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Trap Crops and Insectary Plants in the Order Brassicales

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25 **ABSTRACT** This paper reviews the most important cases of trap crops and insectary
26 plants in the order Brassicales. Most trap crops in the order Brassicales target insects that
27 are specialist in plants belonging to this order, such as the diamondback moth, *Plutella*
28 *xylostella* L. (Lepidoptera: Plutellidae), the pollen beetle, *Meligethes aeneus* Fabricius
29 (Coleoptera: Nitidulidae), and flea beetles in the genera *Phyllotreta* *Psylliodes*
30 (Coleoptera: Chrysomelidae). In most cases, the mode of action of these trap crops is the
31 preferential attraction of the insect pest for the trap crop located next to the main crop.
32 With one exception, these trap crops in the order Brassicales have been used with
33 brassicaceous crops. Insectary plants in the order Brassicales attract a wide variety of
34 natural enemies, but most studies focus on their effect on aphidofagous hoverflies and
35 parasitoids. The parasitoids benefiting from insectary plants in the order Brassicales
36 target insects pests ranging from specialists, such as *P. xylostella*, to highly polyfagous,
37 such as the stink bugs *Euschistus conspersus* Uhler and *Thyanta pallidovirens* Stål
38 (Hemiptera: Pentatomidae). In the order Brassicales, the three most common trap crops
39 are Indian mustard, *Brassica juncea* (L.) Czern, Chinese cabbage, *Brassica rapa* L., and
40 yellow rocket, *Barbarea vulgaris* R. Br., while the three most common insectary plants
41 are sweet alyssum, *Lobularia maritima* (L.) Desv., white mustard, *Sinapis alba* L., and
42 *B. vulgaris*. Except for *Tropaeolum majus* L. (Tropaeolaceae) and *Capparis decidua*
43 (Forssk.) Edgew. (Capparaceae), the tested trap crops and insectary plants in the order
44 Brassicales belong to the family Brassicaceae.

45

46 **KEYWORDS:** Brassicaceae, companion plants, conservation biological control,
47 crucifers, trap cropping

48 Trap crops are plants stands deployed to attract, divert, intercept, and/or retain targeted
49 insects or the pathogens they vector in order to reduce damage in the main crop (Shelton
50 and Badenes-Pérez 2006). Insectary plants are used in biological control conservation to
51 provide floral and/or extrafloral nectar to parasitoids and predators (Atsatt and O'Dowd
52 1976, Colley and Luna 2000). Both trap crops and insectary plants fit into the broad
53 definitions of cover cropping, intercropping, and habitat management to suppress pest
54 populations (Bugg and Waddington 1994, Smith and McSorley 2000, Shelton and
55 Badenes-Pérez 2006, Gurr et al. 2017).

56 The purpose of this review is to synthesize the most relevant and recent literature
57 regarding trap crops and insectary plants in the order Brassicales. This plant order is best
58 known for including the family Brassicaceae, which includes many economically
59 important species, some of which are widely used as vegetables, oils, condiments, and
60 ornamental plants (Al-Shehbaz 2011, Lysak and Koch 2011, Warwick 2011).
61 Additionally, a few species from the order Brassicales that do not belong to the family
62 Brassicaceae have also been tested as trap crops and insectary plants and have been
63 included in this review. The economic importance that many plants in order Brassicales
64 have, apart from their use in pest management, increases the likelihood of being used as
65 trap crops and insectary plants at a commercial level.

66

67 **Trap Crops in the Order Brassicales**

68 With one exception in the family Cleomaceae (Zedler et al. 2016), the plants that have
69 been tested as trap crops in the order Brassicales belong to the family Brassicaceae.

Below are the main insect pests for which the application of trap crops from the order Brassicales has been investigated.

Diamondback moth and other lepidopteran pests

Plutella xylostella is considered one of the world's major insect pests and is the lepidopteran pest for which more studies on the use of trap cropping have been undertaken (Badenes-Pérez and Shelton 2006, Shelton and Badenes-Pérez 2006, Zalucki et al. 2012, Furlong et al. 2013). The most commonly proposed trap crops for *P. xylostella* management include Indian mustard, *Brassica juncea* (L.) Czern., collards, *Brassica oleracea* L. var. *acephala*, Chinese cabbage, *Brassica rapa* L. subsps. *pekinensis* and *parachinensis*, and yellow rocket, *Barbarea vulgaris* R. Br. (Yu et al. 1998, Shelton and Badenes-Pérez 2006, Hasheela et al. 2010, Satpathy et al. 2010, Badenes-Pérez et al. 2014b, Huang et al. 2014a). Glossy varieties of collards and Chinese cabbage, which are preferred by ovipositing *P. xylostella* and are also more resistant to its larvae than waxy varieties, show increased potential in trap cropping (Ulmer et al. 2002, Badenes-Pérez et al. 2004, Musser et al. 2005, Silva et al. 2017). For *P. xylostella*, some types of *B. vulgaris* and *Barbarea verna* (Mill.) Asch. can act as dead-end trap crops, a particular type of trap crops that do not allow survival of larvae of the target insect pest (Shelton and Nault 2004, Shelton and Badenes-Pérez 2006, Badenes-Pérez et al. 2014b). Feeding deterrent saponins in *Barbarea* spp. are responsible for their resistance to *P. xylostella* larvae (Shinoda et al. 2002, Agerbirk et al. 2003b, Badenes-Pérez et al. 2014b). However, at bloom, attraction and resistance to *P. xylostella* is greatly reduced in G-type *Barbarea vulgaris* (Badenes-Pérez et al. 2017b). G-type *B. vulgaris* also shows resistance to other

