

**The effect of annual flower strips on pollinator visitation and fruit set of avocado  
(*Persea americana* Mill.) in Kenya**

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**Abstract**

Wildflower strips are increasingly promoted in pollinator conservation schemes to maintain the stability of ecosystem services and increase crop yield. Yet, the increased area of avocado *Persea americana* Mill. cultivation in sub-Saharan Africa is not accompanied by measures of biodiversity conservation or the promotion of ecosystem services. We investigated the effects of flower strips on flower visitors and avocado fruit set in Kenya. A strip mixture of sunflower *Helianthus annuus* L., coriander *Coriandrum sativum* L., and alfalfa *Medicago sativa* L. was established at the border of four avocado plots, while four other plots with an unmanaged border served as control. The abundance of insect flower visitors and fruit set at 10 m, 55 m, and 100 m from the border of each plot were assessed during the early, peak, and late avocado flowering periods. The honeybee *Apis mellifera* L. and hoverflies Syrphidae

spp. accounted for 22% and 71% of flower visitors, respectively. We found interactions between the treatment, distance to the border, and the avocado flowering intensity on the abundance of honeybees but not on hoverflies. Irrespective of the distance to the border and the avocado's flowering intensity, flower strips acted as a sink for honeybees and hoverflies. Overall, the flower strip mixture of sunflower, coriander, and alfalfa did not increase pollinator abundance and avocado productivity, and it may be necessary to identify plant species for optimal benefits and study the long-term effects of floral strips on pollinators and crop production.

**Keywords:** Agroecology; Ecosystem services; Flower fly; Honeybee; Pollination services.

### **Statements and Declarations**

The authors declare no conflict of interest.

## **1 Introduction**

Animal-mediated pollination is an economically significant ecosystem service that supports wild and crop plant production and contributes to ecosystem functioning and food security (Gallai et al. 2009; Eilers et al. 2011; Breeze et al. 2016). At least 87% of major food crops depend to some extent on animal pollination and together account for 35% of global food production (Klein et al. 2007; Van Der Sluijs 2020). The global demand for pollination services has been growing following the increased cultivation of pollinator-dependent crops and the rapidly growing human population (Aizen et al. 2008; Godfray et al. 2010). However, the current global pollinator decline raises important concerns about the ability of agriculture to meet long-term food demand (Potts et al. 2010a; IPBES 2016). Multiple stressors, including land use intensification, habitat loss and fragmentation, pesticide use, and climate change, are widely reported as the causes of pollinator decline (Potts et al. 2010b; Goulson et al. 2015; Dicks et al. 2021). *Apis mellifera* L. (Hymenoptera: Apidae) managed colonies are

increasingly being used to improve crop pollination (Degrandi-Hoffman et al. 2019; Herrera 2020). Because of pest and disease threats and risks to wild pollinator conservation, the use of managed honeybee colonies for supplemental crop pollination is increasingly being questioned (Goulson and Sparrow 2009; Potts et al. 2010a; 2010b; Rader et al. 2015; Pirk et al. 2016; Vanbergen et al. 2018). As such it is important to study a wide range of native wild pollinators in order to meet the growing demand for crop pollination (Greenleaf and Kremen 2006; Garibaldi et al. 2013; Grass et al. 2018). Most practises that increase pollinator diversity are based on changes to the environment, which increase the amount and quality of resources (food, shelter, reproduction, and overwintering sites) over a large area and a long period. The application of flower strips (patches that are sown with a mixture of flowering plant species) is a widespread practice in agroecology in developed countries because it provides annual or perennial sources of pollen and nectar for pollinators, is cheap, and often has positive impacts on pest control (Balzan et al. 2014; Blaauw and Isaacs 2014; Garibaldi et al. 2014; Rundlöf et al. 2018; Krimmer et al. 2019; Albrecht et al. 2020; Lowe et al. 2021). The provision of permanent and diverse food resources in agricultural landscapes is expected to increase pollinator abundance, diversity, and crop flower visitation (Jönsson et al. 2015). Also, Hoehn et al. (2008) and Garibaldi et al. (2013) found that when there are more pollinator species, there may be more complementary pollination among species or facilitation by other pollinator species.

