Arthropod-Plant Interactions (2025) 19:97
https://doi.org/10.1007/s11829-025-10205-6

REVIEW ARTICLE

Dead-end trap cropping in pest management

Francisco Rubén Badenes-Pérez[1]

Received: 15 October 2025 / Accepted: 10 November 2025 / Published online: 26 November 2025
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Abstract
Dead-end trap cropping is a particular case of trap cropping involving trap crop plants on which targeted insect pests cannot survive. Dead-end trap crops can function as a sink for pests, preventing their movement from the trap crop to the main crop, thus greatly reducing reliance on pesticide applications. Wintercress *Barbarea vulgaris* Aiton (Brassicaceae) and vetiver grass *Chrysopogon zizanioides* (L.) Roberty (Poaceae) are among the plant species most-studied as dead-end trap crops for diamondback moth *Plutella xylostella* L. (Lepidoptera: Plutellidae) and the stemborers *Chilo partellus* Swinhoe (Lepidoptera: Crambidae) and *S. inferens* Walker (Lepidoptera: Noctuidae), respectively. Additional dead-end crops target important pests like cotton bollworm, corn earworm, green peach aphid, western tarnished plant bug, root-knot and root-lesion nematodes, silverleaf whitefly, and different species of fruit flies and thrips. Besides the inherent characteristics of a plant species that make it naturally function as a dead-end trap crop, such as the presence of particular plant secondary metabolites, other types of dead-end trap crops involve the use of transgenesis and the use of biological control agents. This article reviews the topic of dead-end trap cropping, providing also an explanation of some of the mechanisms involved and the factors that affect the successful implementation of this type of trap cropping.

Keywords *Barbarea* · Insect pest · Bt crops · Plant-parasitic nematodes · Suboptimal host-plant choice · Trap plant · Vetiver grass

Introduction

Trap crops are plant stands that attract, intercept, retain, and/or reduce targeted insects or the pathogens they vector in order to reduce damage to the main crop (Shelton and Badenes-Pérez 2006). Trap crops can help reduce insecticide use while preserving conservation biological control (Hokkanen 1991; Shelton and Badenes-Pérez 2006; Badenes-Pérez 2019). Within the general concept of trap cropping, the term dead-end trap cropping was coined to refer to trap crops that are highly attractive to insects, but on which they or their offspring cannot survive (Shelton and Nault 2004). The term dead-end trap cropping was first used to describe the high oviposition preference of the diamondback moth *Plutella xylostella* L. (Lepidoptera: Plutellidae) for wintercress *Barbarea vulgaris* Aiton (Brassicaceae), also known as yellow rocket, on which larvae of *P. xylostella* cannot survive (Idris and Grafius 1994; Serizawa et al. 2001; Shinoda et al. 2002; Agerbirk et al. 2003a; Shelton and Nault 2004). This lack of survival of *P. xylostella* larvae on *B. vulgaris* refers to G-type plants of this species (G referring to glabrous leaves), as opposed to P-type *B. vulgaris* plants (P referring to pubescent leaves) (Agerbirk et al. 2003b; Badenes-Pérez et al. 2014b). Henceforth, G-type *B. vulgaris* plants will be referred to as *B. vulgaris* unless otherwise indicated. Since the term dead-end trap cropping was coined, the interaction between *B. vulgaris* and *P. xylostella* has been highly studied (Shelton and Nault 2004; Badenes-Pérez et al. 2005a, b, 2014a, b; Shelton and Badenes-Pérez 2006; Badenes-Pérez 2019, 2024) and this term has been used when reporting other cases of trap crops involving either no survival or low survival of the target insect pests. This article reviews the studies published on the topic of dead-end trap cropping and provides recommendations regarding the implementation of dead-end trap cropping in different agroecosystems. The review was done by searching the literature available at the

Communicated by HEIKKI MATTI TAPIO HOKKANEN.

✉ Francisco Rubén Badenes-Pérez
fr.badenes@csic.es

[1] Instituto de Ciencias Agrarias, Consejo Superior de Investigaciones Científicas, 28006 Madrid, Spain

Web of Science and Scopus databases with the terms "trap crop*" and "dead-end". Additional articles I knew of and others that were suggested by the editor and reviewers were also included in the review.

Dead-end trap crops versus low-survival trap crops: dead-end trap crops should result in no survival of the target insect pest

