorous coccinellids and lacewings, flowers are

476 substitutable resources since larvae and adults consume both plant material and prey. For
 477 instance, Robinson et al. (2008) observed that the presence of buckwheat flowers enhanced the
 478 longevity and fecundity of the lacewing *Micromus tasmaniae* when aphid prey was low. In our
 479 study, specialist predators collected by vacuum sampling were mostly coccinellids (91%),
 480 rarely lacewings (8%) and syrphids (1%). Lacewings are mainly nocturnal (Vas et al., 1999)
 481 whereas samplings were made in the morning explaining their low representativeness. Syrphids
 482 larvae also show nocturnal behavior and adults may have easily escaped vacuum sampling due
 483 to their fast flight. The effect of flower strips on lacewing and syrphid abundance is therefore
 484 better assessed through interception trapping. This third trapping method allowed us to assess
 485 arthropods moving from the margins to the crop. Fluxes of generalist and specialist predators
 486 moving from flower strips to the melon crop were significantly increased compared to bare soil.
 487 Manipulating floral resources was particularly beneficial for coccinellids and syrphids. Other
 488 studies reported enhanced abundances of these natural enemies in vegetables cultivated with
 489 flower strips. Ribeiro and Gontijo (2017) showed that intercropping alyssum (*Lobularia*
 490 *maritima* L.) with collards (*Brassica oleracea* L.) contributed to increase the abundance of
 491 generalist predators, including coccinellids and syrphids, which translated into a significant
 492 reduction in collard pests, especially aphids. Similarly, White et al. (1995) showed that sowing
 493 phacelia around the borders of cabbage crops significantly increased syrphid populations and
 494 decreased aphid populations. Using field cages, Hogg et al. (2011) showed that the presence of
 495 alyssum enhanced aphid suppression in lettuce through increased syrphid fecundity.
 496 Investigating the optimal spatial distribution of floral resources, Gillespie et al. (2011)
 497 confirmed that adult syrphids were active dispersers and that aphids were suppressed up to 50
 498 m away from the nearest alyssum strip.
 499 To conclude, our results confirmed that flower strips specifically designed for melon crops
 500 attracted significantly more aphid predators than grass margins and bare soil, in agreement with

501 numerous previous studies. Their potential value to promote biocontrol was therefore
502 established. However, the difficult question is whether these natural enemies did migrate in the
503 adjacent crop so that pest regulation can occur. Pitfall traps and vacuum samplings performed
504 within the melon crop both suggested that migration was limited. Results from interception
505 traps, however, indicated enhanced coccinellid and syrphid migration fluxes near flower strips
506 compared to bare soil, suggesting a possible dispersion further in the crop. Whether this
507 potential for regulation resulted in an effective impact on aphid infestation and virus epidemics
508 in melon crops remains unanswered. The fact remains that, like any other pest management
509 strategy, habitat management is not a silver bullet and should be combined with other methods
510 in an integrated pest management program. For melon crops, combining sown flower strips
511 with *Vat* gene resistance to *A. gossypii* and the viruses they carry (Boissot et al., 2016; Schoeny
512 et al., 2017) could be an innovative option worth investigating.

Acknowledgements

We thank Joël Béraud, Michel Pascal and the team IEPV for their involvement in field experiments, Patrick Gognalons, Karine Nozeran, Catherine Wipf-Scheibel, Grégory Girardot, Jonathan Gaudin and trainees for their efficient technical assistance. We thank Claude Girerd for valuable discussion about the seed mix, Philippe Nicot and two anonymous reviewers for constructive comments on this manuscript. We also thank Joël Chadoeuf for sound advices concerning statistical analyses. This study was funded by INRA (AAP2010 Gestion durable des résistances-ParcelR), Agence Nationale de la Recherche (ANR-2010-STRA-001-01 VirAphid) and Ministère de l'Agriculture, de l'Alimentation et de l'Environnement (CTPS 25-C-2011-09 and CASDAR 12-1278 Agath).

Declarations of interest: none

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Figure captions

Figure 1 Flower strip composed of five plant species (cornflower, grass pea, sainfoin, salad burnet and sweet marjoram) selected to boost biological control in melon crop (a) Interception trap used to assess the fluxes of aphid predators from the field margin to the crop (b) Adult coccinellid feeding in a colony of *Uroleucon jaceae* on cornflower. Photo credit: Alexandra Schoeny, INRA

Figure 2 Abundance of spiders assessed by pitfall trapping, within field margins and melon crop, for three types of field margin management, in a field experiment conducted in Avignon. Pitfalls were placed for one week of monitoring at two dates in 2013 and 2014. Data are means across replicates and dates. Bars show standard errors of the mean. Modalities with same letters are not significantly different according to the post hoc multiple comparison test performed (Tukey HSD, $\alpha = 0.05$).