Flower strip benefits for pollinators vary among taxonomic groups because of differences in morphological and functional traits, as such there is therefore a need to design flower strips with plant species that exhibit different phenology and morphology (Tschumi et al. 2016; Van Rijn and Wäckers 2016; Campbell et al. 2017). In general, pollinators with a short proboscis will benefit more from plants with a short corolla (e.g., Apiaceae and Polygonaceae) than from plants with a deep corolla (e.g., Fabaceae) (Balzan et al. 2014).

Also, using native plant species in flower strips is highly encouraged because they are more likely to adapt and support local pollinators than non-native species and because they are less likely to compete with the target crop (Isaacs et al. 2009).

Despite these potential benefits, target crops and plants in flower strips may compete for pollinators, whereby wildflower strips act as a sink and prevent pollinators, resulting in reduced pollination services (Carvalho et al. 2016; Kremen et al. 2019; Osterman et al. 2021). Hence, the effect of flower strips on pollination of target crops depends on the species composition of flower strips and the target crop. For example, annual buckwheat strips increased pollinator diversity of red clover *Trifolium pratense* L. (Fabaceae) but did not increase yield (Rundlöf et al. 2018), whereas floral strips of coriander (*Coriandrum sativum* L. (Apiaceae)) and mint (*Mentha arvensis* L. (Lamiaceae)) resulted in a lower number of flower insect visitors on strawberry (*Fragaria x ananassa* Duchesne (Rosaceae)) plots (Hodgkiss et al. 2019).

Efforts to promote pollinator conservation in African farms are minimal, as farmers lack knowledge of pollinators and their benefits and are less prone to adopting pollinator conservation measures (Kasina et al. 2009; Elisante et al. 2019). It is estimated that changes in natural habitat reduced pollination services by native pollinators, resulting in a 29% decrease in crop revenues (Tibesigwa et al. 2019). The impact of flower strips on crop pollinators and yield has not yet been investigated in African agricultural landscapes, yet the implementation of flower strips could help mitigate potential threats to pollinators and constitute a suitable alternative to honeybee supplementation (Jayne et al. 2014). Plant species with shallow corollas, such as coriander, may represent good candidate species in flower strips to manage insect-pollinators in cropping systems in Kenya (Waiganjo et al. 2007; Van Rijn and Wäckers 2016; Diederichsen et al. 2020). A flower strip mixture of plants with variable corolla length may promote a higher diversity of pollinators and may

result in greater pollination services. Because of its deep corolla ( $\geq 3$  mm), sunflower *Helianthus annuus* L. (Asteraceae), may reduce competition between short and long-proboscis insects (Van Rijn and Wäckers 2016). Using sunflowers in flower strips can generate additional benefits as the plant is widely cultivated in East Africa for oil production and animal feed (Ogello et al. 2017; Adekele and Bababola 2020). Alfalfa *Medicago sativa* L. (Fabaceae), which also has a deep corolla is used as livestock feed for dairy production in East Africa (Van Rijn and Wäckers, 2016; Alemayehu et al. 2020; Restrepo et al. 2020). The combination of both plants in flower strips resulted in increased pollinator diversity and cucumber *Cucumis sativus* L. (Cucurbitaceae) yield in Uzbekistan (Christmann et al. 2007). During the last decade, the cultivation area and production of avocado *Persea americana* Mill. (Lauraceae) have increased by 45% and 55% respectively, making the crop a leading commodity that represents 74% of export fruits and generates US \$53 million annually (HCD 2018; FAO 2020). The crop requires insect pollination for fruit set, among which the Western honeybee *A. mellifera* is the most frequent pollinator, with a relative abundance (10% – 92%) that varies widely among studies (Dymond et al. 2021). Yet, several non-honeybee pollinators such as blowflies (Diptera: Calliphoridae), hoverflies (Diptera: Syrphidae), and wasps (Hymenoptera: Sphecidae) commonly visit avocado flowers and contribute to its pollination (Mulwa et al. 2019; Cook et al. 2020; Dymond et al. 2021). Hoverflies of the sub-family Syrphinae are increasingly considered essential agents in crop production systems because of their double role in pollination and biological pest control (Doyle et al. 2020; Dunn et al. 2020). In avocado-producing regions, hoverflies generally account for less than 15% of the total abundance of avocado pollinators but are rarely identified to species level, making the comparison of species abundance difficult (Dymond et al. 2021). In the tropics, there is a lack of pollinator management and conservation in avocado farms, leading to a 65% pollination deficit (Mulwa et al. 2019; Toukem et al. 2022). Agroecological practices such as

