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Towards transparent and replicable flower selection in agricultural flower strips

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Abstract

Flower strips are increasingly employed as ecologically sustainable methods for attracting beneficial insects to agricultural landscapes. Since flowers differ substantially in an array of characteristics including morphology, nutritional content, and phenology, selecting "the right flowers for the right job" requires the designer to make careful decisions about which flowers to include. These decisions ultimately determine the success of flower strips. Given the importance of flower selection, how do researchers choose which flowers to plant? We conducted a quantitative content analysis to examine how researchers make flower selection decisions in studies aimed at supporting or attracting natural enemies or pollinators to target crops. We collected data on the criteria used to justify selection decisions and we recorded the type of evidence (experiential evidence such as "expert recommendations" or "personal communication" vs. peer-reviewed evidence) used to support selection decisions. We found that the majority of studies relied on experiential data to inform their flower choices. Specific selection criteria varied, but "attractiveness" and "native to region" were most frequently cited for both natural enemies and pollinators. Overall, we found that the prevalent use of experiential evidence for flower selection may limit the replicability and transparency of studies. To address this concern, we introduce a flexible framework aimed at ensuring the clear communication of the flower selection process. Our framework emphasizes evidence-based practices to enhance both replicability and transparency in flower strip design, offering a path toward more rigorous and effective ecological interventions.

KEYWORDS
crop, floral resources, flower strips, insect-mediated ecosystem services, natural enemies, pest pollination

INTRODUCTION

The planting of supplemental flowers adjacent to crops is an increasingly popular strategy for enhancing ecosystem services provided by insects such as pollinators, predators, and parasitoids in agricultural environments (e.g., Albrecht et al., 2020; Lowe et al., 2021; Zamorano et al., 2020). Supplemental flowers (aka "flower strips") are thought to

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support and attract beneficial insects primarily by providing key nutritional resources in the form of carbohydrate-rich nectar and protein-rich pollen. Flowering plants may also provide non-nutritive benefits to insects such as brood sites, hunting areas, and shelter (Woodcock et al., 2014). In addition to supporting the health of well-known pollinators such as bees, floral resources are also beneficial to predatory arthropods such as spiders (Pfannenstiel & Patt, 2012; Taylor & Bradley, 2009; Taylor & Pfannenstiel, 2008; Wardhaugh, 2015), parasitoid wasps (Damien et al., 2020; Lee et al., 2004; Wratten et al., 2003), and predatory beetles (Lundgren & Seagraves, 2011). Done correctly, flower strips are a "win-win" intervention that can support insect biodiversity while enhancing the delivery of insect-mediated ecosystem services such as pollination and pest control.

Recent meta-analyses found that supplemental flower plantings increased pest control services in adjacent fields (Albrecht et al., 2020), but had an inconsistent impact on pollination services (Albrecht et al., 2020; Lowe et al., 2021; Zamorano et al., 2020). Given that flowers vary tremendously in their morphology, phenology, and nutritional profiles, the specific mix of flower species likely plays a crucial role in determining flower strip effectiveness (e.g., Albrecht et al., 2020; Campbell et al., 2017; Hatt et al., 2018, 2020). Indeed, flower-visiting arthropods vary markedly in their preferences for factors such as sugar concentration, flower color, and flower shape (e.g., Campbell et al., 2010; Fornoff et al., 2017; Harder, 1985; Pohl et al., 2011; Rowe et al., 2020; Thompson, 2001). Selecting the "right flowers for the right job" is therefore a critical component in the design of flower plantings.

Given the tremendous diversity of flowering plants, how do researchers and practitioners choose which of the many candidate flower species to include in their flower plantings? The list of potential selection criteria is long and can include agronomic considerations such as growth requirements and phenology; cost considerations; nutritional considerations such as nectar and pollen quality, quantity, and availability; the presence of traits known to be attractive to focal taxa such as color, shape, and odor profile; and considerations based on the provenance of flower taxa. While each crop situation may require a tailored, bespoke mixture of flowers, a clearer understanding of the selection processes used by researchers and practitioners would allow the field to learn from past successes and to refine selection techniques for future projects.

Here, we used quantitative content analysis to investigate the flower selection criteria used by researchers to select flower species for supplemental flower plantings, focusing on studies that aimed to increase pollination and/or pest control services in crops. We then examined the types of evidence used by researchers to justify the selection of particular flowers. When studies cited peer-reviewed literature, we further examined the supporting manuscripts to determine the methodological approach used to generate the supporting data (e.g., experiments, models, reviews, or meta-analyses). Finally, we present a flexible framework for reporting flower selection strategies that will allow for more replicable and transparent flower selection.

METHODS

Our quantitative content analysis aimed to address two key questions: first, what criteria do researchers use when selecting flowers for flower strips aimed at increasing the abundance and diversity of beneficial insects in crops? Second, we aimed to determine the type of evidence most commonly used by researchers to support their flower selections.

