Eur. J. Hortic. Sci. *89*(1) | ISSN 1611-4426 print, 1611-4434 online | https://doi.org/10.17660/eJHS.2024/004 | © ISHS 2024

Original article – Thematic Issue

A comparison of flower borders and intercropping flowering plants for enhancing biological control of key pests in strawberry

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Summary

Sowing flowering plants that can provide alternative food (pollen, nectar, and alternative prey) in strawberry production fields is an eco-friendly promising practice of habitat management for enhancing biological control. However, most studies focus on how to enhance the beneficial diversity or functional diversity but not on how to enhance the functional services provided by those beneficial. Therefore, little is known about the role of spatial management strategies in enhancing biocontrol services against strawberry pests. In this study and within two growing seasons 2020–2021, we assessed the effect of flowering plants and related management practices on the diversity of beneficial insects (predators, parasitoids, and bees) and related pest control services against especially aphids in strawberry plants. We first investigated the diversity of beneficial and herbivores on flowering plants included in a commercially available mixture in 2020. Secondly, we investigated the functional diversity and services in relationship with different management strategies applied to selected flowering plants in 2021. Thus, two management strategies were evaluated: a flower border (FSB), sown in the autumn of 2020 and an intercropping system (FSI) with the presence of flowering strips, sown in early spring of 2021 within strawberry plant rows. In 2020, important numbers of beneficial especially predators and bees were recorded on the flowering plants, especially the cornflower *Centaurea cyanus*. For strawberries, non-harmful or secondary aphids were observed on these plants. However, an important presence of pest thrips was recorded especially on *C. cyanus*. The sowing time of flowering plants likely played an important role in improving the biological control of strawberry pests. An early attraction of natural enemies, both predators, and parasitoids, was observed on FSB due to the early presence of flowers. However, higher numbers of natural enemies and their control services against aphids and thrips were observed on FSI. This could be explained by the presence of complementary food (non-pest aphids) on the intercropped-flowering plants that likely promoted the early reproduction increasing (numerical positive responses) of natural enemies. In conclusion, the fact that FSB promoted a remarkable early presence of natural enemies on the one hand, and FSI ended up with the highest numbers of natural enemies on the other hand, suggests that a combination of both cropping systems of flowering plants could be a promising way for improving the strawberry pest control services. Although the intercropping system provided the highest suppression level of pests in this trial, one disadvantage of this system was the loss of cultivation area. In this trial, about 20% of the strawberry plants were replaced by flowering plants. The question then is whether we can reduce the area of flowering plant strips in the intercropping system, and still achieve good biological control. Moreover, attracting pests such as thrips represents another issue for adopting this strategy in the strawberry farming system on a large scale.

Significance of this study

What is already known on this subject?

- Floral field margins are known to benefit beneficial species diversity and abundance within agricultural systems, but variation in success limits widespread adoption. Several researchers have evaluated the use of flowering plants to attract beneficial insects and reduce pests in strawberries.

What are the new findings?

- Unlike previous studies which focused on the impact of surrounding flowering plants, our study investigated the combined effect of intercropped and surrounding flowering plants with varied planting dates. This combination could significantly improve strawberry pest control.

What is the expected impact on horticulture?

- Adding seasonally managed floral resources near and within strawberry plants offers early and closed food for beneficial insects and reduce their traveling to distant alternative food sources. This enhances biocontrol of key pests in the crop field.

Keywords
strawberry, aphids, thrips, natural enemies, control services, flowering plants, functional diversity

Introduction

Strawberry is an important fruit crop in Belgium for both production (Lieten, 2000), 50.599 tons in 2021 (Statista, 2022), and consumption. A total of 70% to 80% of Belgian strawberries is exported, mainly to European countries, making strawberries an economically important product (VLAM, 2014). Various aphid pests are commonly present in strawberries. They can damage strawberry plants directly and indirectly, and thus they can reduce crop yield through direct feeding and virus transmission (Whitham et al., 1991). In agricultural systems, the activities of natural enemies are disturbed by the effect of agricultural practices such as particularly the use of insecticides that diminish the diversity of natural enemies and their control services (Moreau et al., 2006). *Chaetosiphon fragaefolii* Cockerell for example transmits important viruses such as strawberry mild yellow edge and strawberry crinkle viruses (Krczal, 1982). Another significant problem of aphids (often neglected in IPM programs), is the indirect impact of aphid presence on the biological control of other associated pests. Most predatory insects occurring in strawberry crops are generalists in their feeding regime, this meaning they can feed on aphids, spider mites, thrips, etc. This means that the presence of aphids (even if secondary species in terms of damage) will reduce the number of natural enemies feeding on the target pests.