The term dead-end trap cropping implies the use of a trap crop leading to no survival of the target pest (Shelton and Nault 2004). Some trap crops result in low survival rates of the targeted pests, but do not achieve zero survival. I propose the term low-survival trap crops for these trap crops since they cannot be referred to as dead-end trap crops. Among these are Indian hemp *Crotalaria juncea* L. (Fabaceae), a low-survival trap crop for the legume pod borer *Maruca vitrata* F. (formerly known as *M. testulalis*) (Crambidae) (Jackai and Singh 1983); glossy collards *Brassica oleracea* L. var. *acephala* (Brassicaceae) and *Barbarea rupicola* Moris (Brassicaceae) for management of *P. xylostella* (Badenes-Pérez et al. 2004, 2014b; Musser et al. 2005); radish *Raphanus sativus* L. (Brassicaceae) for management of the pollen beetle *Brassicogethes aeneus* F. (Coleoptera: Nitidulidae) (Veromann et al. 2014); tropical soda apple *Solanum viarum* Dunal (Solanaceae) for management of the tomato fruit borer (cotton bollworm) *Helicoverpa armigera* Hübner (Lepidoptera: Noctuidae) (Srinivasan et al. 2013; Gyawali et al. 2021); Napier grass *Pennisetum purpureum* Schumach (Poaceae) for management of the stem borers *Busseola fusca* Füsca (Lepidoptera: Noctuidae) and *Chilo partellus* Swinhoe (Lepidoptera: Crambidae) (Van den Berg 2006b; Khan et al. 2006, 2007; Van den Berg et al. 2006; Cook et al. 2007); and the grass *Erianthus arundinaceus* (Retz.) Jeswiet (Poaceae) for management of the spotted stem borer *Chilo sacchariphagus* Bojer (Lepidoptera: Crambidae) (Nibouche et al. 2012, 2019) (Table 1). The mechanism by which low-survival trap crops attract and cause low survival is often not well studied. However, in the case of glossy collards, these are more attractive to ovipositing *P. xylostella* than waxy collards and cabbage because glossy collards contain higher amounts of glucosinolates and lower amounts of leaf surface wax (Badenes-Pérez et al. 2004, 2020), the former being associated to preferential *P. xylostella* oviposition (Badenes-Pérez et al. 2020) and the latter being associated with low survival of *P. xylostella* larvae (Eigenbrode and Shelton 1990, 1992; Stoner 1990; Ulmer et al. 2002). In Napier grass, low survival of *C. partellus* larvae seems to be due to sticky sap produced by the plant and to the presence of trichomes in which larvae get stuck (Khan et al. 2000; Van den Berg 2006a). In soda apple, the low larval survival could be due to plant secondary metabolites, particularly solasodine, which is associated with insect resistance (Gyawali et al. 2021; Patel et al. 2021). In *E. arundinaceus*, the terpene (*E*)-β-ocimene seems to be an attractant to *C. sacchariphagus*, though few volatiles differentiate this low-survival trap crop from sugarcane (Jacob et al. 2021). Different genotypes of *E. arundinaceus* have been screened for host-plant resistance against another *Chilo* species, the sugarcane shoot borer *C. infuscatellus* Snellen (Lepidoptera: Crambidae) (Punithavalli et al. 2024). Some of the studied *E. arundinaceus* genotypes have very different content of proteinase inhibitors, phenols, polyphenol oxidase activity, and quantities of nutritive compounds, showing high variability in the levels of resistance to *C. infuscatellus*, and some of them seem to be resistant to this borer (Punithavalli et al. 2024). These genotypes could also be tested with *C. sacchariphagus* to check if any of them could result in no survival of larvae while still being very attractive for ovipositing females. Similarly, as there are more than 700 species in the genus *Crotalaria* (Roux et al. 2013), other plant species in this genus could be screened for their potential as trap crops for *M. vitrata*.

The use of *Desmodium* Desv. (Fabaceae) can produce suicidal germination in species of the witchweed *Striga* Lour. (Orobanchaceae), but as it does not achieve 100%

Table 1 Low-survival trap crops: studies investigating potential dead-end trap crops that did not result in zero survival of the target insect pest

Plant species	Insect pests targeted	Level of testing	References
Barbarea rupicola	Diamondback moth *Plutella xylostella*	P	Badenes-Pérez et al. (2014b)
Glossy collards *Brassica oleracea* var. *acephala*	Diamondback moth *Plutella xylostella*	P, F	Badenes-Pérez et al. (2004) and Musser et al. (2005)
Indian hemp *Crotalaria juncea*	Legume pod borer *Maruca vitrata*	P	Jackai and Singh (1983)
Erianthus arundinaceus	Spotted borer *Chilo sacchariphagus*	P	Nibouche et al. (2012, 2019)
Napier grass *Pennisetum purpureum*	Stemborers *Busseola fusca* and *Chilo partellus*	P	Van den Berg (2006b), Khan et al. (2006, 2007) and Van den Berg et al. (2006)
Radish *Raphanus sativus*	Pollen beetle *Brassicogethes aeneus*	P	Veromann et al. (2014)
Tropical soda apple *Solanum viarum*	Cotton bollworm *Helicoverpa armigera*	P, F	Gyawali et al. (2021)

Levels of testing: potential shown in preliminary studies in the laboratory, greenhouse, and/or screenhouse (P); potential shown in studies in the field (F)