Figure 3 Abundance of generalist predators (a) and aphid specialist predators (b) assessed by vacuum sampling, within field margins and melon crop, for three types of field margin management, in a field experiment conducted in Avignon. Samples were collected at two dates in 2012, 2013 and 2014. Data are means across replicates and dates. Bars show standard errors of the mean. Modalities with same letters are not significantly different according to the post hoc multiple comparison test performed (Tukey HSD, $\alpha = 0.05$).

688 **Figure 4** Fluxes of aphid predators migrating from the field margins to the melon crop assessed
689 by interception trapping, for two types of field margin management, in a field experiment
690 conducted in Avignon. Monitoring was carried out for five weeks in 2014 and six weeks in
691 2015. Data are means across replicates and weeks. Bars show standard errors of the mean.
692 Modalities with same letters are not significantly different according to the Wilcoxon signed-
693 rank test performed ($\alpha = 0.05$).

694 **Table captions**

695

696 **Table 1** Evaluation of the capacity of 20 plant species to host *Aphis gossypii* and *Myzus*
 697 *persicae*. The acceptance rate (percentage of aphids recovered after 24h) and the reproductive
 698 rate (number of offspring per recovered aphid) were assessed in no-choice settling tests
 699 conducted under controlled conditions.

700

701 **Table 2** Evaluation of the capacity of 19 plant species to host four viruses frequently observed
 702 on melon crops in France. The transmission rate (percentage of infected plants) was assessed
 703 through aphid transmission (CABYV) or mechanical inoculation (CMV, WMV, ZYMV) under
 704 controlled conditions.

705

706 **Table 3** Kinetics of flowering for five plant species composing flower strips evaluated in a field
 707 experiment conducted in Avignon between 2011 and 2015. For each plant species, the
 708 percentage of plants at flowering stage was monitored at different dates after melon planting.
 709 Plants were considered at flowering stage when displaying at least one open flower. Data are
 710 means $\pm$ SEM.

711 **Highlights**

712

- 713 • We selected five plant species minimizing aphid and virus risks in melon.
- 714 • We assessed the seed mix in a five-year field experiment.
- 715 • Sown flower strips displayed a flowering continuum conducive to natural enemies.
- 716 • Generalist and specialist predators were significantly enhanced in flower strips.

717 **Figure 1**

718

719 **Figure 2**

720

721

722 **Figure 3**

724 **Figure 4**

729 **Table 1**

Common name ^a	Nb tested plants	<i>Aphis gossypii</i>						Nb tested plants	<i>Myzus persicae</i>						
		% aphids recovered after 24h			Nb offspring per recovered aphid				% aphids recovered after 24h			Nb offspring per recovered aphid			
		Mean	SEM	Group ^b	Mean	SEM	Group ^b		Mean	SEM	Group ^b	Mean	SEM	Group ^b	
Basil	10	83	6	ab	0.0	0.0	c	10	19	4	def	0.0	0.0	d	
Borage	10	24	6	defgh	7.2	1.8	ab	10	95	3	a	4.1	0.3	ab	
Buckwheat	10	3	2	h	2.4	2.3	bc	10	0	0	f	0.0	0.0	d	
Bullwort	10	74	6	abc	1.5	0.3	abc	10	90	4	ab	1.1	0.4	bcd	
Corn marigold	10	4	2	h	2.6	1.3	bc	10	74	7	abc	2.6	0.3	abcd	
Cornflower *	30	67	7	bc	1.4	0.2	bc	30	71	6	bc	1.6	0.4	bcd	
Dill	10	12	2	fgh	0.1	0.1	c	10	77	8	abc	1.5	0.4	abcd	
Field marigold	10	57	7	bcd	0.8	0.2	bc	10	97	3	a	1.1	0.1	abcd	
French marigold	10	71	4	abc	0.0	0.0	c	10	31	3	de	0.2	0.1	bcd	
Grass pea *	20	10	3	gh	0.8	0.3	bc	20	28	5	de	1.0	0.3	bcd	
Lacy phacelia	10	57	7	bcd	18.4	1.3	a	10	48	11	cd	4.0	0.9	abc	
Marigold	10	21	5	efgh	0.4	0.3	bc	10	44	6	cd	0.1	0.1	cd	
Melon **	103	95	1	a	12.0	0.6	a	10	2	2	f	0.1	0.1	d	
Nigella	10	1	1	h	0.0	0.0	c	10	40	10	d	0.8	0.2	bcd	
Pepper **	nt	nt	nt	nt	nt	nt	nt	94	94	1	a	6.0	0.2	a	
Ryegrass	20	32	8	def	0.0	0.0	c	20	9	3	ef	0.0	0.0	d	
Sainfoin *	20	29	8	defg	0.0	0.0	c	20	7	4	f	0.0	0.0	d	
Salad burnet *	20	9	2	gh	0.2	0.1	c	20	5	2	f	0.1	0.1	d	
Sweet marjoram *	20	49	11	cde	0.0	0.0	c	20	32	7	d	0.1	0.1	d	
White campion	10	10	4	fgh	0.0	0.0	c	10	30	6	de	0.0	0.0	d	
Statistical test		Chi2			KW					Chi2			KW		
P-value		< 0,0001			< 0,0001					< 0,0001			< 0,0001		

