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Much more than a pretty thing: harnessing floral plants' functional diversity to achieve the sustainability of the floriculture industry

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Abstract

The floriculture industry is experiencing rapid growth with high profitability driven by its irreplaceable symbolic, therapeutic, and emotional value for decorative and aesthetic purposes. However, this prosperity comes with significant environmental costs, as the industry's pursuit of high-quality flower production is largely shaped by profit-driven motives. This thus creates a paradox: while flowers symbolize natural beauty and harmony, their unsustainable production modes undermine these very ideals. In this context, it is emphasized that floral plants can be both economically important and ecologically significant, particularly their functional roles in supporting key components of terrestrial ecosystems. Two potential applications of floral plants in the agroecosystem are proposed: flower strips in agricultural systems and flower meadows comprising halophytes and hyperaccumulators in degraded landscapes. By harnessing the potential functional diversity of floral plants to provide their respective ecological services, it offers an alternative pathway for the floriculture industry to evolve toward a future that balances beauty with sustainability.

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Floral plants can be both economic and ecologically important in the agricultural system

Ornamental plants have irreplaceable symbolic, therapeutic, and emotional values and are typically cultivated varieties produced by the floriculture industry for decorative and aesthetical purposes[1]. The profitability of floriculture products is much higher than other agricultural commodities per unit area[2]. Thus, the global floriculture industry has prospered in recent years and is expected to grow from 49.8 billion US dollars in 2022 to 106.1 billion US dollars in 2033[3]. Nevertheless, the dramatic growth of this industry has led to severe adverse impacts on the environment, including land shortage, soil degradation, climate change, water scarcity, and chemical pollution[4]. This has thus created a debate questioning floriculture's sustainability and raised concerns among researchers and customers. For instance, the emergence of the Slow Flower Movement reflects the customers' demand for sustainable alternatives to conventional floriculture[5]. On the other hand, the sustainability of the floriculture industry has already become a prominent research topic in recent years[6,7], regarding the global environmental concerns due to the indiscriminate usage of peat, fertilizers, and pesticides[8−11]. In essence, floriculture products such as cut flowers represent both the natural beauty and the industrial unsustainability, causing confusion toward this green but not 'green' industry.

Perhaps our perception of floral plants as mere aesthetical pleasure to humans while isolating their ecological functions from its economic values contribute to the development of today's dilemma of the floriculture industry. In other words, floral plants can provide service not only to humans but also to other key components in the agroecosystem such as pollinators and pests' natural enemies, which unfortunately is rarely considered in the floriculture industry. Numerous scientific studies have revealed that floral plantings play important roles in recruiting and establishing natural insect communities for pollination and natural pest control, which are essential ecosystem services to agricultural productivity and food security[12−15]. In addition, some floral plants equipped with unique characteristics to survive in harsh environments (e.g., heavy metal-contaminated soils or saline soils), known as hyperaccumulators or halophytes, can be implemented in soil rehabilitation and landscape design, where both environmental and aesthetical solutions are needed[16−18]. Therefore, harnessing the potential functional diversity of floral plants to provide their respective ecological services in the agroecosystems can be indispensable for the sustainable development of the floriculture industry. In this context, several applicable potentials of floral plants' functional diversity in agroecosystems are proposed that can be incorporated into the future R&D agenda of the floriculture industry.

Flower strips are of ecological significance in pest control and pollination attraction

Intensive agricultural production has led to significant biodiversity loss and unfavorable homogenization of the agricultural landscape due to excessive use of agrochemicals and fragmentation and deterioration of natural habitats[19,20]. This net biodiversity loss can severely impair ecosystem functions and services due to the disappearance of cornerstone species such as pollinators, predators, and parasitoids[21]. To mitigate such negative consequences, flower strips established along field edges with flower-rich non-crop species are among the most effective and commonly applied agri-environmental measures (AEMs) in developed countries with substantial governmental support such as the Common Agriculture Policy in the European Union, and the Farm Bill in the United States[22,23]. Flower strips can maintain abundant and functionally diverse insect communities by offering resources such as food, shelter, nesting places, oviposition sites, and overwintering opportunities. Such countermeasures can foster sustainable agricultural production through ecological intensification by harnessing biodiversity-based ecosystem services including pollination and natural pest control. Pollination services are important for maintaining crop productivity of 75% of the leading global food crops and amounting to 35% of the global production volumes[24,25]. Similarly, natural pest control services provided by predator and parasitoid arthropods have important economic implications in the intensive agricultural monocultures which can save between 40 billion and 74 billion Euros replacing human controls in pesticide applications, and host plant resistance[26].