Table 2 Dead-end trap crops for management of diamondback moth

Plant species	Crop	Level of testing	References
Upland cress *Barbarea verna*	Cabbage, broccoli	P	Badenes-Pérez et al. (2014b)
Wintercress *Barbarea vulgaris*	Cabbage, broccoli, Chinese cabbage	P, F	Badenes-Pérez et al. (2004, 2005b, 2014b), Lu et al. (2004) and Shelton and Nault (2004)
Bt Indian mustard *Brassica juncea*	Cabbage	P	Cao et al. (2008), Shelton et al. (2008) and Kamble et al. (2013)
Bt collards *Brassica oleracea* var. *acephala*	Cabbage	P	Cao et al. (2005) and Shelton et al. (2008)
Faba bean *Vicia faba* sprayed with crucifer extracts	Chinese kale	P	Zhu et al. (2021)
Glucosinolate-engineered Tobacco *Nicotiana tabacum*	Tabaco (not usual host)	P	Møldrup et al. (2012)

Levels of testing: potential shown in preliminary studies in the laboratory, greenhouse, and/or screenhouse (P); potential shown in studies in the field (F)

removal of the weed (Khan et al. 2001; Cheruiyot et al. 2021), it could also be considered a low-survival trap crop. *Desmodium* and Napier grass are often used together as part of a push–pull strategy to manage *B. fusca*, *C. partellus*, and *Striga* spp. (Cook et al. 2007).

Dead-end trap crops for management of diamondback moth

Plutella xylostella is considered one of the most damaging pests of cruciferous crops and is also known for its ability to develop resistance to insecticides (Talekar and Shelton 1993; Zalucki et al. 2012; Furlong et al. 2013; Li et al. 2016). Thus, management methods alternative to insecticides have been widely investigated for *P. xylostella*, including trap crops (Shelton and Badenes-Pérez 2006; Badenes-Pérez 2019). Among the different dead-end trap crops proposed for management of *P. xylostella* (Table 2), the use of *B. vulgaris* was first proposed due to the lack of survival of *P. xylostella* larvae on this plant (Idris and Grafius 1994). The reason why first-instar larvae of *P. xylostella* cannot survive on *B. vulgaris* is because the plant contains two triterpenoid saponins, 3-*O*-*β*-cellobiosylhederagenin and 3-*O*-*β*-cellobiosyloleanolic acid, which act as feeding deterrents for the larvae (Shinoda et al. 2002; Agerbirk et al. 2003a; Badenes-Pérez et al. 2014b). Mortality of first-instar *P. xylostella* larvae only occurs on the G-type of *B. vulgaris*, while larvae can survive on the P-type of *B. vulgaris* (Agerbirk et al. 2001, 2003a; Badenes-Pérez et al. 2014b). Several studies conducted in laboratory, greenhouse, and screenhouse conditions have demonstrated the potential of *B. vulgaris* as a dead-end trap crop for *P. xylostella* (Badenes-Pérez et al. 2004, 2006, 2014b; Lu et al. 2004; Shelton and Nault 2004). In the field, *B. vulgaris* significantly lowered *P. xylostella* densities when planted in the perimeter of cabbage plots at a percentage of 10% or higher (Badenes-Pérez et al. 2005b; Ruhanen et al. 2023) (Fig. 1).

Besides *B. vulgaris*, other *Barbarea* spp. have been studied as trap crops and *B. verna* (Mill.) Asch. can also be used as a dead-end trap crop for *P. xylostella* as it contains sufficient amounts of feeding-deterrent saponins to prevent survival of *P. xylostella* neonates (Badenes-Pérez et al. 2014b). Other *Barbarea* spp., such as *B. rupicola* Moris, which either do not contain these saponins or contain them in low amounts, can be used as low-survival trap crops, but not as dead-end trap crops (Badenes-Pérez et al. 2014b).

Resistance to other pests is an additional benefit of using *B. vulgaris* and *B. verna* as dead-end trap crops (Badenes-Pérez and López-Pérez 2018; Christensen et al. 2018;



Fig. 1 Experiment with a perimeter dead-end trap crop of *Barbarea* plants around a cauliflower crop in Spain (photo by Francisco Rubén Badenes-Pérez)

Badenes-Pérez 2024). Besides being resistant to *P. xylostella*, *B. vulgaris* has shown resistance to other insects, such as the flea beetle *Phyllotreta nemorum* L. (Coleoptera: Chrysomelidae) (Agerbirk et al. 2001; Nielsen et al. 2010; Kuzina et al. 2011; Hauser et al. 2021), the western flower thrips *Frankliniella occidentalis* Pergande (Thysanoptera: Thripidae), and the ascomycete fungus that causes powdery mildew on Brassicaceae *Erysiphe cruciferarum* Opiz ex L. Junell (Erysiphales: Erysiphaceae) (Badenes-Pérez and López-Pérez 2018; Badenes-Pérez 2024). *Barbarea vulgaris* also shows some resistance to some species of generalist molluscs (Christensen et al. 2018). *Barbarea verna* shows resistance to *E. cruciferarum* and to the cabbage whitefly *Aleyrodes proletella* L. (Hemiptera: Aleyrodidae) (Badenes-Pérez 2024).

Faba bean *Vicia faba* L. (Fabaceae) is not a host plant for *P. xylostella* (Badenes-Pérez et al. 2020). However, applying aqueous extracts of Chinese kale *Brassica oleracea* L. var. *alboglabra* (Brassicaceae) on the foliage of faba bean plants makes them more attractive to ovipositing *P. xylostella* than Chinese kale plants, thus becoming dead-end trap crops (Zhu et al. 2021).

