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FORUM PAPER

Pest trap and natural enemy nursery merged in *Lobularia maritima*?

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Abstract

Planting crops to push or pull pests from a main crop and floral enhancements to attract natural enemies are emerging as pivotal agroecological strategies to shift away from synthetic pesticides. The brassica, *Lobularia maritima,* has great potential to act as a floral enhancement as it is attractive to many insects and improves the fitness of and biocontrol services provided by multiple natural enemies. It has been mainly deployed as an insectary plant; few studies have been conducted on its use as a trap plant. We explored the potential of *L. maritima* as a targeted flower enhancement in sheltered cropping systems through three case studies: (1) as flower strips alongside a cucumber crop, (2) as flower strips alongside a strawberry crop in a replicated on-farm experiment, and (3) as hanging pots under strawberry cultivation gutters. We monitored beneficial and pest insects in flowers and crops and assessed crop damage. *Lobularia maritima* stands out as an excellent floral enhancement plant due to its ease of cultivation and its ability to flower consistently over an extended period. Generalist predatory bugs, such as *Orius laevigatus* and *Macrolophus pygmaeus*, had higher densities on *L. maritima* than on other flowers grown next to strawberries. We found more thrips on *L. maritima* and less thrips on crops in two out of three experiments, compared with controls. Further research is needed to confirm if *L. maritima* is an effective trap crop for thrips and other pests and to detect possible dis-services, such as the attraction of phytophagous bugs.

Keywords Biological control · Companion plant · Integrated pest management · Beneficial insects · Fragaria · Sweet alyssum

Introduction

Trap cropping and floral enhancements emerge as a pivotal agroecological strategy facilitating the shift away from synthetic pesticides, underscoring its significance in sustainable agricultural practices (Albrecht et al. 2020). This approach offers a multifaceted solution, targeting various ecosystem services and dis-services simultaneously, thereby addressing complex ecological dynamics (Sutter et al. 2018). Importantly, it is crucial to recognize that these ecosystem services are interconnected rather than independent entities, emphasizing the need for holistic approaches in agroecological management (Sutter 2016). Selecting appropriate plant species for floral enhancement programs becomes paramount, especially considering the specific requirements of target insect species and the desired outcomes, whether conservation or biological control (Sutter et al. 2017). Thus, understanding the intricate relationships between plant species, insect communities, and ecosystem services is fundamental in effectively harnessing the potential of floral enhancement strategies for sustainable agriculture.

The same plant species can have different effects on biological pest control depending in which cropping system it is deployed. "*A flowering plant which attracts and possibly maintains, with its nectar and pollen resources, a population of natural enemies which contribute to biological pest management on crops*" is an insectary plant (Parolin et al. 2012a). By providing suitable conditions for their establishment and reproduction, it acts as a nursery plant for beneficials. An insectary plant has a direct positive effect on natural enemies, which in turn reduce pest density. As a result, an insectary plant has an indirect positive effect on the main crop (Parolin et al. 2012b). A plant species that serves

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as an insectary plant for a natural enemy can also be a trap plant for an arthropod pest. Trap plants "*attract insects or other organisms like nematodes to protect target crops from pest attack, preventing the pests from reaching the crop or concentrating them in a certain part of the field where they can be economically destroyed*" (Shelton and Badenes-Perez 2006). Target pests have a direct negative effect on the trap plant, which results in an indirect positive effect of the latter on the main crop (Parolin et al. 2012b). Finding floral species that encompass several categories of secondary plants in the same growing system could boost biological control while reducing the workload and complexity.

Lobularia maritima L. Desv. (Brassicaceae), also known as sweet alyssum, is an annual or short-lived perennial herbaceous plant native to the Mediterranean region (Picó and Retana 2003). This low, spreading plant grows up to 30 cm high and has narrow, lanceolate leaves arranged in rosettes. Its inflorescences are initially umbelliform, then elongate into multiflora clusters composed of white or purple-petalled flowers (Lauber et al. 2009). *Lobularia maritima* grows best in sandy, well-drained soil and needs moderate watering (Henson et al. 2006; Landolt and Bäumler 2010). It has been widely cultivated as an ornamental plant and features multiple properties for flower enhancement in agriculture.

Being an excellent source of pollen and nectar, *L. maritima* is very attractive to many natural enemies (Landis et al. 2000; González-Chang et al. 2019). It has an extended, uninterrupted flowering period of around 10 months (Picó and Retana 2003) and establishes rapidly, making it competitive against weeds (Begum et al. 2006; Grasswitz 2013). *Lobularia maritima* was found to enhance the presence of beneficial insects including pollinators (Barbir et al. 2015; Scarlato et al. 2023), aphidophagous hoverflies (Pineda and Marcos-García 2008; Gillespie et al. 2011; Amorós-Jiménez et al. 2014; Harris-Cypher et al. 2023), various parasitoid wasps (Gámez-Virués et al. 2009; Aparicio et al. 2018; Arnó et al. 2018; Buchanan et al. 2018; Madeira et al. 2022) and predatory bugs (Haseeb et al. 2018).

Positive effects on the fitness of natural enemies have also been observed in multiple studies. Supplying *L. maritima* boosted the longevity (Johanowicz and Mitchell 2000; Munir et al. 2018), fecundity (Hogg et al. 2011) or both (Berndt and Wratten 2005; Pumariño and Alomar 2012; Balzan and Wäckers 2013; Araj et al. 2019; Herz et al. 2021), as well as the sex ratio (Berndt and Wratten 2005) and body weight (Nilsson et al. 2011) of various parasitoids and predators. In the presence of *L. maritima*, improved biocontrol services have been recorded against several hemipteran (Hogg et al. 2011; Irvin et al. 2021; Lopez and Liburd 2022; Zuma et al. 2023) and lepidopteran pests (Gámez-Virués et al. 2009; Shrestha et al. 2019). In several cases, this flowering species promoted natural enemies without benefiting pests (Begum et al. 2006; Munir et al. 2018; Scarlato et al. 2023). Its ability to attract beneficial insects and improve biological control makes *L. maritima* as a potential trap plant a useful tool for integrated pest management strategies.

Mainly used as an insectary plant, *L. maritima* also has potential as a trap plant, attracting and retaining target pests, thereby reducing crop damage and yield losses (Tiwari et al. 2020; Arnó et al. 2021; Silva et al. 2022). However, this potential use has been poorly researched and further investigation is needed to fully understand and optimize it in various cropping systems.