Currently, chemical control of strawberry aphids is a common practice of growers to avoid production loss in strawberry crops. The use of synthetic chemicals in agrosystems is becoming more and more restricted, especially in the European Union. Therefore, there is an increasing interest to develop sound environmental management practices such as biological control to protect crops from pests. In this context, the provision of flowering plants to increase the control services provided by natural enemies is a key practice for improving biological control against pests such as aphids (Blaauw and Isaacs, 2012). However, several studies have reported that to enhance biological control, the right flowering plants and related sound management type should be identified and provided rather than focusing on the increasing beneficial diversity per se (Gurr et al., 2017). We aimed in our study to provide empirical evidence about how flowering plants included in a commercial mixture and related habitat manipulation patterns influence the activity of natural enemies, and then how they alter biological control services against mainly strawberry aphids.

Materials and methods

Field samplings

Aphid and thrips populations and their natural enemies, predators, and parasitoids were monitored in plots of strawberries belonging to the Fruit Research Center (pcfruit *npo*), Sint-Truiden (Limburg province), Belgium, from July to September 2020 and from March to September 2021. Common cultivars of strawberry (similar plant density) were planted in the soil (loam) on plastic-covered beds in an experimental field of 10 m × 50 m. Flowering and strawberry plants were surveyed once a week. Standard doses of fertilization were applied in strawberry plots, and only acaricides and fungicides were applied. The strawberry crop was fertigated using one line of t-tape per planting bed. Nitrogen levels in the soil were adjusted weekly using the KNS fertilizer advice. During the season, soil samples were taken every four weeks to determine the existing N in the soil. The N-nutrient advice considers the forecasted plant nitrogen uptake, the latent mineralized soil N, and the current analysed N in the soil. At the beginning of the season, $Ca(NO_3)_2$ is used as nitrogen fertilization. Starting July 31st, KNO_3 was used instead of $Ca(NO_3)_2$. In general, fertilization doses were homogeneous at both strawberry plots delimited in the same field experimental. In 2020, a commercial mixture of flowering plants (23 species) and two other weed species naturally growing in the study area were included in the surveys, in total 25 species, for evaluating their importance in enhancing the beneficial diversity. The flowering plants (FP) involved the following species, including their codes presented in the Figure 1: Alyssum *Lobularia maritima* (1), Basil *Ocimum basilicum* (2), Birdsfoot *Ornithopus sativus* (3), Black Pearl pepper *Capsicum annuum* (4), Blueweed *Echium vulgare* (5), Borage *Borago officinalis* (6), Buckwheat *Fagopyrum esculentum* (7), Common sage *Salvia officinalis* (8), Coriander *Coriandrum sativum* (9), Corn marigold *Glebionis segetum* (10), Cornflower *Centaurea cyanus* (11), Crimson clover *Trifolium incarnatum* (12), Dill *Anethum graveolens* (13), Garden Cosmos *Cosmos bipinnatus* (14), High mallow *Malva sylvestris* (15), Hyssop *Hyssopus officinalis* (16), Lacy phacelia *Phacelia tanacetifolia* (17), Tickseed *Coreopsis grandiflora* (18), Love in a mist *Nigella damascena* (19), Pot marigold *Calendula officinalis* (20), Sunflower *Helianthus annuus* (21), Tansy *Tanacetum vulgare* (22), White goosefoot *Chenopodium album* (23), White mustard *Sinapis alba* (24), Yarrow *Achillea millefolium* (25).

In 2021, flower strips were differentiated by two sowing periods and two spatial arrangements. Border-grown flowering plants FPB (one border strip, 1 m width × 50 m length) were sown in autumn 2020, while intercropped ones FPI were sown in February 2021 and protected from extreme cold conditions using plastic covers. Seven small strips of flowering plants (4 m in length) were established within strawberry plant lines (Figure 1). Four species (*C. cyanus*, *A. millefolium*, *L. maritima*, *C. officinalis*) of flowering plants FP were the main plants included in this study, selected from



Figure 1. The layout of experimental sites, with border strip (FSB), left and intercropping (FPI) right.

