



**HAL**  
open science

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

Alexandra Schoeny, Antoine Lauvernay, Jérôme Lambion, Christophe Mazzia, Yvan Capowiez

### ► To cite this version:

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-02619746v1>

Submitted on 25 May 2020

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial - NoDerivatives 4.0 International License

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

3

4 Alexandra Schoeny<sup>1\*</sup>, Antoine Lauvernay<sup>1</sup>, Jérôme Lambion<sup>2</sup>, Christophe Mazzia<sup>3</sup> and Yvan  
5 Capowiez<sup>4</sup>

6

7 <sup>1</sup>Pathologie Végétale, INRA, 84140, Montfavet, France

8 <sup>2</sup>Groupe de Recherche en Agriculture Biologique, 84911, Avignon, France

9 <sup>3</sup>Université d'Avignon, Aix-Marseille Université, CNRS, IRD, IMBE, 84916 Avignon, France

10 <sup>4</sup>EMMAH, INRA, UAPV, 84914, Avignon, France

11

12 \*Corresponding author: alexandra.schoeny@inra.fr

13

14

15 **Keywords**

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

## 18 **Abstract**

19

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

## 41 **1. Introduction**

42

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

## 104 2. Materials and methods

105

### 106 2.1. Plant screening under controlled conditions

107

#### 108 2.1.1. Plant species shortlist and plant rearing

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

111 Virus-free plants were grown in an insect-proof greenhouse without pesticides. Seedlings were  
112 prepared in flats containing a peat/coco coir substrate (080 Klasmann-Deilmann France,  
113 Bourgoin Jallieu, France) and irrigated daily with bore water. Plantlets were transplanted  
114 individually to plastic pots (9 cm wide × 8 cm high) containing a peat/clay substrate (404  
115 Klasmann-Deilmann France) and irrigated daily with bore water, the pH of which was adjusted  
116 to 5.8. Plants were used at the vegetative stage (3-8 week old depending on plant species, Table  
117 S1). During biotests, plants were irrigated daily with a nutrient solution (Soluveg Essentiel 16-  
118 5-25, Angibaud & Spécialités, La Rochelle, France).

119

#### 120 2.1.2. Aphid rearing

121 Aphids were reared on virus-free plants in growth cabinets equipped with LED tube lights  
122 (4000K) under a photoperiod of 16:8 (L:D) h. *Aphis gossypii* (clone NM1, Thomas et al., 2012)  
123 was reared on 3-5 week old melon plants (cv. Védreantais) at 24/21±1°C day/night. *Myzus*  
124 *persicae* (clone Patho) was reared on 5-8 week old pepper plants (cv. Yolo Wonder) at 21±1°C  
125 day/night. Four weeks before experiments, mass rearing was shifted to synchronous rearing in  
126 order to manipulate 7 day-old apterous female cohorts.

127

### 128 2.1.3. Plant-aphid interaction biotests

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

140

### 141 2.1.4. Plant-virus interaction biotests

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

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

7



153 IAP, aphids were killed by spraying the plants with two systemic insecticides (0.5 ml/l NUPRID  
154 200, Nufarm SAS) at 24h intervals. Plants were then placed in a dedicated greenhouse for 4-5  
155 weeks of incubation.

156 The non-persistently aphid-transmitted CMV, WMV and ZYMV were tested through  
157 mechanical inoculation. Virus sources were infected zucchini plants (*Cucurbita pepo* L. cv.  
158 Diamant). Inoculum was prepared by grinding 2 g of young leaf tissue with a mortar and pestle  
159 in 8 ml of a solution containing 0.03M Na<sub>2</sub>HPO<sub>4</sub> with 0.2% DIECA. Carborundum (75 mg/ml)  
160 and activated charcoal (75 mg/ml) were added before rub-inoculation of test plants. Plants were  
161 rinsed with tap water and placed in a dedicated greenhouse for 3-5 weeks of incubation. Viruses  
162 were detected using a double antibody sandwich enzyme-linked immunosorbent assay (DAS-  
163 ELISA) with specific polyclonal antisera produced in our laboratory. Plants were considered  
164 infected when the absorbance at 405 nm (Multiskan EX, Thermo Electron Corporation) was  
165 three times above the mean value of the healthy controls (Schoeny et al., 2017). The  
166 transmission rate was calculated as the number of infected plants to the total number of tested  
167 plants.

168

## 169 2.2. *In situ* evaluation of field margins

170

### 171 2.2.1. Experimental design

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

8

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.