The aim of this study is to explore the potential of *L. maritima* as a targeted flower enhancement for sheltered crops in different settings and, more specifically, to show its attractiveness to pests and beneficials in relation to the main crop. We conducted three case studies: (1) to assess the attractiveness of several flowering species, including *L. maritima*, to cucumber pests and their natural enemies, as well as associated effects on pest control and crop damage when sown alongside a greenhouse cucumber crop; (2) to evaluate these same parameters focusing on thrips and phytophagous bugs in a tunnel strawberry production system; and (3) to explore the influence of *L. maritima* in hanging pots under an off-ground strawberry crop on the control of thrips and phytophagous bugs.

Material and methods

Flower strip next to greenhouse cucumbers

The first case study was conducted from March to October 2022 in the facilities of Agroscope in Conthey (Valais, Switzerland). Two crop cycles of ungrafted single-stemmed cucumber plants cv. Pradera F1 (Rijk Zwann, Netherlands) were cultivated in two identical open-ground greenhouses (350 m^2, no insect-proof netting on the openings). The first and the second crop cycles were planted in weeks 14 and 28, respectively, and grown for 12 weeks each using a high-wire system. Seven 23-m-long rows were set up in the reference greenhouse (0.45 m between plants, 1.7 m between rows). In the test greenhouse, the cucumber row furthest away from the reference greenhouse was replaced by a flower strip which was sown during week 12.

The flower strip was divided into three parts from north to south. A mix of six flowering species was sown in the northern and southern plots (1 m $\times$ 7.5 m), and single-species plots were sown in the mid-Sect. (6 $\times$ 1 m^2). The six flowering species were *Calendula officinalis* L. (Asteraceae), *Centaurea cyanus* L. (Asteraceae), *Coriandrum sativum* L. (Apiaceae), *Fagopyrum esculentum* Moench (Polygonaceae), *L. maritima* (Brassicaceae) and *Vicia sativa* L. (Fabaceae). The mixed plots remained in place for the duration of the two crop cycles. Single-species plots were removed in week 28 and replaced by a mix of six species sown in week 29 (Fig. 1). The same mix of species was used, except for *V. sativa*, which was replaced by *Medicago sativa* L. (Fabaceae). The proportion of each species in the new mix was adjusted based on observations made in the first mix (Supplementary Information (SI) Table S1).

Two separate drip irrigation systems were installed in the cucumber crop (UNIRAM CNL 16010, 2.3 l/h, 0.3 m between drip holes, two pipes per plant row) and in the flower strip (T-tape 150 TSX, 5 l/h, 0.2 m between drip holes, four rows of pipes spaced 0.2 m apart). Only the cucumber crop was fertilized, and the drip system was disinfected between the two cucumber crop cycles. No insecticides were applied during the two cucumber cycles. Three fungicide treatments were applied in the first crop cycle: Armicarb® (Stähler, 0.3%) against powdery mildew and Airone® WG (Andermatt Biocontrol, 0.3%) against leaf mould during week 16 and Amistar® (Stähler, 0.1%) against cucurbit scab during week 17. In the second crop cycle, five fungicide treatments were applied: Airone® WG (Andermatt Biocontrol, 0.3%) against downy mildew once during week 32, Amistar® (Stähler, 0.1%) against downy mildew twice during week 33 and Armicarb® (Stähler, 0.3%) against powdery mildew once during weeks 35 and 36.

Augmentative releases of natural enemies were carried out in both crop cycles (SI Table S2). *Aphidius colemani* Viereck (Hymenoptera: Braconidae), *Eupeodes corollae* Fabricius (Diptera: Syrphidae) and *Chrysoperla carnea* Stephens (Neuroptera: Chrysopidae) were released against aphids. *Amblyseius swirskii* Athias-Henriot, *A. cucumeris* Oudemans (Acari: Phytoseiidae) and *Orius laevigatus* Fieber (Heteroptera: Anthocoridae) were released against thrips. *Phytoseiulus persimilis* Athias-Henriot (Acari: Phytoseiidae) and *Feltiella acarisuga* Vallot (Diptera: Cecidomyiidae) were released against pest mites. *Encarsia formosa* Gahan (Hymenoptera: Aphelinidae) was released against whiteflies.

Pests, natural enemies and inflorescences were monitored weekly in the flower strip. During the first cucumber crop cycle, data were collected in each single-species plot and in three predefined 1 m^2 patches per mixed flower plot. During the second cucumber crop cycle, a single predefined 1 m^2 patch per mixed plot was sampled. Insects were counted visually on ten leaves per flowering species in each 1 m^2 patch, and each plant species was shaken ten times over a white tray to count thrips. In case of doubt about the identification of a species, a sample was taken back to the laboratory for examination under binoculars.

In addition, the total number of inflorescences per species was recorded in each patch. Pests and natural enemies were monitored weekly in the crop. Insects were counted on six plants per row in every other row. One leaf at the top, middle and bottom of each plant was sampled. Insect damage

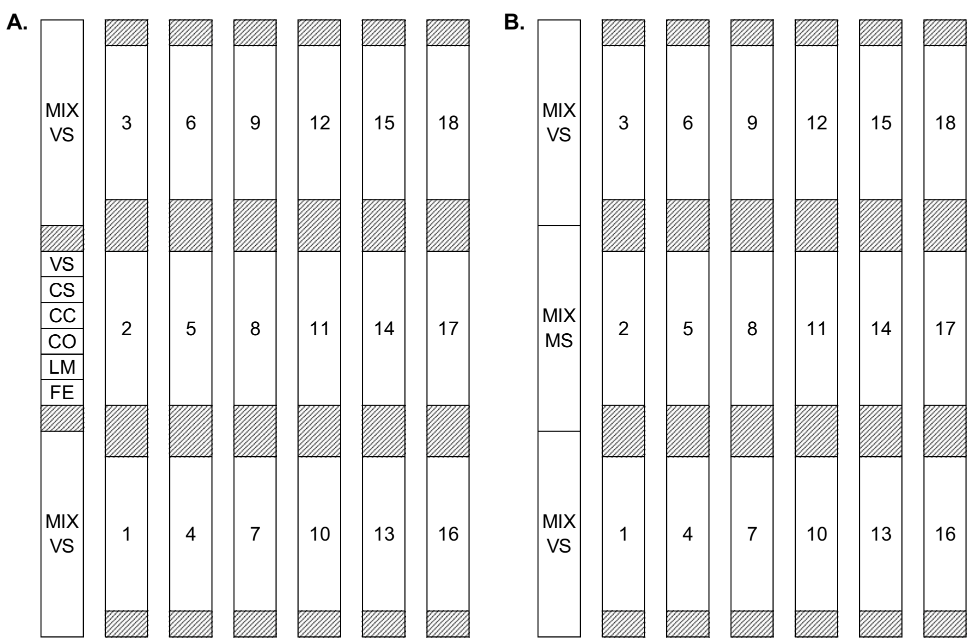


Fig. 1 Design of the flower strip sown next to the first (**A**) and second (**B**) cucumber cycle. The main crop was divided into 18 plots separated by buffer plants (stripped). In the control greenhouse, the flower strip was replaced by a row of cucumber plants resulting in 21 cucumber plots. Single-species plots (1×1m^2): *FE Fagopyrum esculentum*, *LM Lobularia maritima*, *CO Calendula officinalis*, *CC Centaurea cyanus*, *CS Coriandrum sativum*, *VS Vicia sativa*. Mixed species plots (7.5×1m^2): MIX VS = FE + LM + CO + CC + CS + VS, MIX MS = FE + LM + CO + CC + CS + Medicago sativa. All flower plots were sown during week 12 except MIX MS which was sown during week 29

on the crop was assessed twice a week at harvest in 18 plots per greenhouse. The crop line replacing the flower strip in the control greenhouse was left out of this assessment. All cucumbers weighing between 350 and 500g were harvested and sorted. They were then visually inspected and sorted into three categories: marketable cucumbers, cucumbers with insect damage and others (e.g. natural curvature greater than 20mm per 10cm length).