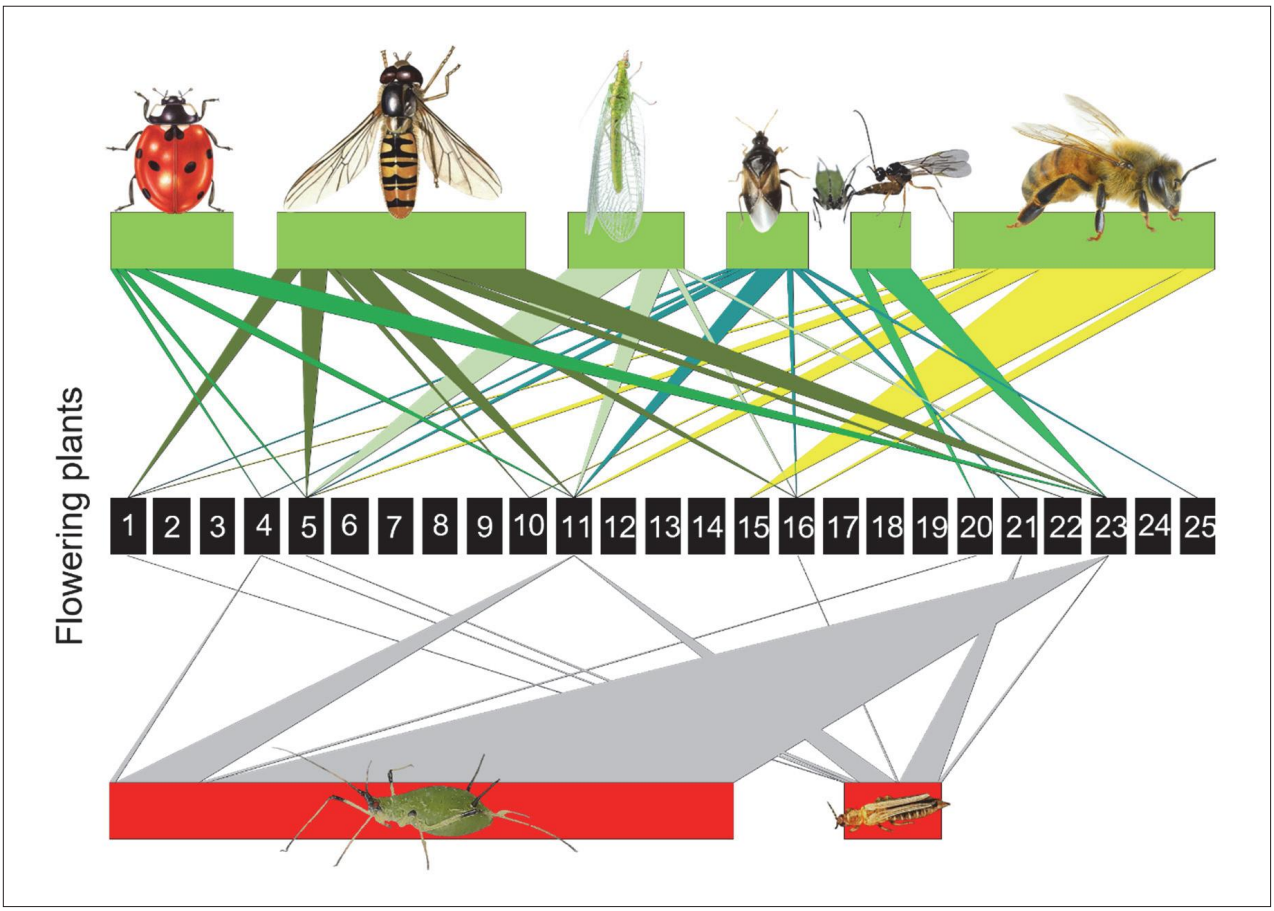


Figure 2. Quantitative food web between flowering plants, target herbivores, and target beneficials recorded in 2020. The series of colored bars represent proportional abundances of pests (bottom), flowering plants (middle), and beneficials (top). The width of links between the three trophic levels illustrates the relative strength (abundance) of each interaction. The code numbers for flowering plants are presented *between brackets* in the Materials and methods section.

the previous mixture, to be used in different spatial management patterns (FP-intercropped strawberries STI and FP-surrounded strawberries STB) to evaluate their control potential in strawberry parcels. Ten plants and ten leaves/five flowers per plant were randomly selected each week to assess the population dynamic of target insects. In the case of flowering plants, 10 plant shoots per species per m^2 (repeated 4 times or 4 quadrants) were randomly selected and scanned for target insects each week.