Quantitative content analysis is a method for systematically analyzing text to extract information about the frequency or occurrence of words, concepts, or themes (Kleinheksel et al., 2020). The process typically involves several steps. First, the researcher reads through the texts to become familiar with key themes relevant to the research question. Next, they generate "codes"—words or phrases that capture meaningful elements of the data—that are then systematically applied to the text. Third, the researchers use the coded data in descriptive or inferential statistical analysis.

Paper selection and screening

Between August and September 2023, we searched Web of Science for studies that investigated the use of supplemental flower plantings using the following search terms in the "Topic" field:

- Flower strip OR insectary
- insectary OR wildflower planting
- wildflower planting Or wildflower strip
- wildflower strip OR Conservation biological control
- Conservation biological control OR floral enhancement

We refined results to the subject's entomology, zoology, animal ecology, crop science, crop protection, agriculture, multidisciplinary horticulture, environmental studies, plant sciences, agronomy, biodiversity conservation, and agricultural policy.

Exclusion criteria

Since we were interested in contemporary approaches to flower strip design, we restricted our search to papers

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published in or after the year 2000. We excluded studies that focused on woody plantings such as trees and hedges as we were interested in studies that used perennial or annual flowers. We only included papers that provided a list of flower species (or that had a citation to a species list). This led to the exclusion of studies that provided only the name of a flower seed mix, without access to the list of species therein.

We only included studies that were targeted at increasing pollinator or pest control services in an adjacent crop and we excluded studies that only sampled insect biodiversity in the general landscape (rather than on a specific crop). While such papers are of high interest, the selection criteria for plantings where the primary goal is biodiversity enhancement will likely differ from those being selected for the explicit role of promoting beneficial insects.

We excluded papers that examined the impact of natural flower diversity, such as the impact of crops being adjacent to native forest or bushland again, as we were interested in plantings done specifically for the purposes of attracting natural enemies to crops. Note that we did not screen for study quality, as our goal was to understand the flower selection strategy and evidence base, rather than formally assessing intervention efficacy.

For each paper, we collected general information about the study such as the country and continent the study was conducted in, the number of flower species used in the supplemental planting, and the target functional group (pollinators or natural enemies, where "natural enemies" include[s] both parasitoids and predators). Studies that investigated both pollinators and natural enemies were classified as "both."

Content analysis

To begin our content analysis, we read through papers with the goal of extracting information about selection criteria and the decision process used by researchers. We classified the selection criteria stated by the authors into one of nine categories: "nutrition," "nativeness," "attractive to focal group," "morphology," "phenology," "agronomic considerations," "agri-scheme," "multi-use," and "unspecified" (Figure 1). The "nutrition" category includes studies that selected plants based on their pollen and/or nectar quantity, quality, or composition; "nativeness" included studies that selected flowers native to the focal region; "attractive to focal taxa" included instances where authors stated that flowers were attractive to the pollinator or natural enemies of interest; "morphology" was used when authors stated that flower selection was based on morphological traits such as flower color, shape, or height; "phenology" was noted where authors stated that selection was based on some feature of flowering time; "agronomic considerations" was recorded when authors indicated they had selected flowers due to factors such as their drought tolerance, growth rate, or specific plant care considerations; "agri-scheme" was used when studies stated that flowers were selected because flower species were part of an existing government scheme; "multi-use" was used when flowers were selected because the plants served some purpose other than just attracting insects including nitrogen fixation, providing resources for non-insect wildlife or aesthetics. The classification "unspecified" was used for papers where we could not determine a clear rationale for flower selection. Note that studies could state multiple criteria in which case we recorded every applicable categorization. In each study, we also calculated the number of different criteria categories used to select flowers.

We next aimed to understand the type of evidence used to support the choice of flower species. When papers provided citations to peer-reviewed manuscripts to support their choice of flowers, we classified the supporting evidence as "peer reviewed." If the authors cited "personal experience," "unpublished results," "expert recommendations," or "preliminary research" without further presentation of data or citations, we classified the supporting evidence as "experiential." If no supporting evidence was discernible, we classified the supporting evidence as "unclear." Note that studies could have multiple types of supporting evidence in which case we recorded every applicable categorization.

In cases where citations to peer-reviewed literature were provided as the evidence for flower selection, we read the supporting paper and classified it depending on the type of work used to obtain data. Papers were classified as "abundance/diversity" if they examined the effect of flower species on the abundance, species richness, or the diversity of target arthropods; "physiology" for studies that examined the effect of flowers on an aspect of insect health such as fecundity, weight, longevity; "attraction" if a study investigated the attractiveness of a flower in the lab, typically through the use of olfactometers; "model" if the study consisted of in silico simulations or mathematical models; "plant traits" if the study quantified some metric of flower nutrition (e.g., nectar volume and pollen yield) or described some aspect of a plant's care/survivorship. In a small number of cases, we were unable to retrieve or read the cited publication because it was in a language we could not read or the manuscript was housed in a journal we did not have access to. In these cases, we coded the papers as "inaccessible." All analyses were conducted in R (2024.09.1 + 394). Chi-square tests were run using "chisq.test" in the base R "stats" package.