the introduction of flower strips appear as one potential way to reduce this pollination deficit and increase avocado production. In Chile, native flower strips comprised of up to 11 plant species increased bee abundance on adjacent avocado plots (Muñoz et al. 2021). In this study, we tested the effects of flower strips composed of coriander, sunflower, and alfalfa on honeybee and hoverfly communities and their effects on avocado fruit set in Kenya.

## **2 Materials and methods**

### **2.1 Study area**

The study was conducted at the orchards of Kakuzi PLC (Thika, Kenya) in Murang'a county (0°59'1.05648" S, 37°14'45.83256" E, 1,430 m asl) during five months in the avocado growing season (July – November 2020). The landscape is characterised by a mosaic of large-scale plantations of avocado, macadamia *Macadamia* spp. (Proteaceae), eucalyptus *Eucalyptus* spp. (Myrtaceae), blueberry *Vaccinium* sect. *Cyanococcus* Rydb. (Ericaceae), Rhodes grass *Chloris gayana* Kunth (Poaceae) and natural grasslands. The plantation is organised into 38 plots of similar size (i.e., 3.5 ha per plot), age (3.5 years on average), variety ('Hass'), and management practices. Blackjack *Bidens pilosa* L. (Fabaceae) was the most common herb on the plantation. Pollination on the plantation was managed with two honeybee colonies, which were 700 m apart. There was no significant difference in distance to honeybee colonies for the plots of the two treatments (apiary 1:  $t = 1.22$ ;  $df=1,6$ ;  $P = 0.26$ ; apiary 2:  $t = 0.30$ ;  $df=1,6$ ;  $P = 0.77$ ). Neither herbicides nor insecticides were applied during the study.

### **2.2 Study design**

In the plantation, eight plots were chosen at random, 500 m apart. In four plots, a flower strip of 2.5 m × 100 m was established along the southern border (hereafter referred to as "flower strip plots"), while the remaining four plots without flower strips served as the control treatment (Figure 1). The flower strip was sown in July 2020 and consisted of sunflower,

coriander, and alfalfa. These species were selected based on seed availability and nectar accessibility for both short- and long-tongued insects. The mean corolla depth, the depth at which nectar is available, is 3.29 mm for sunflower, 3.95 mm for alfalfa, and 0 mm for coriander (Van Rijn and Wäckers, 2016). A mixture of coriander (0.43 g/m<sup>2</sup>) and alfalfa (0.27 g/m<sup>2</sup>) seeds were sown on a 0.75 m-wide strip between sunflower rows (0.36 g/m<sup>2</sup> of seeds). To increase the flowering duration of the sunflower in the strips, two more seeding rounds of sunflower (0.11 g/m<sup>2</sup> of seeds) were performed at 3-week intervals. All weeds in the flower strips were removed four and six weeks after sowing.

