https://doi.org/10.17221/161/2024-PPS

The cultural control of some important pests in cabbage (*Brassica oleracea* var. *capitata* L.) and onion (*Allium cepa* L.) using companion plants

*Monica Novljan, Tanja Bohinc, Stanislav Trdan**

Department of Agronomy, Biotechnical Faculty, University of Ljubljana, Ljubljana, Slovenia

**Corresponding author: stanislav.trdan@bf.uni-lj.si*

Citation: Novljan M., Bohinc T., Trdan S. (2026): The cultural control of some important pests in cabbage (*Brassica oleracea* var. *capitata* L.) and onion (*Allium cepa* L.) using companion plants. Plant Protect. Sci., 62: 1−26.

Abstract: Cabbage (*Brassica oleracea* var. *capitata* L.) and onion (*Allium cepa* L.) are two of the most important vegetables in the world, and many insect pests are a problem in their production. Currently, especially in Europe, restrictions on the use of pesticides are increasingly being encouraged, so the need to find and use alternative methods is increasingly urgent. Cultural control of insect pests using companion plants, including cover crops, intercrops, and trap crops, has been proven to help manage these insect pests. Companion plants reduce plant insects primarily by disrupting host-seeking activity, disrupting oviposition, increasing the plant's natural enemies, or luring the pests to alternative food sources. This review outlines successful examples from around the world of the use of companion crops in controlling insect pests, focusing on the main pests of cabbage and onions in Europe. Details regarding the working mechanism of each of the three companion plants are discussed further in this article. We concluded that these companion plant tree forms effectively reduce the number of generalist and specialist plant pests attacking cabbage and onion.

Keywords: cabbage pests; onion pests; cover crops; cultural pest control; intercrops; trap crops

According to the statistics of the Food and Agriculture Organization of the United Nations (Food and Agriculture Organization Statistics/FAOSTAT 2023), onion (*Allium cepa* L.) is the second most popular vegetable in the world after tomatoes, while cabbage (*Brassica oleracea* var. *capitata* L.) takes the fourth position. The last recorded data from 2022 reported a total production of 4.97 mil. t and 110.62 mil. t of green and dry onions and 72.60 mil. t of cabbage worldwide. In the European Union (EU) area, the numbers reached 6.26 mil. t and 3.66 mil. t of total production of onions and cabbage, respectively.

Various insect pests can pose serious threats to the production of cabbage and onions. In Europe, the common insect pests of cabbage include the members of the order Lepidoptera, Diptera, Hemiptera, Coleoptera, and Thysanoptera, such as diamondback moth (DBM) (*Plutella xyllostela* L.), cabbage moth (*Mamestra brassicae* L.), small white butterfly (*Pieris rapae* L.), large white butterfly (*Pieris brassicae* L.), cabbage root fly (*Delia radicum* L.), turnip root fly (*Delia floralis* Fallén), cabbage flea beetles (*Phyllotreta* spp.), cabbage aphid (*Brevicoryne brassicae* L.), and onion thrips

Supported by the L4-4554 applied research project, funded by the Slovenian Research Agency (ARIS) and the Ministry of Agriculture, Forestry and Food of the Republic of Slovenia. Part of the co-authors' activities in preparing this review paper was funded within Horticulture, No. P4-0013-0481, a program funded by ARIS.

https://doi.org/10.17221/161/2024-PPS

(*Thrips tabaci* Lindeman) (Fail & Pénzes 2004; Ordás & Cartea 2008; Ahuja et al. 2011). In more recent years, the group of stink bugs (Heteroptera: Pentatomidae) has also begun to damage cultivated cabbage in Europe, for example, from the genus *Eurydema* (Trdan et al. 2006a; Bohinc & Trdan 2010; Barić & Pajač 2011). Meanwhile, onion thrips and onion fly *(Delia antiqua* Meigen) are two main insect pests in the production of onions worldwide, including in Europe (Mishra et al. 2014).

Conventional methods for controlling pests on plants are usually carried out chemically using pesticides (Pavela 2016; Magierowitz et al. 2019). However, nowadays, due to higher environmental standards, there is a decline in the number of registered pesticides in Europe (Pinheiro et al. 2020). Moreover, in 2020, the EU (2023a) announced the 'Farm to Fork' strategy, highlighting a 50% reduction in the use and risk of chemical pesticides and a 50% reduction in the use of more hazardous pesticides, both by 2030. The goal of reducing chemical pesticide applications with minimal alternative solutions is causing increased problems of weeds and arthropod species (Meissle et al. 2010).

In implementing integrated pest management (IPM), sustainable biological, physical, and other non-chemical methods must be preferred over chemical methods if they provide satisfactory pest control (Gurr et al. 2000; EU 2023b). Apart from insecticides and plant resistance, one of the simplest ways to minimise pest damage is to use companion plants (Finch & Collier 2000). Companion planting is a well-known strategy to manage insect pests and support a natural enemy population through vegetative diversification (Reddy 2017; Sarkar et al. 2018). During the planting period, the primary role of the companion plant is usually not production. However, some companion plants can be harvested before or after the main crops are planted or sown (Gandarin et al. 2022). Based on these definitions, the authors concluded that the term companion plants can include cover crops, intercrops, and trap crops, which will be the focus of this article.

Firstly, cover crops are defined as low-growing plant species planted to protect the soil surface, conserve soil and water, maintain soil productivity, and, to some extent, maintain weeds and insect pests (Khan 2002). Secondly, intercrops are defined as two or more crop species or genotypes grown together and coexisting on the same field (Brooker et al. 2015). Intercropping acts as an intensification in both time and space dimensions (Vandermeer 1992), and a successful design of intercropping results in functional diversity, which limits pest or pathogen expansion and gives us a better understanding of host-pest or host-pathogen interactions (Finckh & Karpenstein-Machan 2002). Lastly, trap crops are susceptible plants purposely planted in companionship to the main crops to reduce pest numbers or lure the pests away from the main crops, which means reducing the damage caused by the pests (Gray & Koch 2002). Not only that, but trap crops also act like a sink for pests that could be vectors for other diseases (Sarkar et al. 2018).

In this article, we summarise the successful use of the companion plants mentioned above to control the main insect pests of cabbage and onions worldwide, focusing on a list of the main pests in Europe. The purpose of this summary is to give information to the readers regarding the type of companion plants that effectively control the main insect pests in cabbage and onion, including their description and mode of action. This review is important so the readers can choose the type of companion plants to deploy based on each type's advantages and disadvantages.

MATERIAL AND METHODS

In the process of obtaining scientific articles, the Google Scholar search engine was used. Some of the following keywords were used: companion plants, intercrops, trap crops, undersowing, living mulch, alternative control, non-chemical control, cabbage, onion, *Brassica, Allium,* insect pests, vegetable, Lepidoptera, Diptera, Hemiptera, Coleoptera, Thysanoptera, onion thrips, onion fly, flea beetles, butterfly, moth, aphids, stink bugs, clover, *Trifolium,* and net yield. The keywords were used either solely or combined with two or three [Electronic Supplementary Material (ESM) Table S1]. Additional studies were discovered among the citations in the article found from search engines and by recommendations of colleagues (ESM Table S2).

During the literature review, the authors summarised the findings into three tables. These tables were based on the purpose of the companion plants as a cover crop, intercrop, or trap crop. In the summary of the effects of cover crops, the authors defined cover crops as companion plants that generally cover soil surfaces between the plants and

https://doi.org/10.17221/161/2024-PPS

help maintain insect pests. Therefore, the results of searches with other keywords, such as "undersowing" or "living mulch", are included. The cover crop type of companion plants is typically sown in contrast to planted, with the understanding that they are not intended for harvesting. In the summary of the intercrops, the authors categorised the plants that were planted together with the main crops at the same growing time and can contribute to the overall net yield of the field. Furthermore, in the summary of the trap crop effect, the authors sought out successful cases of multicultural planting in which the trap cropping effect was present.

RESULTS AND DISCUSSION

We summarised the articles we gained in Tables 1–3, each containing the successful cases of the deployment of cover crops, intercrops, and trap crops in cabbage and onion cultivations. Table 1 lists the cover crop species that successfully controlled the main insect pests in cabbage and onion, along with the efficacy measurement and the working mechanism. Table 2 lists the species of plants that, when planted along with cabbage and onion, reduce the incidence of insect pest attack, along with their other efficacy and working mechanisms. Table 3 lists the species that act as a trap crop for cabbage's or onion's pests while planted together.

Cover crops. Cover crops are most suitable for transplanted plants with long vegetation periods, such as cabbage, leek, tomato, and pepper. The most suitable cover crops are legumes, grasses, or cereals (Kolota & Adamczewska-Sowinska 2013). Results in Table 1 confirmed this statement, showing that many studies were related to the use of cover crops in cabbage cultivation, which is a transplanted crop. In contrast, only one case was found in onion, a sown crop. The species of cover crops that are commonly used were species of clovers, including white, strawberry, subterranean, and alessandrinum clovers (*Trifolium repens* L., *Trifolium fragiferum* L., *Trifolium subterraneum* L., and *Trifolium alexandrinum* L.) (Leguminaceae), and cereals (Poaceae), including rye, wheat, and oat (*Secale cereale* L., *Triticum aestivum* L., and *Avena sativa* L.).

Table 1 summarised that to control flea beetles (*Phyllotreta* spp.) (Coleoptera: Chrysomelidae), cabbage root flies (*Delia radicum brassicae* L.) (Diptera: Anthomyiidae), turnip root flies (*Delia floralis* Fallen) (Diptera: Anthomyiidae), cabbage aphids (*Brevicoryne brassicae* L.) (Hemiptera: Aphididae), cabbage moth (*Mamestra brassicae* L.) (Lepidoptera: Pieridae), large white butterfly (*Pieris brassicae* L.) (Lepidoptera: Pierridae) and onion thrips (*Thrips tabaci* Lindeman) (Thysanoptera: Thripidae) in cabbage, most of the succesful studies used clover species. Additionally, in the control of green peach aphids (*Myzus persicae* Sulzer) (Hemiptera: Aphididae), diamondback moth (*Plutella xyllostella* L.) (DBM) (Lepidoptera: Plutellidae), small white butterfly/ imported cabbageworm (*Pieris rapae* L.) (Lepidoptera: Pieridae), and cabbage looper (*Trichoplusia ni* Hübner) (Lepidoptera: Noctuidae), the species of cereals were successfully used. Almost all the studied pests are specialists for the cruciferous family, except for the cabbage moth (*M. brassicae*) and green peach aphids (*M. persicae*), which have much broader host ranges.

Our summary of the cover crops' working mechanism included these four main mechanisms: *(i)* acting as a physical or visual disturbance for insects in finding host plants (Roberts & Cartwright, 1991; Mwaja & Masiunas 1996; Finch & Kienneger 1997; Hamid et al. 2006), *(ii)* disturbing the oviposiion process (Theunissen et al. 1995; Björkman et al. 2007; Björkman et al. 2010), *(iii)* enhancing more parasitisation or predation by natural enemies (Theunissen et al. 1995; Bryant et al. 2013), and *(iv)* triggering the self-defense mechanism of plants (Theunissen et al. 1995; Bottenberg et al. 1997).