203

#### 204 2.2.2. Plant development monitoring

205 The development of sown strips was monitored 2-3 times before melon planting with the  
206 quadrat technique. A 1-m<sup>2</sup> wooden frame was randomly placed in the north and south strips and  
207 the percentage of plant cover was visually estimated.

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

213

#### 214 2.2.3. Arthropod monitoring

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

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

225 Vacuum sampling was used at two dates in 2012 (21/06, 03/07), 2013 (20/06, 01/07) and 2014  
226 (20/06, 10/07). At each date and for each modality, four samplings were made in the morning  
227 in the melon crop (inter-rows 6 and 12) and field margins (for flower and grass strips: two in

10

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

232 Interception trapping was used in 2014 (13/06-18/07) and 2015 (29/05-10/07). Lightweight tent  
233 traps (BT2003, Bugdorm, MegaView Science Co., Taiwan) made of black polyester fabric  
234 (96x26 mesh/square inch, mesh aperture: 680 µm) were used (Figure 1a). They are 60 cm wide,  
235 60 cm long and 60 cm high, with a dome-shaped window (45 cm wide and 27 cm high) in one  
236 panel. Insects entering the trap tend to fly upwards until they fall into the collecting bottle (500  
237 ml) half-filled with a 30% ethanol solution with 5 µl/l detergent (Teepol 610 S, ref 86350,  
238 Sigma-Aldrich) to kill and preserve the catch. Four tent traps were set up (two facing the bare  
239 soil and two facing the flower strips) for 5-6 weeks of monitoring. Collecting bottles were  
240 changed weekly.

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

247

### 248 2.3. Data analysis

249

#### 250 2.3.1. Biotests under controlled conditions

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

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

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

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

266

### 267 2.3.2. Field experiments

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

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

275 As no significant correlation was found, we considered each strip (north and south) and each  
276 sampling date as independent values and computed mean values accordingly. We then tested  
277 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.

## 283 3. Results

284

### 285 3.1. Plant screening under controlled conditions

286

#### 287 3.1.1. Evaluation of the risk of aphid infestation

288 For *A. gossypii*, the mean percentage of aphids recovered after 24h (acceptance rate) ranged  
289 from 1 to 95% and the mean number of offspring per recovered aphid (reproductive rate) ranged  
290 from 0 to 18.4 (Table 1). The acceptance rates obtained for basil, bullwort and French marigold  
291 were not significantly different from that obtained for melon ( $\chi^2 = 1729$ ,  $df = 18$ ,  $p\text{-value} <$   
292  $0.0001$ ). The reproductive rates for borage, bullwort, lacy phacelia were not significantly  
293 different from that obtained for melon (Kruskal-Wallis test:  $K = 293$ ,  $df = 18$ ,  $p\text{-value} < 0.0001$ ).

294 For *M. persicae*, the mean acceptance rate ranged from 0 to 97% and the mean reproductive  
295 rate ranged from 0 to 6.0 (Table 1). The acceptance rates obtained for borage, bullwort, corn  
296 marigold, dill, field marigold were not significantly different from that obtained for pepper ( $\chi^2$   
297  $= 1832$ ,  $df = 19$ ,  $p\text{-value} < 0.0001$ ). The reproductive rates for borage, corn marigold, dill, field  
298 marigold, lacy phacelia were not significantly different from that obtained for pepper ( $K = 293$ ,  
299  $df = 19$ ,  $p\text{-value} < 0.0001$ ). A plant species was considered as a suitable host for an aphid species  
300 when its acceptance rate and/or reproductive rate were not significantly different from the  
301 reference rates obtained on plant species used for aphid rearing (melon for *A. gossypii* and  
302 pepper for *M. persicae*). Thus, in the case of *A. gossypii*, five species were accepted as hosts:  
303 basil, borage, bullwort, French marigold and lacy phacelia (Table 1). *M. persicae* was able to  
304 use six species as hosts: borage, bullwort, corn marigold, dill, field marigold and lacy phacelia  
305 (Table 1). Considering the potential impact they could have on *A. gossypii* and/or *M. persicae*  
306 populations and subsequently on virus transmission, eight plant species were considered high

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

309

### 310 3.1.2. Evaluation of the risk of virus infection

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

323

### 324 3.1.3. Combining risks of aphid infestation and virus infection to select plant species

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



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

332

333 3.2. *In situ* evaluation of the flowering capacity of the seed mix

334

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

345

346 3.3. *In situ* evaluation of aphid predator abundance in field margins and melon crop

347

348 3.3.1. Pitfall trapping

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

354 (Figure 2). Within the melon crop, no difference was observed between the field margin  
355 management modalities. The mean numbers of spiders trapped per week ranged from  $10.0 \pm$   
356  $1.0$  to  $15.7 \pm 4.0$ , i.e. similar to that assessed in bare soil (Figure 2).