### **2.3 Monitoring of insect flower visitors**

Three months after flower strip establishment, insect flower visitors were monitored during three visits at 3-week intervals between 10.00 AM and 3.00 PM on sunny days. Monitoring occurred both on flower strips and the avocado plots in September (early avocado blooming), October (peak avocado blooming) and November 2020 (late avocado blooming). The order of plots was randomised during each monitoring visit to minimise bias due to the time of day. During each survey, the number of insect flower visitors was recorded on parallel transects at 10 m, 55 m, and 100 m from the border plot. Along each transect, four avocado trees separated by 20 m were each observed for 8 min to count flower-visiting insects, which were classified into one of the following morphospecies groups: honeybee (*A. mellifera*), halictid bees, other bees, hoverflies (Syrphidae), blowflies (Calliphoridae), other flies, ladybirds/ladybugs (Coccinellidae), wasps (Hymenoptera) and butterflies (Lepidoptera). Specimens were caught with a hand net and preserved in 70% ethanol for further identification to species level. Insects were morphologically identified at the International Centre of Insect Physiology and Ecology (*icipe*) in Kenya, except for Syrphidae, whose identification was carried out in Belgium at the Royal Museum for Central Africa. In addition, we also looked at how GenBank could be used to identify specimens by their DNA

barcodes (Supplementary materials S1 and S2). In parallel, four quadrats of 3.75 m<sup>2</sup> each and spaced by 20 m were delimited within the flower strip to assess the flower coverage (total number of flowering plants per quadrat) and abundance of flower-visiting insects (i.e., the number of individual insect visiting at least one flower in the quadrat). Flower-visiting insects were counted for five minutes in each quadrat and identified to species and morphospecies where possible.

#### **2.4 Fruit set assessment**

Avocado fruit set was assessed in September and October 2020 on the transects used for the surveys of insect flower visitors (i.e., 10 m, 55 m, and 100 m from the flower strip in flower strip plots, or the border in control plots). Along each transect, four trees spaced by 20 m were selected to count the number of flowers on two randomly selected panicles on the east side of the mid-canopy of the tree (Figure 1). Two weeks later, the number of flowers that developed into fruits was recorded.

#### **2.5 Statistical analyses**

All statistical analyses were carried out in R version 3.5.2 (R Core Team 2019). Honeybee data were analysed separately from those of the hoverfly data due to the eusociality and recruitment behaviour of the former. Hoverflies made up 91% of all non-honeybee flower visitors. The abundance of honeybees, hoverflies, and fruit set were log<sub>10</sub>-transformed to obtain normality. To account for autocorrelation in the data distribution of honeybees (Durbin Watson test: D-W statistic = 1.29; P-value = 0) and hoverflies (Durbin Watson test: D-W statistic = 1.35; P-value = 0), an autocorrelation structure was included in the linear mixed models to assess the effects of flower strips, distance to the border, sampling time, and interactions using the nlme package (Pinheiro et al. 2020). The mean plant density was included as a random effect. Fruit set (expressed as the proportion of flowers that developed into fruits) was analysed using a linear mixed model as a function of treatment (control vs.

flower strip plots), distance to the border (10 m, 55 m, and 100 m), sampling time (early, peak, and late avocado blooming periods), and interactions among these. The random effect structure included 'tree' nested within 'plot'. Other insect visitors were not analysed because they accounted for less than 10% of the total non-honeybee visits. Models were validated graphically when there was no evidence of dispersion and autocorrelation in the residuals. Coefficient values of the models were tested using the Wald t-test while effects were tested using F-tests. We also did linear regressions at the tree level to see if there was a link between fruit set (i.e., the number of fruits per panicle) and the number of honeybees and hoverflies, as well as between fruit set and the distance to apiaries.

### **3 Results**

#### **3.1 Flower visiting insect communities**

A total of 373 honeybees and 1,348 non-honeybee flower visitors were recorded on avocado plots during observations. Overall, honeybees accounted for 21.5% and 21.8% of total flower-visiting insects on control plots and flower strip plots, respectively. Hoverflies were the most common, with a relative abundance of 71% both on control plots and flower strip plots (Figure 2). The morphological identification revealed 11 species of hoverflies: *Syritta flaviventris* Macquart (414 individuals), *Eristalinus taeniops* (Wiedemann) (48 individuals), *Eristalinus quinquelineatus* (Fabricius) (41 individuals), *Eristalinus tabanoides* (Jeannicke) (33 individuals), *Senaspis haemorrhoea* (Gerstaecker) (15 individuals), *Phytomia pallida* De Meyer, Goergen and Jordaens (178 individuals), *Phytomia incisa* (Wiedemann) (214 individuals), *Paragus borbonicus* Macquart (25 individuals), *Asarkina* sp. (42 individuals), *Eristalinus* sp. (15 individuals), and *Chrysotoxum continuum* (Bezzi) (102 individuals). The halictid bee *Lasioglossum (Afrodialictus)* sp. (Hymenoptera: Halictidae) and the horsefly *Tabanus taeniola* Palisot de Beauvois (Diptera: Tabanidae) were also recorded, each with a relative abundance of less than 1% on both control plots and flower strip plots. Wasps were