The development stages considered were nymphs and adults for pests, larvae and adults for ladybirds, eggs, and larvae for hoverflies and lacewings, nymphs, and adults for *Orius*, mummies for parasitoids, and adults for bees. The adults of hoverflies and lacewings visiting the selected flowering plants both in the border and intercropping strips were also included in the counting to evaluate the impact of sowing dates and spatial arrangements on these beneficial adults (offspring producers). We used four scores for classifying aphid infestations per strawberry leaf/whole flowering plant. A = 0, no aphids; B = 1–4 aphids (slight infestation); C = 5–9 aphids (moderate infestation); D > 9 aphids (heavy infestation). Concerning the thrips, we also used four scores for classifying thrips infestation per flower but only on flowering plants, respectively A = 0, no thrips; B = 1–2 thrips; C = 3–5 thrips; and D > 5 thrips. Concerning the natural enemies, all individuals observed were counted. For bees, all adults of honey and solitary bees visiting the scanned plant for 30 seconds were counted.

Data analysis

All data obtained from counts of target pests and beneficial were converted to mean numbers and proportions and then analyzed using Minitab 18 software and Mathematica 5.1. The chi-square goodness of fit test was applied to determine the significance of differences between study plots ($p \leq 0.05$) with a null hypothesis of a 50:50 chance of the target population distributing in study plots.

Results

In the monitoring of 2020, only four species of flowering plants, especially *C. album* and *C. cyanus* hosted aphids, while six species, especially *C. cyanus* and *H. annuus*, hosted thrips. In the natural enemy community, four predatory groups and two species of parasitic wasps (*Aphidius ervi* and *Praon volucre*) were found on the flowering plants. Among them, hoverflies followed by ladybirds and lacewings were the most abundant. Quantitative interactions between flowering plants, pests (aphids and thrips), and beneficials were illustrated in the food web constructed using whole data sets collected in 2020 (Figure 2).

Ladybirds were only found on four species of flowering plants ($\chi^2 = 38.94$, $df = 3$, $p < 0.001$), and 71% of their individuals were detected on *C. album* followed by *C. cyanus* with 18% of individuals. Hoverfly offspring was observed on seven species of flowering plants especially ($\chi^2 = 52.60$, $df = 6$, $p < 0.001$) *C. album* (38%) followed by *C. cyanus* (15%). Offspring of lacewings were observed on four species of flowering plants mainly ($\chi^2 = 84.38$, $df = 3$, $p < 0.001$) on *E. vul-*