357

### 358 3.3.2. Vacuum sampling

359 The abundance of generalist predators was significantly affected by both the management type  
360 (p-value = 0.026) and the sampling location (p-value < 0.001). There was also a significant  
361 management type\*sampling location interaction (p-value = 0.037) indicating that the effect of  
362 management type changed according to sampling location. Within the field margins, the mean  
363 number of generalist predators trapped per suction was significantly higher in the flower strip  
364 ( $18.3 \pm 5.4$ ) than in bare soil ( $3.3 \pm 0.6$ ) which corresponds to an average increase of 455%  
365 (Figure 3a). The abundance of generalist predators was intermediate in grass strip ( $13.1 \pm 4.1$ )  
366 (Figure 3a). Within the melon crop, in contrast, the effect of management type was not  
367 significant with abundances ranging from  $3.2 \pm 0.7$  to  $4.1 \pm 0.8$  individuals trapped per suction  
368 (Figure 3a).

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

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

379

### 380 3.3.3. Interception trapping

381 Tent traps facing flower strips intercepted significantly more aphid predators than those facing  
382 bare soil: +95% for generalist predators (Wilcoxon signed-rank test:  $V = 191$ ,  $p\text{-value} = 0.009$ ),  
383 +174% for specialist predators ( $V = 166$ ,  $p\text{-value} = 0.005$ ) (Figure 4). Specialist predators  
384 (coccinellids, lacewings, syrphids) represented 20-27% of total predators. The impact of the  
385 field margin management type varied depending on the taxa: the mean numbers of coccinellids  
386 and syrphids trapped per week were significantly enhanced near flower strips compared to bare  
387 soil ( $V = 162$ ,  $p\text{-value} = 0.034$  and  $V = 133.5$ ,  $p\text{-value} = 0.001$ , respectively), whereas the effect  
388 on lacewings was not significant ( $V = 42$ ,  $p\text{-value} = 0.15$ ).

389

## 390 4. Discussion

391

392 In this study, we implemented a multi-step plant selection process to design flower strips  
393 adapted to melon crops. In a first step, we evaluated the capacity of 18 candidate plant species  
394 to host *A. gossypii* and/or *M. persicae*. Host plants could harbor and increase the populations of  
395 these aphid species, thus generating pest and vector reservoirs near the crop. Based on our  
396 results under controlled conditions, eight plant species were considered a high risk for aphid  
397 infestation for melon crops and ruled out: borage, bullwort, corn marigold, dill, field marigold,  
398 French marigold and lacy phacelia. These are new host descriptions for *A. gossypii* (bullwort,  
399 lacy phacelia) and *M. persicae* (borage) compared to previous reports (Blackman and Eastop,  
400 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

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

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

449 Three complementary trapping methods were used to monitor generalist and specialist  
450 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.



513 **Acknowledgements**

514

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

524

525 Declarations of interest: none

526 **References**

527

528 Bass, C., Denholm, I., Williamson, M.S., Nauen, R., 2015. The global status of insect resistance  
529 to neonicotinoid insecticides. *Pesticide Biochemistry and Physiology* 121, 78-87.

530

531 Blackman, R.L., Eastop, V.F., 2000. Aphids on the world's crops. An identification and  
532 information guide. Second edition. John Wiley and Sons Ltd, Chichester, England, 466 pp.

533

534 Blackman, R.L., Eastop, V.F., 2006. Aphids on the world's herbaceous plants and shrubs.  
535 Volume 1: host lists and keys. John Wiley and Sons Ltd, Chichester, England, 1024 pp.

536

537 Boissot, N., Schoeny, A., Vanlerberghe-Masutti, F., 2016. Vat, an amazing gene conferring  
538 resistance to aphids and viruses they carry: from molecular structure to field effects. *Frontiers*  
539 *in Plant Science* 7, 18.

540

541 Costello, M.J., Daane, K.M., 1998. Influence of ground cover on spider populations in a table  
542 grape vineyard. *Ecological Entomology* 23, 33-41.

543

544 Desbiez, C., Lecoq, H., 1997. Zucchini yellow mosaic virus. *Plant Pathology* 46, 809-829.

545

546 Ditner, N., Balmer, O., Beck, J., Blick, T., Nagel, P., Luka, H., 2013. Effects of experimentally  
547 planting non-crop flowers into cabbage fields on the abundance and diversity of predators.  
548 *Biodiversity and Conservation* 4, 1049-1061.