The first mechanism happens as the number of green surrounding the host plants is the major factor that prevents insect pests from finding the host plants (Collier & Finch 2003). We observed this mechanism in the control of aphid (Hemiptera: Aphididae) (Table 1). Smith (1976) reported that in cage experience, the adult cabbage aphids (*Brevicoryne brassicae*) were more attracted to potted Brussels sprouts (*Brassica oleracea* var. *gemmifera)* surrounded by bare soil than to ones surrounded by rings of grass or artificial green rings. In the field experience by the same author, a weedy background was found to decrease the aphid population in Brussels sprouts, as it decreased the number of alatae attracted to crop plants. Finch and Kienneger (1997) reported a 95% reduction of the infestation of cabbage aphids (*B. brassicae*), stating that clover causes visual camouflage and physical

https://doi.org/10.17221/161/2024-PPS

Table 1. List of research projects that have successfully implemented cover cropping systems in reducing insect pests in cabbage and onion

Main crops	Main insect pests	Cover crops species	Sources	Efficacy	Mechanism	Yield reduction (present/ absent)
	Coleoptera					
Cabbage (*Brassica oleracea* var. *capitata*)	Flea beetles (*Phyllotreta* spp.) (Coleoptera: Chrysomelidae)	Green clover (*T. subterraneum* cv. Geraldton)	Lehmhus et al. (1996)	A reduced count of adult pests, and a higher count of natural enemies, especially syrphid larvae and parasitised larvae	Abstract only – mechanism unknown	Present, detail unknown
		White clover (*Trifolium repens* L.) and subterranean clover (*Trifolium subterraneum* L.)	Theunissen et al. (1995)	Lower feeding damage by flea beetles and the damage was only limited to monocropped plots	Not described in the article	Present, but unmarketable yields were significantly higher in monocrop treatment (17.6%) compared to undersown treatment (less than 7%)
		White clover (*T. repens*)	Wiech (1996)	A lower count of adult beetles in undersown plots	Abstract only – mechanism unknown	Present. The yields of early and late cabbages were reduced by 25 and 46%, respectively
		Strawberry clover (*Trifolium fragiferum* L.) and subterranean clover (*T. subterraneum* L.)	Lehmhus et al. (1996)	A less infestation of cabbage flea beetle on cabbage heads from undersown plots	Abstract only – mechanism unknown	No information
		White clover (*T. repens*)	Chairini et al. (2005)	A lower count of egg clusters and larvae of beetles, as well as an increase of carabid predators in the undersown plots	Not described in the article	No information
		White clover (*T. repens* cv. Haifa) in spring and alessandrinum clover (*Trifolium alexandrinu*m L.) in summer	Hamid et al. (2006)	37% and 27% less infestation by flea beetles in spring and summer, respectively	Physical barrier by clover hindered the movement of beetles and rendered the crops unfavorable to them	Present in undersowing 9 days before planting and on planting day. Absent in undersowing treatments 9 days after planting
		Wheat (*Triticum aestivum* L.)	Köneke & Böckmann (2024)	In 6 trials between 2017 and 2021, the feeding damage and flea beetles count on cabbage are generally higher in control compared to in the area with companion plants	Multicrop planting caused less immigration and more emigration of flea beetles in and out of the system, respectively	Present. The yield reductions of 7 to 40% in different experiments were recorded

https://doi.org/10.17221/161/2024-PPS

Table 1. To be continued...

Main crops	Main insect pests	Cover crops species	Sources	Efficacy	Mechanism	Yield reduction (present/ absent)
Cabbage (*Brassica oleracea* var. *capitata*)	**Diptera**					
	Cabbage root flies (*Delia radicum brassicae* L.) (Diptera: Anthomyiidae)	Clover (*Trifolium* spp.)	Langer (1994)	A better yield and quality of cabbages in undersown plots (less feeding damage)	Abstract only – mechanism unknown	No information
		Green clover (*T. subterraneum* cv. Geraldton)	Freuler et al. (1995)	A better quality of harvested products from undersown plots because of less feeding damage	Abstract only – mechanism unknown	No information
		White clover (*T. repens*) and subterranean clover (*T. subterraneum*)	Theunissen et al. (1995)	A lower percentage of egg-infested plants from undersown plots	Disruption for female flies in reaching the plant's stem base for oviposition	Present. See previous entry in Table 1 (Freuler et al. 1995)
		Strawberry clover (*T. fragiferum*) and subterranean clover (*T. subterraneum*)	Lehmhus et al. 1997	A less infestation of cabbage root flies on cabbage heads from undersown plots	Abstract only – mechanism unknown	No information
	Turnip root flies (*Delia floralis* Fallen) (Diptera: Anthomyiidae)	Red clover (*Trifolium pratense* L.)	Björkman et al. (2007); Björkman et al. (2010)	Reduction of oviposition rate by 42% in 2003 and 55% in 2004 in the undersown areas	Disruption of oviposition behavior by non-host plants.	No information
	Hemiptera					
	Cabbage aphids (*Brevicoryne brassicae* L.) (Hemiptera: Aphididae)	Rye (*Secale cereale* L.)	Roberts & Cartwright (1991)	11% fewer aphid populations	Rye acted as a physical barrier and deterred the movement of insects within the plots	Present. The yield in rye-undersown field was 28% less than in cabbage monoculture, but the undersown treatment resulted higher marketable yield
		Green clover (*T. subterraneum* cv. Geraldton)	Freuler et al. (1995)	Less feeding damage in harvested products from undersown plots	Abstract only – mechanism unknown	No information
		Green clover (*T. subterraneum* cv. Geraldton)	Lehmhus et al. (1996)	A reduced count of insect pests and a higher count of natural enemies	Abstract only – mechanism unknown	Present, detail unknown
		White *clover* (*T. repens*) and subterranean clover (*T. subterraneum* L.)	Theunissen et al. (1995)	A much larger number of parasitised aphids in the undersown plots	Increased parasitisation on pest	Present. See previous entry in Table 1 (Theunissen et al. 1995)
		White clover (*T. repens*)	Wiech (1996)	A lower count of aphids in undersown plots	Abstract only – mechanism unknown	Present. See previous entry in Table 1 (Wiech 1996)

https://doi.org/10.17221/161/2024-PPS

Table 1. To be continued...

Main crops	Main insect pests	Cover crops species	Sources	Efficacy	Mechanism	Yield reduction (present/ absent)
Cabbage (*Brassica oleracea* var. *capitata*)	Cabbage aphids (*Brevicoryne brassicae* L.) (Hemiptera: Aphididae)	Strawberry clover (*T. fragiferum*) and subterranean clover (*T. subterraneum*)	Lehmhus et al. (1997)	A lower count of cabbage aphids as well as a higher density of syrphid larvae in undersown plots	Abstract only – mechanism unknown	No information
		Subterranean clover (*T. subterraneum*)	Finch & Kienneger (1997)	95 and 78% reduction in the number of eggs laid/ plant/day in the years 1992 and 1993	Physical interference and visual camouflage by clover	No information
		Rye (*S. cereale*), hairy vetch (*Vicia villosa* Roth.), and their mixture	Kotliński (2011)	A reduced aphid population in the undersown areas by 86.1% to 100%	Not described in the article	No information
		Wheat (*Triticum aestivum* L.)	Köneke & Böckmann (2024)	In 6 trials between 2017 and 2021, the counts of the plants with > 10 *B. brassicae* were always higher in control plot compared to the plot with companion plants	Wheat act as inappropriate landing place for aphids that making their movement lest effective	Present. See previous entry in Table 1 (Köneke & Böckmann 2024)
	Green peach aphids (*Myzus persicae* Sulzer) (Hemiptera: Aphididae)	Green clover (*T. subterraneum* cv. Geraldton)	Lehmhus et al. (1996)	A reduced count of thrips and a higher count of natural enemies in undersown plots	Abstract only – mechanism unknown	Present, detail unknown
		Wheat (*Triticum aestivum* L.)	Köneke et al. (2023)	A lower count of aphids in undersown plots.	Not described in the article	Absent.The average cabbage weight was similar between the treatments
		Wheat (*Triticum aestivum* L.)	Köneke & Böckmann (2024)	In 3 trials between 2018 and 2021, the *M. persicae* aphid counts were always higher in control plot compared to the plot with companion plants	Wheat act as inappropriate landing place for aphids that making their movement lest effective	Present. See previous entry in Table 1 (Köneke & Böckmann 2024)
	Lepidoptera					
	Diamondback moth (*Plutella xyllostella* L.) (DBM) (Lepidoptera: Plutellidae)	Rye (*S. cereale*) sown in autumn and then destroyed in spring	Mwaja et al. (1996)	Less infestation of DBM larvae and lower cabbage damage rating in undersown plots	Cover crop residue deterred colonisation of cabbage by insect pest	No information
		Rye (*S. cereale*) sown in autumn and then mown in spring, with or without additional sowing of red clover (*T. pratense.*) in spring	Bottenberg et al. (1997)	Lower population of DBM larvae and pupae per plant in the undersown area	Cabbages grown in treatment had smaller size and less number of leaves, resulting in lower colonisation rates by insect pest	Present. Average cabbage height in rye mulch treatment, with or without additional red clover sowing, were significantly lower in two years, compared to the sole cabbage planting

https://doi.org/10.17221/161/2024-PPS

Table 1. To be continued...

Main crops	Main insect pests	Cover crops species	Sources	Efficacy	Mechanism	Yield reduction (present/ absent)
Cabbage (*Brassica oleracea* var. *capitata*)	Diamondback moth (*Plutella Syllostella* L.) (DBM) (Lepidoptera: Plutellidae)	subterranean clover (*T. subterraneum*)	Finch & Kienneger (1997)	42% reduction in the number of eggs laid per plant per day	Physical interference and visual camouflage by clover	No information
	Cabbage moth (*Mamestra brassicae* L.) (Lepidoptera: Pieridae)	White *clover* (*T. repens*) and subterranean clover (*T. subterraneum*)	Theunissen et al. (1995)	A significantly lower count of *M. brassicae* eggs in 1990. 41% fewer plants with feeding injuries in 1991	Not described in the article	Present. See previous entry in Table 1 (Theunissen et al. 1995)
		White clover (*T. repens*)	Wiech (1996); Wiech (2000)	A lower count of larvae in undersown plots	Abstract only – mechanism unknown	Present. See previous entry in Table 1 (Wiech 1996; Wiech 2000)
		White clover (*T. repens* cv. Pertina) and subclover (*T. subterraneum* cv. Geraldton)	Brandsæter et al. (1998)	Lower number of eggs/plants in undersown plots. A 20% more marketable cabbages from the plots with living mulch	Not described in the article	Absent in the treatment with white clover, present (11% reduction) in the treatment with subclover
		White clover (*T. repens*)	Chairini et al. (2005)	A significantly lower oviposition in the cabbage with undersowing	Not described in the article	No information
	Cabbage looper (*Trichoplusia ni* Hübner) (Lepidoptera: Noctuidae)	Rye (*S. cereale*) sown in autumn and then destroyed in spring	Mwaja et al. (1996)	A lower infestation of larvae and cabbage's damage rating in undersown plots	Cover crop residue deterred colonisation of cabbage by insect pest	No information
		Rye (*S. cereale*) sown in autumn and then mown in spring, with or without additional sowing of redclover (*T. pratense* L.) in spring	Bottenberg et al. (1997)	A lower population of larvae per plant from the undersown area	Cabbages grown in treatment had smaller size and fewer number of leaves, resulting in lower colonisation rates by insect pest	Present. See previous entry in Table 1 (Bottenberg et al. 1997)
		Oat (*Avena sativa* L.)	Bryant et al. (2013)	A lower insect abundance when oat cover crops weren't immediately killed after cabbage transplanting.	Cover crops enhanced the population of natural enemies and reduced the pest population	Present when the oat was killed more than 9–14 days after cabbage transplanting, with yield reduction up to 50%

https://doi.org/10.17221/161/2024-PPS

Table 1. To be continued...