identified as *Polistes* spp. and blowfly identification was limited to *Chrysomya* spp.; both taxa had a very low abundance, accounting for less than 1% of total flower-visiting insects (Figure 2). Coccinellids and butterflies accounted for less than 1% of the total flower-visiting insects. Within the flower strips, honeybees and hoverflies accounted for 53% and 31% of the total flower-visiting insects (Figure 3). Halictid bees, blowflies, horseflies, coccinellids, and butterflies each had a relative abundance of less than 1% on the flower strips.

We obtained 58 DNA barcodes (seven for Hymenoptera and 51 for Diptera), which were made publicly available in GenBank. For five out of the seven Hymenoptera, we did not obtain a reliable best match (i.e. p-distance between the query and best match > 2) in GenBank (Supplementary material S2). We obtained a reliable best match for *Apis mellifera* and a crabonid, *Philantus loefingi*. For 11 out of the 51 Diptera, we did not obtain a reliable best match. Two out of the three calliphorid species, *Chrysomya marginalis* and *Chrysomya putoria*, had a reliable best match, while for none of the four Rhiniidae GenBank returned a reliable best match (Supplementary material S2). For six out of the 44 DNA barcodes representing Syrphidae, three species *Asarkina* sp., *Eristalinus quinquelineatus*, and *Eristalinus* cf. *taeniops* obtained an unreliable best match. For all the best matches in GenBank, the taxon identification corresponded to our morphological identification.

### **3.2 Effect of flower strips on flower-visiting insect communities**

Regression coefficients of models explaining the variation in abundance of honeybees and hoverflies as a function of treatment, distance to the border, and sampling time are summarised in Table 1. We retained the three-way interaction (treatment\*distance\*sampling time) for the honeybee analysis because it explained higher variance (conditional R<sup>2</sup> = 0.33; marginal R<sup>2</sup> = 0.08) than did the two-way interaction (treatment\*distance) (conditional R<sup>2</sup> = 0.31; marginal R<sup>2</sup> = 0.03). Similarly, the three-way interaction on the hoverfly abundance

explained higher variance (conditional  $R^2 = 0.30$ ; marginal  $R^2 = 0.09$ ) than did the two-way interaction model (treatment\*distance) (conditional  $R^2 = 0.33$ ; marginal  $R^2 = 0.02$ ).

Overall, flower strip plots had a significantly lower abundance of honeybees (mean  $\pm$  standard error of means:  $1.15 \pm 0.13$  bees per tree) than control plots ( $1.45 \pm 0.14$  bees per tree) (F-value = 5.14; df = 1, 279; P-value = 0.02). However, there was neither an effect of sampling time (F-value = 1.48; df = 1, 279; P-value = 0.22) nor of distance to the border (F-value = 1.08; df = 1, 279; P-value = 0.29) on honeybee abundance. Yet, there were significant interactions among treatment, sampling time, and distance to the border on honeybee abundance (F-value = 8.86; df = 1, 279; P-value = 0.003). In control plots, honeybee abundance decreased with distance to the border on the early blooming of avocado but increased with the distance to the border at the late avocado blooming (F-value = 3.61; df = 1, 139; P-value = 0.05). In flower strip plots, we observed the opposite, with honeybee abundance increasing with distance to the border at the first sampling, while abundance decreased with distance at the last sampling (F-value = 3.98; df = 1, 140; P-value = 0.04). Figure 4 shows that there was the same abundance of honeybees in flower strips and control plots at the peak of avocado blooming.