549

- 550 Edwardson, J.R., Christie, R.G., 1991. Watermelon mosaic virus-II. In: The Potyvirus group.  
551 Volume III. University of Florida Monograph 16-III, pp1015-1034.  
552
- 553 Edwardson, J.R., Christie, R.G., 1997. Cucumber mosaic Virus In: Viruses infecting peppers  
554 and other solanaceous crops. Volume I. University of Florida Monograph 18-1, pp133-159.  
555
- 556 Fernandez D.E., Cichon, L.I., Sanchez, E.E., Garrido, S.A., Gittins C., 2008. Effect of different  
557 cover crops on the presence of arthropods in an organic apple (*Malus domestica* Borkh) orchard.  
558 Journal of Sustainable Agriculture 2, 197-211.  
559
- 560 Fiedler, A.K., Landis, D.A., Wratten, S.D., 2008. Maximizing ecosystem services from  
561 conservation biological control: the role of habitat management. Biological Control 45, 254-  
562 271.  
563
- 564 Gilbert, F.S., 1981. Foraging ecology of hoverflies: morphology of the mouthparts in relation  
565 to feeding on nectar and pollen in some common urban species. Ecological Entomology 6, 245-  
566 262.  
567
- 568 Gillespie, M., Wratten, S., Sedcole, R., Colfer, R., 2011. Manipulating floral resources  
569 dispersion for hoverflies (Diptera: Syrphidae) in a California lettuce agro-ecosystem. Biological  
570 Control 59, 215-220.  
571
- 572 Gontijo, L.M., 2019. Engineering natural enemy shelters to enhance conservation biological  
573 control in field crops. Biological Control 130, 155-163.  
574

- 575 Gontijo, L.M., Beers, E.H., Snyder, W.E., 2013. Flowers promote aphid suppression in apple  
576 orchards. *Biological Control* 66, 8-15.  
577
- 578 Gurr, G.M., Wratten, S.D., Altieri, M.A., 2004. Ecological engineering for pest management.  
579 *Advances in habitat manipulation for arthropods*, 244 pp. CSIRO Publishing, Collingwood,  
580 Australia.  
581
- 582 Gurr, G.M., Wratten, S.D., Landis, D.A., You, M.S., 2017. Habitat management to suppress  
583 pest populations: progress and prospects. *Annual Review of Entomology* 62, 91-109.  
584
- 585 Hogg, B.N., Nelson, E.H., Mills, N.J., Daane, K.M., 2011. Floral resources enhance aphid  
586 suppression by a hoverfly. *Entomologia Experimentalis et Applicata* 141, 138-144.  
587
- 588 Kavallieratos, N.G., Tomanovic, Z., Sarlis, G.P., Vayias, B.J., Zikic, V. and Emmanouel, N.E.,  
589 2007. Aphids (Hemiptera: Aphidoidea) on cultivated and self-sown plants in Greece. *Biologia*  
590 62, 335-344.  
591
- 592 Landis, D.A., Wratten, S.D., Gurr, G.M., 2000. Habitat management to conserve natural  
593 enemies of arthropod pests in agriculture. *Annual Review of Entomology* 45, 175-201.  
594
- 595 Laubertie, E.A., Wratten, S.D., Hemptinne, J.L., 2012. The contribution of potential beneficial  
596 insectary plant species to adult hoverfly (Diptera: Syrphidae) fitness. *Biological Control* 61, 1-  
597 6.  
598