Main crops	Main insect pests	Cover crops species	Sources	Efficacy	Mechanism	Yield reduction (present/ absent)
Cabbage (*Brassica oleracea* var. *capitata*)	Small white butterfly/ imported cabbageworm (*Pieris rapae* L.) (Lepidoptera: Pierridae)	Rye (*S. cereale)* sow in autumn and then destroyed in spring	Mwaja et al. (1996)	A lower infestation of larvae and cabbage's damage rating in undersown plots	Cover crop residue deterred colonisation of cabbage by insect pest	No information
		Rye (*S. cereale*) sown in autumn and then mown in spring, with or without additional sowing of red clover (*T. pratense* L.) in spring	Bottenberg et al. (1997)	lower population of larvae per plant from the undersown area	Cabbages grown in treatment had smaller size and fewer number of leaves, resulting in lower colonisation rates by insect pest	Present. See previous entry in Table 1 (Bottenberg et al. 1997)
		Oat (*A. sativa*) undersowing, killed on cabbage planting day or a few days after	Bryant et al. (2013)	A lower larvae count when oat cover crops weren't immediately killed after cabbage transplanting.	Cover crops enhanced the population of natural enemies and reduced the pest population	Present. See previous entry in Table 1 (Bryant et al. 2013)
	Large white butterfly (*Pieris brassicae* L.) (Lepidoptera: Pierridae)	Subterranean clover (*T. subterraneum* L.)	Finch & Kienneger (1997)	100% reduction in the number of eggs laid per plant per day	Physical interference and visual camouflage by clover	No information
	Thysanoptera					
	Onion thrips (*Thrips tabaci* Lindeman) (Thysanoptera: Thripidae)	Clover (*Trifolium* spp.)	Langer (1994)	A better yield and quality of cabbages in undersown plots	Abstract only – mechanism unknown	No information
		White *clover* (*T. repens*) and subterranean clover *(T. subterraneum)*	Theunissen et al. (1995)	A significantly lower number of non-marketable cabbage heads	The stress induced by the competition with cover crops made physiological changes in plants and made them less attractive to insects	Present. See previous entry in Table 1 (Theunissen et al. 1995)
		Strawberry clover (*T. fragiferum* L. cv. Palestine) and spurrey (*Spergula arvensis* L.*)*.	Theunissen & Schelling (1996)	A lower count of onion thrips population inside cabbage heads, as well as higher quality of cabbage heads	Abstract only – mechanism unknown	No information
		Strawberry clover (*T. fragiferum*) and subterranean clover (*T. subterraneum*)	Lehmhus et al. (1997)	A less infestation thrips in cabbage heads from undersown plots	Abstract only – mechanism unknown	No information
		White clover (*T. repens*)	Pobozniak & Wiech (2005)	Fewer thrips were found inside the cabbage heads from undersown areas	Abstract only – mechanism unknown	No information

https://doi.org/10.17221/161/2024-PPS

Table 1. To be continued...

Main crops	Main insect pests	Cover crops species	Sources	Efficacy	Mechanism	Yield reduction (present/ absent)
Onion (*Allium cepa* L.	Onion thrips (*T. tabaci*) (Thysanoptera: Thripidae)	Buckwheat (*F. esculentum* Moench.), lacy phacelia (*Phacelia tanacetifolia* Benth.), orchard grass (*Dactylis glomerata* L.), and white clover (*T. repens)*	Trdan et al. (2006b)	In 2004, 70% of onions with lady phacelia weren't damaged, and neither were 50% of onions with orchard grass and white clover. In 2005, the damage of thrips in all undersown plots was low, in general under 20%.	The undersown crops maintained the population of natural enemies of onion thrips	No information

https://doi.org/10.17221/161/2024-PPS

Table 2. List of research projects that have successfully implemented intercropping systems in reducing insect pests in cabbage and onion

Main crops	Main insect pests	Intercrop species	Sources	Efficacy	Mechanism	Yield reduction (present/absent)
	Coleoptera					
Cabbage (*B. oleracea* var. *capitata*)	Flea beetles (*Phyllotreta* spp.) (Coleoptera: Chrysomelidae)	French marigold (*Tagetes patula nana* var. *Kolombina*) and pot marigold (*Calendula officinalis* var. *Promyk*)	Jankowska et al. (2009)	A lower count of adult flea beetles in the intercrop plots compared to the monoculture plots from 2003–2005	The intercrops enhanced the population of natural enemies	No information
	Hemiptera					
	Aphids (all Aphididae spp. unspecified) (Hemiptera: Aphididae)	Coriander (*Coriandrum sativum* L.)	Morris & Li (2000)	A decline in aphid counts from plants that were in closer distance to coriander	Increased predation by hoverflies, which were attracted by coriander	No information
		Leafy daikon (*Raphanus sativus*), barley (*Hordeum vulgare* L.)	Sekine et al. (2021a)	A reduction in aphid count (all stages) because of intercropping	Interference of visual host plant finding cues of insect pests	No information
		Chenopodium/white goosefoot (*Chenopodium album* L.)	Hithesh et al. (2025)	The lowest aphids count in the main crops for two years in a row	The intercrops provided food source for natural enemy (coccinelids) and supporting their longevity, so they effectively reduced insect pests	Absent. The highest cabbage yield was obtained from the chenopodium intercropping plot, which was almost doubled than the yield from the monoculture plot
	Cabbage aphids (*B. brassicae*) (Hemiptera: Aphididae)	French marigold (*T. patula nana* var. *Kolombina*) and pot marigold (*C. officinalis* var. *Promyk*)	Jankowska et al. (2009)	A lower count of adult aphids in the intercrop plots compared to the monoculture plots from 2003-2005. Lower percentages of plants with aphid infestations	The intercrops enhanced the population of natural enemies, including parasitoid wasps *Diaretiella rapae* M'Intosh	No information
		Onion (*A. cepa*)	Baidoo et al. (2012)	50% fewer infestations of aphids in intercropped cabbage along with less damaged cabbage head and leaves	Onion produced confusing olfactory and visual cues that affect insects' ability to disperse	Absent. The weight of cabbage head in the row planting of 4 rows of cabbage to 1 row of onion is twice compared to other treatments due to less damaged head at harvest

https://doi.org/10.17221/161/2024-PPS

Table 2. To be continued...

Main crops	Main insect pests	Intercrop species	Sources	Efficacy	Mechanism	Yield reduction (present/absent)
	Cabbage aphids (*B. brassicae*) (Hemiptera: Aphididae)	Alfalfa (*Medicago sativa* L.)	Laxman et al. (2019)	A smaller population of cabbage aphids because of alfalfa intercrop	Abstract only – mechanism unknown	No information
	Lepidoptera					
Cabbage (*B. oleracea* var. *capitata*)	Diamondback moth (*P. xyllostella*) (DBM) (Lepidoptera: Plutellidae)	French marigold (*T. patula nana* var. *Kolombina*) and pot marigold (*C. officinalis* var. *Promyk*)	Jankowska et al. (2009)	A lower count of DBM larvae and pupae in the intercrop plots compared to the monoculture plots	The intercrops enhanced the population of natural enemies	No information
		Onion (*A. cepa*), tomato (*Solanum lycopersicum* L.), pepper (*Capsicum annuum* L.)	Asare-Bediako et al. (2010)	A lower DBM population, higher yield, and less leaf damage in/from the intercropped area. The performance is comparable with the organophosphate insecticide chlorpyrifos	Intercrops disturb the life cycle of DBM and hence increase plant health and growth	Absent. Average cabbage weights per plant were respectively 61, 17, and 69% higher than the average of the monocrop control at harvest
		Tomato (*S. lycopersicum* L.) and chilli (*Capsicum annuum* L.)	Aung et al. (2018)	The reduction of the count of DBM larvae both in the winter and summer seasons	Intercrops gave out confusing olfactory and visual cues to the insect pests	No information
		Alfalfa (*M. sativa* L.), turnip (*Brassica rapa* L., subsp. *rapa*)	Laxman et al. (2019)	A smaller population of DBM because of alfalfa intercrop. A higher parasitisation of DBM larvae because of turnip intercrop	Abstract only – mechanism unknown	No information
		Onion (*A. cepa*)	Fening et al. (2020)	A smaller count of DBM larvae in the intercropped cabbage. A higher count of natural enemies (ladybird beetles, hoverflies, and spiders) in the intercrop plots	Onion scent repelled the DBM larvae, especially later in the season when the onion developed more foliage	Absent. The yields of cabbage were similar in sole cropping and in intercropping with onions
		Chenopodium/white goosefoot (*Chenopodium album* L.)	Hithesh et al. (2025)	The lowest larvae count in the main crops for two years in a row	The flowers of intercrops provide the food source for natural enemies and further enhancing their longevity	Absent. See previous entry in Table 2 (Hithesh et al. 2025)

Plant Protection Science, 62, 2026 (1): 1–26

https://doi.org/10.17221/161/2024-PPS

Table 2. To be continued...

Main crops	Main insect pests	Intercrop species	Sources	Efficacy	Mechanism	Yield reduction (present/absent)
Cabbage (*B. oleracea* var. *capitata*)	Cabbage moth (*M. brassicae*) (Lepidoptera: Pieridae)	Corn flowers (*Centaurea cyanus* L.)	Balmer et al. (2014)	Increased larval and egg parasitation and egg predation of the herbivore, reduced herbivory rates, and increased crop biomass	Companion plants, which were specially chosen to benefit a larval parasitoid but not its host, significantly increase parasitisation in intensive crop fields	Absent. In the first year, companion plants gave positive effect (18% raise) to the yield. In second year, the yields of cabbage were similar on with or without intercrop
		French marigold (*T. patula nana* var. *Kolombina*) and pot marigold (*C. officinalis* var. *Promyk*)	Jankowska et al. (2009)	A lower count of egg clusters in the intercrop plots compared to the monoculture plots	The intercrops enhanced the population of natural enemies	No information
	Small white butterfly/imported cabbageworm (*P. rapae*) (Lepidoptera: Pierridae)	French marigold (*T. patula nana* var. *Kolombina*) and pot marigold (*C. officinalis* var. *Promyk*)	Jankowska et al. (2009)	A lower count of butterfly eggs in the intercrop plots	The intercrops enhanced the population of natural enemies	No information
		Garlic (*Allium sativum* L.)	Yong et al. (2013)	The reduction of population densities of white butterflies by 48% and an increased count of natural enemies	Abstract only – mechanism unknown	No information
		Leafy daikon (*R. sativus*), barley (*H. vulgare* L.)	Sekine et al. (2021a)	A reduction in egg and larvae count because of intercropping	Interference of visual host plant finding cues	Present. The max. yield in intercropping treatment was 85% of yield in cabbage monocrop treatment
		White mustard (*Sinapsis alba* L.)	Hithesh et al. (2025)	The lowest larvae count in the main crops for two years in a row	The flowers of intercrops provide the food source for natural enemies and further enhancing their longevity	Absent. The yield of the plot with white mustard intercrop is one-third higher than the yield from the monocropping plot
	Large white butterfly (*P. brassicae*) (Lepidoptera: Pierridae)	Turnip (*Br. rapa* L., subsp. Rapa)	Laxman et al. (2019)	A smaller population of butterfly larvae because of alfalfa intercrop. A higher parasitisation of butterfly larvae because of turnip intercrop.	Abstract only – mechanism unknown	No information
	Thysanoptera					
	Onion thrips (*T. tabaci* Lindeman) (Thysanoptera: Thripidae)	Leafy daikon (*R. sativus*), barley (*H. vulgare* L.)	Sekine et al. (2021a)	A reduction in egg and larvae count because of intercropping.	Interference of visual host plant finding cues	No information

Table 2. To be continued...