93 pests (Christensen et al. 2014, Badenes-Pérez and López-Pérez 2018). Garden cress,
94 *Lepidium sativum* L., has been shown to be even more attractive to ovipositing *P.*
95 *xylostella* than *B. vulgaris*, but survival of *P. xylostella* larvae on *L. sativum* is very high
96 (Newman et al. 2016). Transgenic Bt collards, *B. oleracea* var. *acephala*, and Bt Indian
97 mustard, *B. juncea*, have also been tested as trap crops in greenhouse conditions,
98 significantly reducing *P. xylostella* populations (Shelton et al. 2008). White mustard,
99 *Sinapis alba* L., has also been tested successfully as a trap crop for *P. xylostella*
100 (Danarzadeh et al. 2014). Ovipositing *P. xylostella* also showed high preference for field
101 mustard, *Sinapis arvensis* L., although survival of *P. xylostella* larvae on this plant is very
102 high (Sarfraz et al. 2011). Sweet alyssum, *Lobularia maritima* (L.) Desv., appears to be
103 highly attractive to *P. xylostella* adults, while survival of *P. xylostella* larvae is low (de
104 Groot et al. 2005). However, since *P. xylostella* adults feed on nectar from *L. maritima*
105 (Winkler et al. 2009b), attraction to *L. maritima* could be due to feeding on the flowers
106 rather than to ovipositing on the plant.

107 Ethiopian mustard, *Brassica carinata* A. Braun, has been tested successfully as a
108 trap crop for the large white butterfly, *Pieris brassicae* L. (Lepidoptera: Pieridae) (Kumar
109 2017). For another specialist herbivore, the cabbage head caterpillar, *Crocidolomia*
110 *pavonana* Fabricius (Lepidoptera: Pyralidae), Chinese cabbage, *B. rapa* subsp.
111 *pekinensis* and *chinensis*, broccoli, *B. oleracea* var. *italica*, and Indian mustard, *B. juncea*,
112 show potential as trap crops (Srinivasan and Krishna Moorthy 1992, Smyth et al. 2003,
113 Karungi et al. 2010, Zedler et al. 2016). *Brassica juncea* can also be used as a trap crop
114 for the cabbage webworm, *Hellula undalis* Fabricius (Lepidoptera: Crambidae)
115 (Srinivasan and Krishna Moorthy 1992). Given the oviposition preference of the cabbage

116 looper, *Trichoplusia ni* Hübner (Lepidoptera: Noctuidae) for cabbage compared to cotton
117 (Li and Liu 2015), cabbage could be used as a trap crop for *T. ni* in cotton.

118

119 Pollen beetle, flea beetles, cabbage seedpod weevils, and other coleopteran pests

120 The pollen beetle, *Meligethes aeneus* Fabricius (Coleoptera: Nitidulidae), feeds on pollen
121 from cruciferous plants and it can be an important pest in flowering cruciferous crops
122 (Hokkanen 2000). *Brassica napus* L., *Brassica nigra* L., *B. rapa*, *Eruca sativa* Mill., and
123 *Raphanus sativus* (L.) Domin, show potential as trap crops for *M. aeneus* management
124 (Hokkanen et al. 1986, Ekbom and Borg 1996, Frearson et al. 2005, Cook et al. 2007,
125 Veromann et al. 2014). These trap crops can also increase parasitism of *M. aeneus* larvae
126 (Jönsson and Anderson 2007, Kaasik et al. 2014).

127 Flea beetles, particularly crucifer specialists in the genera *Phyllotreta* and
128 *Psylliodes* (Coleoptera: Chrysomelidae), can also be important pests (Cárcamo et al.
129 2008, Soroka and Grenkow 2013, Tangtrakulwanich et al. 2014). Some *Phyllotreta* spp.
130 show distinct preferences for host plants and one study found that the decreasing order of
131 attraction to the studied *Phyllotreta* spp. was *E. sativa*, *B. juncea*, *B. nigra*, *R. sativus*,
132 *Sinapis alba* L., *B. rapa*, and *B. napus* and *Camelina sativa* (L.) Crantz (Metspalu et al.
133 2014). *Barbarea vulgaris*, *B. rapa*, *S. alba*, and *S. arvensis* have been suggested as trap
134 crops to manage *Phyllotreta cruciferae* Goeze (Root and Tahvanainen 1969, Altieri and
135 Gliessman 1983, Altieri and Schmidt 1986). Because of its saponin content, G-type *B.*
136 *vulgaris* is also resistant to *Phyllotreta nemorum* L. (Agerbirk et al. 2003b, Agerbirk et
137 al. 2003a, Nielsen et al. 2010a, Nielsen et al. 2010b, Kuzina et al. 2011, Christensen et al.
138 2014). In other studies, *Phyllotreta* spp. densities did not decrease with trap cropping,

139 but crop yields increased, probably as a result of changes in the behavior of *Phyllotreta*
140 spp. (Parker et al. 2016). As the relative attraction of plants to *Phyllotreta* spp. can change
141 throughout the crop season (Badenes-Pérez et al. 2017b), one study recommended using
142 a mixture of trap crops (*B. napus*, *R. sativus*, and *S. alba*) (Bohinc and Trdan 2013). Like
143 in the case of *P. xylostella*, the flea beetles *P. cruciferae* and *P. chrysocephala* prefer
144 glossy varieties of *Brassica* spp., but damage by these flea beetles is inversely correlated
145 to the presence of leaf-wax on the plant (Bodnaryk 1992, Lambdon et al. 1998).
146 *Psylliodes chrysocephala* L. has been successfully managed using *B. rapa* as a trap crop
147 (Barari et al. 2005).

148 The cabbage seedpod weevil, *Ceutorhynchus obstrictus* Marsham (Coleoptera:
149 Curculionidae), formerly known as *C. assimilis* Paykull, has been managed using turnip
150 rape, *B. rapa*, as a trap crop in canola, *B. napus*, in Canada (Cárcamo et al. 2007). This
151 same trap crop, however, did not reduce populations of *C. pallidactylus* Marsham in *B.*
152 *napus* in the UK (Barari et al. 2005).