Flower strip next to covered strawberries in a replicated on-farm experiment

The second case study was conducted from March to October 2021 in four commercial off-ground strawberry crops located between Conthey and Martigny (Valais, Switzerland). Everbearing strawberries cv. Vivara (Salvi Vivai, Italy) were planted in substrate bags (Pro-Mix GBX, Premier Tech, Canada) placed under plastic tunnels. Irrigation and fertilization were carried out using a drip system. A flower strip was sown next to each of the four tunnel groups. Crop and flower strip features varied between plots (Table 1).

Pests and natural enemies were monitored weekly in the flower strips from week 23 to 32 (in all plots). Samples were collected by aspiration (ecoVac – Insektensauger, ecoTech Umwelt-Messsysteme GmbH) of ten linear metres per flowering species with the nozzle at vegetation level. Each sample was cooled, transferred into a labelled bag and frozen. Insects were then identified and counted under a binocular. Pest and natural enemies were monitored weekly in the crop from week 24 to 35 (in plots 1 to 3; no data collection in weeks 26, 33 and 34). Insects were collected by shaking one flower spike on each of 40 strawberry plants next to the flower strip and 40 others located 20 m from it. The number of flowers per spike was counted at each sampling round and used to calculate the number of insects per flower. In addition, the percentage of fruit with visible thrips or bug damage was assessed weekly from week 23 to 36 (in plots 1 to 3).

Potted *L. maritima* in covered strawberries

The third case study was conducted from March to August 2022 in a commercial off-ground strawberry crop in Saxon (Valais, Switzerland). In March, everbearing strawberries cv. Vivara (Salvi Vivai) were planted in substrate bags (Pro-Mix GBX, Premier Tech) placed under two identical plastic tunnels (400 m^2). Four 50-m-long rows (8 plants per linear metre) were set up in each tunnel. Irrigation and fertilization were carried out using a drip system.

The two following treatments were compared: (1) strawberry plants above hanging pots of *L. maritima*; and (2) strawberry plants only (control). Each tunnel was divided into three parts (separated by buffer zones) where three replicates of each treatment were set up alternately. *Lobularia maritima* was sown in $60 \times 17 \times 14$ cm^3 white pots (50 seeds/pot) in week 9. The pots were fastened with two

Table 1 Crop and flower strip features in the case study conducted in 2021 next to covered strawberry crops

Plot	Crop features	Flower strip features
1	Plantation in March 2021 3 tunnels of 10.0 m × 60.0 m 6 off-ground rows per tunnel 8 plants per linear metre	Sowing in week 11 (2021) 4 × 16 m × 1.9 m (i. e. 30.4 m^2 per flowering species) Perpendicular to the tunnels, at the north-east end
2	Plantation in March 2020 8 tunnels of 6.0 m × 66.0 m 4 off-ground rows per tunnel 8 plants per linear metre	Sowing in week 12 (2021) 4 × 16.5 m × 2.0 m (i. e. 33.0 m^2 per flowering species) Parallel to the tunnels on the east side
3	Plantation in March 2021 15 tunnels of 5.0 m × 93.0 m 2 off-ground double rows per tunnel 8 plants per linear metre	Sowing in week 12 (2021) 4 × 15.5 m × 3.0 m (i. e. 46.5 m^2 per flowering species) Parallel to the tunnels on the east side
4	Plantation in March 2021 9 tunnels of 4.9 m × 135.0 m 3 off-ground rows per tunnel 6 pots per linear metre	Sowing in week 12 (2021) 4 × 8.5 m × 2.5 m (i. e. 21.3 m^2 per flowering species) Parallel to the tunnels on the west side

Each flower strip was divided into 4 parts:

1. L. maritima (11.6 g/a)
2. M. sativa (600 g/a)
3. Trifolium repens L. (Fabaceae) (300 g/a)
4. a mix of 12 flowering species (550 g/a, composition: *F. esculentum*, *Phacelia tanacetifolia* Benth., *Linum usitatissimum* L. (Linaceae), *Helianthus annuus* L. (Asteraceae), C. officinalis, *Lupinus polyphyllus* Lindl. (Fabaceae), *T. repens*, *Ornithopus perpusillus* L. (Fabaceae), *Anethum graveolens* L. (Apiaceae) and *C. sativum*, *Malva sylvestris* L. (Malvaceae))

wires to the gutters supporting the strawberry crop (1 pot for two linear metres) in week 14 (Fig. 2). Irrigation was carried out using a drip system.

Pest and natural enemies were monitored weekly in *L. maritima* and in the crop from week 17 to 33. Insects were collected by shaking one flower spike on each of 28 *L. maritima* plants and/or 28 strawberry plants in each repetition of both treatments. In addition, the number of flowers per spike was counted at each sampling round, and the percentage of fruit with visible thrips or bug damage was assessed at each harvest.

Data analysis

The experiment conducted in 2021 in sheltered cucumbers consisted in the comparison of two greenhouses managed differently (i.e. flower strip treatment in one greenhouse vs. no intervention in the other). Similarly, the experiment conducted in 2022 in sheltered strawberries consisted in the comparison between six plots with different management methods (i.e. three plots with potted *L. maritima* vs. three plots with no intervention). There is no true statistical replication in these experiments. Further, although we conducted a replicated on-farm trial in sheltered strawberries in 2021, the limited number of replicates results in small statistical power. For these reasons, we preferred presenting the mean differences (with standard error where possible), instead of presenting non-parametric mean comparison with p-values, leading to potentially misleading conclusions.