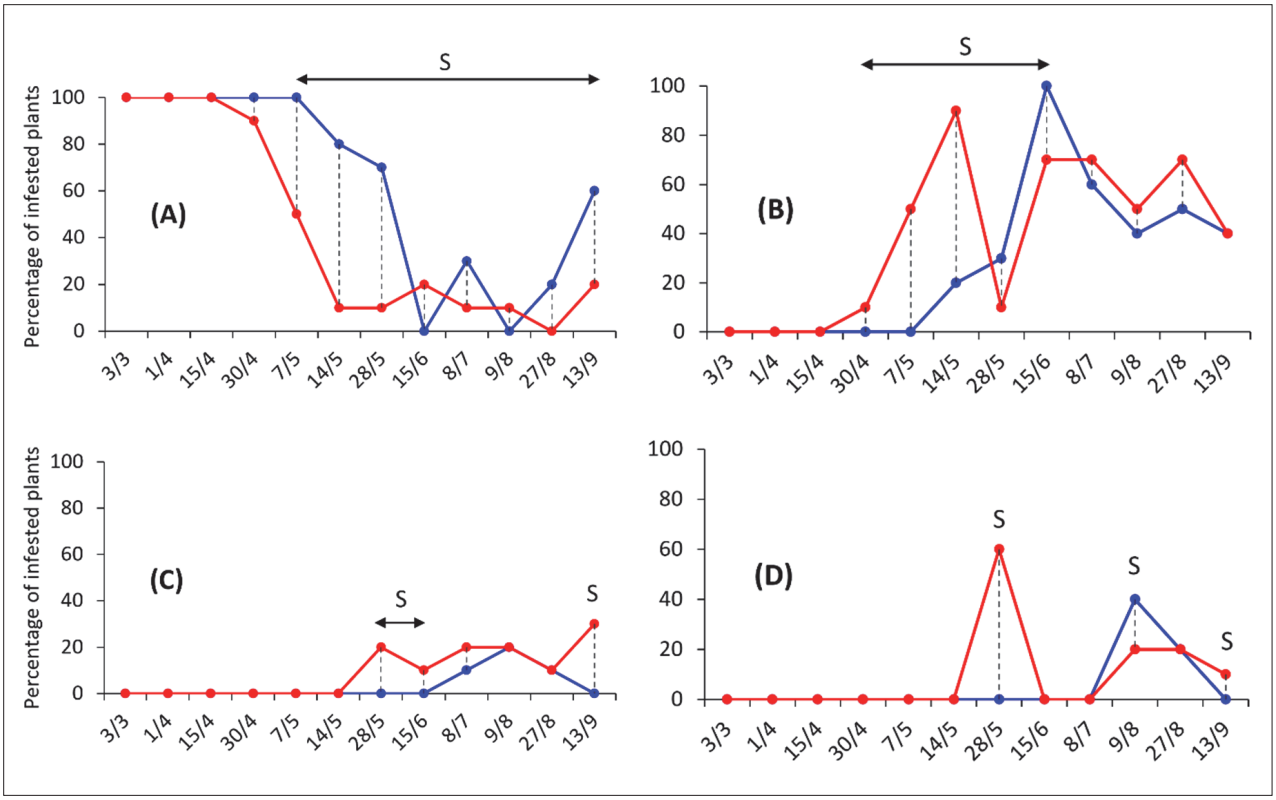


Figure 3. Effect of flowering plants growing either in the border (red lines) or within strawberry beds (blue lines) on the abundance (% of infested plants) of strawberry aphids in 2021. The graphics (A, B, C, D) refer to the percentage of aphid-infested plants (aphid-free, slightly infested, moderately infested, and heavily infested, respectively). Percentages of infested plants were compared using Chi-square goodness of fit test, S = significant differences, $p < 0.05$).

gare (63%) followed by *C. cyanus* (25%). *Orius* nymphs and adults were found on seven flowering plants mainly (χ^2 = 44.63, *df* = 6, $p < 0.001$) on *C. cyanus* (36%) followed by *E. vulgare* (18%). In the parasitoid community, mummies were detected only on two species of flowering plants (χ^2 = 4.00, *df* = 1, $p = 0.046$), *C. album* with 75% of recorded mummies but only 4% of parasitism rate, and *C. officinalis* with 25% of mummies but 100% of parasitism rate. Concerning the bees, their adults were observed active on six species of flowering plants, especially *M. sylvestris* and *C. cyanus*.

In the monitoring of 2021, both sowing time and spatial position of flowering plants have different impacts on the natural enemies and their prey/hosts either on flowering plants or strawberry plants (Figure 3). In terms of temporal occurrence, predators were observed on FPB one month before being observed on FPI, while no parasitoid mummies were found on FPB during the whole season. In terms of predator abundance, significantly (χ^2 = 12.52, *df* = 1, $p < 0.001$) more predator individuals were recorded on FPI (76%) compared to FPB. In strawberry plots, significant differences between STI plants and STB plants in the number of aphids and their natural enemies were found (Figure 2). Parasitoid mummies were observed on STI plants one month before detection on STB plants.

Discussion

The functional diversity of natural enemies reflects the beneficial species that can feed on crop pests. Most predatory insects are classified as generalists, which means they can feed on multiple species of herbivores. However, parasitoid species can be simply categorized in terms of their host range as specialist and generalist, narrow and broad-host-range patterns (Price, 1980; Alhmedi et al., 2018). Such knowledge is essential for helping in the prediction of spatial movement patterns of natural enemies occurring on flowering plants and strawberry plants in relationship with the population dynamic of their prey or hosts.