- 599 Lecoq, H., Bourdin, D., Wipf-Scheibel, C., Bon, M., Lot, H., Lemaire, O., Herrbach, E., 1992.  
600 A new yellowing disease of cucurbits caused by a luteovirus, cucurbit aphid-borne yellows  
601 virus. *Plant Pathology* 41, 749-761.  
602
- 603 Lecoq, H., Desbiez, C., 2012. Viruses of cucurbit crops in the Mediterranean region: an ever-  
604 changing picture. *Advances in Virus Research* 84, 67-126.  
605
- 606 Limburg, D.D., Rosenheim, J.A., 2001. Extrafloral nectar consumption and its influence on the  
607 survival and development of an omnivorous predator, larval *Chrysoperla plorabunda*  
608 (Neuroptera: Chrysopidae). *Environmental Entomology* 30, 595-604.  
609
- 610 Losey, J.E., Vaughan, M., 2006. The economic value of ecological services provided by insects.  
611 *BioScience* 56, 311-323.  
612
- 613 Mansion-Vaquié, A., Ferrante, M., Cook, S.M., Pell, J.K., Lövei, G.L., 2017. Manipulating  
614 field margins to increase predation intensity in fields of winter wheat (*Triticum aestivum*).  
615 *Journal of Applied Entomology* 141, 600-611.  
616
- 617 Marko V., Keresztes B., 2014. Flowers for better pest control? Ground cover plants enhance  
618 apple orchard spiders (Araneae), but not necessarily their impact on pests. *Biocontrol Science*  
619 *and Technology* 24, 574-596.  
620
- 621 Morales, I., Sanchez, J.A., Alomar, O., Lacasa, A., Ferreres, A., 2006. Susceptibility to virus  
622 infection of candidate plants used to enhance predatory dicyphine (Heteroptera: Miridae).  
623 *IOBC-WPRS Bulletin* 29, 255-260.

624

625 Paredes, D., Cayuela, L., Campos M., 2013. Synergistic effects of ground cover and adjacent  
626 vegetation on natural enemies of olive insect pests. *Agriculture, Ecosystems & Environment*  
627 173, 72-80.

628

629 Perring, T.M., Gruenhagen, N.M., Farrar, C.A., 1999. Management of plant viral diseases  
630 through chemical control of insect vectors. *Annual Review of Entomology* 44, 457-481.

631

632 Ribeiro, A.L., Gontijo, L.M., 2017. Alyssum flowers promote biological control of collard  
633 pests. *BioControl* 62, 185-196.

634

635 Robinson, K.A., Jonsson, M., Wratten, S.D., Wade, M.R., Buckley, H.L., 2008. Implications  
636 of floral resources for predation by an omnivorous lacewing. *Basic and Applied Ecology* 9,  
637 172-181.

638

639 Samu, F., 2003. Can field-scale habitat diversification enhance biocontrol potential of spiders?  
640 *Pest Management Science* 59, 437-442.

641

642 Schoeny, A., Desbiez, C., Millot, P., Wipf-Scheibel, C., Nozeran, K., Gognalons, P., Lecoq,  
643 H., Boissot, N., 2017. Impact of Vat resistance in melon on viral epidemics and genetic structure  
644 of virus populations. *Virus Research* 241, 105-115.

645

646 Tscharncke, T., Karp, D.S., Chaplin-Kramer, R., Batary, P., DeClerck, F., Gratton, C., Hunt, L.,  
647 Ives, A., Jonsson, M., Larsen, A., Martin, E.A., Martinez-Salinas, A., Meehan, T.D., O'Rourke,  
648 M., Poveda, K., Rosenheim, J.A., Rusch, A., Schellhorn, N., Wanger, T.C., Wratten, S., Zhang,

29

649 W., 2016. When natural habitat fails to enhance biological pest control - Five hypotheses.  
650 Biological Conservation 204, 449-458.

651

652 Thomas, S., Dogimont, C., Boissot, N., 2012. Association between *Aphis gossypii* genotype  
653 and phenotype on melon accessions. Arthropod-Plant Interactions 6, 93-101.

654

655 Vas, J., Abraham, L., Markó, V., 1999. Study of nocturnal and diurnal activities of lacewings  
656 (Neuropteroidea: Raphidioptera, Neuroptera) by suction trap. Acta Phytopathologica et  
657 Entomologica Hungarica 34, 149-152.

658

659 Weber, M.G., Porturas, L.D., Keeler, K.H., 2015. World list of plants with extrafloral nectaries.  
660 <http://www.extrafloralnectaries.org/> (accessed 29 January 2018).

661

662 White, A.J., Berry, N.A., Wratten, S.D., Weigmann, U., 1995. Habitat manipulation to enhance  
663 biological control of brassica pests by hover flies (Diptera: Syrphidae). Journal of Economic  
664 Entomology 88, 1171-1176.