Results

Flowering period of *L. maritima* compared with six other floral species

Lobularia maritima started to flower approximately one month after sowing and produced inflorescences continuously throughout both cucumber crop cycles (Fig. 3). It represented 81.2% of all inflorescences recorded in the flower strip. *Fagopyrum esculentum* flowered earliest, three weeks after sowing. Flowering peaked for three weeks and then rapidly decreased with no flowering during the second cucumber crop cycle. *Fagopyrum esculentum* produced 15.2% of all inflorescences in the flower strip. *Calendula officinalis* started to flower eight weeks after sowing and continued to do so for the rest of the cucumber crop cycles. It represented 3% of the total number of inflorescences counted in the flower strip. *Coriandrum sativum* produced a small number of flowers in weeks 9 to 11, corresponding to just 0.6% of all inflorescences. *Centaurea cyanus* and *V. sativa* developed poorly with negligible flowering.

In the new mixed plot sown in week 29 at the beginning of the second cucumber crop cycle, *L. maritima* began to flower 5 weeks after sowing (Fig. 4). As in the first mixed plots, flowering was continuous throughout the crop but *L. maritima* produced only 8.7% of the total number of inflorescences. Again, *F. esculentum* flowered earliest at four weeks after sowing. Flowering peaked for four weeks and then rapidly declined. No flowers were recorded on any of the other plant species during the second cucumber crop cycle.

Fig. 2 Footage of the experiment conducted in 2022 in sheltered strawberries with hanging pots of Lobularia maritima under the cultivation gutters

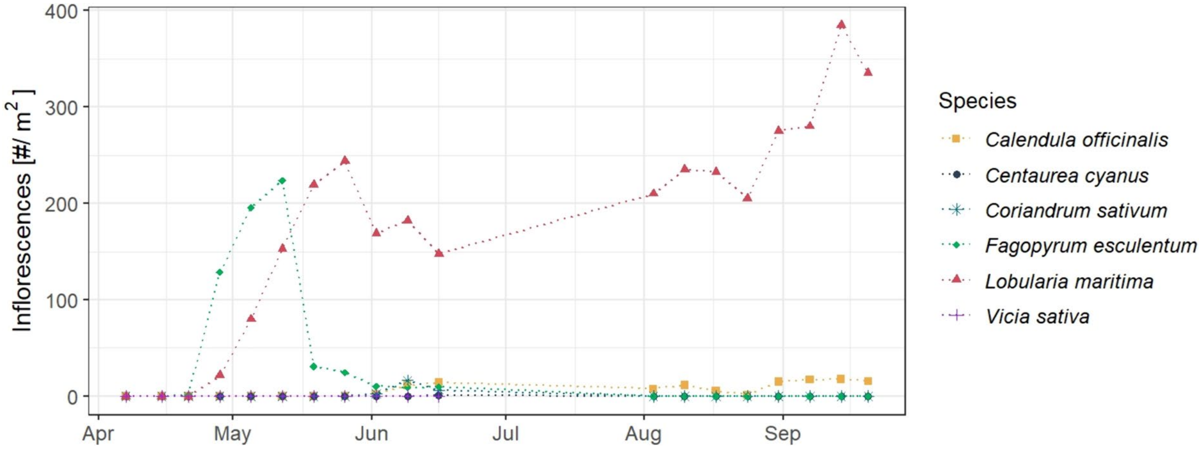


Fig. 3 Average number of inflorescences per species and repetition recorded during the first (April to July) and second (August to October) cucumber crop cycles in the mixed plots sown on 24.03.21 (week 12). No monitoring was carried out between July and August

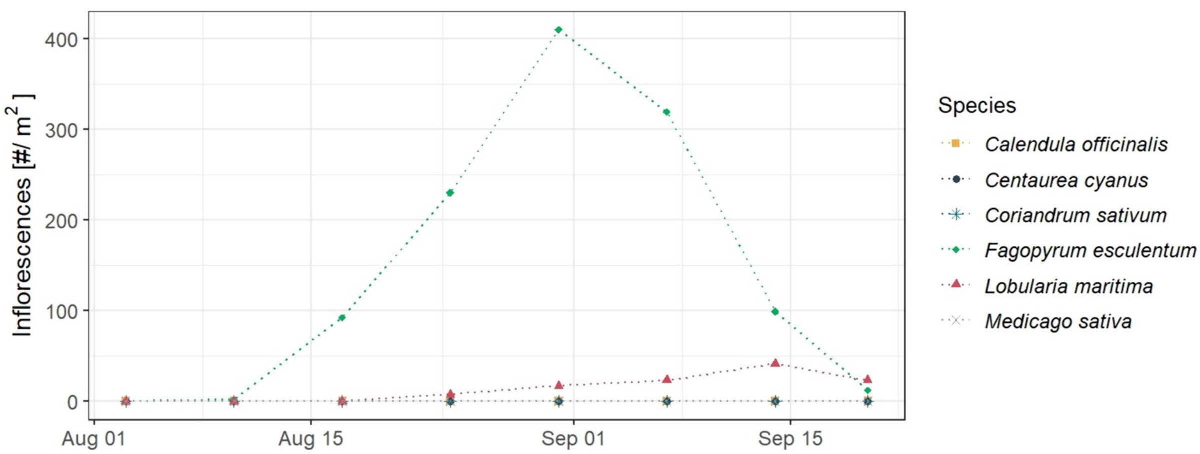


Fig. 4 Average number of flowers per species and repetition recorded during the second cucumber crop cycle in the mixed plot sown on 20.07.21 (week 29)

Attractiveness of *L. maritima* to pests and natural enemies compared with six other floral species

In the flower strip next to the greenhouse cucumbers, *L. maritima* attracted the most insects during both crop cycles, i.e. 25.4% and 31.4% of all insects recorded, respectively (Fig. 5). Twenty to 350 times more thrips were recorded on *L. maritima* than on other plant species. In contrast, it attracted up to 22 times less aphids than other plant species and a negligible number of pest mites. In the second cucumber crop cycle, the phytophagous bug, *Lygus rugulipennis* Poppius (Heteroptera: Miridae), was observed on both *L. maritima* and *C. officinalis*, with a stronger presence on the first flowering species.

Few natural enemies were found in the flower strip during the first cucumber crop cycle. *Calendula officinalis* attracted the most individuals, in particular *A. colemani*. Larger populations were observed in the flower strip during the second crop cycle. *Lobularia maritima* and *C. officinalis* were the most attractive species to beneficial insects, accounting for 60.5% and 25.8% of all individuals, respectively. *Macrolophus pygmaeus* Rambur (Hemiptera: Miridae) was found on both species. However, more than twice as many individuals were found on *L. maritima* as on *C. officinalis*. *Lobularia maritima* also attracted *O. laevigatus*, which was not found on any other flowering species.