For hoverflies, a higher mean abundance was observed on control plots ( $4.71 \pm 0.31$  hoverflies per tree) than on flower strip plots ( $3.82 \pm 0.27$  hoverflies per tree) (F-value = 4.65; df = 1, 279; P-value = 0.03). Neither sampling time (F-value = 2.38; df = 1, 279; P-value = 0.12), nor distance to the border (F-value = 0.01; df = 1, 279; P-value = 0.99) influenced the abundance of hoverflies. Also, there was no interaction between sampling time and distance to the border on the abundance of hoverflies on control plots (F-value = 0.03; df = 1, 139; P-value = 0.86) (Figure 4). However, hoverfly abundance increased with distance to the border at the early avocado blooming, while it decreased with distance to the border at the

late avocado blooming (F-value = 6.10; df = 1, 140; P-value = 0.01). At the second sampling, the hoverfly abundance in flower strip plots did not vary across distances (Figure 4).

### 3.3 Effect of flower strips on fruit set

The mean fruit set in flower strip plots ( $0.17 \pm 0.01$ ) did not differ significantly from that in control plots ( $0.17 \pm 0.01$ ) (F-value = 0.67; df = 1, 188; P-value = 0.41) (Figure 5). Also, there was no effect of the distance to the border (F-value = 2.06; df = 1, 188; P-value = 0.15), nor an interaction with the treatment (F-value = 1.90; df = 1, 188; P-value = 0.16) on the fruit set.

No relationship was detected between fruit set and honeybee ( $\beta = 0.007$ ; F-value = 1.45; P-value = 0.23) or hoverfly ( $\beta = 0.008$ ; F-value = 0.29; P-value = 0.59) abundance at the tree level (Figure 6). Similarly, there was no relationship between fruit set and distance to honeybee colonies ( $\beta = -0.00009$ ; F-value = 1.83; P-value = 0.18).

## 4 Discussion

Our findings revealed a diverse group of insects such as Hymenoptera (*A. mellifera*, Halictidae, and other hymenoptera), Diptera (Syrphidae, Calliphoridae, Tabanidae, and Coccinellidae), and Lepidoptera, foraging both on flower strips and adjacent avocado plots. The relative abundance of honeybees (about 21%) was lower compared to previous findings in East Africa and New Zealand, which showed that honeybees in avocado farms represent between 50% and 94% of the total pollinators (Mulwa et al. 2019; Dymond et al. 2021; Okello et al. 2021; Toukem et al. 2022). We found in this study a higher relative abundance of hoverflies (71%), compared to the 12% recorded in previous studies (Dymond et al. 2021; Sagwe et al. 2022). A relatively low diversity of hoverflies (*Eristalinus* spp., *Syritta* sp., and *Phytomyia* sp.) was reported in small avocado farms in Kenya, while in Tanzania, only one species of hoverflies *Eristalinus* spp. was found (Mulwa et al. 2019; Okello et al. 2021; Sagwe et al. 2022). Differences in farming practices that include the use of pesticides and

landscape composition, such as proportions of natural habitats, may explain this difference in abundance and density of pollinators among study areas. Similarly, to our findings, blowflies, rhiniids, wasps, and butterflies are common flower-visiting insects reported in avocado trees (Mulwa et al. 2019; Dymond et al. 2021; Okello et al. 2021). The response of honeybees to the flower strip varied with the sampling time and distance to the flower strip. The increased honeybee abundance with distance to the flower strip during early avocado blooming may be explained by the fact that there were more floral resources in avocado plots than in flower strips during that period, which drove honeybees away to the flower strip, whereas in late avocado blooming, flower strips provided resources for honeybees.