153 The yellowmargined leaf beetle, *Microtheca ochroloma* Stål (Coleoptera:
154 Chrysomelidae), can also be an important pests in cruciferous crops (Balusu and
155 Fadamiro 2011, Balusu et al. 2017). Turnip, *Brassica rapa* subsp. *rapa*, has been
156 successfully tested as a trap crop for *M. ochroloma* in *B. oleracea* crops (Balusu et al.
157 2015).

158

159 Pentatomid bugs and other hemipteran pests

160 The harlequin bug, *Murgantia histrionica* Hahn (Hemiptera: Pentatomidae), is not
161 a crucifer specialist, but it shows high preference for crucifers (McPherson and

162 McPherson 2000, Wallingford et al. 2011). *Brassica juncea* and *B. rapa* are so far the
163 most promising trap crops for management of *M. histrionica* (Sullivan and Brett 1974,
164 Bender et al. 1999, Wallingford et al. 2013). Aggregation pheromones and
165 isothiocyanates are likely to increase the effectiveness of trap crops for *M. histrionica*
166 (Thrift et al. 2018). Another pentatomid bug, the Bagrada bug, *Bagrada hilaris*
167 Burmeister (Hemiptera: Pentatomidae), shows high preference for certain plants, which
168 could be used as trap crops, namely *E. sativa*, *B. rapa*, and *R. sativus* (Huang et al. 2014b,
169 Joseph et al. 2017). The southern green stink bug, *Nezara viridula* L. (Hemiptera:
170 Pentatomidae), has also been successfully managed in sweet corn using *B. nigra* and *S.*
171 *alba* as trap crops (Rea et al. 2002). Densities of the red cabbage bug, *Eurydema ornata*
172 L. (Hemiptera: Pentatomidae), were reduced in a cauliflower crop using flowering *B.*
173 *vulgaris* as a trap crop (Badenes-Pérez et al. 2017b).

174 Sweet alyssum, *L. maritima*, shows potential as a trap crop for the management
175 of the wheat bug, *Nysius huttoni* White (Hemiptera: Lygaeidae) (Tiwari et al. 2018).
176 Densities of cabbage aphid, *Brevicoryne brassicae* L. (Hemiptera: Aphididae) can also
177 be reduced using *B. juncea* and *S. alba* as trap crops (Kloen and Altieri 1990, Srinivasan
178 and Krishna Moorthy 1992).

179

180 Cabbage fly

181 The cabbage fly, *Delia radicum* L. (Diptera: Anthomyiidae), can be an important insect
182 pests of cruciferous crops (Soroka et al. 2004, Joseph and Martinez 2014). For this
183 crucifer specialist insect, *B. napus* ‘Yudal’ and *B. rapa* have been successfully tested as
184 trap crops (Rousse et al. 2003, Kergunteuil et al. 2015a). Synthetic volatiles could also

185 be used to enhance the effectiveness of trap crops for *D. radicum* (Kergunteuil et al. 2012,
186 Kergunteuil et al. 2015a, Lamy et al. 2016, Lamy et al. 2017).

187

188 Turnip sawfly

189 For the turnip sawfly, *Athalia rosae* L. (Hymenoptera: Tenthredinidae), there is one case
190 of trap cropping in canola, *B. napus*, using early-planting varieties of *B. napus* as a trap
191 crop (Sáringer 1989).

192

193 **Additional remarks on the use of trap crops in the order Brassicales**

194 Different trap crops in the order Brassicales show high potential and/or have been
195 successfully tested to manage *C. obstrictus*, *D. radicum*, *M. aeneus*, *M. ochroloma*, *N.*
196 *huttoni*, *N. viridula*, *Phyllotreta* spp., *P. xylostella*, and *P. chrysocephala* (Table 1). Most
197 applications of trap crops from the order Brassicales refer to insects specialized in plants
198 of this order. Among these specialists, trap cropping is particularly indicated in the case
199 of insects that are likely to develop resistance to insecticides, such as *P. xylostella* and *M.*
200 *aeneus* (Hokkanen 1991, Badenes-Pérez and Shelton 2006, Shelton and Badenes-Pérez
201 2006, Furlong et al. 2008, Furlong et al. 2013, Riggi et al. 2016). Among the five
202 generalist insect pests for which trap crops from the order Brassicales have been
203 successfully tested, one of them, *N. viridula*, is considered highly polyfagous (Todd
204 1989), while the other four, *B. hiliaris*, *M. histrionica*, *N. huttoni*, and *T. ni*, show high
205 preference for plants in this order (Eyles 1965, Capinera 2001, Shikano et al. 2010,
206 Wallingford et al. 2011, Huang et al. 2014b)..

207 Plants in the order Brassicales contain glucosinolates, which for specialist insects,
208 such as *P. xylostella*, have been shown to be oviposition stimulants and feeding stimulants
209 (van Loon et al. 2002, Hopkins et al. 2009, Badenes-Pérez et al. 2011). Even when
210 glucosinolates are transgenetically expressed in plants that are normally not host-plants
211 for *P. xylostella*, this specialist insect oviposits on them (Møldrup et al. 2012). Increasing
212 plant glucosinolate content can make trap crops more attractive to *P. xylostella* (Badenes-
213 Pérez et al. 2010, Badenes-Pérez et al. 2014a). The other specialists known to be affected
214 by glucosinolates or their hydrolysis products are the pollen beetle, *M. aeneus* (Blight and
215 Smart 1999, Cook et al. 2006); the cabbage seedpod weevils *C. obstrictus* and *C.*
216 *pallidactylus* (Free and Williams 1978, Cook et al. 2006); the flea beetles *Phyllotreta* spp.
217 and *Psylliodes chrysocephala* (Nielsen 1989, Bartlet et al. 1994, Giamoustaris and Mithen
218 1995, Nielsen et al. 2001); the cabbage fly, *D. radicum* (Marazzi et al. 2004, Marazzi and
219 Städler 2004); and the cabbage webworm, *H. undalis* (Mewis et al. 2003). In these cases
220 increasing glucosinolate content in trap crops could enhance their effectiveness. As
221 glucosinolate content affects these specialist herbivores, it is not surprising that some of
222 these trap crops in the order Brassicales can be effective against several of these
223 specialists.