As in the cucumber experiment, *L. maritima* was the most attractive species for insects in the flower strip next to covered strawberries (Fig. 6). It accounted for 39.7% of all the individuals recorded in the flower strip, exceeding the 12 species mix on which 25.9% of insects were observed. *Lobularia maritima* attracted 1.7 to 3.1 times more thrips and 1.2–3.3 times more phytophagous bugs

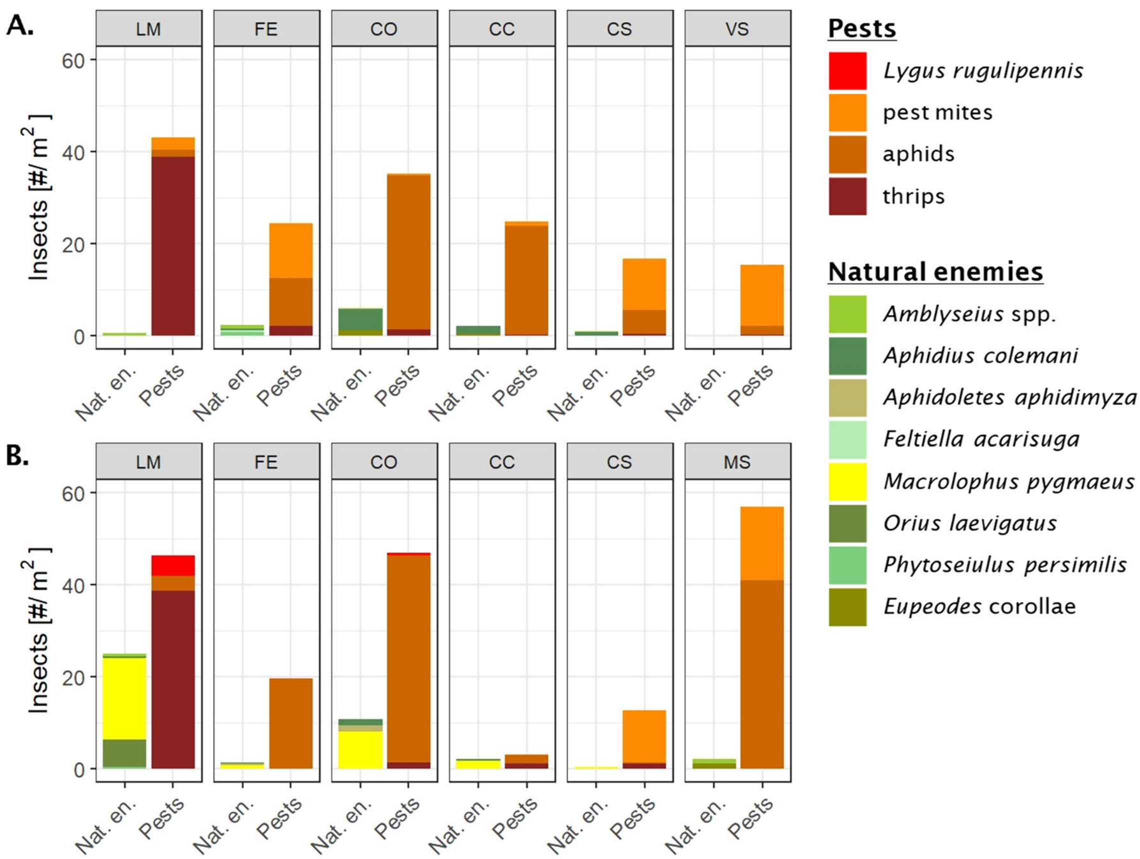
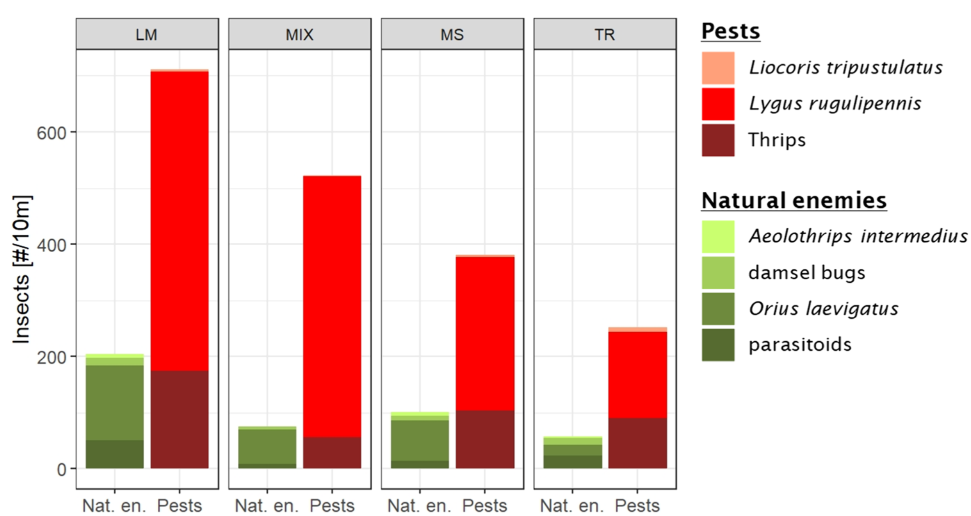


Fig. 5 Cumulative number of pests and natural enemies (Nat. en.) recorded in 2021 in the different species in the flower strip during the first (**A**) and second (**B**) cucumber crop cycles. *LM Lobularia maritima*, *FE Fagopyrum esculentum*, *CO Calendula officinalis*, *CC Centaurea cyanus*, *CS Coriandrum sativum*, *VS Vicia sativa* (in the first crop cycle only) and *MS Medicago sativa* (in the second crop cycle only)

Fig. 6 Cumulative number of pests and natural enemies (Nat. en.) recorded in 2021 in the different species in the flower strip next to the sheltered strawberry crop. Samples were collected by aspiration of ten linear metres per flowering species with the nozzle at vegetation level. *LM Lobularia maritima*, *MIX* 12 species mix, *MS Medicago sativa*, *TR Trifolium repens*



than other flowering species. *Lygus rugulipennis* was the most prevalent species of phytophagous bugs.

Regarding natural enemies, *L. maritima* attracted 1.9–7.4 times more *O. laevigatus* and 2.1–5.7 times more parasitoids than other flowering species. It accounted for 46.5% of all recorded natural enemies, followed by *M. sativa* (22.9%), the 12 species mix (17.3%), and *T. repens* (13.3%).

Effect of floral enhancement measures on population densities of pests and natural enemies in cucumber and strawberry crops

In the first cucumber crop cycle, equally low numbers of pests and natural enemies were observed in the crop grown next to the flower strip as in the reference crop (Fig. 7). The main pests present in the crop were whiteflies, thrips, pest mites and aphids. Thrips represented the greatest risk of direct harvest losses, while aphids and whiteflies were more likely to transmit viruses and indirectly affect yield via plant vigour. Among natural enemies, *Amblyseius* spp. were the most prevalent.