Main crops	Main insect pests	Intercrop species	Sources	Efficacy	Mechanism	Yield reduction (present/absent)
	Diptera					
Onion (*A. cepa*)	Onion flies (*D. antiqua*) (Diptera: Anthomyiidae)	Green geranium (*Pelargonium × hortorum*), red pelagornium (*Pelargonium × hortorum*), *Stellaria media*, carrot (*D. carota* ssp. sativus), dahlia [*Dahlia variabilis* (green)], pennyroyal (*Mentha pulegium*), flowering tobacco (*Nicotiana × sandereae*), black-bindweed (*Sallopia convolvulus*), lobelia (*Lobelia erinus*), dahlia (*Dahlia variabilis* (red)), French marigold (*T. patula*), strawflower (*Helichrysum bracteatum*), white goosefoot (*Chenopodium album*), lemon mint (*Mentha piperita × citrata*)	(Finch et al. 2003)	Consecutively from top to bottom of plant species, only 8-57% of total fly eggs were laid around the host plants surrounded by those companion plants, compared to the number of eggs around host plants grown in bare soil	The non-host plant disrupted the activity of onion flies in finding the host plants. The disruption was the effect of the green color of non-host plants and not so much of their odors or tastes	No information
	Thysanoptera					
	Onion thrips (*T. tabaci* Lindeman) (Thysanoptera: Thripidae)	Carrot (*Daucus carota* L.)	Uvah & Coaxer (1984)	A 50% decrease in onion thrips population with mixed planting of carrots and onion. The increased populations of Carabid and Staphylinid egg predators.	Interference in host plant recognition by plant density and proximity of the carrots to the onions	No information on onion yield, but intercropping carrots and onions resulted in 67% more undamaged carrots compared to sole carrots treatment at harvest
		Rosemary (*Rosmarinus officinalis* L.), holy basil (*Ocimum sanctus* L.), common basil (*Ocimum basilicum* L.), and Puerto rican oregano (*Lippia micronera* B.)	Cabrera-Ascensio & Vélez (2006)	The reductions of the counts of adult and nymph of *T. tabaci* in comparison to the control plants, with the maximum reduction were achieved using *L. micronera* intercrop.	Abstract only – mechanism unknown	No information

https://doi.org/10.17221/161/2024-PPS

https://doi.org/10.17221/161/2024-PPS

Table 2. To be continued...

Main crops	Main insect pests	Intercrop species	Sources	Efficacy	Mechanism	Yield reduction (present/absent)
Onion (*A. cepa*)	Onion thrips (*T. tabaci* Lindeman) (Thysanoptera: Thripidae)	Carrot (*D. carota*), French beans (*Phaseolus vulgaris* L.), and spider plant (*Cleome gynandra* L.)	Gachu et al. (2012)	A significant reduction in thrips population by up to 45.2% and 21.6%, respectively by spider plants and carrots. The reduction of damage severity up to 15.7%	The intercrops provided visual and physical interference to thrips	Present in the intercropping of onion and carrot (total yield reduction up to 19%), but absent in the intercropping with French beans and spider plant
		Cotton (*Gossypium hirsutum* L), tomato (*S. lycopersicum*), chili (*C. annuum*), and okra (*Abelmoschus esculentus* L.)	Khaliq et al. (2016)	Thrips population was reduced by 68.6%, 31.2%, 25.8%, and 9.6% when onion was intercropped with cotton, tomato, chili, and okra	Particularly in intercropping with cotton, the thrips population was observed to be moving towards cotton seedlings from the main crops. The mechanism of the intercropping with other plants is unknown	Absent. An 11.39% increase in onion bulb weight was recorded by using a 20 cm plant-to-plant distance
		Carrot (*D. carota*)	Moraiet et al. (2017)	A reduced thrips population up to 11.79 thrips/plant	Abstract only, mechanism unknown	Present. The maximum yield was recorded on sole onion treatment
		Lettuce (*L. sativa*)	El-Fakharany (2018)	A significant reduction of the thrips population in onion	Not explained in the article	Absent. The yields of onion were similar with or without intercropping
		Wheat (*T. aestivum*), mustard (*Brassica rapa* subsp. *oleifera*), and fennel (*Foeniculum vulgare* Mill.)	Basri & Ansari (2020)	Reduction in thrips population density because of planting these intercrops as barrier crops	Intercrops acted as physical barriers against thrips to find host plants	Absent. The maximum yield was achieved in intercropping with wheat, detail unknown
		Barley (*H. vulgare*)	Sekine et al. (2021b)	A significantly reduced thrips population in onion. An increase in the carabid beetle population	Barley acts as a physical barrier against thrips in finding the host plants	Absent. A comparable onion bulb size between monoculture and trimmed-barley intercrop was recorded
		Barley (*H. vulgare)*	Uesugi et al. (2023)	Lower abundance of thrips in areas with intercrops	Enhancement of natural enemies, especially hoverfly larvae *(Sphaerophoria macrogaster* Thomson) which was observed to predate thrips	No information

https://doi.org/10.17221/161/2024-PPS

Table 3. List of research projects that have successfully implemented trap cropping systems in reducing insect pests in cabbage and onion

Main crops	Main insect pests	Cover crops species	Sources	Efficacy	Yield reduction (present/ absent)
Cabbage	**Coleoptera**				
	Flea beetles (*Phyllotreta* spp.) (Coleoptera: Chrysomelidae)	Oil radish (*Raphanus sativus* L.)	Bohinc & Trdan (2012)	Oil radish was shown as the most attractive trap crop to the flea beetle. Additionally, it did not show competitiveness to main crops, and provided pollen for beneficial insects	Inconsistant. Oil radish caused yield reduction in 50% of the case
		white mustard (*Sinapsis alba* L.), oilseed rape (*Brassica napus* L.), oil radish (*R. sativus* L. var. *oleiformis*)	Bohinc & Trdan (2013)	Higher damage index by flea beetles on trap crops during the growth period	No information
	Diptera				
	Cabbage root flies (*D. radicum brassicae* L.) (Diptera: Anthomyiidae)	Chinese cabbage (*B. rapa* subsp. *pekinensis*), turnip (*Brassica rapa* subsp. *rapa*)	Rousse et al. (2003)	Female flies were the most attractive to Chinese cabbage and turnip. Turnip was found to be the most attractive for the fly parasites *Aleochara bilineata* and *A. bipustulata*, resulting in less feeding damage and more pupae parasitisation	No information
	Hemiptera				
	Cabbage stink bugs (*Eurydema* spp.) (Hemiptera: Pentatomidae)	Oil rape (*B. napus*)	Bohinc & Trdan (2012)	Oil rape was shown as the most attractive trap crop to the cabbage stink bugs	Generaly absent. Oil rape caused yield reduction only in 25% of the case
	Cabbage aphids (*B. brassicae* L.) (Hemiptera: Aphididae)	Kale (*B. oleracea* var. *acephala*), cauliflower (*B. oleracea* var. *botrytis*), broccoli (*B. oleracea* var. *italica*), Chinese cabbage (*B. campestris* L. ssp. *pekinensis*), Indian mustard (*B. juncea* L. Czern.), and their mixture	Lubanga et al. (2012)	Inconsistant result was recorded. The cabbage in trap cropping areas generally has fewer aphids per plant in 50% of the case	No information
	Lepidoptera				
	Diamondback moth (*P. xyllostella* L.) (DBM) (Lepidoptera: Plutellidae)	Indian mustard (*Brassica juncea* L. Czern.)	Srinivasan & Moorthy (1991)	A significantly smaller larval population on the cabbage grown with trap crop compared to cabbage grown solely	Absent. In all trap crops treatment, the marketable yields were higher than in the monocrop
		Mustard (*S. alba* L.)	Pawar & Lawande (1995)	A reduced incidence of the larvae on cabbage. When planted in the maximum cost-benefit ratio of 1 : 6	Absent. An increase of up to 75% in marketable cabbage yield was achieved

Plant Protection Science, 62, 2026 (1): 1–26

https://doi.org/10.17221/161/2024-PPS

Table 3. To be continued...

Main crops	Main insect pests	Cover crops species	Sources	Efficacy	Yield reduction (present/ absent)
Cabbage	Diamondback moth (*P. xyllostella* L.) (DBM) (Lepidoptera: Plutellidae)	Indian mustard (*B. juncea*), cabbage (*B. oleraceae* var. *capitata*) variety 'Tastie'	Luther et al. (1996)	Six times higher count of DBM larvae in pupae in trap crops compared to the main crops	Absent. The yields between the monoculture and trap-cropped cabbage were comparable
		Indian mustard (*B. juncea*)	Åsman (2002)	In the laboratory experiment, the moth's preference to lay egg on mustard compared to on cabbage was recorded. In the field experiment, a significantly larger number of eggs were laid on trap crops compared to primary crops	No information
		Indian mustard (*B. juncea*) trap crop, in integration with egg parasitoid of pink bollworm (*Trichogrammatoidea bactrae* Nagaraja)	Krishnamoorty et al. (2003)	In two growing periods, a higher number of DBM larvae per plant was recorded in the control plots compared to plots with trap crops	No information
		Chinese cabbage (*B. rapa* subsp. *pekinensis*)	Satpathy et al. (2010)	In a preliminary experiment in the laboratory and net house, a favorability to Chinese cabbage by the DBM was found	No information
		Kale (*B. oleracea* var. *acephala*), cauliflower (*B. oleracea* var. botrytis), broccoli (*B. oleracea* var. *italica*), Chinese cabbage (*B. campestris* L. ssp. *pekinensis)*, Indian mustard (*B. juncea* L. Czern.), and their mixture	Lubanga et al. (2012)	The results of the oviposition of DBM in trap crops varied, but a reduced oviposition of up to 86% was reported in the use of mixed *Brassicaceae* plants as trap crops. As a single trap crop, kale and indian mustard reduced the oviposition up to 46 and 56%, respectively	No information
		White mustard (*S. alba*)	Daniarzadeh et al. (2014)	An up to 8.74 times higher number of average DBM adults in white mustard compared to it in the cabbage	No information
		Mixture of Red Russian kale (*Brassica oleracea* var. *acephala*) and glossy collards (*Brassica oleracea* var. *italica*) as trap crops, planted together with insectary plant species sweet alyssum (*L. maritima*) or buckwheat (*F. esculentum*)	Shrestha et al. (2019)	89 and 161 times higher density of DBM larvae on the collard and kale trap crops, respectively, compred to on cabbage cash crop. Insectary plants contributed to the consumption of pests that aggregated on the trap crop	Absent. In trap crop treatments, the yields were generally higher than in monoculture, except when sweet alyssum was applied together with trap crops, which caused 8% yield reduction

https://doi.org/10.17221/161/2024-PPS

Table 3. To be continued...