224 Given the success of trap crops from the order Brassicales in the management of
225 specialist herbivores, trap cropping could also be tested for other specialist herbivores
226 where it has not been tested, such as the swede midge, *Contarinia nasturtii* Kieffer
227 (Diptera: Cecidomyiidae), and the turnip root fly, *Delia floralis* Fallén (Diptera:
228 Anthomyiidae). *Contarinia nasturtii* shows host-plant preferences (Chen et al. 2011,
229 Williams and Hallett 2018). *Delia floralis* also shows host-plant preferences and,

230 furthermore, it is known to respond positively to increasing glucosinolate content
231 (Simmonds et al. 1994, Hopkins et al. 1997, Hopkins et al. 1999).

232

233 **Insectary plants in the Order Brassicales**

234 With the exception of garden nasturtium, *Tropaeolum majus* L. (Tropaeolaceae), and
235 *Capparis decidua* (Forssk.) Edgew. (Capparaceae), the insectary plants tested in the order
236 Brassicales belong to the family Brassicaceae. Below are the most common insectary
237 plants investigated in the order Brassicales.

238

239 *Lobularia maritima*

240 Besides buckwheat, *Fagopyrum esculentum* Moench (Caryophyllales), and *Phacelia*
241 *tanacetifolia* Benth. (Boraginales), sweet alyssum, *Lobularia maritima* (L.) Desv., is one
242 of the most commonly used insectary plant (Landis et al. 2000, Fiedler and Landis 2007a,
243 Hogg et al. 2011a, Laubertie et al. 2012, Parolin et al. 2012, Brennan 2016, Burgio et al.
244 2016). Several studies have shown the attractiveness and preference of adult hoverflies
245 for *L. maritima* (Colley and Luna 2000, Ambrosino et al. 2006, Pineda and Marcos-
246 García 2008, Hogg et al. 2011a, Amorós-Jiménez et al. 2014, Barbir et al. 2015). Fewer
247 studies have tested the effect of *L. maritima* on the densities of hoverfly larvae, the actual
248 aphidofagous stage, and/or their aphid prey, on adjacent crops (Pineda and Marcos-García
249 2008, Gillespie et al. 2011, Hogg et al. 2011b, Nelson et al. 2012).

250 Compared to other insectary plants, such as *F. esculentum* and *P. tanacetifolia*, the effect
251 of *L. maritima* on the fitness of the aphidofagous hoverfly *Episyrphus balteatus* De Geer
252 was considered medium (Laubertie et al. 2012). The reduction of aphid populations with

253 *L. maritima* is not only mediated by hoverflies, it can also be due to generalist predators.
254 For example, *L. maritima* reduced densities of woolly apple aphid, *Eriosoma lanigerum*
255 Hausmann (Hemiptera: Aphididae), through the increase in generalist spiders and
256 predatory bugs (Gontijo et al. 2013). Through this increase in generalist predators, *L.*
257 *maritima* has also been linked to a reduction in the populations of the whitefly, *Bemisia*
258 *tabaci* Gennadius (Hemiptera: Aleyrodidae), and *P. xylostella* (Ribeiro and Gontijo
259 2017).

260 *Lobularia maritima* is known to be attractive to different braconid, eulophid, and
261 ichneumonoid parasitoids and its nectar can increase the longevity and fecundity in these
262 parasitoids (Johanowicz and Mitchell 2000, Berndt and Wratten 2005, Lavandero et al.
263 2006, Winkler et al. 2009a, Winkler et al. 2009b, Pease and Zalom 2010, Sivinski et al.
264 2011, Aparicio et al. 2018, Arnó et al. 2018). For example, when comparing several
265 plants, *L. maritima* was one of the best to increase the fecundity and longevity of
266 *Necremnus tutae* Ribes and Bernardo (Hymenoptera: Eulophidae), *Stenomesus* sp. nr.
267 *japonicus* Ashmead (Hymenoptera: Eulophidae), and *Bracon* sp. nr. *nigricans* Szépligeti
268 (Hymenoptera: Braconidae), parasitoids of the tomato moth, *Tuta absoluta* Meyrick
269 (Lepidoptera: Gelechiidae) (Arnó et al. 2018). Compared to a water control, *L. maritima*
270 increased the longevity of the parasitoids *Diadegma semiclausum* Hellen (Hymenoptera:
271 Ichneumonidae) and *Dolichogenidea tasmanica* Cameron (Hymenoptera: Braconidae)
272 (Irvin et al. 2006, Tompkins et al. 2010). *Lobularia maritima* can also have additional
273 benefits in conservation biological control. For example, in the parasitoid *D. tasmanica*
274 access to *L. maritima* resulted in an equal sex-ratio, rather than a male-biased sex ratio in
275 the absence of *L. maritima* flowers (Berndt and Wratten 2005). *Lobularia maritima* has

276 also been shown to increase parasitism of *Myzus persicae* Sulzer (Hemiptera: Aphididae)
277 by the parasitoid *Aphidius colemani* Viereck (Hymenoptera: Braconidae), which
278 longevity and fecundity also increased in the presence of this flowering plant (Jado et al.
279 2018). However, presence of *L. maritima* did not result in a significant increase of
280 parasitism of the leafroller *Epiphyas postvittana* Walker (Lepidoptera: Tortricidae) by
281 *Dolichogenidea* spp. (Bell et al. 2006), but it increased the longevity of *Trichogramma*
282 *carverae* Oatman and Pinto (Hymenoptera: Trichogrammatidae), a parasitoid of *E.*
283 *postvittana* eggs (Begum et al. 2006).