In the second cucumber crop cycle, pest and natural enemy populations recorded in the reference crop were 3.4 and 4.3 times larger, respectively, than in the crop next to the flower strip. The main differences between the two treatments were observed in the numbers of aphids and *A. colemani*. Populations of aphids and parasitoid wasps were reduced by 93% and 99%, respectively, in the cucumbers grown next to the flower strip compared to the reference crop. Thrips populations decreased by 32% in the cucumbers next to the flower strip compared to the reference crop.

Similarly, the number of thrips per strawberry flower decreased by 31% in the strawberry rows next to the flower strip compared with rows 20 m away from it (Fig. 8). Similar numbers of *L. rugulipennis* and *O. laevigatus* were found at both distances.

In the experiment carried out in 2022 with potted *L. maritima* under off-ground strawberries, no difference in thrips and phytophagous bug populations was found between those plots with and those without flower enhancement.

Effect of floral enhancement measures on crop damage in cucumbers and strawberries

Similar percentages of crop damage were found in both the greenhouses with and without flower strips during the first cucumber crop cycle (Fig. 9A, B). In contrast, twice as much damage was measured in the greenhouse with the flower strip as in the reference greenhouse during the second crop cycle.

Comparable percentages of strawberries damaged by thrips were observed next to and 20 m from the flower strip in covered strawberries (Fig. 9C, D). Damage caused by tarnished plant bugs tended to be lower in strawberry plants grown next to the flower strip than in those 20 m away.

In the 2022 case study, lower thrips damage was recorded in strawberry plants above suspended pots of *L. maritima* than in the control plots. On average over the season, the number of strawberries damaged by thrips was reduced by 50% in plots with *L. maritima* (Fig. 10). Damage reduction

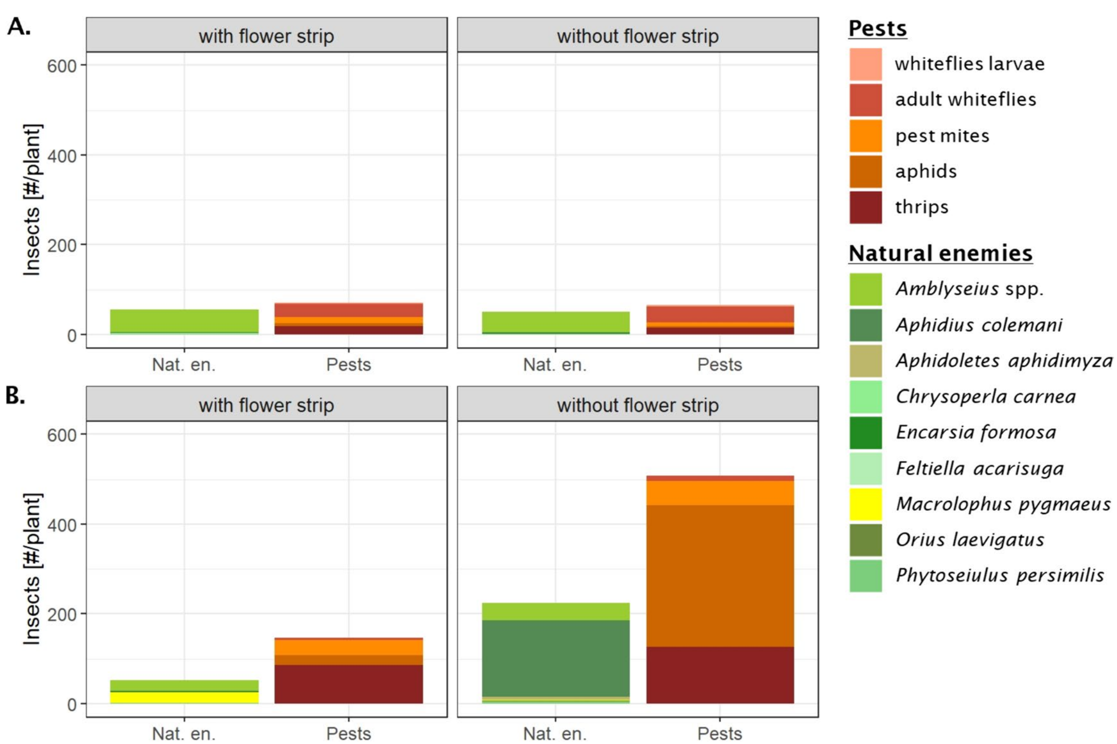


Fig. 7 Cumulative number of pests and natural enemies (Nat. en.) per plant in the crop recorded in 2021 during the first (**A**) and second (**B**) cucumber crop cycles

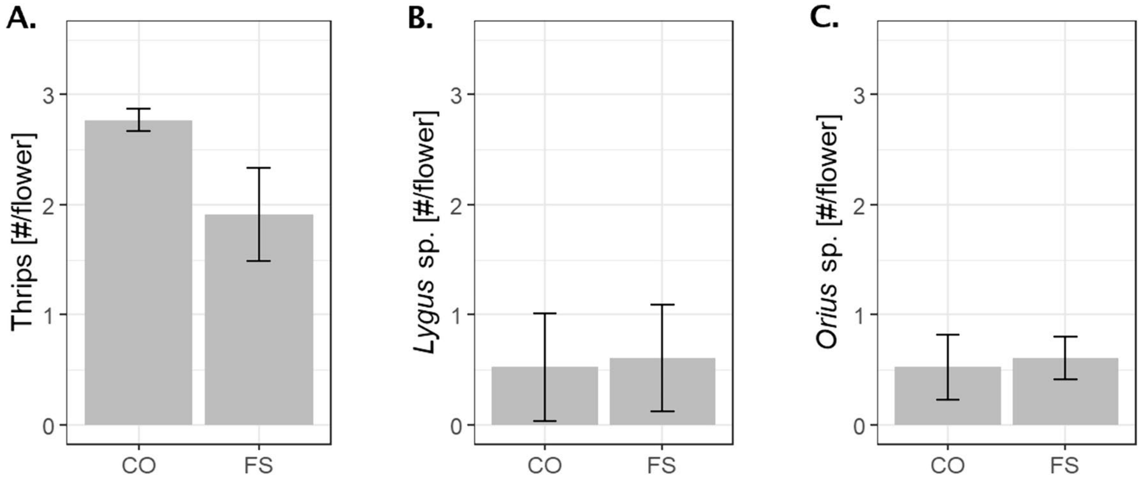


Fig. 8 Cumulative number of thrips (**A**), *Lygus rugulipennis* (**B**) and *Orius laevigatus* (**C**) per strawberry flower recorded in 2021 in the sheltered strawberry crop. *CO* strawberry plants 20 m away from the flower strip (control), *FS* strawberry plants next to the flower strip. Error bars represent the standard error of the mean