Main crops	Main insect pests	Cover crops species	Sources	Efficacy	Yield reduction (present/ absent)
Cabbage	Diamondback moth (*P. xyllostella* L.) (DBM) (Lepidoptera: Plutellidae)	Kai choi (*B. juncea*) in integration with entomopathogenic nematode (EPN) *Steinernema feltiae* Filipjev	Budhathoki et al. (2022)	A reduced abundance of DBM larvae on cabbage and kale main crops. A reduced leaf damage in some treatment combinations	Present when planting distance between main crops and trap crops was < 30 cm or less, absent when this planting distance was modified to 60 cm
		Indian mustard (*B. juncea*) and buckwheat (*F. esculentum*)	Sapkota et al. (2022)	A reduced population of DBM larvae on cabbage by 20 and 9% for Indian mustard and buckwheat, respectively, on day 86th after transplanting	Absent. The use Indian mustard and buckwheat increased the yield by 13% and 7%, respectively
	Cabbage looper (*T. ni* Hübner) (Lepidoptera: Noctuidae)	Red Russian kale (*B. oleracea* var. *acephala*), and glossy collards (*B. oleracea* var. *italica*)	Shrestha et al. (2019)	37 and 18 times higher density of cabbage looper' larvae on the kale and collard trap crops, respectively	See previous entry in this table
	Small white butterfly/ imported cabbageworm (*P. rapae* L.)	Indian mustard (*B. juncea*), cabbage (*B. oleracea* var. *capitata*) variety 'Tastie'	Luther et al. (1996)	Three times higher count of larvae in trap crops compared to the main crops	Present. See previous entry in Table 3 (Luther et al. 1996)
	(Lepidoptera: Pieridae)	Kai choi (*B. juncea*) in integration with entomopathogenic nematode (EPN) *Steinernema feltiae* Filipjev	Budhathoki et al. (2022)	A reduced abundance of butterfly larvae on cabbage and kale main crops. A reduced the leaf damage in some combinations	Present. See previous entry in Table 3 (Budhathoki et al. 2022)
	Thysanoptera				
Onion (*A. cepa*)	*T. tabaci* Lindemann (Thysanoptera: Thripidae)	lacy phacelia (*Phacelia tanacetifolia* Benth.), buckwheat (*Fagopyrum esculentum* Moench.), and carrot (*Daucus carota* L.)	Buckland et al. (2017)	All trap crops, when flowering or in a lush vegetative state, supported all stages of onion thrips. Fewer thrips eggs were counted in onion compared to in trap crops	No information
		Marigold (*T. erecta*), fennel (*Foeniculum vulgare* Miller), coriander (*C. sativum*), and carrot (*D. carota*)	Chandio et al. (2020)	Lower counts of thrips in onion grown in trap crops compared to monoculture. Marigold, fennel, coriander and carrot reduced the thrips count by 57, 54, 51, and 46%, respectively.	Absent. Between 7–23% more yields were achieved by trap crops

https://doi.org/10.17221/161/2024-PPS

interference for aphids in finding the host plants. The confusion caused by background plants also directly disturbs the oviposition process, which we summarised as the second mechanism. This mechanism was observed in the control of flies (Diptera: Anthomyiidae). Finch (1995) reported that a grass background attracted mainly male flies, while female flies preferred bare soil. Additionally, Theunissen et al. (1995) observed that the female cabbage root fly is disturbed by clover in reaching the plant's stem base for oviposition, while Björkman (2007, 2010) explained that the oviposition behaviour by turnip root flies (*Delia floralis* Fallén) is also disturbed by clover. Morley et al. (2005) reported that the female adult flies of D. radicum, after landing on the host (cabbage) or non-host plants (clover), left the plants after 2.25 min and 8.5 min, respectively. Their landings on the non-host plants strongly disrupt them from finding host plants. Finch and Collier (2000) explained this phenomenon as the 'appropriate or inappropriate landing' theory. Generally, when the female insect pests land on the host plants (appropriate landing), the rather complicated ovipositing process starts, and eventually, the number of eggs is laid. However, the ovipositing process should be repeated when they land in a non-host plant (inappropriate landing). Multicultural planting creates a diverse background that increases the chance that the insects will lose the host plant much more.

The third mechanism is related to the work of natural enemies in reducing insect pests. Root (1973) was the first to mention this theory, stating that the lower number of pest insects in the complex environment is because predators and parasitoids are more effective in such settings. Theunissen et al. (1995) reported more parasitised aphids in undersown plots than in the control plot. Bryant et al. (2013) explained that the increased number of natural enemies is the reason for less cabbage looper (T. *ni*) and imported sabbageworm (*P. rapae*) infestation, in which oat mulch increased the predator abundance by 30–50%. Additionally, other researchers agree that the number of natural enemies is increased in the cover crop system (Lehmhus et al. 1996, 1997, Chairini et al. 2005). Still, they did not explain the relation between the increased number and suppression of insects.

Dassou and Tixier (2016) explained that natural control in plant-diversified systems is more likely to occur in specialists than in generalist herbivores. The specialists are more vulnerable to cover crops, mostly due to host-finding disruption, in which they are strongly relying on the glucosinolate cue to find the host plants (Robin et al. 2017). Also, increased predation might put them under further pressure (Bryant et al. 2013). Our results confirmed the theory because the first three mechanisms hold for most of the specialist insect pests related to this study. Unfortunately, for generalist pests, cabbage moth (*M. brassicae*) and green peach aphid (*M. persicae*), almost all researchers did not elaborate on the working mechanism of the cover crops in controlling them. Therefore, there is still a lack of understanding of how the system reduces the population of generalist species.

The fourth working mechanism is based on the theory that competition-induced changes in cabbage plant quality occur when the intercrops are present (Theunissen et al. 1995). The stress induced by the competition with cover plants alters the physiology of the main crops, making them more toxic, less attractive, or less nutritious (Björkman et al. 2011). Theunissen et al. 1995 mentioned that a smaller cabbage head, caused by cover crop-induced stress, is more compact and less sensitive to pest attack. Bottenberg et al. (1997) confirmed this and observed that cabbages grown in cover cops had a smaller size and number of leaves and less DBM larvae infestation. Ahuja et al. (2011) stated that the self-defence mechanism of cruciferous plants is mainly to synthesise glucosinolates. This specific secondary metabolite mediates the interaction between cruciferous plants and their associated insect herbivores. Species with higher glucosinolates are less preferred by insect pests, especially the generalist species such as lepidopteran larvae (*Spodoptera* sp., *Mamestra* sp.) that do not have the mechanism to tolerate this compound (Bohinc et al. 2014; Jeschke et al. 2017). More specialist crucifer pests can adapt to or detoxify high concentrations of glucosinolate or even benefit from it (Winde & Wittstock et al. 2011). However, their host preferences could also still be influenced by other factors such as the plants' nutritional contents and environmental conditions (Badenez-Perez 2023).

Cover crops often become too strong or too weak, and both can result in poor productivity of the main crops. Too strong a growth can cause competition with the main crops (Lotz et al. 1997), while too weak a growth results in poor coverage

https://doi.org/10.17221/161/2024-PPS

and severe weed infestation (Bryant et al. 2013, Bilenky et al. 2022). Most studies reported the yield reduction because of cover crops (Table 1), with only a few exceptions. In attempts to reduce competition with cover crops while keeping the weed suppression, the dosage of sown cover crops should be ideal (Stivers-Young & Teasdale 2004), and a termination of cover crops after the main crop is established is recommended (Brandsæter 1998; Bryant et al. 2013). The timing for the termination should be carefully chosen, considering the growth habit of cover crops. Bryant et al. 2013 reported that keeping the oat cover crops until 9–14 days after the cabbage transplanting date did not reduce yield. However, even though the yield of the main crop is reduced, it often happens that the marketable yield is higher in cover crop plots due to lower insect damage (Brandsæter et al. 1998; Mandal & Dash 2012), which can also be counted as one important measurement of success.

Intercrops. Intercropping aims to achieve better yield, productivity, and profitability (Guvenc & Yildirim 2006), while controlling plant pests is also desired. Because of those multiple purposes, the selections of the intercropped plants are very diverse, from vegetable plants, cereal crops, or aromatic and herbal plants (Table 2).

We summarised that the most common mechanisms by which intercrops reduce the pest are: *(i)* disturbing the pests to find host plants, by acting as a physical barrier (Uvah & Coaxer 1984; Finch et al. 2003; Gachu et al. 2012; Basri & Ansari 2020; Sekine et al. 2021a, 2021b) or giving out visual or olfactory interference (Baidoo et al. 2012; Aung et al. 2018; Fening et al. 2020), *(ii)* disrupting the oviposition or life-cycle of pests (Asare-Bediako et al. 2010), and *(iii)* enhancing the number of natural enemies and increase predation or parasitism (Morris & Li 2000; Trdan et al. 2006b; Jankowska et al. 2009; Balmer et al. 2014; Uesugi et al. 2023, Hithesh et al. 2025). These mechanisms are similar to cover crops, which were already explained previously. The additional explanation should be given only on the third mechanism, in which some researchers elaborated on how natural enemies reduced the pest populations. Morris & Li (2000) explained that coriander (*C. sativum*) intercrop attracted the population of hoverflies (Syrphidae), which later predate aphids (all Aphididae spp., unspecified) pests in the planting area. Additionally, Balmer et al. (2014) explained that cornflowers (*Centaurea cyanus* L.), which were specifically chosen to benefit larval parasitoid *Microplitis mediator* Halida (Hymenoptera: Braconidae) and egg parasitoids *Telenomus* sp. (Hymenoptera: Scelionidae) and *Trichogramma* spp. (Hymenoptera: Trichogrammatidae), significantly increase parasitisation of cabbage moth (*M. brassicae*) larvae and eggs. Additionally, Hithesh et al. explained that the use of flowering Asteraceae flowers, such as chenopodium/white goosefoot (*Chenopodium album* L.), provides a food source that is rich in sugar and protein and enhances the longevity of natural enemies in the system, including the coccinelids (Coleoptera: Coccinelidae) that prey on aphids (*Aphididae* spp.).

In attempts to reduce insect pest infestation, intercropping with the plants that produce strong volatiles, or what we call ‚aromatic plants‘, is very common, particularly through a ‚push and pull‘ strategy. This strategy is done by using stimuli to make the protected resource unattractive or unsuitable for insect pests (push), and at the same time luring them towards an attractive alternative source (pull) (Cook et al. 2007) or to trap crops (Hassanali et al. 2008). The difference between the 'push and pull' strategy and trap crops is that 'push and pull', while the classic trap crops solely use the pest attraction. More details about trap crops will be discussed in the next chapter. In cabbage production, lemongrass [*Cymbopogon citratus* (DC.) Stapf] worked as a repellent, and marigold (*Tagetes erecta* L.) worked as an attractant to sweet potato flea beetle (*Chaetocnema confinis* Crotch)*.* *B*oth plants were effective in reducing the defoliation by this insect. In onion production, rosemary (*Rosmarinus officinalis* L.), holy basil (*Ocimum sanctus* L.), common basil (*Ocimum basilicum* L.), and Puerto Rican oregano (*Lippia micromera* Schauer) were effective as repellent plants in suppressing onion thrips (Cabrera-Ascensio & Vélez 2006).