284 In some parasitoids exposure to *L. maritima* flowers did not significantly increase
285 longevity compared to a water control (Rahat et al. 2005, Lavandero et al. 2006, Vattala
286 et al. 2006, Nafziger and Fadamiro 2011). While exposure to *L. maritima* flowers did not
287 increase the longevity of the parasitoid *D. semiclausum* in one study (Lavandero et al.
288 2006), it did in another study (Winkler et al. 2009b). Longevity of a different species of
289 *Diadegma*, *D. insulare* Cresson (Hymenoptera: Ichneumonidae), also increased with
290 exposure to *L. maritima* (Johanowicz and Mitchell 2000). These differences on the
291 influence of *L. maritima* nectar on the parasitoid's fitness could be due to differences in
292 parasitoid head size related to the size of the aperture and depth of the corolla of the *L.*
293 *maritima* flowers tested. Two different studies have reported different corolla sizes in *L.*
294 *maritima* flowers (Vattala et al. 2006, Winkler et al. 2009b). Accessibility to parasitoids
295 is easier in flowers with broad corolla apertures and shallow-intermediate corolla depths
296 (Vattala et al. 2006). Some parasitoids cannot reach the nectar of *L. maritima* (Vattala et
297 al. 2006).

298 *Lobularia maritima* can also attract, provide pollen, and increase the longevity of
299 omnivorous natural enemies, such as *Orius* spp. (Pumariño and Alomar 2012). *Lobularia*
300 *maritima* also attracts the predator *Jalysus wickhami* Van Duzee (Hemiptera: Berytidae)
301 (Pease and Zalom 2010). Besides being used alone, *L. maritima* is often used in mixtures
302 of insectary plants (Bugg and Waddington 1994, Grasswitz 2013, Ramsden et al. 2015,
303 Balzan et al. 2016). Compared to other insectary plants, *L. maritima* stays in bloom for
304 a long time and it attracts less bees that can outcompete hoverflies (Picó and Retana 2001,
305 Ambrosino et al. 2006, Hogg et al. 2011a).

306

307 *Sinapis alba*

308 White mustard, *Sinapis alba* L., increased parasitism by *Aphidius* spp. in aphids
309 found on wheat (*Metopolophium dirhodum* Walker, *Rhopalosiphum padi* L., and *Sitobion*
310 *avenae* F.) (Damien et al. 2017). *Sinapis alba* also increased the fecundity and longevity
311 of *D. semiclausum* and *Cotesia glomerata* L. (Hymenoptera: Braconidae), parasitoids of
312 *P. xylostella* and *Pieris* spp. (Lepidoptera: Pieridae), respectively (Winkler et al. 2009b).
313 It also increased the fecundity of *S. nr. japonicus*, a parasitoid of *T. absoluta* (Arnó et al.
314 2018). *Sinapis alba* increased the longevity of the parasitoids *D. tasmanica* and *T.*
315 *carverae* (Begum et al. 2006, Tompkins et al. 2010). The longevity increase for *T.*
316 *carverae* was not as high with *S. alba* as with *L. maritima* flowers (Begum et al. 2006).
317 *Sinapis alba* has also been shown to increase the longevity and fecundity of the aphid
318 parasitoid *A. colemani* (Jado et al. 2018). In the presence of *S. alba* flowers, parasitism
319 of *M. persicae* by *A. colemani* increased (Jado et al. 2018). *Sinapis alba* did not
320 significantly increase the longevity of *Micrococtonus hyperodae* Loan (Hymenoptera:

321 Braconidae), a parasitoid of the Argentine stem weevil, *Listronotus bonariensis* Kuschel
322 (Coleoptera: Curculionidae) (Vattala et al. 2006). This insectary plant also increased the
323 abundance of *Ecphyllus silesiacus* Ratz. (Hymenoptera: Braconidae), a parasitoid of elm
324 bark beetles of the genus *Scolytus* (Coleoptera: Scolytidae) (Manojlovic et al. 2001).
325 Compared to other insectary plants, such as *F. esculentum* and *P. tanacetifolia*, the effect
326 of *S. alba* on the fitness of the aphidofagous hoverfly *Episyrphus balteatus* De Geer was
327 considered low (Laubertie et al. 2012). Although not associated to natural enemies in the
328 study, densities of *A. gossypii* were reduced in zucchini by the presence of *S. alba* (Hooks
329 et al. 1998). *Sinapis alba* is also used in mixtures of insectary plants (Balzan et al. 2014,
330 Jönsson et al. 2015).

331

332 *Barbarea vulgaris*

333 Yellow rocket, *B. vulgaris*, has been shown to increase the parasitism of *P. xylostella* by
334 *D. insulare* (Badenes-Pérez et al. 2017b). This parasitoid feeds on nectar of *B. vulgaris*
335 flowers (Idris and Grafius 1995, 1997) and it is also greatly attracted to non-flowering *B.*
336 *vulgaris* (Badenes-Pérez et al. 2017b). *Diadromus collaris* Gravenhorst (Hymenoptera:
337 Ichneumonidae), another parasitoid of *P. xylostella*, can also be found on *B. vulgaris*
338 (Badenes-Pérez et al. 2017b).

339

340 *Brassica* spp.

341 *Brassica rapa* L. has been used to reduce densities of cotton aphid, *Aphis gossypii* Glover,
342 in cotton, reduction associated to an increase in lady beetles (Parajulee and Slosser 1999).
343 Nectar from *B. napus* increased the longevity of the stink bug egg parasitoid *Trissolcus*

344 *basalis* Wollaston (Hymenoptera: Scelionidae) (Rahat et al. 2005). Other *Brassica* spp.
345 can attract aphidofagous hoverflies (Hogg et al. 2011a). *Brassica juncea* is the only
346 species in the Brassicaceae family in which extraforal nectaries have been found, which
347 can be used by parasitoids, such as *Cotesia glomerata* L., *C. marginiventris* Cresson,
348 *Diaeretiella rapae* M'Intosh (Hymenoptera: Braconidae), and *Trybliographa rapae*
349 Westwood (Hymenoptera: Figitidae) (Mathur et al. 2013).