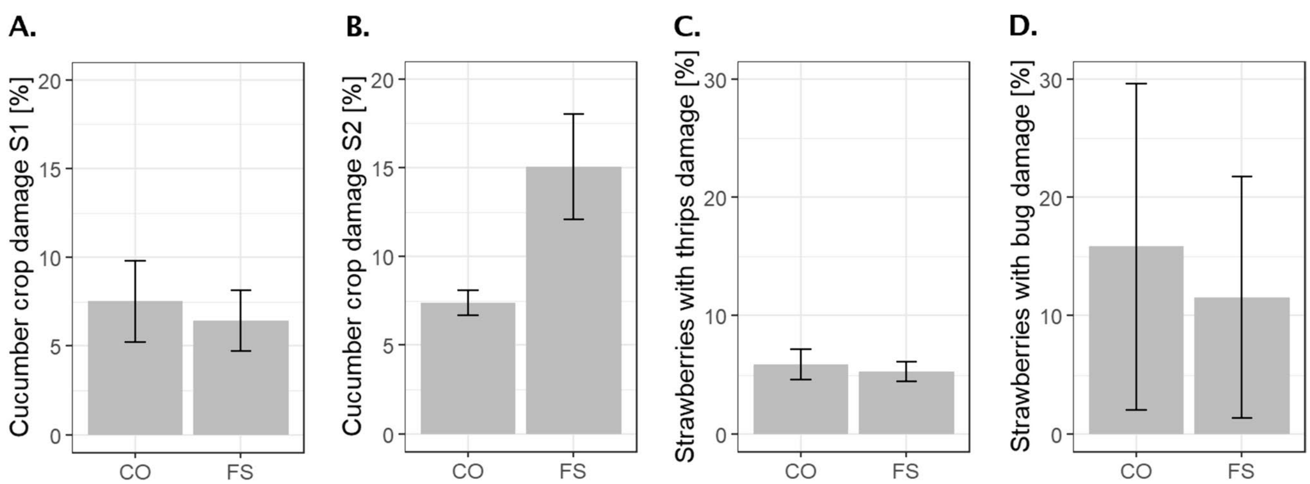


Fig. 9 Average percentage of crop damage recorded in 2021 in the first (**A**) and second (**B**) cucumber crop cycles. Average percentage of strawberries with damage caused by thrips (**C**) and tarnished plant bugs (**D**) recorded in 2021 in the covered strawberry crops. In A and B: *CO* cucumber greenhouse without flower strip (control), *FS* cucumber greenhouse with flower strip. In C and D: *CO* strawberry plants 20 m from the flower strip (control), *FS* strawberry plants next to the flower strip. Error bars represent the standard error of the mean

varied from 3 to 84% in the different sampling rounds. In contrast, 44% more strawberries with damage caused by tarnished plant bugs were found in the plots with *L. maritima* than in the control.

Discussion

This research illustrates the potential of *L. maritima* as a targeted flower enhancement in sheltered crops. This flowering species was found to be well adapted and practical for greenhouse and tunnel cultivation. It was suitable for soil and pot growing and performed well in both conditions. *Lobularia maritima* attracted many insects and has a high potential in integrated management of thrips in strawberries. However, a potential increase in phytophagous bug populations and associated crop damage needs to be considered in future research.

In line with previous results (Picó and Retana 2003; Irvin et al. 2021), *L. maritima* grown next to the greenhouse cucumber crop had an early, extended and uninterrupted flowering period. It had the longest and most abundant flowering of all the tested plant species, comprising more than 80% of all the recorded inflorescences. Blooming started four weeks after sowing and continued for more than five months thereafter. At the last

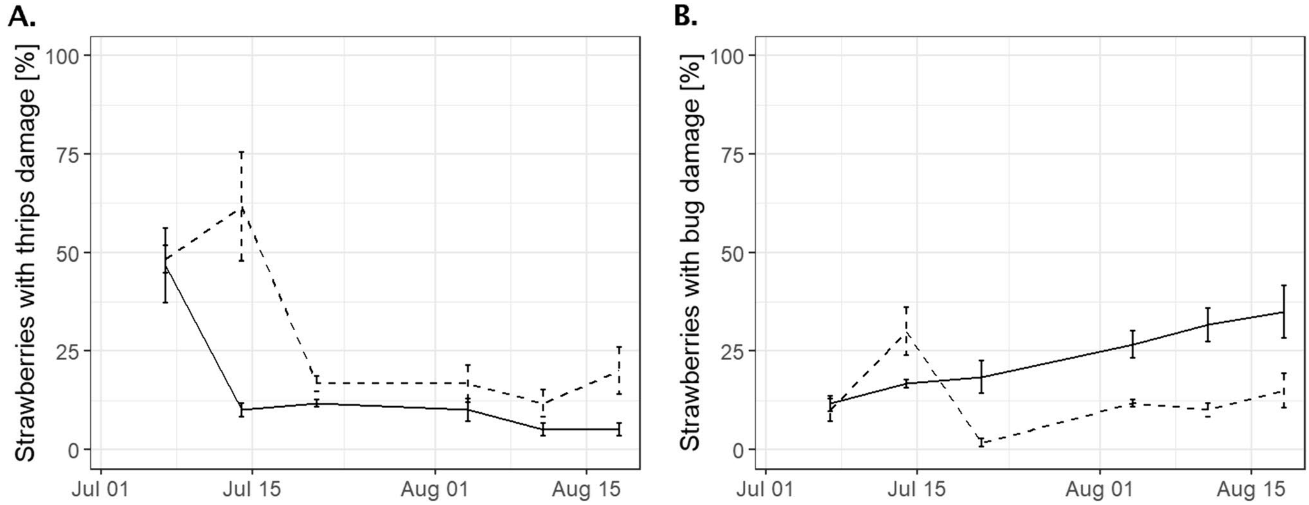


Fig. 10 Average percentage of strawberries with damage caused by thrips (**A**) and tarnished plant bugs (**B**) recorded in 2022 in the covered strawberry crops. *Solid line* strawberry plots with potted *Lobularia maritima*, *dashed line* strawberry plots without potted L. maritima (control). Error bars represent the standard error of the mean

monitoring, *L. maritima* was still producing more than 300 inflorescences per m^2. *Fagopyrum esculentum*, another common insectary plant, started flowering a week earlier than *L. maritima*, but only for a short period of about five weeks. This species had to be reseeded to obtain new flowers during the season. However, it rapidly developed after the summer sowing and started flowering within four weeks. In contrast, *C. officinalis* began to flower one month after *L. maritima* but bloomed continuously thereafter. In a previous study, seed germination of *L. maritima* peaked at 10°C and progressively decreased at both higher and lower temperatures (Picó and Retana 2003). Consistent with this, *L. maritima* established and flowered more rapidly after spring sowing when temperatures were lower than after summer sowing. Therefore, we recommend sowing it under greenhouse early in spring or possibly in autumn (provided the infrastructure is kept frost-free during the winter) to ensure an optimal development.