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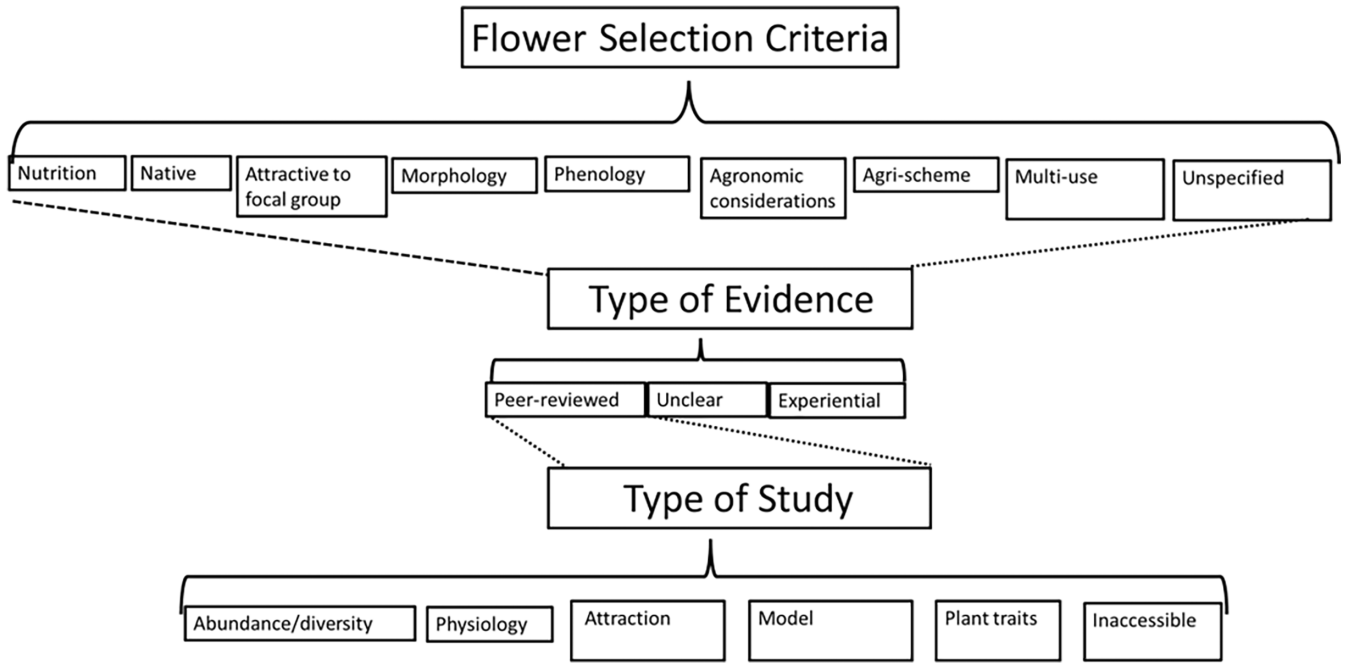


FIGURE 1 A diagrammatic representation of the methodology behind this paper. Papers that met our inclusion criteria were screened to determine the "Flower selection criteria" used to select flowers for supplemental flower plantings. We then examined all included papers to determine what type of evidence was used to justify flower selection. Last, for papers that cited peer-reviewed manuscripts, we found the cited papers and determined the methodology used in the study ("Type of study"). Definitions of all terms can be found in *Methods*.

RESULTS

General data characteristics

Our search terms returned 6396 manuscripts 134 of which remained after we removed studies that did not meet our criteria. The main reasons papers were excluded were that they did not examine the impact of flower interventions on a crop or they focused on naturally occurring vegetation rather than on planted supplemental flowers.

Sixty-seven papers focused on attracting natural enemies, 50 focused on pollinators, and 18 focused on both pollinators and predators. The majority of publications were from Europe (60%) and North America (29%), with smaller numbers of studies from Oceania (2%), Asia (3%), South America (2%), and Africa (2%). Most studies included annual crops (110 studies) compared to 30 studies that included perennial crops. There was no significant difference between the number of perennial/annual crops used in studies that focused on pollinators, natural enemies, or both pollinators and natural enemies (χ^2 test, all $p > 0.05$). Note that some studies included both types, hence the sum exceeds the number of papers. The five most common crops were wheat (16 studies), apple (12), tomato (9), cabbage (7), and strawberry (6).

Studies used 16.4 ± 16.7 (mean ± SD) flower species in flower plantings, with a maximum of 100 and a minimum of 1. The median number of flower species in a planting was 11.

Selection criteria

Overall, researchers stated 2.14 ± 1.24 different criteria as justification for flower selection.

For studies of pollinators, "attractive to focal taxa" (78%) was the most frequently cited criterion, followed by "native to region" (46%), "nutrition" (32%), and phenology (32%). Flower morphology (22%), agronomic considerations (14%), and multi-use (10%) were less frequently cited (Figure 2). Note that these numbers sum over 100% since multiple criteria can be cited in a single study.