Table 3 Dead-end trap crops for management of beet armyworm, bollworm, sugarcane borer, pod borer, and stem borer

Plant species	Bollworm and borer species	Crop species	Level of testing	References
Vetiver grass *Chrysopogon zizanioides*	Spotted stem borer *Chilo partellus* and Pink stem borer *Sesamia inferens*	Maize, Rice	P, F	Van den Berg (2006b), Glas et al. (2007) and Lu et al. (2018)
Bt cotton *Gossypium hirsutum*	Cotton bollworm *Helicoverpa armigera*	Cotton	F	Lu et al. (2022)
Bt rice *Oriza sativa*	Striped rice stemborer *Chilo suppresalis*	Rice	P, F	Jiao et al. (2018)
Maize *Zea mays*	Cotton bollworm *Helicoverpa zea*	Tomato	P, F	Rhino et al. (2016)
Bt maize *Zea mays*	Beet armyworm *Spodoptera exigua* H	Maize	P, F	Song et al. (2025)
	Stalk borer *Eldana saccharina*	Sugarcane	P	Keeping et al. (2007)

Levels of testing: potential shown in preliminary studies in the laboratory, greenhouse, and/or screenhouse (P); potential shown in studies in the field (F)

Dead-end trap crops for management of beet armyworm, bollworm, pod borer, and other lepidopteran borers

Vetiver grass *Chrysopogon zizanioides* (L.) Roberty (Poaceae) can be used as dead-end trap crop for the spotted stem borer *C. partellus* (Van den Berg 2006b; Glas et al. 2007; Lu et al. 2018) and for the pink borer *Sesamia inferens* Walker (Lepidoptera: Noctuidae) (Lu et al. 2018, 2019; Tang et al. 2024) (Table 3). However, when exposed to vetiver grass stems, third-instar larvae of the striped rice stemborer *Chilo suppressalis* Walker (Lepidoptera: Crambidae) can survive on it (Lu et al. 2025). Different chemoconstituents seem to be involved in the attractiveness and resistance of vetiver grass to *C. suppressalis* and *S. inferens* (Lu et al. 2017b, 2025; Tang et al. 2024). The compounds involved in the attraction to *C. suppressalis* females are caryophyllene, β-ocimene, linalool, and α-pinene (combined in particular ratios), and also α-cedrene and phytone (Lu et al. 2017b, 2025). Different components seem to be involved in *C. suppressalis* mortality on vetiver grass, such as low content of methionine and high content of tannins (Lu et al. 2017a; Tang et al. 2024).

Tidalmarsh flatsedge *Cyperus serutinus* Rottb. (Cyperaceae) has shown potential as a dead-end trap crop for the pink borer *S. inferens* in rice (Liu et al. 2011). In preliminary tests, no *S. inferens* larvae survived to pupation on *C. serutinus*. However, oviposition preference for this sedge species is not significantly different than rice (Liu et al. 2011).

Dead-end trap crops for management of flies, aphids, whiteflies, thrips, and western plant bug

The scarlet firethorn *Pyracantha coccinea* M. Roem. (Rosaceae) can be used as a dead-end trap crop for the spotted-wing drosophila *Drosophila suzukii* Matsumura (Diptera: Drosophilidae) (Ulmer et al. 2020) (Table 4). The lack of survival of *D. suzukii* larvae on *P. coccinea* fruits could be attributed to their saponins, tannins, and other plant secondary metabolites (Sarikurkcu and Tepe 2015). Other species of fruit flies, the oriental fruit fly *Bactrocera dorsalis* Hendel (Diptera: Tephritidae), the melon fly *B. cucurbitae* Coquillett (Diptera: Tephritidae), and the pumpkin fruit fly *Zeugodacus tau* Walker (Diptera: Tephritidae), can be managed using passion fruit *Passiflora edulis* Sims (Passifloraceae) as a dead-end trap crop (Yang et al. 2023). Oviposition by these fruit flies makes passion fruit release hydrogen cyanide, which arrests embryonic development, thereby producing an ovicidal effect (Yang et al. 2023).

Nicothiana benthamiana Domin (Solanaceae) can be used as a dead-end trap crop for the silverleaf whitefly *Bemisia tabaci* Gennadius (Hemiptera: Aleyrodidae), the green

Table 4 Dead-end trap crops for management of flies, aphids, whiteflies, thrips, and western plant bug

Plant species	Target insect species	Crop species	Level of testing	References
Nicotiana benthamiana	Silverleaf whitefly *Bemisia tabaci*, green peach aphid *Myzus persicae*, flower thrips *Frankliniella intonsa*, western flower thrips *Frankliniella occidentalis*	Cucumber, eggplant pepper, squash, tobacco	P, F	Han et al. (2024)
Passion fruit *Passiflora edulis*	Oriental fruit fly *Bactrocera dorsalis*, melon fly *B. cucurbitae*, and pumpkin fruit fly *Zeugodacus tau*	Guava, papaya	F	Yang et al. (2023)
Scarlet firethorn *Pyracantha coccinea*	Spotted-wing drosophila *Drosophila suzukii*	Strawberry	P, F	Ulmer et al. (2020)
Foxtail barley *Hordeum jubatum*	Western tarnished plant bug *Lygus hesperus*	Alfalfa	P	Barlow et al. (1999)