Due to its long flowering period, *L. maritima* provided pollen and nectar throughout the growing season. It attracted the highest number of insects amongst all the flowering species tested alongside cucumbers and strawberries. However, natural enemies were slow to colonize it in our cucumber case study. Only a few predatory mites were recorded in *L. maritima* during the first crop cycle and the flower strip had no effect on the presence of pests and natural enemies in the crop. It took until the second crop cycle to observe larger populations of generalist predatory bugs and a strongly reduced presence of pests in the crop next to the flower strip compared to the reference greenhouse. This reduction was mainly due to a decreased number of aphids, which either migrated to the flower strip or were controlled by natural enemies. As a result, populations of *A. colemani* also strongly decreased in the crop.

Interestingly, the flower strip boosted the presence of *M. pygmaeus* in the crop although this mirid predator was previously found to be unable to maintain itself on cucumber plants (Perdikis and Lykouressis 2003). *Calendula officinalis* is known as a natural host of this zoophytophagous species (Ingegno et al. 2011) and used as a banker plant to foster its establishment and biocontrol services in tomato greenhouses (Ardanuy et al. 2022). Consistent with this, *M. pygmaeus* moved from the adjacent tomato greenhouse and naturally colonized *C. officinalis* in our cucumber case study. However, we recorded twice as many individuals of this species on *L. maritima*, highlighting the latter's potential as a banker plant for *M. pygmaeus*. Further research should be conducted to assess if growing *L. maritima* alongside various crops proves beneficial to *M. pygmaeus* and increases its biocontrol services. This would be useful as this generalist predator feeds on multiple pests such as whiteflies, spider mites, thrips and moths.

Another positive trait of *L. maritima* recorded in both case studies carried out in 2021 is its high attractiveness for *O. laevigatus*. Higher densities of this predatory bug were recorded on *L. maritima* than on all the other floral species tested. Bennison et al. (2011) mentioned *L. maritima*'s potential use as a combined trap plant for the Western flower thrips, *Frankliniella occidentalis* Pergande (Thysanoptera: Thripidae) and banker plant to promote the predatory bug *O. laevigatus*. No such dual effect of *L. maritima* could be demonstrated in the present case studies, however this should be further researched as it would be ideal for optimizing thrips control. In another experiment, the presence of *L. maritima* in a strawberry cropping system positively influenced the population growth of the predatory bug and the biocontrol services it provided against aphids (Zuma et al. 2023). In our cucumber case study, the higher density of *O. laevigatus* may have contributed to reducing aphid pressure during the second crop cycle.

Despite a strong reduction in pest populations in the second cucumber crop cycle, insect crop damage was twice as high next to the flower strip as in the reference greenhouse. Although *L. rugulipennis* was not directly recorded in the crop (probably due to its high mobility), most of the additional damage was caused by this pest. In the flower strip, the phytophagous bug was mainly found on *L. maritima*, highlighting the importance of considering possible dis-services in future assessments of this flowering species. For example, twice as many tarnished plant bugs were found in flowered strips composed of *L. maritima* as in mown border strips set up along an asparagus crop (Buchanan et al. 2018). Miridae were reported to be attracted to *L. maritima* and larger populations of homopteran pests were recorded in the inter-rows of an organic vineyard when this floral species was sown (Burgio et al. 2016). Further, Köneke et al. (2023) reported *L. maritima* to cause an increase of flea beetle infestation when intercropped with cabbage. Contrarily to the results of the cucumber case study, damage caused by tarnished plant bugs tended to be lower in strawberries next to the flower strip as in those 20 m from it. Regarding thrips, approximately one third fewer individuals were found on cucumber plants next to the flower strip as in the reference greenhouse. A similar reduction was observed between strawberries grown next to the flower strip and those 20 m from it. However, there was no effect of the flower strips on thrips damage in the crops grown in 2021. As both flower strips were composed of several species, the contribution of *L. maritima* to this result remains to be determined.

Finally, the results of the case study carried out in 2022 provide some insights into its use for the management of thrips, possibly as a trap crop. While similar thrips populations were recorded on strawberry plants grown above hanging pots of *L. maritima* as in control plots, thrips damage was halved in flowered plots. We assume that *L. maritima* is a trap plant for thrips, as previously reported by Bennison et al. (2011), and that its position in the crop plays a key role in reducing crop damage. In our case study, *L. maritima* was grown in hanging pots below the cultivation gutters. We postulate that winged adult thrips preferred potted *L. maritima* to strawberry plants for oviposition and that the young non-winged larvae, which cause the most damage, were then unable or unwilling to climb back onto the crop. These results should be considered carefully, as they are based on observations only and thrips pressure was relatively low in 2022. However, this is the first time to our knowledge that such a phenomenon has been reported.

We believe that *L. maritima* has great potential as a multifunctional companion plant and that further investigations are necessary to reveal it. These should include considerations on the optimal position (i.e. potted vs. in-ground plants, connected vs. disconnected from the main crop) and density of this floral species in the main crop. Various combinations of *L. maritima* with other flowering plants could also be tested in order to mitigate potential dis-services, such as the attraction of tarnished plant bugs to the main crop. Further experiments should also aim to prove the attractiveness of *L. maritima* to predatory bugs and the usefulness of this property in different cropping systems (e.g. biocontrol services of *M. pygmaeus* on crops other than tomatoes).

Conclusions

We illustrated the potential of *L. maritima* for flower enhancement in sheltered crops and postulated its possible applications for biological control of thrips. *Lobularia maritima* is a flowering species with many advantages. It is easy to grow, performs well in pots and in open ground, and is suitable for open-field and covered cultivation. *Lobularia maritima* has a long and abundant flowering period compared to other floral species, making it attractive to insects, in general. Generalist predatory bugs, such as *Orius laevigatus* and *Macrolophus pygmaeus*, had higher densities on *L. maritima* than on other flowers grown next to the main crop. We found more thrips on *L. maritima* and less thrips on crops in two out of three experiments, compared with controls. Further research is needed to confirm if *L. maritima* is an effective trap crop for thrips and other pests and to detect possible dis-services, such as the promotion of phytophagous bugs. We assume that a targeted management of *L. maritima* in the main crop would make it possible to take advantage of both its attractiveness to natural enemies (parasitoids, predatory bugs) and its properties as a trap plant for thrips.

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Declarations

Conflict of interest The authors have no competing interests to declare that are relevant to the content of this article.

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