For studies of natural enemies, "attractive to focal taxa" (79%) was the most common criterion for flower selection followed by "native to region" (48%), "nutrition," (28%) and phenology (25%). Multi-use (13%), agronomic considerations (9%), and flower morphology (4%) and "agri-scheme" (1%) were less frequently cited (Figure 2).

In studies including both natural enemies and pollinators, "attractive to focal taxa" was the most common criterion (72%) for flower selection followed by "native to region" (39%). "Morphology" (17%), "nutrition" (11%), and "phenology" (29%) were next.

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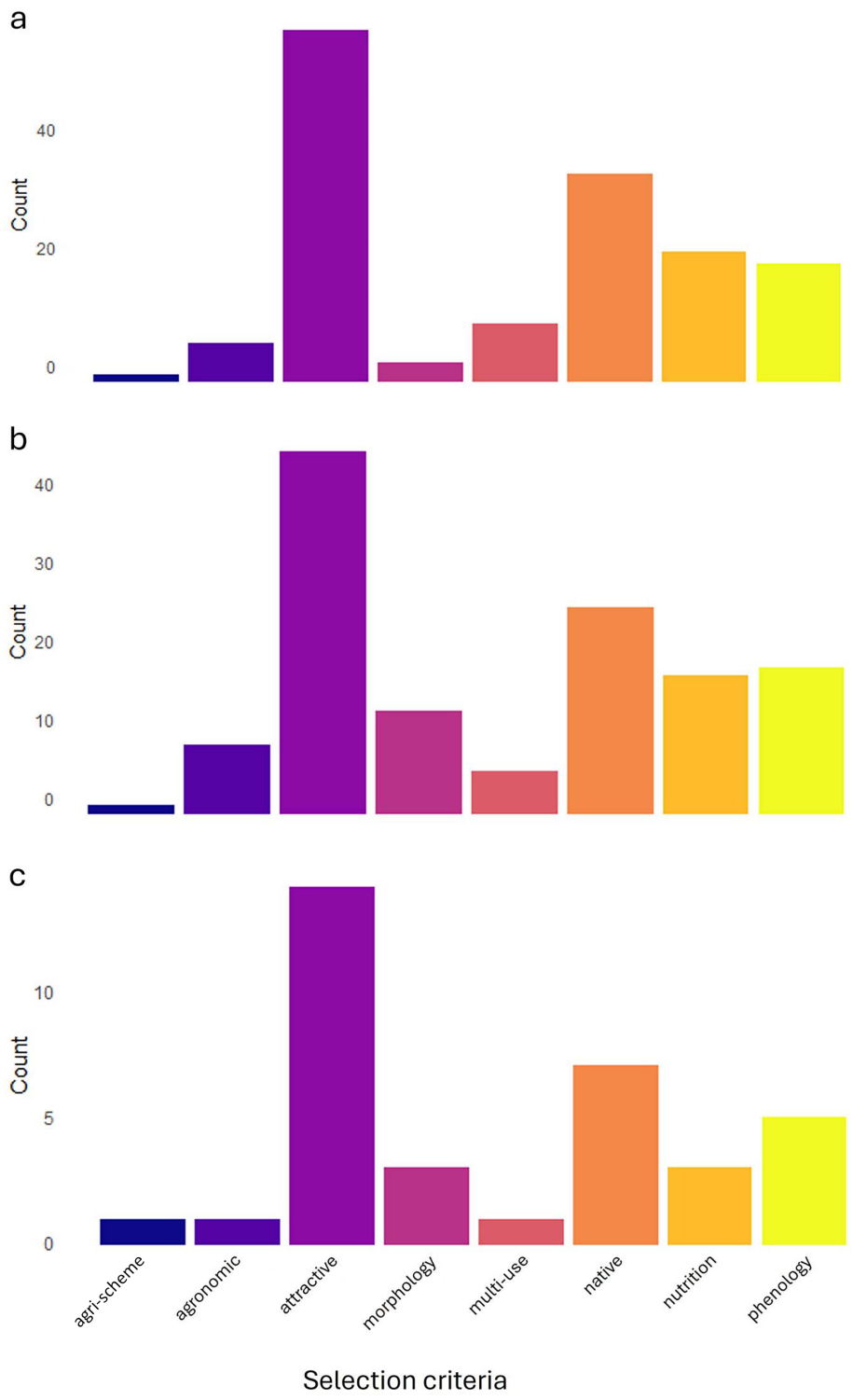


FIGURE 2 Counts of the number of papers that used each selection criterion. (a) Studies focused on natural enemies, (b) studies focused on pollinators, (c) studies focused on both pollinators and natural enemies. Note that papers can cite multiple selection criteria.

Agronomic considerations (6%), "agri-scheme" (6%), and "multi-use" (6%) were less commonly cited (Figure 2).