- 730 nt= not tested
- 731 ^a Plant species with an asterisk are included in the flower mix
- 732 Plant species with two asterisks are reference species:
- 733 Melon is reference species for *Aphis gossypii* risk assessment
- 734 Pepper is reference species for *Myzus persicae* risk assessment
- 735 ^b Plants with the same letters are not significantly different
- 736 Grey zones highlight acceptance and reproductive rates not significantly different to the reference rates obtained on plant species used for aphid rearing
- 737 (melon for *A. gossypii* and pepper for *M. persicae*).

738 **Table 2**

739

Common name ^a	Virus (isolate)					
	CABYV (FIP)	CMV (14)	WMV (LL1A)	WMV (LL2B3)	ZYMV (E9)	ZYMV (124L11)
	Nb infected plants / nb tested plants ^b					
Basil	0/8 b	6/8 ab	0/8 b	0/8 b	0/8 b	0/8 b
Borage	0/8 b	7/8 a	0/8 b	0/8 b	0/8 b	0/8 b
Buckwheat	0/8 b	14/16 a	10/16 ab	11/16 a	0/8 b	0/8 b
Bullwort	0/8 b	0/8 b	8/8 a	8/8 a	8/8 a	8/8 a
Corn marigold	0/8 b	6/6 a	0/6 b	0/6 b	0/6 b	0/6 b
Cornflower *	0/8 b	13/16 a	0/8 b	0/8 b	0/8 b	0/8 b
Dill	3/8 a	0/8 b	8/8 a	8/8 a	8/8 a	8/8 a
Field marigold	0/8 b	8/8 a	8/8 a	8/8 a	0/8 b	0/8 b
French marigold	0/8 b	8/8 a	0/8 b	0/8 b	0/8 b	0/8 b
Grass pea *	0/8 b	0/8 b	0/8 b	0/8 b	0/8 b	0/8 b
Lacy phacelia	0/8 b	8/8 a	6/6 a	6/6 a	0/6 b	0/6 b
Marigold	0/8 b	8/8 a	0/8 b	0/8 b	0/8 b	0/8 b
Melon	36/100 a	27/28 a	27/28 a	27/28 a	20/20 a	20/20 a
Nigella	0/8 b	8/8 a	8/8 a	8/8 a	8/8 a	8/8 a
Ryegrass	0/8 b	0/8 b	0/8 b	0/8 b	0/8 b	0/8 b
Sainfoin *	0/8 b	0/6 b	0/6 b	0/6 b	0/6 b	0/6 b
Salad burnet *	0/8 b	0/8 b	0/8 b	0/8 b	0/8 b	0/8 b
Sweet marjoram *	0/8 b	7/8 a	0/7 b	0/7 b	0/7 b	0/7 b
White campion	0/8 b	5/6 a	0/6 b	0/6 b	0/6 b	0/6 b
Statistical test	Chi2	Chi2	Chi2	Chi2	Chi2	Chi2
P-value	< 0,0001	< 0,0001	< 0,0001	< 0,0001	< 0,0001	< 0,0001

740

741 ^a Plant species with an asterisk are included in the flower mix742 ^b Plants with the same letters are not significantly different

743 Grey zones highlight transmission rates not significantly different to the reference rates obtained on

744 melon.

745 **Table 3**

Common name	Scientific name	Days after melon planting					
		[1-10]	[11-20]	[21-30]	[31-40]	[41-50]	[51-60]
Cornflower	<i>Centaurea cyanus</i>	12±12	56±14	71±8	87±6	73±7	34±6
Grass pea	<i>Lathyrus sativus</i>	82±10	97±3	83±11	19±9	2±1	0±0
Sainfoin	<i>Onobrychis viciifolia</i>	1±1	21±7	43±6	45±9	50±14	42±3
Salad burnet	<i>Sanguisorba minor</i>	0±0	8±3	31±8	20±7	21±10	39±7
Sweet marjoram	<i>Origanum majorana</i>	0±0	0±0	0±0	2±2	28±19	2±2

746

Graphical abstract

Comment citer ce document :