350

351 *Raphanus raphanistrum*

352 Different parasitoids of the olive moth, *Prays oleae* Bernard (Lepidoptera: Plutellidae),
353 feed on the nectar of wild radish, *Raphanus raphanistrum* L. (Nave et al. 2016).
354 *Raphanus raphanistrum* flowers are also very attractive to aphidofagous hoverflies
355 (Sajjad and Saeed 2010). *Raphanus raphanistrum* is also used in mixtures of insectary
356 plants (Bugg and Waddington 1994).

357

358 *Diplotaxis* spp.

359 The wall rockets *Diplotaxis muralis* (L.) DC. and *D. tenuifolia* (L.) DC. have been used
360 to attract aphidofagous hoverflies (Hogg et al. 2011a, Barbir et al. 2014, Barbir et al.
361 2015). *Diplotaxis eruroides* L. has been shown to increase the longevity and fecundity
362 of the aphid parasitoids *A. colemani* and *Diaeretiella rapae* McIntosh (Hymenoptera:
363 Braconidae) (Araj and Wratten 2015, Jado et al. 2018). Presence of *D. eruroides* flowers
364 also increased parasitism of *M. persicae* by *A. colemani* increased (Jado et al. 2018).

365

366 *Iberis umbellata*

367 Garden candytuft, *Iberis umbellata* L., increased the number of predators, but did not
368 significantly reduce the populations of *P. rapae* and *T. ni* (Bigger and Chaney 1998).
369 *Iberis umbellata* has also been used in mixtures of insectary plants (Bugg and
370 Waddington 1994).

371

372 *Tropaeolum majus*

373 Nectar from garden nasturtium, *T. majus*, increased the longevity of *Trissolcus basalis*, a
374 parasitoid of stink bug eggs, and of *Copidosoma koehleri* Blanchard (Hymenoptera:
375 Encyrtidae), a parasitoid of the potato tuber moth, *Phthorimaea operculella* Zeller
376 (Lepidoptera: Gelechiidae) (Baggen et al. 1999, Rahat et al. 2005).

377

378 *Capparis decidua*

379 Kair trees, *C. decidua*, are also known to be highly attractive to hoverflies (Sajjad and
380 Saeed 2010).

381

382 *Hirschfeldia incana*

383 Shortpod mustard, *Hirschfeldia incana* (L.) Lagr.-Foss., increased wing length and sugar
384 levels in *Episyrphus balteatus* De Geer (Diptera: Syrphidae), but it did not significantly
385 increase its longevity (Pinheiro et al. 2013).

386

387 *Capsella bursa-pastoris*

388 Shepherd's purse, *Capsella bursa-pastoris* L., has been shown to increase the longevity
389 and fecundity of the aphid parasitoid *D. rapae* (Araj and Wratten 2015). Aphidofagous
390 hoverflies also feed on flowers of *C. bursa-pastoris* (Villa et al. 2016).

391

392 **Additional remarks on the use of insectary plants in the order Brassicales**

393 A total of 15 plant species in the order Brassicales have been successfully tested
394 as insectary plants (Table 2). Among these, *L. maritima* and *Brassica* spp. are the ones
395 with most applications to benefit natural enemies.

396 In insectary plants, attraction to natural enemies is mainly a function of the period
397 of peak bloom, floral area, and corolla size (Patt et al. 2003, Vattala et al. 2006, Fiedler
398 and Landis 2007b, Sivinski et al. 2011). Besides *B. juncea*, extrafloral nectaries have
399 been found in *Capparis retusa* Griseb and *C. cynophallophora* L. (Capparaceae) (Pelotto
400 and Del Pero Martínez 1998, Di Sapio et al. 2001), but nothing is known about their use
401 by natural enemies. Besides nectar and pollen, natural enemies have additional
402 requirements, such as alternative hosts, overwintering habitat, protection from tillage, and
403 refuge from adverse biotic and abiotic conditions (Gillespie et al. 2016). That is the
404 reason why high densities of parasitoids can also be found non-flowering plants
405 (Badenes-Pérez et al. 2017b). Insectary plants can attract insects at both local and
406 landscape scales (Jönsson et al. 2015). The landscape context in which natural pest
407 suppression takes place is also very important (Tscharntke et al. 2007, Gillespie et al.
408 2016, Rega et al. 2018).

409 While attracting and feeding natural enemies, insectary plants can also feed insect
410 pest species and reduce pest suppression (Irvin et al. 2006, Jonsson et al. 2010, Balzan

411 and Wäckers 2013). Depending on the natural enemy, the insect pest, and the insectary
412 plant species, the benefit to the different natural enemies of the insectary plants from the
413 order Brassicales usually exceeds the benefit to insect pests (Ambrosino et al. 2006,
414 Lavandero et al. 2006, Winkler et al. 2009b, Winkler et al. 2010). Insectary plants can
415 also be beneficial for other reasons, such as providing nectar and pollen to pollinators
416 (Baggen et al. 1999, Jauker and Wolters 2008, Wratten et al. 2012).

417

418 **Concluding remarks**

419 In the order Brassicales the most studied trap crops are *B. rapa*, *B. juncea*, *B. vulgaris*,
420 and *B. napus*, while the most common insectary plants are *L. maritima*, *S. alba*, *B. rapa*,
421 and *B. vulgaris*. In some cases, such as *B. rapa* and *B. vulgaris*, plants can be used as
422 both trap crops and insectary plants. They may be used at the same time when attracting
423 flower pests such as *M. aeneus*, but in other cases, they are used at different growth stages,
424 such as in the case of *B. vulgaris*, which at bloom loses attractiveness to *P. xylostella*
425 (Badenes-Pérez et al. 2017b). As trap cropping can be an alternative to insecticides and
426 reduce the use of insecticides that would negatively affect beneficial insects attracted to
427 insectary plants, the use of trap crops and insectary plants is very compatible. This can
428 be particularly important in the case of pests feeding on crops at the flowering stage,
429 where pest management should be respectful of the natural enemies and the pollinators
430 feeding on nectar and pollen (Badenes-Pérez et al. 2017a).

431

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Table 1. Recent and most relevant studies on the use of trap crops from the order Brassicales in insect pest management.