Studies that focused on natural enemies were significantly less likely to cite "morphology" as a justification for flower selection (4%) compared to studies focused on pollinators (22%) and studies that focused on both pollinators and natural enemies (17%) ($\chi^2 = 9.6$, $p = 0.008$). There was no significant difference between focal taxa for any of the other selection criteria (all $p > 0.5$). Selection criteria did not significantly differ between studies that

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included perennial or annual crops (Fisher's exact test; all $p > 0.05$).

Types of evidence

For studies focused on pollinators, 70% cited at least some experiential evidence as support for their flower choices; 54% cited peer-reviewed publications as support for flower selection; and 4% cited preexisting government schemes as the justification for flower choices (Figure 3). In 4% of cases, the rationale for flower selection was unclear. Note that numbers sum to more than 100% because studies often used multiple types of evidence.

For studies focused on natural enemies, 58% cited peer-reviewed publications as support for flower selection; 48% used at least some experiential evidence as support for their flower selection; and 4% cited preexisting government schemes as the justification for flower selection (Figure 3). In 9% of cases, the rationale for flower selection was unclear.

For studies that considered both pollinators and natural enemies, 72% used at least some experiential evidence as support for their flower selections; 44% cited peer-reviewed publications as support for flower choice; and 11% cited preexisting government schemes as the justification for flower choice (Figure 3). The type of evidence used in flower selection was unclear in 12% of cases.

Studies of pollinators were significantly more likely to use experiential data compared to studies focused on natural enemies or both natural enemies and pollinators ($p = 0.022$, $\chi^2 = 7.6$). Focal taxa did not impact the use of peer-reviewed, agri-scheme, or unclear evidence (all $p > 0.5$).

Of pollinator-focused studies, 41% used experiential evidence as the sole justification for flower choice compared to 28% of studies focused on natural enemies. Experiential data were used as the sole justification for flower choice in 50% of studies focused on both natural enemies and pollinators.

There were statistically significant geographical patterns in the use of experiential information in flower selection (Fisher's exact test; $p = 0.01$), such that no studies from South America relied solely on experiential data, whereas 67% of studies in Oceania cited only experiential evidence as the support for flower selection. Studies based in Europe relied solely on experiential evidence to select flowers in 44% of studies compared to studies based in North America (18%), Africa (33%), and Asia (25%).

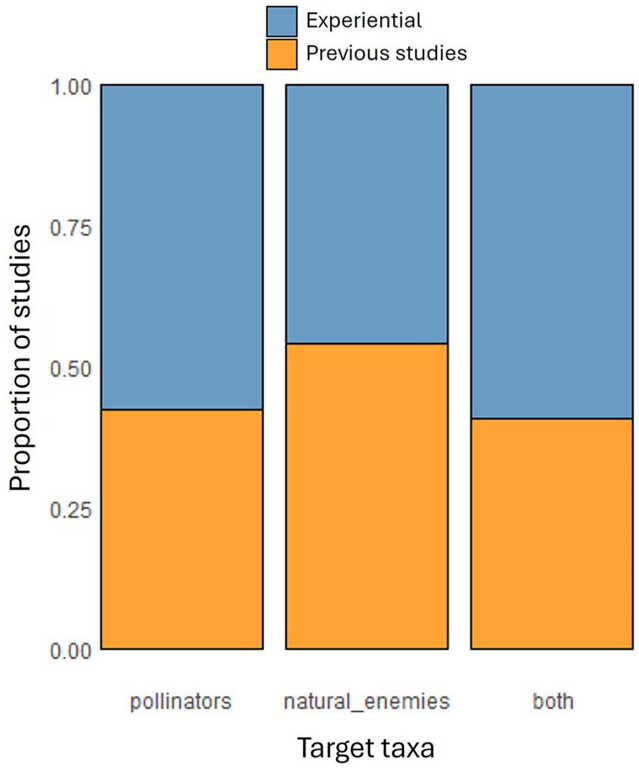


FIGURE 3 Proportion of studies that cited experiential data or previous studies in their justification for flower selection in studies focused on pollinators, natural enemies or both (pollinators + natural enemies). Note these totals exclude the government schemes and unclear categories.

Methodology of supporting studies

We recorded 149 studies cited as evidence for flower selection (Appendix S1) of which 12 could not be retrieved because they were written in a language other than English or the reference could not be found on Google Scholar or Web of Science.

For papers targeted at pollinators, the majority of supporting studies (60.7%) were experiments that examined the effect of flowers on the abundance, visitation rates, or diversity of insects. The other categories were each represented by less than 10% of supporting studies.

For papers targeted at natural enemies, most supporting studies examined the impact of flowers on the abundance, visitation rates, or diversity of insects (43.4%), 18.2% of supporting studies were reviews, and 19.2% were studies that examined the impact of flowers on some facet of physiology. The other groups were each represented by less than 10% of supporting studies.

For papers targeted at pollinators and natural enemies, most supporting studies examined the impact of flowers on the abundance or diversity of insects (62.1%), 17.2% were reviews, and 10.2% focused on aspects of physiology and/or longevity. The remaining categories (plant traits, not found, and unclear) accounted for less than 10% each of supporting studies.