Levels of testing: potential shown in preliminary studies in the laboratory, greenhouse, and/or screenhouse (P); potential shown in studies in the field (F)

peach aphid *Myzus persicae* Sulzer (Hemiptera: Aphididae), the flower thrips *Frankliniella intonsa* Trybom (Thysanoptera: Thripidae), and the western flower thrips *Frankliniella occidentalis* Pergande (Thysanoptera: Thripidae) in several cucurbitaceous and solanaceous crops (Han et al. 2024). These insect pests prefer *N. benthamiana* over pepper *Capsicum annuum* L. (Solanaceae), squash *Cucurbita moschata* Duchesne (Cucurbitaceae), cucumber *Cucurbita sativus* L. (Cucurbitaceae), cultivated tobacco *Nicotiana tabacum* L. (Solanaceae), and eggplant *Solanum melongena* L. (Solanaceae), despite not being able to survive on *N. benthamiana* (Han et al. 2024). Release of the volatile undecane by *N. benthamiana* has been shown to attract *B. tabaci* to this dead-end trap crop (Zhang et al. 2025).

Lygus bugs are very amenable to trap cropping management (Holopainen and Hokkanen 2024). Foxtail barley *Hordeum jubatum* L. (Poaceae) could be used as a dead-end trap crop for the western tarnished plant bug *Lygus hesperus* Knight in alfalfa *Medicago sativa* L. (Fabaceae) given its high oviposition preference and no larval survival on *H. jubatum* in preliminary studies conducted in the laboratory (Barlow et al. 1999). However, despite *L. hesperus* showing the highest oviposition preference for *H. jubatum*, the presence of *L. hesperus* adults on *H. jubatum* was the lowest among other plant species tested together, including alfalfa and five weed species (Barlow et al. 1999). This indicates that further experiments in the field are necessary to confirm the potential of *H. jubatum* as a dead-end trap crop for *L. hesperus* in alfalfa.

Dead-end trap crops for management of plant-parasitic nematodes

Resistant *Me1-Me3* hybrid pepper *C. annuum* and French marigold *Tagetes patula* L. (Asteraceae) have been proposed as dead-end trap crops for the management of root-knot nematodes *Meloidogyne* spp. Göldi (Tylenchida: Heteroderidae) and the root-lesion nematode *Pratylenchus penetrans* (Cobb) Filipjev and Schuurmans Stekhoven (Tylenchida: Pratylenchidae), respectively (Pudasaini et al. 2006; Hooks et al. 2010; Navarrete et al. 2016). Presence of French marigold induces egg hatch in *P. penetrans*, but nematode juveniles starve because marigold is not a host plant for this nematode, thereby reducing nematode densities in the soil (Pudasaini et al. 2006, 2008). Similarly, resistant pepper can greatly reduce *Meloidogyne* spp. infestation in the soil (Navarrete et al. 2016). Host root exudates have also been used to stimulate nematode egg hatching in the absence of actual host plants (Ngala et al. 2024).

Dead-end trap cropping can be temporary and depend on the insect and plant stages

Dead-end trap cropping can be affected by the stage of both the insect and the dead-end trap crop plants. For example, neonates of *P. xylostella* cannot survive on *B. vulgaris* (Badenes-Pérez et al. 2004; Lu et al. 2004), but third- and fourth-instar larvae can (Newman et al. 2016). Furthermore, the attractiveness of *B. vulgaris* to ovipositing *P. xylostella* is greater before flowering, while at flowering some neonates can survive on it, thus not serving as a dead-end trap crop at that stage (Badenes-Pérez et al. 2017). Moreover, due to the low amounts of saponins in leaves of young *B. verna* and *B. vulgaris* plants (less than 4–5 weeks old), these young plants may not be fully resistant to *P. xylostella* (Badenes-Pérez et al. 2014a; de Los Reyes et al. 2024). Similarly, vetiver grass *C. zizanioides*, which can be used as a dead-end trap crop for *C. partellus*, seldom flowers in temperate areas, but in tropical areas produces flowering stems in which *C. partellus* larvae can survive at very low levels (Van den Berg 2006b).