Like in the case of cover crop use, yield reductions are also observed with the intercropping system, but far less frequently (Table 2). The big advantage of the intercropping system is in the achievement of net yield, instead of the main crops' yield. Varghese (2013) achieved the best net yield of cabbage in the intercropping with radish (*Raphanus sativum* L.), spinach (*Spinacia oleracea* L.), or coriander (*Coriandrum sativum* L.), all compared to monoculture, even though, by the growth parameters, cabbage grows better in monoculture. Choudhuri (2016) also reported similar situations

https://doi.org/10.17221/161/2024-PPS

with the combination of cabbage and garden pea (*Pisum sativum* L.). The ratio of main crops, such as intercrops, is often important to maximise the net yield while suppressing insect pests. Baidoo et al. (2012) discovered that planting four rows of cabbage alternately with one row of onion resulted in the best cabbage yield, the least cabbage leaf damage was achieved, and the least infestation of cabbage aphids (*B. brassicae*) in cabbage leaves; in comparison to other proportions. Sarma et al. (2015) recommended intercropping potato (*Solanum tuberosum* L.) and cabbage in a row system with a 1 : 1 ratio to reach the maximum yield and control advantages.

Trap crops. The working mechanism of trap crops is to attract insect pests away from the main crops during a critical period by providing them with an alternative preferred choice. To reach this aim, an effective trap crop system should have at least double the pest attraction activity during this period (Sarkar et al. 2018). Because of this reason, usually in cabbage production, related cruciferous species were used as successful trap crops (Table 3). However, when the target pest is a generalist, the trap crops that are unrelated to the main crops could work, for example, the use of marigold (*Tagetes erecta* L.), coriander (*C. sativum*), and carrots (*Daucus carota* L.) as trap crops of onion (Chandio et al. 2020).

Theoretically, when designing a trap crop system, some aspects such as insect preferences, spatial arrangement of trap crops, and incorporating supplemental insecticidal control should be considered (Shelton & Badenes-Pérez 2006). The cultural method, like using resistant plant varieties and trap crops, also strengthens the protection against insect pests (Hondelmann et al. 2016). While choosing the trap crops for cabbage species, many researchers associate glucosinolate type and level in cruciferous plants with the susceptibility of plants against insect pests. A field experiment by Bohinc et al. (2013a) studied four cruciferous species and their correlation to the feeding habit of cabbage flea beetles (*Phyllotreta* spp.). The results concluded that oil radish (*Raphanus sativus* L.) was preferred by these beetles compared to the other three species, and that the preference was correlated with high content of glucobrassicin, one type of glucosinolate. Furthermore, Bohinc et al. (2013b), using a similar approach, found that oil rape (*Brassica napus* L.) is the most suitable trap crop species for cabbage stink bugs (*Eurydema* sp.).

Preliminary research in the laboratory can be a helpful method to determine the insect's most favourable trap crops. Åsman (2002) tested the host preference for the leek moth (*Acrolepiopsis assectella* Zeller*)* in laboratory conditions, and based on the oviposition behaviour, it was concluded that the morphology of the leaves played an important role, in which the moths prefer species with bigger leaf areas. Later in the field trial, chive trap crops were found to suppress the leek moth in leek cultivation effectively. In other experiences, flea beetles were also discovered to favour trap crops with larger leaf areas or leaf density (George et al. 2013; George et al. 2019). Hondelmann et al. (2016) conducted a greenhouse experiment that indicated that adult whiteflies favour marrow-stem kale (*Brassica oleracea* var. *medullosa* Thell.), Savoy cabbage (*B. oleracea* var. *sabauda* L.), or kale (*B. oleracea* var. *sabellica* L.), compared to some other cruciferous plants tested. The continuous trial in the field showed that marrow-stem kale effectively controlled the whitefly population in Brussels sprouts (*B. oleracea* var. *gemmifera* DC) cultivation.

In a trap cropping system, a mixture of trap crops sometimes works better than just one trap crop species. Bohinc and Trdan (2013) recommended the sowing of a mixture of trap crops for cabbage production because a single trap crop they tested, which was oil radish (*Raphanus sativus* L.), oilseed rape *(Brassica napus* var. *napus)*, and white mustard (*Sinapis alba* L.), protected medium-late cabbage cultivar from cabbage flea beetles in a different stage of the growing period. Parker et al. (2016) tested *Brassica juncea* (L.) Czern., *Brassica napus*, and/or *Brassica rapa* subsp. *pekinensis* (Lour.) Kitam. as a singular and a mixture of three trap crops in broccoli (*Brassica oleracea* var. *italica* Plenck) cultivation. The result shows that when the abundance of crucifer flea beetles (*Phyllotreta cruciferae* Goeze) was high, the mixture of three trap crops gave the best control measure compared to singular or no-trap crops. The maximum yield was achieved in a plot with a mixture of three trap crops. Meanwhile, George et al. (2019) and Sapkota et al. (2022) observed that some trap crop species are better at attracting the pest in an early vegetative state. Then the effectiveness gradually decreases as the plants mature, so modifying trap crop age by sowing them at a few different times during the season can enhance their effectiveness.

https://doi.org/10.17221/161/2024-PPS

Like in the intercropping system, the trap cropping also rarely causes yield reduction (Table 3). These reductions might happen when the sensitive trap crop is overwhelmed and the pest infestation becomes uncontrollable and spreads back to the main crops (Trdan 2005) or when the trap crop is located too close to the main crop (Budhathoki et al. 2022) and causes competition with the main crops. Some researchers incorporate pesticides to kill the pests that infest trap crops (Gray & Koch 2002). Instead of chemical pesticides, Budhathoki et al. (2022) achieved satisfactory control of diamondback moth (*Plutella xylostella* L.) using the combination of Kai choi *(Brassica juncea*) trap crops and entomopathogenic nematode *Steinernema feltiae* Filipjev. This one study has proven that the deployment of companion plants can be further integrated with other types of biological control or biopesticides, and that together they can provide sufficient control of insect pests while remaining a sustainable option.

CONCLUSION

A long history of research in companion plants exists, including using cover crops, intercrops, and trap crops to suppress agricultural insect pests. This review lists numerous successful examples. According to our review, most companion plants work by interfering with host-seeking activity, disturbing oviposition, enhancing the natural enemies of plant pests, repelling insect pests from the area of the main crops, or acting as an alternative food source. We have described those mechanisms and provided examples to explain how companion plants reduce insect pests. We also explained that using cover crops can result in yield loss due to competition or weed suppression. Furthermore, we discussed important factors that can be considered to maximise yield while effectively reducing pests.

The most important thing is choosing the most suitable species or mixture of species as companion plants based on the target pests and deploying them in the optimum arrangement. We hope our review will provide vegetable growers with insight into deciding on the most suitable form and combination of companion plants based on their target pests. Based on recent studies, this review is also useful for other researchers as a foundation for discovering more optimisation in deploying companion plants. Based on our summary, we concluded that cover crops, intercrops, and trap crops effectively reduce the number of generalist and specialist plant pests attacking cabbage and onions. Further research could incorporate other biological measures, such as biotic agents and biopesticides, to provide farmers with even better and more sustainable recommendations in a future where chemical approaches will no longer be an option.

Author contributions

M.N.: preparation, investigation, writing – original draft; T.B.: methodology, writing – review and editing; S.T.: conceptualisation, methodology, writing – review and editing, supervision, project administration, funding acquisition. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

The authors declare no conflict of interest.

REFERENCES

Åsman K. (2002): Trap cropping effect on oviposition behaviour of the leek moth *Acrolepiopsis assectella* and the diamondback moth *Plutella xylostella*. Entomologia Experimentalis et Applicata: 105: 153–164.

Ahuja I., Rohloff J., Bones A.M. (2011): Defence mechanisms of Brassicaceae: implications for plant-insect interactions and potential for integrated pest management. Sustainable Agriculture, 2: 623–670.

Asare-Bediako E., Addo-Quaye A.A., Mohammed A. (2010): Control of diamondback moth (*Plutella xylostella)* on cabbage *(Brassica oleracea* var. capitata*)* using intercropping with non-host crops. American Journal of Food Technology, 5: 269–274.

Aung T.Z., Myint A.A., Mi K.M., Win E.P., Oo T.T., Thaung M. (2018): Effect of intercropping on the infestation of diamondback moth, *Plutella xylostella* (L.) (Lepidoptera: Plutellidae) on cabbage. Journal of Agricultural Research, 5: 8–17.

Badenes-Pérez F.R. (2023): Plant glucosinolate content and host-plant preference and suitability in the small white butterfly (Lepidoptera: Pieridae) and comparison with another specialist lepidopteran. Plants, 12: 2148.

Baidoo P.K., Mochiah M.B., Apusiga K. (2012): Onion as a pest control intercrop in organic cabbage *(Brassica oleracea)* production system in Ghana. Sustainable Agriculture Research, 1: 36–41.

https://doi.org/10.17221/161/2024-PPS

Balmer O., Géneau C.E., Belz E., Weishaupt B., Förderer G., Moos S., Luka H. (2014): Wildflower companion plants increase pest parasitation and yield in cabbage fields: Experimental demonstration and call for caution. Biological Control, 76:19–27.

Barić B., Pajać I. (2011): Harmful stink bugs on cabbage and their control. Glasilo Biljne Zaštite, 11: 214–217.

Basri R., Ansari M.S. (2020): Effect of barrier crops as a management tool against *Thrips tabaci* in onion ecosystem. Journal of Entomological Research, 44: 239–248.

Bilenky M.T., Nair A., McDaniel M.D. (2022): Effect of summer cover crops on cabbage yield, weed suppression, and N mineralisation in a low input cropping system. Frontiers in Sustainable Food Systems, 6: 1021639.

Björkman M., Hambäck P.A., Rämert B. (2007): Neighbouring monocultures enhance the effect of intercropping on the turnip root fly (*Delia floralis*). Entomologia Experimentalis et Applicata, 124: 319–326.

Björkman M, Hambäck P.A., Hopkins R.J., Rämert B. (2010): Evaluating the enemies hypothesis in a clover-cabbage intercrop: effects of generalist and specialist natural enemies on the turnip root fly (*Delia floralis*). Agricultural and Forest Entomology, 12: 123–132.

Björkman M., Klingen I., Birch A.N.E., Bones A.M., Bruce T.J.A., Johansen T.J., Meadow R., Mølmann J., et al. (2011): Phytochemicals of *Brassicaceae* in plant protection and human health–influences of climate, environment and agronomic practice. Phytochemistry, 72: 538–556.

Bohinc T., Košir I.J., Trdan S. (2013a): Glucosinolates as arsenal for defending Brassicas against cabbage flea beetle (*Phyllotreta* spp.) attack. Zemdirbyste-Agriculture, 100: 199–204.

Bohinc T., Hrastar R., Košir I.J., Trdan S. (2013b): Association between glucosinolate concentration and injuries caused by cabbage stink bugs *Eurydema* spp.(Heteroptera: Pentatomidae) on different Brassicas. Acta Scientiarum. Agronomy, 35: 1–8.

Bohinc T., Devetak M., Trdan S. (2014): Quantity of glucosinolates in 10 cabbage genotypes and their impact on the feeding of *Mamestra brassicae* caterpillars. Archives of Biological Sciences – Belgrade, 66: 867–876.