Trap Crop Species	Target Insect Pest	Main Crops	References
Coleopteran pests			
Indian mustard (<i>Brassica juncea</i>)	Flea beetles (<i>Phyllotreta</i> spp.)	Broccoli	(Parker et al. 2016)
Canola (<i>Brassica napus</i>)	Pollen beetle (<i>Meligethes aeneus</i>)	Canola, cauliflower	(Hokkanen et al. 1986, Frearson et al. 2005, Cook et al. 2006, Cook et al. 2013)
	Flea beetles (<i>Phyllotreta</i> spp.)	Broccoli, cabbage	(Bohinc and Trdan 2013, Parker et al. 2016)
Black mustard (<i>Brassica nigra</i>)	Pollen beetle (<i>Meligethes aeneus</i>)	Canola	(Veromann et al. 2012, Kaasik et al. 2014, Veromann et al. 2014)
	Southern green stink bug (<i>Nezara viridula</i>)	Sweet corn	(Rea et al. 2002)
	Flea beetles (<i>Phyllotreta</i> spp.)	Canola, Camelina	(Metspalu et al. 2014)
Turnip rape (<i>Brassica rapa</i>)	Pollen beetle (<i>Meligethes aeneus</i>)	Canola	(Cook et al. 2007)
	Cabbage-stem flea beetle (<i>Psylliodes chrysocephala</i>)	Canola	(Barari et al. 2005)
	Flea beetles	Canola	(Metspalu et al. 2014)

	(<i>Phyllotreta</i> spp.)		
Chinese cabbage (<i>Brassica rapa pekinensis</i>)	Flea beetles (<i>Phyllotreta</i> spp.)	Broccoli	(Parker et al. 2016)
Arugula (<i>Eruca sativa</i>)	Pollen beetle (<i>Meligethes aeneus</i>)	Canola	(Veromann et al. 2012, Kaasik et al. 2014, Veromann et al. 2014)
	Flea beetles (<i>Phyllotreta</i> spp.)	Canola	(Metspalu et al. 2014)
Radish (<i>Raphanus sativus</i>)	Pollen beetle (<i>Meligethes aeneus</i>)	Canola	(Veromann et al. 2012, Kaasik et al. 2014, Veromann et al. 2014)
	Flea beetles (<i>Phyllotreta</i> spp.)	Cabbage, canola	(Bohinc and Trdan 2013, Metspalu et al. 2014)
White mustard (<i>Sinapis alba</i>)	Southern green stink bug (<i>Nezara viridula</i>)	Sweet corn	(Rea et al. 2002)
	Flea beetles (<i>Phyllotreta</i> spp.)	Broccoli, cabbage	(Bohinc and Trdan 2013)
Field mustards (<i>Sinapis arvensis</i> and <i>Brassica rapa</i>)	Flea beetles (<i>Phyllotreta</i> spp.)	Collards	(Altieri and Gliessman 1983, Altieri and Schmidt 1986)
Turnip rape (<i>Brassica rapa</i>)	Cabbage seedpod weevil (<i>Ceutorhynchus obstrictus</i>)	Canola	(Cárcamo et al. 2007)

Turnip (<i>Brassica rapa</i>)	Yellowmargined leaf beetle (<i>Microthea ochroloma</i>)	Cabbage, mustard	(Balusu et al. 2015)
Dipteran pests			
Canola (<i>Brassica napus</i>)	Turnip sawfly (<i>Athalia rosae</i>)	Canola (early-planted seedlings)	(Sáringier 1989)
Canola (<i>Brassica napus</i> `Yudal´)	Cabbage fly (<i>Delia radicum</i>)	Broccoli, white mustard, canola `Darmor-bzh´	(Kergunteuil et al. 2015b, Kergunteuil et al. 2015a)
Chinese cabbage (<i>Brassica rapa pekinensis</i> and <i>B. rapa chinensis</i>)	Cabbage fly (<i>Delia radicum</i>)	Broccoli	(Rousse et al. 2003, Kergunteuil et al. 2015a, Lamy et al. 2017)
Hemipteran pests			
Yellow rocket (<i>Barbarea vulgaris</i>)	Red cabbage bug (<i>Eurydema ornata</i>)	Cauliflower	(Badenes-Pérez et al. 2017b)
Indian mustard (<i>Brassica juncea</i>)	Harlequin bug (<i>Murgantia histrionica</i>)	Cabbage, collard	(Sullivan and Brett 1974, Wallingford et al. 2013)
	Cabbage aphid (<i>Brevicoryne brassicae</i>)	Cabbage	(Srinivasan and Krishna Moorthy 1992)
Chinese cabbage (<i>Brassica rapa</i>)	Harlequin bug (<i>Murgantia histrionica</i>)	Cabbage	(Sullivan and Brett 1974)
Turnip rape	Bagrada bug	Broccoli, cauliflower	(Joseph et al. 2017)

<i>(Brassica rapa)</i>	<i>(Bagrada hilaris)</i>		
Arugula <i>(Eruca sativa)</i>	Bagrada bug <i>(Bagrada hilaris)</i>	Broccoli, cauliflower	(Joseph et al. 2017)
Sweet alyssum <i>(Lobularia maritima)</i>	Wheat bug <i>(Nysius huttoni)</i>	Kale	(Tiwari et al. 2018)
Radish <i>(Raphanus sativus)</i>	Bagrada bug <i>(Bagrada hilaris)</i>	Broccoli, cauliflower	(Huang et al. 2014b)
White mustard <i>(Sinapis alba)</i>	Cabbage aphid <i>(Brevicoryne brassicae)</i>	Broccoli	(Kloen and Altieri 1990)
Lepidopteran pests			
Yellow rocket <i>(Barbarea vulgaris)</i>	Diamondback moth <i>(Plutella xylostella)</i>	Broccoli, cabbage	(Badenes-Pérez et al. 2004, Shelton and Nault 2004, Badenes-Pérez et al. 2005b, Badenes-Pérez et al. 2005a, Badenes-Pérez et al. 2006, Badenes-Pérez et al. 2014b)
Ethiopian mustard <i>(Brassica carinata)</i>	Cabbage butterfly <i>(Pieris brassicae)</i>	Cabbage	(Kumar 2017)
Indian mustard <i>(Brassica juncea)</i>	Diamondback moth <i>(Plutella xylostella)</i>	Cabbage, cauliflower	(Srinivasan and Krishna Moorthy 1991, 1992, Luther et al. 1996, Yu et al. 1998, Badenes-Pérez et al. 2004, Shelton et al. 2008, Hasheela et al. 2010, Zedler et al. 2016)