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DISCUSSION

The most cited criteria for flower selection were "attractiveness" and "nativeness." However, in 41% of studies, "attractiveness" was supported only by experiential evidence. For studies that provided citations, "attractiveness" in supporting publications had varied meanings and could refer to counts of insects on plants in the field, attraction to plant stimuli (e.g., odors) in the lab, or to features of the plant that were expected to be attractive (such as provision of nectar). The lack of a consistent definition of the term "attractiveness" may limit the extent to which many selection protocols are replicable. We recommend that researchers clearly define what "attractive" means whenever they use this term.

Flower traits such as phenology, morphology, and nutrition of pollen/nectar were rarely cited as reasons for plant selection. This was surprising, given that trait-based selection could streamline the flower selection process by negating the need for detailed species-specific data on flower visitation rates. For example, Hatt et al. (2018) found that the presence/absence of ultraviolet patterning on flowers and "accessibility" (determined by corolla morphology) was correlated with increased abundance of parasitoid wasps. Trait-based selection protocols would be particularly useful in regions of the world for which detailed information on flower use by beneficial insects is lacking. However, attempts to use trait-based selection can be hampered by a lack of information about insect-relevant flower traits. Trait databases such as AusTraits and TRY contain a wealth of plant trait data, but often do not include key pollinator-relevant traits such as nectar volume/concentration/composition, pollen yield, and flower accessibility. There is thus an urgent need for researchers to collect insect-relevant trait data (see, for example, the data collected in Chalcoff et al., 2006; Pamminger et al., 2019; Vaudo et al., 2020), and submit these data to openly available databases.

A large percentage of the studies we reviewed relied entirely on experiential evidence (including unpublished experiments) in their flower selection strategy with the majority using at least some experiential evidence to justify flower selection. Some types of experiential evidence, such as "expert recommendations," reflect the deep knowledge of local practitioners; however, without further explanation or quantification, these flower choices are neither replicable nor transparent. Systematic methods of eliciting expert advice such as expert elicitation can allow for quantifiable, replicable, and transparent use of expert knowledge (Martin et al., 2012). Moreover, formal expert elicitation studies provide a traceable, permanent record of expert advice that can be used by other practitioners in the region.

There were strong geographic differences in experiential data use such that, in North America, only 18% of studies relied only on experiential evidence, whereas in Oceania, 75% of studies cited experiential evidence as the sole justification for flower selection. We suspect that the reliance on experiential data was driven by a dearth of published data on local plant–insect interactions. We therefore reiterate the priority need for increased collection of pollinator-relevant plant trait data, combined with observations and experiments on the preferences of local beneficial insects, particularly in understudied regions such as Oceania, Africa, and Asia.

Towards replicable and transparent flower selection: The flower strip design process

Overall, we found that key details about the rationale used by researchers for selecting flowers were often incomplete or unclear. For example, papers in our review only cited an average of two flower selection criteria (usually attractiveness and nativeness) despite the likelihood that other factors such as seed availability and flower growth requirements influenced their decisions. Studies also relied heavily on undefined experiential information. This largely ad hoc approach to flower selection reduces transparency and hinders replicability, both of which are cornerstones of good scientific practice. At best, the lack of transparency makes it difficult for researchers to build on the design lessons of their predecessors; at worst, it limits our ability to meaningfully assess, refine, and advance flower selection protocols, thus hindering the advancement of the field.

In disciplines such as engineering and marketing, design frameworks have long been employed to streamline processes, enhance communication, and ultimately produce transparent, replicable, and effective outcomes. Adopting a similar approach in the form of a systematic framework for flower selection would not only ensure that interventions are replicable and transparent but would also help researchers think critically and mindfully about their design process, potentially yielding better results.

Since the requirements and research aims of researchers are highly diverse, a strict protocol for flower selection is neither feasible nor desirable. Instead, we propose a flexible framework for *describing* the flower strip design process that reduces ambiguity and increases replicability and transparency (Figure 4). In developing the framework, we have borrowed heavily from the field of engineering design and from frameworks used to design agent-based models, both of which face the challenge of developing protocols for the design of diverse

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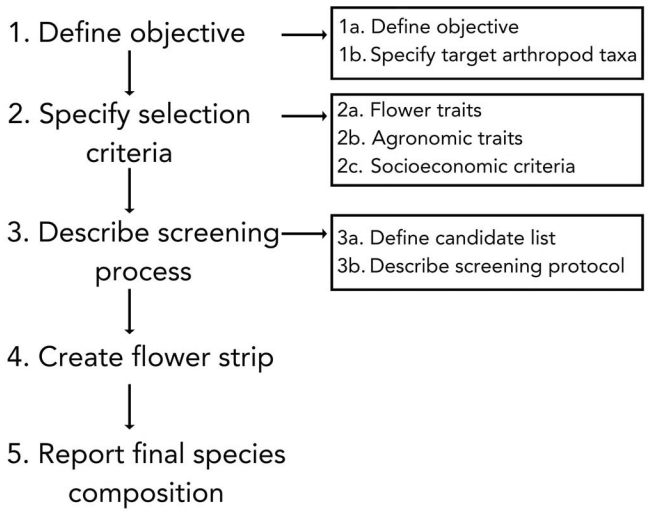


FIGURE 4 Proposed framework for communicating the design processes underlying flower planting design.

products and user requirements. Our flexible template can thus be fine-tuned and adapted to meet particular situations. Importantly, it can be used to ensure that input and consideration from multiple stakeholders are included in the design process.