Bohinc T., Trdan S. (2010): Stink bugs (*Pentatomidae*) as a crop pests and methods of their control. Acta Agriculturae Slovenica, 97: 53–61. (In Slovenian)

Bohinc T., Trdan S. (2012): Trap crops for reducing damage caused by cabbage stink bugs *(Eurydema* spp.*)* and flea beetles *(Phyllotreta* spp.*)* on white cabbage: fact or fantasy? Journal of Food, Agriculture & Environment, 10: 1365–1370.

Bohinc T., Trdan S. (2013): Sowing mixtures of *Brassica* trap crops is recommended to reduce *Phyllotreta* beetles injury to cabbage. Acta Agriculturae Scandinavica, Section B – Soil & Plant Science, 63: 297–303.

Bottenberg H., Masiunas J., Eastman C., Eastburn D. (1997): Yield and quality constraints of cabbage planted in rye mulch. Biological Agriculture & Horticulture, 14: 323–342.

Brandsæter L.O., Netland J., Meadow R. (1998): Yields, weeds, pests and soil nitrogen in a white cabbage-living mulch system. Biological Agriculture & Horticulture, 16: 291–309.

Brooker R.W., Bennett A.E., Cong W.F., Daniell T.J., George T.S., Hallett P.D., Hawes C., Iannetta P.P.M., et al. (2015): Improving intercropping: A synthesis of research in agronomy, plant physiology and ecology. New Phytologist, 206: 107–117.

Bryant A., Brainard D.C., Haramoto E.R., Szendrei Z. (2013): Cover crop mulch and weed management influence arthropod communities in strip-tilled cabbage. Environmental Entomology, 42: 293–306.

Buckland K.R., Alston D.G., Reeve J.R., Nischwitz C., Drost D. (2017): Trap crops in onion to reduce onion thrips and iris yellow spot virus. Southwestern Entomologist, 42: 73–90.

Budhathoki S., Sipes B.S., Shikano I., Myers R.Y., Manadhar R., Koonhui W. (2022): Integrating trap cropping and entomopathogenic nematode foliar sprays to manage diamondback moth and imported cabbage worm. Horticulturae, 8: 1073.

Cabrera-Asencio I., Vélez A.L. (2006): Companion crops and insecticides to control populations of *Thrips tabaci* L. and *Liriomyza trifolii* B. in onion. Journal of Agriculture of the University of Puerto Rico, 90: 115–123.

Chandio S.A., Gilal A.A., Rajput L.B., Brohi M.U., Sahto J.G.M., Bhatti M.A., Sheik A. (2020): Performance of various trap crops in the management of *Thrips tabaci* Lindeman in onion crop. Pure and Applied Biology (PAB), 9: 2476–2481.

Cook S.M., Khan Z.R., Pickett J.A. (2007): The use of push-pull strategies in integrated pest management. Annual Review of Entomology, 52: 375–400.

Chairini F., Gamba U., Conte L., Spagnolo S., Pinna M. (2005): Undersowing to control insect pests on vegetable crops. Bolletino di Agricoltura Biologica, 2: 47–57. (In Italian)

Choudhuri P. (2016): Intercropping in cabbage (*Brassica oleracea* L. var. *capitata*) for growth, yield, quality and sustainable soil health under foothills of Eastern Himalayan region. Journal of Applied and Natural Science, 8: 1740–1747.

Collier R.H., Finch S.S. (2003): The effect of increased crop diversity on colonisation by pest insects of brassica crops. In: The BCPC International Congress: Crop Science and Technology, Volumes 1 and 2. Proceedings of an international congress held at the SECC, Glasgow, Scotland, Nov 10–12, 2003: 439–444.

Dassou A.G., Tixier P. (2016): Response of pest control by generalist predators to local-scale plant diversity: a meta-analysis. Ecology and Evolution, 6: 1143–1153.

https://doi.org/10.17221/161/2024-PPS

Daniarzadeh S., Karimzadeh J., Jakakizand A. (2014): The strategy of trap cropping for reducing the populations of diamondback moth in common cabbage. Archives of Phytopathology and Plant Protection, 47: 1852–1859.

El-Fakharany S.K.M. (2018): Effect of different host plants on the onion thrips, *Thrips tabaci* Lind. and the land snail, *Monacha* spp. population abundance according to intercropping some vegetable crops and the final yield. Journal of Plant Protection and Pathology, 9: 195–200.

European Union (2023a): Farm to Fork targets – Progress. Available at: https://food.ec.europa.eu/plants/pesticides/sustainable-use-pesticides/farm-fork-targets-progress_en (Accessed on Dec 12, 2023)

European Union (2023b): Integrated Pest Management (IPM). Available at: https://food.ec.europa.eu/plants/pesticides/sustainable-use-pesticides/integrated-pest-management-ipm (Accessed on Dec 12, 2023)

Fa S.K.M. (2018): Effect of different host plants on the onion thrips, *Thrips tabaci* Lindeman and the land snail, *Monacha* spp. population abundance acording to intercropping some vegetable crops and the final yield. Journal of Plant Protection and Pathology, 9: 195–200.

Fail J., Pénzes B. (2004): Species composition of Thysanoptera in white cabbage heads. Acta Phytopathologica et Entomologica Hungarica, 39: 165–171.

Faostat (2023): Statistical Database. Food and Agriculture Organization of the United Nations, Rome. Available at: https://www.fao.org/faostat/en/#data (Accessed on Dec 12, 2023)

Fening K.O., Maccharty D.S., Tegbe R.E. (2020): Effect of intercropping and soil amendment on the population dynamics of major pests and natural enemies of white cabbage. West African Journal of Applied Ecology, 28: 96–112.

Fickh M.R., Karpenstein-Machan M. (2002): Intercropping for pest management. In: Pimentel D. (ed.): Encyclopedia of Pest Management. Marcel Dekker Inc., New York: 423–425.

Finch S. (1995): Effect of trap background on cabbage root fly landing and capture. Entomologia Experimentalis Et Applicata, 74: 201–208.

Finch S., Kienegger M. (1997): A behavioural study to help clarify how undersowing with clover affects host-plant selection by pest insects of brassica crops. Entomologia Experimentalis et Applicata, 84: 165–172.

Finch S., Collier R.H. (2000): Host-plant selection by insects–a theory based on 'appropriate/inappropriate landings' by pest insects of cruciferous plants. Entomologia Experimentalis et Applicata, 96: 91–102.

Finch S., Billiald H., Collier R.H. (2003): Companion planting–do aromatic plants disrupt host-plant finding by the cabbage root fly and the onion fly more effectively than non-aromatic plants? Entomologia Experimentalis et Applicata, 109: 183–195.

Freuler J., Mayer H., Pignon P., Liniger C. (1995): Undersowing cabbage and leek plants with clover during 1994 and 1995. Integrated control in field vegetable crops. In: Finch S., Brunel E. (eds.): Proceedings of the meeting, held Guitte, France, Nov 6–8, 1995, Bulletin OILB/SROP, 19: 107.

Gachu S.M., Muthomi J.W., Narla R.D., Nderitu J.H., Olubayo F.M., Wagacha J.M. (2012): Management of thrips (*Thrips tabaci*) in bulb onion by use of vegetable intercrops. International Journal of AgriScience, 2: 393–402.

Gandarin A., Celette F., Naudin C., Piva G., Valantin-Morison M., Vrignon-Bremas S., Verret V., Mediene S. (2022): Intercropping with service crops provides multiple services in temperate arable systems: a review. Agronomy for Sustainable Development, 42: 39.

George D., Collier R., Whitehouse D.M. (2013): Can imitation companion planting interfere with host selection by Brassica pest insects? Agricultural and Forest Entomology, 15: 106–109.

George D., Port G., Collier R. (2019): Living on the edge: using and improving trap crops for flea beetle management in small-scale cropping systems. Insects, 10: 286.

Gray F.A., Koch D.W. (2022): Trap crops. In: Pimentel D. (ed.): Encyclopedia of Pest Management. Marcel Dekker Inc., New York: 852–854.

Gurr G.M., Wratten S.D., Barbosa P. (2000): Success in conservation biological control of arthropods. In: Gurr G., Wratten S. (eds): Biological Control: Measures of Success. Springer, Dordrecht: 105–132.

Guvenc I., Yildirim E. (2006): Increasing productivity with intercropping systems in cabbage production. Journal of Sustainable Agriculture, 28: 29–44.

Hamid H.A., Dalla Monta L., Battisti A. (2006): Undersowing cruciferous vegetables with clover: the effect of sowing time on flea beetles and diamondback moth. Bulletin of Insectology, 59: 121–127.

Hassanali A., Herren H., Khan Z.R., Pickett J.A., Woodcock C.M. (2008): Integrated pest management: the push-pull approach for controlling insect pests and weeds of cereals, and its potential for other agricultural systems including animal husbandry. Philosophical Transactions of the Royal Society B: Biological Sciences, 363: 611–621.

Hithesh G.R., Suroshe S.S., Keerthi M.C., Fand B.B. (2025): Companion planting of flowering annuals enhances the colonisation of natural enemies in white cabbage fields. Journal of Plant Diseases and Protection, 132:

Hondelmann P., Paul C., Meyhofer R. (2016): Combining crop resistance and trap plants for cabbage whitefly control. In: Meadow R. (ed.): Proceedings of the IOBC/WPRS Working Group "Integrated Protection in Field Vegetables", Hamburg, Oct 4–7, 2015, IOBC/WPRS Bulletin, 118: 15–21.

https://doi.org/10.17221/161/2024-PPS

Jankowska B., Poniedzialek M., Jedrszczyk E. (2009): Effect of intercropping white cabbage with French Marigold (*Tagetes patula nana* L.) and Pot Marigold (*Calendula officinalis* L.) on the colonisation of plants by pest insects. Folia Horticulturae (ISHS), 21: 95–103.

Jeschke V., Kearney E.E., Schramm K., Kunert G., Shekhov A., Gershenzon J., Vassão D.G. (2017): How glucosinolates affect generalist lepidopteran larvae: growth, development and glucosinolate metabolism. Frontiers in Plant Science, 8: 1995.

Khaliq A., Afzal M., Khan A.A., Raza A.M., Kamran M., Tahir H., Aqeel M.A., Ullah M.I. (2016): Management of *Thrips tabaci* (Thysanoptera: Thripidae) through agronomic practices in onion field plots. Pakistan Journal of Zoology, 48: 1675–1680.

Khan Z.R. (2002): Cover Crops. In: Pimentel D. (ed.): Encyclopedia of Pest Management. Marcel Dekker Inc., New York: 155–158.

Kolota E., Adamczewska-Sowinska K. (2013): Living Mulches in vegetable crops production: perspectives and limitations (A review). Acta Scientiarum Polonorum – Hortorum Cultus, 12: 127–142.

Kotliński S. (2011): Influence of nitrogen fertilisation of cabbage grown in mulches of winter cover crops on reducing the population of the cabbage aphid (L.). Journal of Fruit and Ornamental Plant Research, 74: 87–96.

Köneke A., Uesugi R., Herz A. (2023): Effects of wheat undersowing and sweet alyssum intercropping on aphid and flea beetle infestation in white cabbage in Germany and Japan. Journal of Plant Diseases and Protection, 130: 619–631.

Köneke A., Böckmann E. (2024): Wheat companion plants reduced aphid and flea beetle infestations in Brassica vegetable crops in a multiple-year field study in central Germany. Crop Protection, 182: 106732.