665 **Figure captions**

666

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

672

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

679

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

686

687



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**

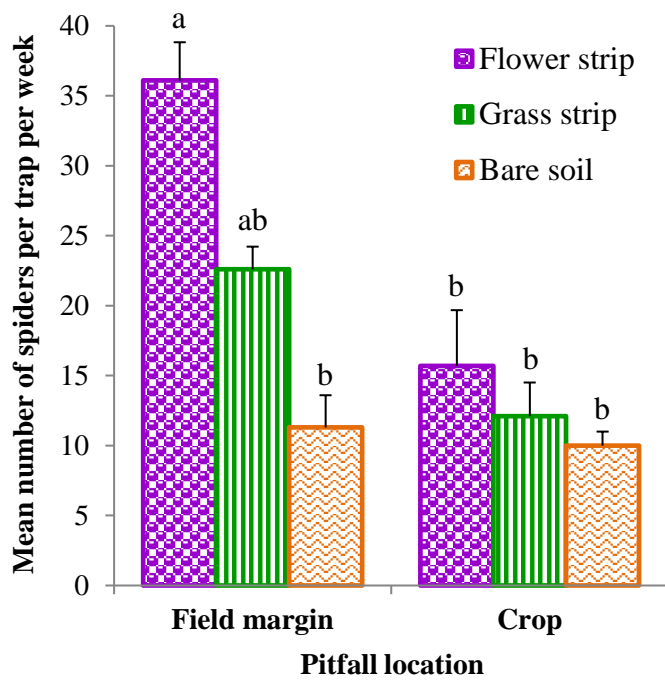
718



719 **Figure 2**

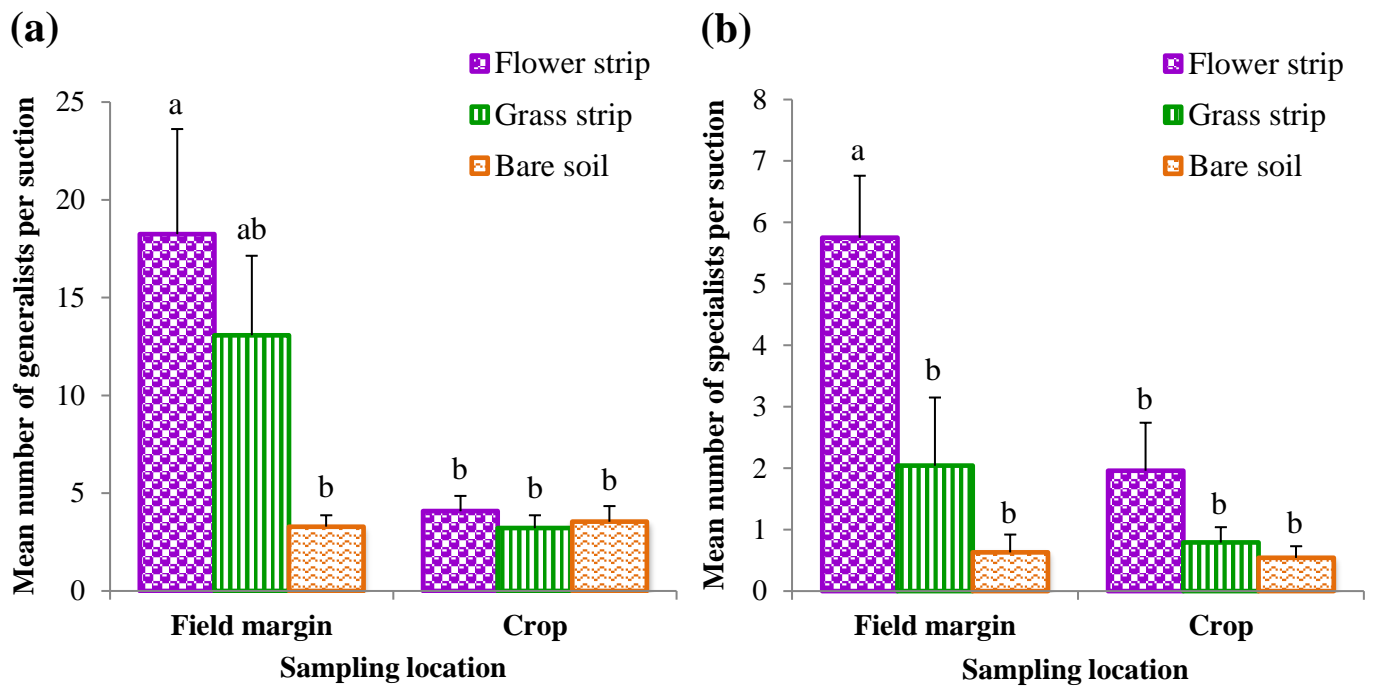
720

721



722 **Figure 3**

723



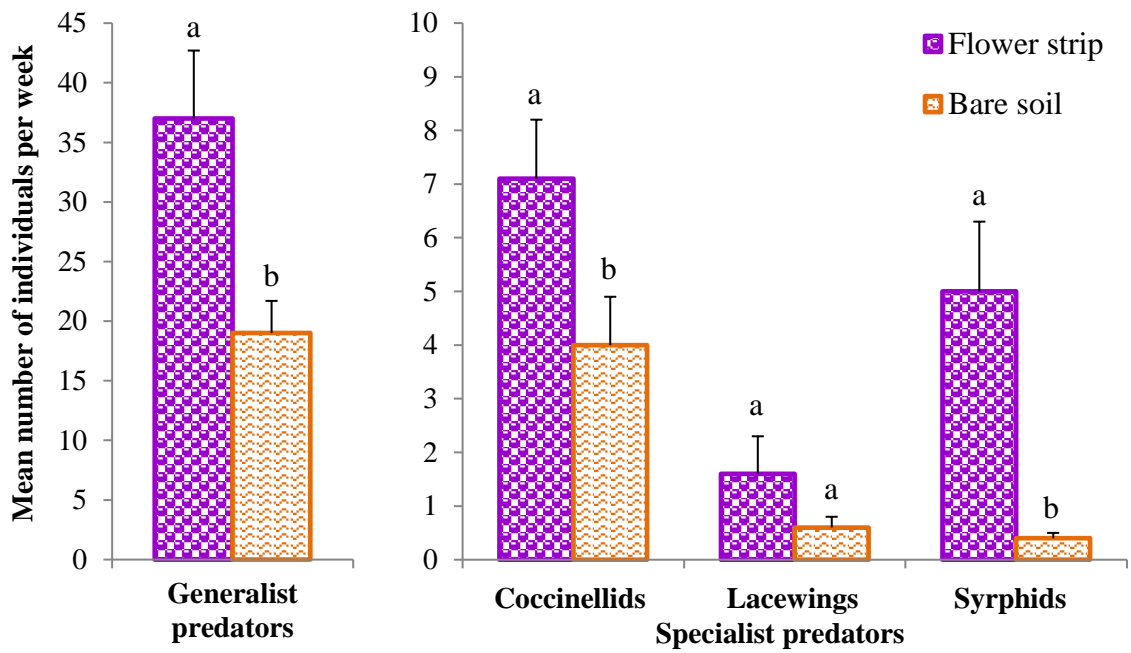
724 **Figure 4**

725

726

727

728



Common name <sup>a</sup>	<i>Aphis gossypii</i>							<i>Myzus persicae</i>						
	Nb tested plants	% aphids recovered after 24h			Nb offspring per recovered aphid			Nb tested plants	% aphids recovered after 24h			Nb offspring per recovered aphid		
		Mean	SEM	Group <sup>b</sup>	Mean	SEM	Group <sup>b</sup>		Mean	SEM	Group <sup>b</sup>	Mean	SEM	Group <sup>b</sup>
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
<b>Statistical test</b>				Chi2			KW				Chi2			KW
<b>P-value</b>				< 0,0001			< 0,0001				< 0,0001			< 0,0001

Comment citer ce document :



- 730 nt= not tested
- 731 <sup>a</sup> 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 <sup>b</sup> 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 <sup>a</sup>	Virus (isolate)					
	CABYV (FIP)	CMV (14)	WMV (LL1A)	WMV (LL2B3)	ZYMV (E9)	ZYMV (124L11)
	Nb infected plants / nb tested plants <sup>b</sup>					
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
<b>Statistical test</b>	Chi2	Chi2	Chi2	Chi2	Chi2	Chi2
<b>P-value</b>	< 0,0001	< 0,0001	< 0,0001	< 0,0001	< 0,0001	< 0,0001