Below we describe in detail our proposed framework for describing the flower planting design process. Box 1 illustrates a case study applying our framework while designing a flower planting for an urban community farm.

1. Define objectives
   1a. *Define the functional objective* in terms of the ecosystem service(s) being targeted (e.g., pollination and pest control). Objectives will ideally be specific, measurable, achievable, relevant, and time bound (e.g., "Increase flower visitation by bees on apple crop relative to control trees over three years" or "increase biodiversity of arthropods on target crop over 10 years" or "increase the abundance and diversity of natural enemies on target crop in 2 months").
   1b. *Specify target taxa*: Thinking critically about which taxa are likely to deliver the ecosystem services in question is important for developing selection criteria aimed at finding flowers that attract and/or support the target taxa. For example, if the objective is to decrease aphid abundance on a target crop, then target taxa could be syrphid flies, parasitoid wasps, and/or lacewings. Target taxa should be listed to the lowest appropriate taxonomic level.
2. Specify selection criteria
   Research should define, in detail, all of the criteria that will be used to select flowers for the flower strip. We suggest considering criteria related to flower traits, agronomy, logistics, and socioeconomic factors.
   2a. *Flower traits* should include considering factors intrinsic to flowers such as their morphology, phenology, and nutritional status.
   2b. *Agronomic criteria* include those factors that affect plant growth, such as drought tolerance, soil preferences, and competitiveness. Logistical criteria can include factors such as seed availability. Agronomic criteria can also include exclusions based on the potential to cause ecosystem disservices, for example, exclusion of weedy species or of species known to harbor pests.
   2c. *Socioeconomic criteria* include considerations such as seed costs, cultural significance, and aesthetic value.
   Justifications should be clearly articulated for each design criterion (with citations, where possible). Researchers should avoid ambiguous terms such as "attractive to focal taxa" and should instead explain the specific metric(s) used to determine "attractiveness." Multiple metrics can be used, so long as they are clearly defined. For example, "Flowers were considered attractive to bees if common garden experiments (citation) found them to have more visitation than other flowers or if they appeared on the Fictional Pollinator charity list of pollinator-attractive plants." Whenever possible, the source of evidence to support each selection criterion should be clearly cited. If a literature search is conducted, details of the literature search methodology should be provided.
   While citations to pilot studies are often unavoidable, underlying data should be made available either through a supplementary resource or by posting to repositories such as GitHub. Experiential supporting evidence should be clearly described (e.g., "observations of high visitation rates at local flower shop in Sydney, Australia" (Latty pers comms)).
3. *Define flower screening protocol*: In most cases, there will be multiple potential "candidate" flower species that meet the selection criteria. For others to understand the screening process, it is important to provide an explanation of the procedure used to select the final flower set.
   3a. Provide the initial set of candidate species alongside an explanation of how this list was populated. For example, the initial candidate set might include all "bee-friendly" flowering plants listed in a particular guide or all flowers with "open nectaries" available as seed within X country.

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BOX 1 Worked example showing flower selection framework for an urban community farm

Objectives

1a. To increase native pollinator abundance and diversity on a multiple crop community farm over three years. To increase yield and quality on strawberry and tomato plants within the polyculture.
1b. Target taxa are native bees including Megachilidae, Exonerua, Colletidae, Apidae as well as flies in the family Calliphoridae, Bombyliidae, Syrphidae, and Rhiniidae.

Selection criteria

2a. Open flowers with nectar and pollen provisions. White and yellow flowers preferred. Flowers with a long flowering period preferred. Native flowers preferred.
2b. Must be available as seed in Australia; must be drought-resistant.
2c. Low seed costs preferred; prioritize medicinal or edible species as the farm is used as a teaching space for a variety of community activities.

Screening protocol

3a. An initial candidate list of flowers was composed based on reports from local agencies combined with datasets from Tasker et al. 2020, and Makinson et al. 2017 Unpublished flower visitation data was also used to compile a list of plants.
3b. We narrowed the list by checking for seed availability within Australia. We then used a scorecard system that scored plants on their watering requirements, flowering period, and nectar provisions where plants received higher scores for having low watering requirements, longer flowering periods and higher nectar production rates (Table 1). The 20 species with the highest overall score were selected for the trial.

Flower strip design

4a. Plants were planted in a randomized design in a row along one end of the urban farm. Each species was planted in a 1 m × 1 m patch.