Schoeny, A. (Auteur de correspondance), Lauvernay, A., Lambion, J., Mazzia, C., Capowiez, Y. (2019). The beauties and the bugs: A scenario for designing flower strips adapted to aphid management in melon crops. *Biological Control*, 136 (103986), 1-10. , DOI : 10.1016/j.biocontrol.2019.05.005

Figure S1 Schematic representation of the experimental design with spatial pattern of arthropod samplings in field margins and melon crop in 2014

Table S1 Biotests conducted in controlled conditions to evaluate the capacity of 20 plant species to host two aphid species and four viruses frequently observed on melon crops in France

Common name ^a	Scientific name	Botanical family	Nb of weeks after sowing	Aphid risks ^c		Virus risks ^d		Global risks ^e
				Biotests	Literature	Biotests	Literature	
Basil	<i>Ocimum basilicum</i> L.	Lamiaceae	6-7	Ag	Ag, Mp	C	C, W	Ag, Mp, C, W
Borage	<i>Borago officinalis</i> L.	Boraginaceae	4	Ag, Mp	Ag	C	C	Ag, <u>Mp</u> , C
Buckwheat	<i>Fagopyrum esculentum</i> Moench	Polygonaceae	4	Ø	Ag, Mp	C, W	C	Ag, Mp, C, <u>W</u>
Bullwort	<i>Ammi majus</i> L.	Apiaceae	5	Ag, Mp	Mp	W, Z	C, W, Z	<u>Ag</u> , Mp, C, W, Z
Corn marigold	<i>Chrysanthemum segetum</i> L.	Asteraceae	5	Mp	Mp	C	C	Mp, C
Cornflower *	<i>Centaurea cyanus</i> L.	Asteraceae	4-5	Ø	Ø	C	C	C
Dill	<i>Anethum graveolens</i> L.	Apiaceae	5-6	Mp	Ag, Mp	CA, W, Z	C	Ag, Mp, <u>CA</u> , C, <u>W</u> , <u>Z</u>
Field marigold	<i>Calendula arvensis</i> L.	Asteraceae	3-5	Mp	Ag, Mp	C, W	C	Ag, Mp, C, <u>W</u>
French marigold	<i>Tagetes patula</i> L.	Asteraceae	6	Ag	Ag, Mp	C	C	Ag, Mp, C
Grass pea *	<i>Lathyrus sativus</i> L.	Leguminosae	4	Ø	Ø	Ø	C	C
Lacy phacelia	<i>Phacelia tanacetifolia</i> Benth.	Hydrophyllaceae	4	Ag, Mp	Mp	C, W	C, W	<u>Ag</u> , Mp, C, W
Marigold	<i>Calendula officinalis</i> L.	Asteraceae	5	Ø	Ag, Mp	C	C	Ag, Mp, C
Melon **	<i>Cucumis melo</i> L.	Cucurbitaceae	3-5	Ag	Ag, Mp	CA, C, W, Z	CA, C, W, Z	Ag, Mp, CA, C, W, Z
Nigella	<i>Nigella damascena</i> L.	Ranunculaceae	5	Ø	ni	C, W, Z	ni	<u>C</u> , <u>W</u> , <u>Z</u>
Pepper **	<i>Capsicum annuum</i> L.	Solanaceae	5-8	na	na	na	na	na
Ryegrass	<i>Lolium perenne</i> L.	Poaceae	7-8	Ø	Mp	Ø	ni	Mp
Sainfoin *	<i>Onobrychis viciifolia</i> Scop.	Leguminosae	5-7	Ø	Ø	Ø	ni	Ø
Salad burnet *	<i>Sanguisorba minor</i> Scop.	Rosaceae	5-6	Ø	Ø	Ø	ni	Ø
Sweet marjoram *	<i>Origanum majorana</i> L.	Lamiaceae	6-8	Ø	Ø	C	ni	<u>C</u>
White campion	<i>Silene latifolia</i> Poir.	Caryophyllaceae	6	Ø	Mp	C	C	Mp, C

na= not applicable

ni= no information available

^a Plant species with an asterisk are included in the flower mix

Plant species with two asterisks are reference species:

Melon is reference species for *Aphis gossypii* and virus risk assessment

Pepper is reference species for *Myzus persicae* risk assessment

^b Plants with the same letters are not significantly different

^c Aphid risks according to Blackman and Eastop 2006, Kavallieratos et al., 2007

Ag (*Aphis gossypii*)

Mp (*Myzus persicae*)

^d Virus risks according to:

CA (CABYV): Lecoq et al., 1992

C (CMV): Edwardson and Christie, 1997

W (WMV): Edwardson and Christie, 1991

Z (ZYMV): Desbiez and Lecoq, 1997

^e Underlined risks correspond to new descriptions compared to literature

Ø= risk considered as negligible according biotests and/or literature