The first goal of this work was to test the preference of beneficial (natural enemies and bees) and herbivores to flowering plant species by monitoring the quantitative occurrence of target insects over time. The commercially available wildflower mixture tested in this study has already been identified as being a potentially suitable source of pollen and nectar for a wide array of beneficial insects. Our interest was particularly focused on ladybirds, hoverflies, parasitic wasps, lacewings, and predatory bugs as natural enemies in addition to bees (both honey and wild solitary bees). Based on the results, the data analysis showed that in 2020 there was a remarkable preference for ladybirds and hoverflies to *C. album* and *C. cyanus*. While *C. album* has been reported as one of the ten most widely distributed and problematic weed species in the world (Holm et al., 1977), such knowledge may help in exploring the positive side of this plant in agrosystems. Lacewings and *Orius* spp. showed a strong preference for *C. cyanus* and *E. vulgare*. The presence of predatory insects on *C. cyanus* was observed early in the season and since the beginning of May 2021. The important presence of functional parasitoids was recorded on *C. officinalis* also in mid-June due to the presence of the less-problematic aphid *M. euphorbiae* on this plant. Remarkable numbers of hoverfly adults were observed visiting the FP Alyssum *L. maritima*. The presence of Alyssum was already reported to have a strong positive impact on hoverfly egg production, which led to more hoverfly larvae and fewer aphids on cropping plants (Hogg

et al., 2011). As efficient pollinators, the data on the insect visitations showed a strong preference of bees for the flowers of high-mallow *M. sylvestris*, and less for the flowers of *C. cyanus*. The attraction of pest thrips to some flowering plants especially *C. cyanus* represents a challenge to the adoption of these plants in IPM programs. However, optimizing the area occupied by these plants could mitigate the unwanted effects and maintain and increase at the same time the natural enemies of the flowering plants when their preys are scarce on strawberry plants.

In the experiment carried out in 2021, the addition of specific flowering plants and the proposed management design strongly enhanced aphid suppression through significant increases in the number of natural enemies and a decrease in the numbers of aphids and thrips. Degrees of thrips control on strawberry plants were found to be impacted by the distance from the flowering plants. More control success was found on strawberry plants adjacent to flowering plants. Alyssum has been reported to strongly affect hoverfly fecundity (Laubertie et al., 2006), which could be related to our observation that high numbers of hoverfly adults visit the flowers of this plant for their pollen and nectar. The sowing timing of flowering plants likely played an important role in improving the biological control of strawberry pests. The early incidence of flowers (source of pollen and nectar) with aphid absence on the border plants induced early attraction of natural enemy adults but have not increased the numbers of offspring on those flowering plants. In other words, they induced positive numerical responses of beneficial but significantly lower than intercropped flowering plants. By early hosting aphids, these latter plants contributed more likely to the significant increase in the numerical but also functional responses of natural enemies on strawberries by increasing the build-up of their start population (inducing the early production of offspring). Thus, significant numerical increases in beneficial offspring and their control services were observed on the intercropped strawberries. Given our finding that the autumn-sown plants provided an early food source for beneficial adults, and the spring-sown plants provided an early food source for inducing their offspring production, a combination of both sowing systems of flowering plants can help growers in improving the biological control of strawberry aphids and thrips. A disadvantage of this system is the loss of cultivation area. In this trial, about 20% of the strawberry plants were replaced by flowering plants, which of course impacts heavily on the strawberry production per field area. Thus, the question then is whether we can reduce the area occupied by flowering plants in the intercropping system, and still achieve adequate biological control. Another disadvantage, high numbers of harmful bugs were observed on the flowering plants but only late in the season and since the second half of July.

Conclusion

Preventive biocontrol system through conservation tactics may help to overcome many problems of biocontrol, like the issues of appropriate timing, pest detection, the high quantity of natural enemies required for release (both for the inundation as the inoculation strategy), and other related requirements (Messelink et al., 2014). Given the fact that preventive measures in biological control programs should be preferred for protecting crops, the presence of flowering plants late in the season is thus less useful in terms of providing sufficient biocontrol services, as the curative biocontrol of pests in open (or semi-open) field conditions is very difficult. Hence, removing or mowing the flowering plants from mid-July in strawberry fields/tunnels is a recommended process to reduce the negative migration (from strawberries to flowering plants) of natural enemies. Finally, it is wise to mention also that adding floral resources between strawberry plants should prevent beneficiaries from wasting time and energy in traveling to distant alternative food sources. We conclude that functional diversity and resulting impacts on aphids and thrips will be enhanced in crop fields where floral resources are available and soundly managed.

Acknowledgments

We are grateful to the technical team of the Experimental Garden for the Strawberry and Small Fruits for maintaining the experimental plots. This work was funded by the cross-border cooperation European program “Interreg, France-Wallonia-Flanders, Proverbio 1.1.359”.

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Received: May 19, 2023
Accepted: Oct. 1, 2023

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