3b. Describe the screening process. Provide an explanation of how the final mix of species was selected (Table 1). Flowers could, for example, be assigned a rank based on how much they are preferred by the focal insect taxa. Most metrics of arthropod preference are easy to calculate, require no specialized software, and do not require the collection of plant and insect traits. However, different methods of calculating preference can lead to very different results (Pizante et al., 2023), so metrics of preference need to be selected cautiously. Alternatively, Glenny et al. (2023) suggest using a "scorecard" to select good "all rounder plants" for restoring seminatural ecosystems. The scorecard grades each flower across a number of variables and can then be used to select the highest scoring plants across each blooming period (Table 2). A similar approach was used by Cresswell et al. (2019), who used a score-based approach to select flowers that had traits that supported multiple ecosystem services (Cresswell et al., 2019). Scorecards are relatively simple to implement and can include multiple attributes but may fail to select plants that play a specialized role (e.g., attracting specialist taxa).

Network-based selection protocols use interaction data to determine which plants play key functional roles within a flower community (e.g., Tavella et al., 2022). The calculation of network metrics is relatively straightforward; however, it requires the input of extensive visitation data, which may be time consuming to collect.

"Optimization"-based flower selection protocols use computer algorithms to select the optimal mix of plants to meet specified criteria. These may be challenging for non-coders to implement as they typically require specialist programming skills. Some authors have combined network and optimization protocols by using network metrics as inputs, which are then optimized (Windsor et al., 2021).

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TABLE 1 Different ways of screening flowers including a description of the method, pros, cons, and citations.

Method	Description	Pros	Cons	Citations
Preference ranking	Flower species are ranked by some measure of preference, usually taking into account visitation rates and flower abundance. The highest ranked flowers are selected.	1. Does not require extensive flower trait data 2. Common preference metrics are easy to calculate	1. Different preference metrics can yield different rankings (see Pizante et al., 2023) 2. Requires visitation data 3. Single attribute (cannot handle trade-offs)	Pizante et al. (2023)
Network metrics	Flower selection is based on network metrics such as centrality.	1. Does not require extensive flower trait data 2. Metrics relatively easy to calculate (with software)	1. Requires extensive interaction data 2. Ecological interpretation of network metrics is not always clear	Sabatino et al. (2021), Tavella et al. (2022)
Scorecards	Flowers receive a score for each selected criterion and the flowers with the highest overall score are selected. Weightings can be used to increase the "weight" of particular criteria.	1. Easy to implement 2. Scoring system may be subjective	1. Requires some trait data	Cresswell et al. (2019), Glenny et al. (2023)
Optimization algorithms	Uses algorithm to select plant mixes that optimize multiple criteria	1. Handles multiple attributes 2. Can select plants that complement one another (rather than selecting the "most attractive" plants)	1. Can require extensive trait data 2. Difficult to implement as it requires programming and optimization skills	M'Gonigle et al. (2017), Williams and Lonsdorf (2018)
Network metrics + Optimization algorithms	Finds optimal flower mixes using network metrics as inputs	1. Handles multiple attributes 2. Can select plants that complement one another (rather than selecting the "most attractive" plants)	1. Requires visitation data 2. Difficult to implement as it requires programming and optimization skills	Windsor et al. (2021)

TABLE 2 Example scorecard for screening potential flowers for inclusion in the flower strip.

Flower species	Drought tolerance (1–5)	Flowering period (1–5)	Nectar production rate (0–3)	Nativeness score	Total score
Brachyscome angustifolia	5	5	3	2	15
Scaevola aemula	3	4	3	2	12
Westringia fruticosa	5	5	2	2	14
Carpobrotus glaucescens	5	4	2	2	13
Dianella caerulea	5	2	0	2	9

Note: The 20 highest scoring plants will be included. Nativeness score was calculated as follows: Native to Sydney basin, +2; Native to Australia, +1; exotic, 0. The scorecard is an example only and the scores do not represent real scores for any plants, nor does it include the complete list of plants.

Whichever method is ultimately selected, it is important that researchers clearly articulate the procedure they use to select mixes.

4. *Flower strip design*: Although we have focused here on flower selection, other design decisions such as the number of each flower species, the density of plantings, and the spatial arrangement of flowers are all key decisions that could impact the outcomes of experiments and thus should be clearly reported.

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5. *Report final species composition*: Report any changes to the species flower list, as a result of, for example, the failure of flowers to germinate, attack by herbivores, and lack of flowering.

CONCLUSIONS

Using flowers to support biodiversity holds tremendous promise as a "win-win" solution that can benefit farmers and nature. However, advancing our understanding of flower plantings requires clear communication of design decisions so that future researchers can build on the discoveries and advances of their predecessors. The selection framework we have described here can help improve the replicability and transparency of flower selection, leading to greater advancement of the field.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data (Latty & Mourmourakis, 2025) are available from the University of Sydney Library repository: https://hdl.handle.net/2123/34474.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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