Krishnamoorthy A., Rama N., Mani M., Pattar G.L. (2003): Biological control of diamondback moth, *Plutella xylostella* (Linnaeus) in cabbage, integrating egg parasitoid, *Trichogrammatoidea bactrae* Nagaraja with trap crop. Biological control of lepidopteran pests: Procedings of the Symposium of Biological Control of Lepidopteran Pests, Banglore, Jul 17–18, 2002: 275–278.

Langer V. (1994): Undersowing in white cabbage: effects on pests and on cabbage yield and quality. SP Rapport, 2: 51–58.

Laxman G., Sharma R.K., Sinha S.R. (2019): Management of insect pests of cabbage with intercropping and their planting pattern. Indian Journal of Entomology, 81: 69–72.

Langer V. (1994): Undersowing in white cabbage: effects on pests and on cabbage yield and quality. SP Rapport, 2: 51–58.

Lehmhus J., Vidal S., Hommes M. (1996): Population dynamics of herbivorous and beneficial insects found in plots of white cabbage undersown with clover. Bulletin OILB/SROP, 19: 115–121.

Lehmhus J., Hommes M., Vidal S. (1997): Effects of undersowing and straw mulch on insect herbivores and their natural enemies in white cabbage. Mitteilungen der Deutschen Gesellschaft fur Allgemeine und Angewandte Entomologie, 11: 289–292.

Lotz L.A.P., Groeneveld R.M.W., Theunissen J., Van den Broek R.C.F.M. (1997): Yield losses of white cabbage caused by competition with clovers grown as cover crop. Netherlands Journal of Agricultural Science, 45: 393–405.

Lubanga U.K., Karung J., Kyamanywa S., Ekbom B. (2012): Assessing the potential of trap cropping in the management of different insect taxa on white cabbage. International Journal of Tropical Insect Science, 32: 218–223.

Luther G.C., Valenzuela H.R., Defrank J. (1996): Impact of cruciferous trap crops on lepidopteran pests of cabbage in Hawaii. Environmental Entomology, 25: 39–47.

Magierowicz K., Górska-Drabik E., Golan K. (2019): Effects of plant extracts and essential oils on the behavior of *Acrobasis advenella* (Zinck.) caterpillars and females. Journal of Plant Diseases and Protection, 127: 63–71.

Mandal S.M.A., Dash D. (2012): Effect of intercropping on the incidence of insect pests and yield in cabbage. Journal of Plant Protection and Environment, 9: 26–28.

Meissle M., Mouron P., Musa T., Bigler F., Pons X., Vasileiadis V.P., Otto S., Antichi D., et al. (2010): Pests, pesticide use and alternative options in European maise production: current status and future prospects. Journal of Applied Entomology, 134: 357–375.

Mishra R.K., Jaiswal R.K., Kumar D., Saabale P.R., Singh A. (2014): Management of major disease and insect pests of onion and garlic: A comprehensive review. Journal of Plant Breeding and Crop Science, 6: 160–170.

Moraiet M.A., Ansari M.S., Duchovskiené L. (2017): Influence of transplanting date and intercropping on thrips population and production of onion. Scientific Works of the Institute of Horticulture, Lithuanian Research Centre for Agriculture and Forestryland Aleksandras Stulginsky University, Sodininkystė Ir Daržininkystė, 36: 1–2.

Morley K., Finch S., Collier R.H. (2005): Companion planting – behaviour of the cabbage root fly on host plants and non-host plants. Entomologia Experimentalis et Applicata, 117: 15–25.

Morris M.C., Li F.Y. (2000): Coriander (*Coriandrum sativum*) "companion plants" can attract hoverflies, and may reduce pest infestation in cabbages. New Zealand Journal of Crop and Horticultural Science, 28: 213–218.

Mwaja V.N., Masiunas J.B., Eastman C.E. (1996): Rye (*Secale cereale* L.) and hairy vetch (*Vicia villosa* Roth) intercrop management in fresh-market vegetables. Journal of the American Society for Horticultural Science, 121: 586–591.

https://doi.org/10.17221/161/2024-PPS

Ordás A., Cartea M.E. (2008): Cabbage and kale. In: Prohens J., Nuez F. (eds): Vegetables I: *Asteraceae*, *Brassicaceae*, *Chenopodicaceae*, and *Cucurbitaceae*. Springer, New York: 119–149.

Parker J.E., Crowder D.W., Eigenbrode S.D., Snyder W.E. (2016): Trap crop diversity enhances crop yield. Agriculture, Ecosystems & Environment, 232: 254–262.

Pavela R. (2016): History, presence, and perspective of using plant extracts as commercial botanical insecticides and farm products for proetction against insects – A review. Plant Protection Science, 52: 229–241.

Pawar D.B., Lawande K.E. (1995): Effects of mustard as a trap crop for diamondback moth on cabbage. Journal of Maharashtra Agricultural Universities, 20: 185–186.

Pinheiro L.A., Dader B., Wanumen A.C., Pereira J.A., Santos S.A.P., Medina P. (2020): Side effects of pesticides on the olive fruit fly parasitoid *Psyttalia concolor* (Szepligeti): A review. Agronomy-Basel, 10: 1755.

Pobozniak M., Wiech K. (2005): The effect of undersowing cabbage with white clover on thrips infestation and flight activity. Communications in Agricultural and Applied Biological Sciences, 70: 517–526.

Reddy P.P. (2017): Companion planting. In: Agro-Ecological Approaches to Pest Management for Sustainable Agriculture. Springer, Singapore: 149–164.

Robberts B.W., Cartwright B. (1991): Alternative soil and pest management practices for sustainable production of fresh-market cabbage. Journal of Sustainable Agriculture, 1: 21–35.

Robin A.H.K., Hossain M.R., Park J.I., Kim H.R., Nou I.S. (2017): Glucosinolate profiles in cabbage genotypes influence the preferential feeding of diamondback moth (*Plutella xylostella*). Frontiers in Plant Science, 8: 1244.

Root R.B. (1973): Organisation of a plant-arthropod association in simple and diverse habitats: the fauna of collards (*Brassica oleracea*). Ecological Monographs, 43: 95–124.

Rousse P., Fournet S., Porteneuve C., Brunel E. (2003): Trap cropping to control *Delia radicum* populations in cruciferous crops: first results and future applications. Entomologia Experimentalis et Applicata,109: 133–138.

Sapkota B., Regmi R., Thapa R.B., Tiwari S. (2022): Indian mustard and buckwheat as trap plants of diamondback moth (*Plutella xylostella* L.) in cabbage cultivation. Journal of Agriculture and Environment, 23: 122–130.

Sarkar S.C., Wang E., Wu S., Lei W. (2018): Application of trap cropping as companion plants for the management of agricultural pests: A review. Insects, 9: 128.

Sarma P.K., Joshi P.K., Verma S.K., Rangare S.B., Yadav V. (2015): Production potential and completion indices in potato (*Solanum tuberosum* L.) + cabbage (*Brassica oleracia* var. capitata) and cluster bean (*Cyamopsis tetragonalobus*) intercropping system in Chhattisgarh plains. Trends in Biosciences, 8: 1121–1125.

Satpathy S., Shivalingaswamy T.M., Kumar A., Rai A.B., Rai M. (2010): Potentiality of Chinese cabbage (*Brassica rapa* subsp. *pekinensis*) as a trap crop for diamondback moth (*Plutella xylostella*) management in cabbage. Indian Journal of Agricultural Sciences, 80: 238–241.

Sekine T., Kanao K., Inawashiro S., Hori M. (2021a): Insect pest management by intercropping with leafy daikon (*Raphanus sativus*) in cabbage fields. Arthropod-Plant Interactions, 15: 669–681.

Sekine T., Masuda T., Inawashiro S. (2021b): Suppression effect of intercropping with barley on *Thrips tabaci* (Thysanoptera: Thripidae) in onion fields. Applied Entomology and Zoology, 56: 59–68.

Shelton A.M., Badenes-Pérez F.R. (2006): Concepts and applications of trap cropping in pest management. Annual Review of Entomology, 51: 285–308.

Shresta B., Finke D.L., Pinero J.C. (2019): The 'Botanical Triad': the presence of insectary plants enhances natural enemy abundance on trap crop plants in an organic cabbage agro-ecosystem. Insects, 10: 181.

Smith J.G. (1976): Influence of crop background on aphids and other phytophagous insects on Brussels sprouts. Annals of Applied Biology, 83:1–13.

Srinivasan K., Moorthy P.N.K. (1991): Indian mustard as a trap crop for management of major lepidopterous pests on cabbage. Tropical Pest Management, 37: 26–32.

Stivers-Young L., Teasdale J.R. (2004): Cultivation and interseeding for weed control in transplanted cabbage. Weed Technology, 18: 665–672.

Theunissen J., Booij C.J.H, Lotz B. (1995): Effects of intercropping white cabbage with clovers on pest infestation and yield. Entomologia Experimentalis et Applicata, 74: 7–16.

Theunissen J., Schelling G. (1996): Undersowing crops of white cabbage with strawberry clover and spurrey. Bulletin OILB/SROP, 19: 28–135.

Trdan S., Valič N., Žnidarčič D., Vidrih M., Bergant K., Zlatič E., Milevoj L. (2005): The role of Chinese cabbage as a trap crop for flea beetles (Coleoptera: *Chrysomelidae*) in production of white cabbage. Scientia Horticulturae, 106: 12–24.

Trdan S., Žnidarčič D., Valič N. (2006a): Field efficacy of three insecticides against cabbage stink bugs (Heteroptera: *Pentatomidae*) on two cultivars of white cabbage. International Journal of Pest Management, 52: 79–87.

Trdan S., Žnidarčič D., Valič N., Rozman L., Vidrih M. (2006b): Intercropping against onion thrips, *Thrips tabaci* Lindeman (Thysanoptera: Thripidae) in onion production: on the suitability of orchard grass, lacy phacelia, and buckwheat as alternatives for white clover. Journal of Plant Diseases and Protection, 113: 24–30.

https://doi.org/10.17221/161/2024-PPS

Uesugi R., Konishi-Furihata R., Tabuchi K., Yoshimura H., Shimoda T. (2023): predacious natural enemies associated with suppression of onion thrips, *Thrips tabaci* (Thysanoptera: Thripidae), in intercropped onion-barley agroecosystems. Environmental Entomology, 52:183–196.

Uvah I.I.I., Coaker T.H. (1984): Effect of mixed cropping on some insect pests of carrots and onions. Entomologia Experimentalis et Applicata, 36: 159–167.

Vandermeer J.H., Andermeer J.H. (1992): The ecology of intercropping. Cambridge University Press, Cambridge.

Varghese L. (2013): Evaluation of cabbage intercropped with seed spices on black clay soil. Agricultural Advances, 2: 237–241.

Wiech K. (1996): Intercropping as possible method of cabbage pest control in Poland. In: Proceedings of the Brighton Crop Protection Conference: Pests & Diseases, Brighton, Nov 18–21, 1996: 675–678.

Wiech K. (2000): The reaction of some Lepidoptera pests on undersowing late cabbage with white clover. Vegetable Crops Research Bulletin, 52: 13–17.

Winde I., Wittstock U. (2011): Insect herbivore counteradaptations to the plant glucosinolate–myrosinase system. Phytochemistry, 72: 1566–1575.

Yong M., Xiwu G., Junqi J., Yun W. (2013): Effects of intercropping of cabbage and garlic on major pests and arthropod community in spring cabbage fields. Journal of South China Agricultural University, 34: 352–355.

Received: September 8, 2024
Accepted: June 6, 2025
Published online: October 10, 2025