	Cabbage head caterpillar (<i>Crocitoloma pavonana</i>)	Cabbage	(Srinivasan and Krishna Moorthy 1991, 1992)
	Cabbage webworm (<i>Hellula undalis</i>)	Cabbage	(Srinivasan and Krishna Moorthy 1992)
Collards (<i>Brassica oleracea acephala</i>)	Diamondback moth (<i>Plutella xylostella</i>)	Cabbage	(Badenes-Pérez et al. 2004, Musser et al. 2005)
Cabbage (<i>Brassica oleracea capitata</i>)	Cabbage looper (<i>Trichoplusia ni</i>)	Cotton	(Li and Liu 2015)
Chinese cabbage (<i>Brassica rapa</i>)	Diamondback moth (<i>Plutella xylostella</i>)	Cabbage, cauliflower	(Yu et al. 1998, Satpathy et al. 2010, Badenes-Pérez et al. 2014b)
	Cabbage head caterpillar (<i>Crocitoloma pavonana</i>)	Cabbage, cauliflower	(Smyth et al. 2003, Karungi et al. 2010, Zedler et al. 2016)
Garden cress (<i>Lepidium sativum</i>)	Diamondback moth (<i>Plutella xylostella</i>)	Aubretia, broccoli, ornamental kale	(Newman et al. 2016)
White mustard (<i>Sinapis alba</i>)	Diamondback moth (<i>Plutella xylostella</i>)	Cabbage	(Danarzadeh et al. 2014)

Table 2. Recent and most relevant studies on the use of insectary plants from the order Brassicales in insect pest management.

Insectary Plant Species	Natural Enemies Benefited	Target Insect Pest	References
Yellow rocket (<i>Barbarea vulgaris</i>)	Parasitoids	Diamondback moth	(Idris and Grafius 1995, Badenes-Pérez et al. 2017b)
<i>Brassica</i> spp.	Aphidophagous hoverflies	Aphids	(Hogg et al. 2011a)
	Lady beetles	Aphids	(Parajulee and Slosser 1999)
	Parasitoids	Aphids, cabbage white butterfly, cabbage fly, stink bugs	(Rahat et al. 2005, Mathur et al. 2013)
Kair tree (<i>Capparis decidua</i>)	Aphidophagous hoverflies	Aphids	(Sajjad and Saeed 2010)
Shepherd's purse (<i>Capsella bursapastoris</i>)	Aphidophagous hoverflies	Aphids	(Villa et al. 2016)
	Parasitoids	Aphids	(Araj and Wratten 2015)
Wall Rockets (<i>Diplotaxis</i> spp.)	Aphidophagous hoverflies	Aphids	(Hogg et al. 2011a, Barbir et al. 2014, Barbir et al. 2015)
	Parasitoids	Aphids	(Araj and Wratten 2015, Jado et al. 2018)
Shortpod mustard (<i>Hirschfeldia incana</i>)	Aphidophagous hoverflies	Aphids	(Pinheiro et al. 2013)
Garden candytuft	Predators	-	(Bigger and Chaney 1998)

<i>(Iberis umbellata)</i>			
Sweet alyssum (<i>Lobularia maritima</i>)	Aphidophagous hoverflies	Aphids	(Colley and Luna 2000, Ambrosino et al. 2006, Pineda and Marcos-García 2008, Gillespie et al. 2011, Hogg et al. 2011a, Hogg et al. 2011b, Laubertie et al. 2012, Nelson et al. 2012, Amorós-Jiménez et al. 2014, Barbir et al. 2015)
	Parasitoids	Aphids, tomato moth, diamondback moth, light brown apple moth, stink bug	(Johanowicz and Mitchell 2000, Begum et al. 2004, 2006, Irvin et al. 2006, Winkler et al. 2009a, Winkler et al. 2009b, Pease and Zalom 2010, Araj and Wratten 2015, Aparicio et al. 2018, Arnó et al. 2018, Jado et al. 2018)
	Spiders and other natural enemies	Aphids, whiteflies, diamondback moth, stink bug	(Pease and Zalom 2010, Pumariño and Alomar 2012, Gontijo et al. 2013, Ribeiro and Gontijo 2017, Aparicio et al. 2018)
Radish (<i>Raphanus raphanistrum</i>)	Aphidophagous hoverflies	Olive moth	(Sajjad and Saeed 2010)
	Parasitoids	Aphids	(Nave et al. 2016)
White mustard (<i>Sinapis alba</i>)	Aphidophagous hoverflies	Aphids	(Laubertie et al. 2012)

	Parasitoids	Aphids, brown apple moth, diamondback moth, tomato moth, bark beetles	(Arnó et al. 2018, Jado et al. 2018)
Garden nasturtium (<i>Tropaeolum majus</i>)	Parasitoids	Potato tuber moth, stink bug	(Baggen et al. 1999, Rahat et al. 2005)

Figure 1. Yellow rocket, *Barbarea vulgaris*, can be used simultaneously as a trap crop and an insectary plant. In the picture, adults of the long hoverfly, *Sphaerophoria scripta* L. (Diptera: Syrphidae), feeding on *B. vulgaris* flowers.

Figure 2. Sweet alyssum, *Lobularia maritima*, is one of the most common insectary plants. In the picture, flowering *L. maritima* next to a cauliflower plant.