Hoverflies were the most abundant pollinators observed on avocado trees. The hoverfly community was dominated by *S. flaviventris*, *S. haemorrhoea*, *P. pallida*, *P. incisa*, *M. tarsatus*, *E. taeniops*, *E. vicarians*, and *E. tabanoides* from the subfamily Eristalinae, which have a pollen-carrying capacity that is comparable to that of honeybees (Chisausky et al. 2020; Doyle et al. 2020; Dunn et al. 2020; Sagwe et al 2022). Unlike honeybees and other bees, hoverflies are not central-place foragers (i.e., animals that carry resources back to a particular site), which may explain the lack of interactions between treatments, distance to the border, and avocado's flowering intensity on the abundance of hoverflies. This is in addition to the fact that hoverflies prefer plots with flower strips better than avocado flowers.

For honeybees and hoverflies, the flower strip seemingly acted as a sink as their abundances were higher on control plots compared with plots with the flower strip, irrespective of the avocado's flowering intensity or distance to the border. This explains the honeybee and hoverfly's preference for sunflower, coriander, and alfalfa over avocado flowers, which led to the high abundance of pollinators in the flower strip. Our result, therefore, seems in agreement with the 'concentrator' hypothesis, which predicts flower strip competition for pollinators with the target crop and concentrates pollinator populations within the flower strip

(Kremen et al. 2019; Osterman et al. 2021). This could be one explanation for why a comparable avocado fruit set between plots with and without the flower strip was observed. This also means that flower strips did not have either a positive or negative effect on fruit set in adjacent avocado trees. This is encouraging as some farmers are concerned that floral strips may compete with adjacent crops for pollinators and result in lower crop pollination (Lundin et al. 2017). Another explanation could be the short time frame of our experiment, which did not allow us to detect a significant effect of the flower strips on pollinators. The use of perennial flower strips may support crop production in the long run because it gives pollinators time to build up their population and gradually increase their activities on farms (Scheper et al. 2013; Albrecht et al. 2020).

Our findings are in line with previous studies in Europe that reported comparable pollination services of fruit trees between plots with and without the flower strip (Campbell et al. 2017; Hodgkiss et al. 2019), even in cases where flower strips increased local abundance of pollinators (Albrecht et al. 2020). Despite the relatively high diversity (25 species of Fabaceae and Apiaceae), size (500 m<sup>2</sup> per plot) and age (one year) of the flower strip, fruit set on cider apple orchards in the UK did not increase up to 150 m from the flower strip (Campbell et al. 2017). Indeed, the effects of flower strips and within-field distances on the fruit set are highly variable across studies because of the interactions with field and landscape factors such as the landscape context, the species richness, and the size and age of the flower strips (Rundlöf et al. 2018; Krimmer et al. 2019; Albrecht et al. 2020). In European agrosystems, the benefits of flower strips on pollination services become visible from the second year after establishment, with a 27% increase in pollination services compared to fields with three-month-old flower strips (Blaauw and Isaacs 2014; Albrecht et al. 2020). Albrecht et al. (2020) added that pollination services decreased with an increasing number of arable crops in the surrounding landscape and an increasing distance to the flower strip. In

our study, the surrounding landscape within a 2 km radius was composed of avocado trees, and in such a case, the existing populations of pollinators were likely depleted to the extent that the ecological contrast brought by short-lived and small-sized flower strips may not have been great enough to produce visible positive impacts on pollinators and related services within a short time (Scheper et al. 2013).

In conclusion, the flower strip mixture of *H. annuus*, *M. sativa*, and *C. sativum* supported mostly honeybees and diverse species of hoverflies, which did not significantly increase avocado pollination on adjacent plots. Flower strip benefits seem to result from a complex interplay of several factors, which could not be determined in this study because of the short duration of the experiment. Therefore, there is a need to carry out a multi-year experiment to better evaluate the effects of flower strips on pollinator and crop production. Alternatively, the total area of the flower strips (1,000 m<sup>2</sup>) was low in the large plantation (133 ha) to resort to any effect. The composition of flower strips should be tailored to the needs of endangered and efficient pollinator species to maximise benefits and limit counter effects as flower strips can act as a sink. We also recommend studies to estimate the costs of establishing flower strips (seeds, planting, maintenance, and withholding acreage) and recovering them through the increase in crop production.

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