Biological control-assisted dead-end trap cropping

In addition to diverting insect pests away from the main crop, trap crops can also enhance pest management by attracting natural enemies (Hokkanen 1991; Shelton and Badenes-Pérez 2006; Sarkar et al. 2018; Badenes-Pérez 2019). This type of trap cropping is known as biological control-assisted trap cropping (Shelton and Badenes-Pérez 2006). For example, *B. vulgaris* is a case of biological control-assisted dead-end trap cropping. By using *B. vulgaris* as a dead-end trap crop for *P. xylostella*, management of this pest can be further enhanced because *B. vulgaris* also attracts natural enemies of *P. xylostella*, such as the parasitoids *Diadegma insulare* Cresson (Hymenoptera: Ichneumonidae) and *Diadromus collaris* Gravenhorst (Hymenoptera: Ichneumonidae) (Idris and Grafius 1995; Badenes-Pérez et al. 2017). In central Spain, *D. insulare* can provide high levels of paratism of *P. xylostella* larvae (above 60%) and pupae (Badenes-Pérez et al. 2017). The attraction of *B. vulgaris* (specially at the non-flowering stage) to these parasitoids represents an added benefit of using this dead-end trap crop (Badenes-Pérez et al. 2017).

Some varieties of maize *Zea mays* (Poaceae) used as conventional and low-survival traps crops for the corn earworm *Helicoverpa zea* Boddie (Lepidoptera: Noctuidae) provide favourable habitats for different generalist predators like ants, spiders, minute pirate bugs, and lady bugs, which can then predate on *H. zea*, transforming them into dead-end trap crops for this insect species (Rhino et al. 2016). Maize varieties with large husk extension can difficult the penetration of *H. zea* larvae into the maize kernel and the longer the residence time on the silks, the higher the exposure to predation by natural enemies (Rhino et al. 2016). Sufficient presence of these natural enemies is a requirement for these maize varieties to be able to work as dead-end trap crops. For this reason, this type of biological control-assisted dead-end trap cropping may only work temporarily and in areas where there is sufficient presence of natural enemies. Without sufficient presence of natural enemies, these maize varieties would only be considered conventional trap crops or low-survival trap crops.

Lamy et al. (2024) attempted to transform a trap crop of Chinese cabbage *B. rapa* ssp. *pekinensis* into a dead-end trap crop for the cabbage root fly *Delia radicum* L. (Diptera: Anthomyiidae) by applying the entomopathogenic fungus *Metarhizium brunneum* to the trap crop. Although this treatment combination did not provide full control of *D. radicum*, it significantly reduced densities of *D. radicum* (Lamy et al. 2024).

Genetically engineered dead-end trap crops

Besides *Barbarea* spp., three trap crop species that elicit high oviposition preference in *P. xylostella* are Indian mustard *B. juncea* (L.) Czern., Chinese cabbage *Brassica rapa* L. ssp. *pekinensis*, and glossy collards *B. oleracea* L. var. *acephala* (Srinivasan and Krishna Moorthy 1991; Badenes-Pérez et al. 2004, 2014b; Lu et al. 2004; Musser et al. 2005; Satpathy et al. 2010). Survival of *P. xylostella* on Indian mustard and Chinese cabbage is relatively high, while is relatively low on glossy collards (Badenes-Pérez et al. 2004; Lu et al. 2004; Satpathy et al. 2010). To prevent the survival of *P. xylostella* larvae on these trap crops, *Bacillus thuringiensis* (Bt) transgenic collard and Indian mustard lines have been developed, thus essentially making them work as dead-end trap crops (Cao et al. 2005, 2008; Shelton et al. 2008; Kamble et al. 2013). Bt Chinese cabbage has been shown to be resistant to *P. xylostella* and other lepidopterans (Cho et al. 2001; Kim et al. 2008) and most likely remains highly attractive to ovipositing *P. xylostella*, though this has not been tested (Table 2).

Bt potatoes *Solanum tuberosum* L. (Solanaceae) have also been developed for management of the Colorado potato beetle *Leptinotarsa decemlineata* Say (Coleoptera: Chrysomelidae) (Kadoić Balaško et al. 2020; Salim et al. 2021). Though not tested as dead-end trap crops, Bt potatoes were suggested as a dead-end trap crop planted earlier than the main standard potato crop (Shelton and Badenes-Pérez 2006). However, to prevent resistance development in *L. decemlineata*, standard potatoes would need to be planted soon after Bt potatoes to allow some survival of *L. decemlineata* (Hoy 1999).

Bt cotton *Gossypium hirsutum* L. (Malvaceae) can be used as a dead-end trap crop for the cotton bollworm *Helicoverpa armigera* Hübner (Lepidoptera: Noctuidae) (Lu et al. 2022). Bt maize can be used as a dead-end trap crop for the beet armyworm *Spodoptera exigua* Hübner (Lepidoptera: Noctuidae) and the sugarcane borer *Eldana saccharina* Walker (Lepidoptera: Pyralidae) (Keeping et al. 2007; Song et al. 2025) (Table 3). *Spodoptera exigua* female moths showed no oviposition preference between Bt and non-Bt maize plants under undamaged conditions, but they preferentially oviposited on Bt maize when non-Bt maize plants were damaged (Song et al. 2025). Similarly, ovipositing moths of *C. suppressalis* show no preference for either non-Bt or Bt rice, but they avoid plants showing conspecific damage (Jiao et al. 2018). This indicates that the use of Bt maize and Bt rice as a dead-end trap crops for *S. exigua* and *C. suppresalis*, respectively, would remain even more effective when infestations of the non-Bt crop is high, as damage to the non-Bt plants will keep Bt plants more attractive to ovipositing females. With most of the plants in the field

consisting of non-Bt crop plants where the pest can survive, and a small percentage of plants being the Bt crop plants as dead-end trap crops, the resistance management that should be associated to the deployment of Bt crops is ensured.