740

741 <sup>a</sup> Plant species with an asterisk are included in the flower mix

742 <sup>b</sup> 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

747 **Graphical abstract**

748

749

750

751

752

753

754

755

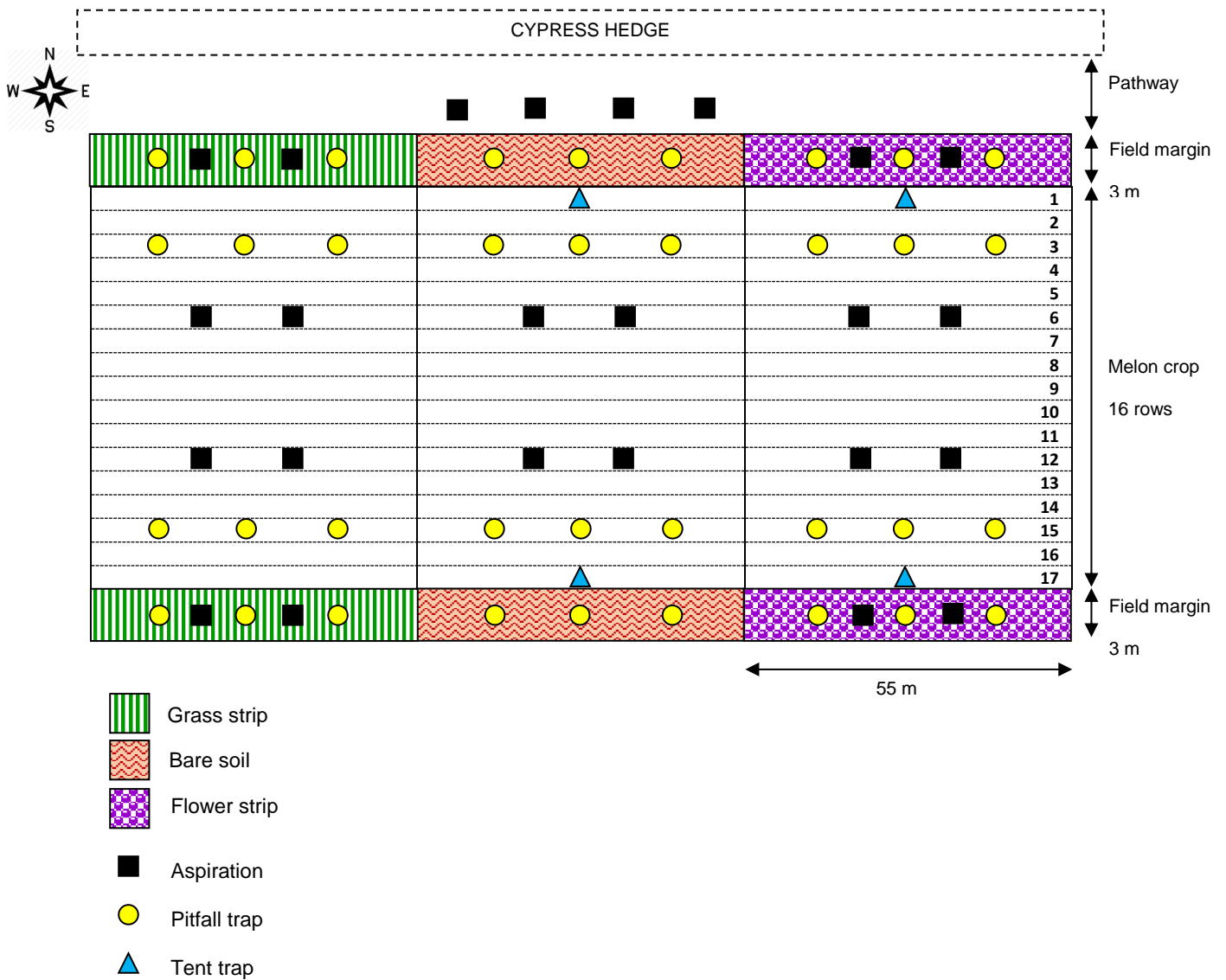
756

757



758

**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 <sup>a</sup>	Scientific name	Botanical family	Nb of weeks after sowing	Aphid risks <sup>c</sup>		Virus risks <sup>d</sup>		Global risks <sup>e</sup>
				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	∅	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	∅	∅	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	∅	∅	∅	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	∅	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	∅	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	∅	Mp	∅	ni	Mp
Sainfoin *	<i>Onobrychis viciifolia</i> Scop.	Leguminosae	5-7	∅	∅	∅	ni	∅
Salad burnet *	<i>Sanguisorba minor</i> Scop.	Rosaceae	5-6	∅	∅	∅	ni	∅
Sweet marjoram *	<i>Origanum majorana</i> L.	Lamiaceae	6-8	∅	∅	C	ni	<u>C</u>
White campion	<i>Silene latifolia</i> Poir.	Caryophyllaceae	6	∅	Mp	C	C	Mp, C

na= not applicable

ni= no information available

<sup>a</sup> 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 assessmentPepper is reference species for *Myzus persicae* risk assessment<sup>b</sup> Plants with the same letters are not significantly different<sup>c</sup> Aphid risks according to Blackman and Eastop 2006, Kavallieratos et al., 2007Ag (*Aphis gossypii*)Mp (*Myzus persicae*)<sup>d</sup> 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

<sup>e</sup> Underlined risks correspond to new descriptions compared to literature

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