Glucosinolates are known to be important attractants and oviposition stimulants for *P. xylostella* larvae and ovipositing adult females (Badenes-Pérez et al. 2020). By using genetic engineering, glucosinolates have been incorporated into tobacco *Nicotiana tabacum* L. (Solanaceae), which can then attract ovipositing *P. xylostella*, whose larvae however cannot survive on this non-host plant, making it act as a dead-end trap crop (Møldrup et al. 2012).

Suboptimal host-plant choice in dead-end trap cropping

The preference-performance hypothesis, which states that oviposition preference should be highly correlated to host plant suitability for larvae (Jaenike 1978), tends to fit the behavior of oligophagous insects like *P. xylostella* (Gripenberg et al. 2010; Zhang et al. 2012; Badenes-Pérez et al. 2020). On the other hand, suboptimal host-plant choice, i.e., high ovipositional preference for host plants on which offspring cannot survive, has been reported in many insect species, especially among Lepidoptera (Thompson 1988; Thompson and Pellmyr 1991). Suboptimal host-plant choice has been explained in the context of host expansion, enemy-free space, and the presence of plant chemoconstituents that act as stimulants and deterrents in the process of host plant choice and oviposition of the insect (Thompson and Pellmyr 1991; Renwick and Chew 1994; Larsson and Ekbom 1995). The oviposition preference for *B. verna* and *B. vulgaris* on which *P. xylostella* larvae cannot survive occurs because female moths are exposed to glucosinolates (oviposition stimulants) on the surface of leaves, where saponins are not present (Badenes-Pérez et al. 2011). The limited overlapping of *P. xylostella* and *B. vulgaris* in their natural habitats reduces the selection pressure on *P. xylostella* to adapt to *B. vulgaris* (Badenes-Pérez et al. 2006). Similarly, the experiments with glucosinolate-engineered *N. tabacum* (Møldrup et al. 2012), vetiver grass (Lu et al. 2017a; Tang et al. 2024), and Bt crops (Cao et al. 2008; Shelton et al. 2008), indicate that the insect choice for dead-end trap crops is often connected with the presence of host-plant associated stimulants and the inability of the insect to properly assess host quality and detect deterrents or toxins. The same happens in the case of the dead-end trap crops for plant-parasitic nematodes when egg hatching stimuli are perceived by the nematodes in the presence of non-hosts or resistant host-plants (Pudasaini et al. 2008; Navarrete et al. 2016).

Expanding the concept of dead-end trap cropping

Shelton and Nault (2004) introduced the concept of dead-end trap cropping for *P. xylostella* management as a strategy that utilizes a plant species that is highly attractive for oviposition but on which *P. xylostella* cannot survive. Although high preferential attraction is key in most dead-end trap crops, there are cases not necessarily associated to inherent sustained preferential attraction, such as the use of tidal-marsh flatsedge *C. serutinus* for management of *S. inferens* (Liu et al. 2011) and those with a key component of biological control, as in the attraction to generalist predators of *H. zea* in some varieties of corn (Rhino et al. 2016). I propose a broader definition of dead-end trap crops as trap crops that due to their inherent characteristics or to added chemical or biological components prevent the survival of the target insect or its offspring.

Recommendations for the deployment of dead-end trap crops

Dead-end trap crops should be deployed in a manner that maximizes their effectiveness. For example, in dead-end trap crops that cause local attraction and arrestment of the target pest, as is the case with *B. vulgaris*, they should be planted in the border or perimeter of the field (Badenes-Pérez et al. 2005b). Increasing the perimeter to area ratio of the field should increase the effectiveness of this type of trap cropping (Hannunen 2005). When *B. vulgaris* is planted in the border of cabbage fields, *P. xylostella* moths lower their movement towards the middle of the cabbage crop and *P. xylostella* moths are found mostly resting on *B. vulgaris*, which indicates that arrestment and retention is occurring (Badenes-Pérez et al. 2005b, 2017). Retention of the target pest is considered a key factor for the success of a trap crop (Holden et al. 2012). Planting *B. vulgaris* in the middle of the field, instead of planting it only in the perimeter of the field, can make it ineffective as a trap crop (Sherbrooke et al. 2020). Plant age and planting density are also important factors to take into account (Badenes-Pérez et al. 2005a). Like in the case of conventional trap cropping (Hokkanen 1991; Banks and Ekbom 1999; Shelton and Badenes-Pérez 2006), a minimum percentage of the total crop area should be planted with the dead-end trap crop in order to make it effective. General guidelines for trap cropping recommend that about 10% of the total crop area be planted with the trap crop, but the percentage of trap crop needed for each particular system has to be determined for each case (Hokkanen 1991; Badenes-Pérez et al. 2005b; Shelton and Badenes-Pérez 2006). In the case of *B. vulgaris*, planting a higher density of plants and larger/older plants at the vegetative stage (tested for plants 6- to 14-weeks old)

increases attraction to *P. xylostella* moths (Badenes-Pérez et al. 2005a). However, *B. vulgaris* and *B. verna* lose their effectiveness as dead-end trap crops for *P. xylostella* when they reach the flowering stage (Badenes-Pérez et al. 2017). Fertilization might be necessary to ensure the good condition of the dead-end trap crop plant and in the case of *B. vulgaris* sulfur fertilization can increase glucosinolate content and make plants more attractive to ovipositing *P. xylostella* (Badenes-Pérez et al. 2010).

Dead-end trap crops, which can function as a sink for the target pest, can reduce reliance on pesticide applications more than conventional trap crops. However, the limitations for the adoption of dead-end trap cropping are similar to those of the adoption of trap cropping, such as the cost of setting land aside for trap crops that cannot be marketed, logistical considerations, and knowledge on how to properly implement the trap cropping system (Shelton and Badenes-Pérez 2006). As trap cropping can be quite specific to the target pests (Shelton and Badenes-Pérez 2006), the effectiveness of dead-end trap crops can be affected by their susceptibility to other pests, especially if the purpose is to eliminate or reduce pesticide use (Badenes-Pérez 2024). If possible, the choice of a dead-end trap crop should take this factor into account. For example, *B. vulgaris* is more susceptible to the cabbage whitefly *A. proletella* than *B. verna* (Badenes-Pérez 2024). As both *B. vulgaris* and *B. verna* can be used as dead-end trap crops for *P. xylostella* management (Badenes-Pérez et al. 2014b), in areas with high infestation of *A. proletella*, *B. verna* could be chosen over *B. vulgaris* to prevent using insecticides for *A. proletella* control (Badenes-Pérez 2024). Seeds of *B. verna* and *B. vulgaris* are easily available and inexpensive in several European countries.

Conclusions and future research directions

The species most studied as dead-end trap crops are wintercress *B. vulgaris*, vetiver grass *C. zizanioides*, and several Bt crops. Trap cropping is usually more effective in relatively larger insects that a have the ability to direct their movement towards preferred host plants, such as insects belonging to the orders Coleoptera and Lepidoptera (Potting et al. 2005). Although most cases of dead-end trap cropping target insect pests belonging to the orders Lepidoptera and Coleoptera, there are examples of insects belonging to other orders that have also been successfully managed with dead-end trap crops. Some of the dead-end trap crops successfully tested have the potential of being a feasible alternative to insecticide use in the management of important economic pests, such as the diamondback moth, cotton bollworm, corn earworm, silverleaf whitefly, green peach aphid, western tarnished plant bug, root-knot and root-lesion nematodes, and different species of fruit flies and thrips. Some of these pests are also well-known for their resistance to insecticides (Zalucki and Furlong 2017; Venkatesan et al. 2022; Walsh et al. 2022; Shehzad et al. 2023). The use of Bt crops as trap crops in non-Bt crops minimizes the use of Bt crops as opposed to the common use of Bt crops, in which only the refugia consist of non-Bt crops and the majority of the field is planted with a Bt crop. In the cases of Bt crops used for management of *S. exigua* and *C. suppressalis*, the preferential oviposition of these species on plants not presenting conspecific damage (Jiao et al. 2018; Song et al. 2025) could make the Bt dead-end trap crop even more effective when infestation levels are high. All those cases in which the potential of dead-end trap crops has only been shown in preliminary laboratory and greenhouse experiments, should, when possible, be tested in field conditions.

Increasing plant species diversification in agroecosystems can provide a variety of synergies and tradeoffs (Hokkanen and Menzler-Hokkanen 2018; Ratnadass et al. 2021; Moreau et al. 2025). As most studies conducted with dead-end trap crops focus on specific target pests, further research should study how different species of pests and beneficial organisms, as well as other ecosystem services, could be affected with the deployment of dead-end trap crops. Overall, because of the reduction in pesticide applications, dead-end trap crops are particular suitable for organic agriculture, for conservation biological control and pollinator conservation, and for those cases in which the target insect pest has developed resistance to insecticides.

Low-survival trap crops deserve further research, which could be helpful for increasing trap cropping effectiveness and for finding new dead-end trap crops. Perhaps different varieties and species belonging to the same genus of these low-survival trap crops have potential as dead-end trap crops. Discovery of new dead-end trap crops and proper use of the current ones can extend the applications of dead-end trap cropping in pest management.

Acknowledgements I thank the Editor-in-Chief, Heikki M.T. Hokkanen, and two anonymous reviewers for providing several references and/or helpful suggestions.

Author contributions Francisco Rubén Badenes-Pérez wrote this review as a single author.

Funding Open Access funding provided thanks to the CRUE-CSIC agreement with Springer Nature. This review received no external funding.

Data availability No datasets were generated or analysed during the current study.

Declarations

Competing interests The author declares that they have no competing interests.

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