Burgeoning evidence shows that different flower strip mixtures can conserve multiple functional groups of flower visitors for realizing ecosystem functions in natural enemy enhancement, herbivore suppression, and crop production promotion[14,27−31]. For example, the nectar source provided by flower strips can increase a parasitoid wasp's life span by up to 14.7-fold and increase their host searching span from 3 d to up to 2 weeks[32]. A field study observing flower-visitor communities on 14 flower plantings revealed that flower strips can not only attract pollinators such as bees or hoverflies, but also many ecologically and economically important species such as parasitic wasps and non-syrphid Diptera[33] . A quantitative synthesis by Albrecht et al.[24] from 35 studies across 529 sites in North America, Europe, and New Zealand agroecosystems provided general empirical evidence that flower strips enhancing natural pest control service to crops by 16% on average. Their results also demonstrated that increasing species richness of flowering plants can not only promote rare pollinator species and pollinator diversity but also pollination services.

Ornamental plants in floriculture include a wide range of species from annual to perennial accommodating seasonal annual flowers with differential traits in color, scents, and sizes[33]. This diversity, consisting of both native and exotic species in the form of modern cultivars and other wild relatives provide a resource pool to select the best combination for flower strip establishment adapted to different crops, soil, and climate conditions (see Fig. 1). Hence, developing floriculture products with more diverse floral traits capable of conserving multiple functional groups of flower visitors to realize ecosystem services may promote the floriculture industry toward applicability and sustainability in agroecosystems with more ecological significance. Nevertheless, efficient provision of such trait-based service should consider its functional diversity (i.e., color richness), functional stability (i.e., species diversity), and functional intensity (i.e., flower sizes and abundances)[12]. For example, flower color is one functional trait perceived differently by humans and insect pollinators[34]. Therefore, more efforts with in-depth investigations and field observations are still required with adoption of rational, science-based, and pragmatic approaches to realize such goals.

Using halophytes and hyperaccumulators in soil remediation and landscape design

Halophytes and hyperaccumulators are equipped with unique traits in adapting to harsh conditions such as high salinity and heavy metals (HMs) or rare earth element (REEs) rich soil. Halophytes are plants that can complete the life cycle in high salt environments with over 200 mM NaCl (equals to 20 dS/m). Halophytes can be divided into euhalophytes, recretohalophytes, and pseudohalophytes based on their salt uptake and distribution mechanisms. For instance, euhalophytes, generally have succulent leaves or stems, can regulate their osmotic balance and adjust ionic balance to avoid ionic toxicity by high salinity. Recretohalophytes can secrete salts through salt glands or bladders. Pseudohalophytes would not absorb salts but exclude salt from roots by enhancing apoplastic barriers. Salt-accumulating halophytes continuously accumulate salt from the external saline environment by promoting water infiltration and salt leaching, thus reducing the concentration of salt ions in the soil[35,36]. Hyperaccumulators are those plants that can actively take up exceedingly large amounts of heavy metals/rare earth elements (100−1,000 fold higher than non-hyperaccumulators) without showing phytotoxicity symptoms[35]. Both halophytes and hyperaccumulators are of great value in the restoration of salinized and contaminated soil and many efforts have been made to exploit their potential to reduce damage by salinity and heavy metal/rare earth elements pollution and preserving soil functions in the agroecosystem[35,37−39]. For example, the genus Spartina and Halimione can not only tolerate high salinity but also accumulate heavy metals, showing their pronounced capacity for phytoremediation and phytostabilization of As, Cu, Fe, Mn, Pb, and Zn[17,37]. Many

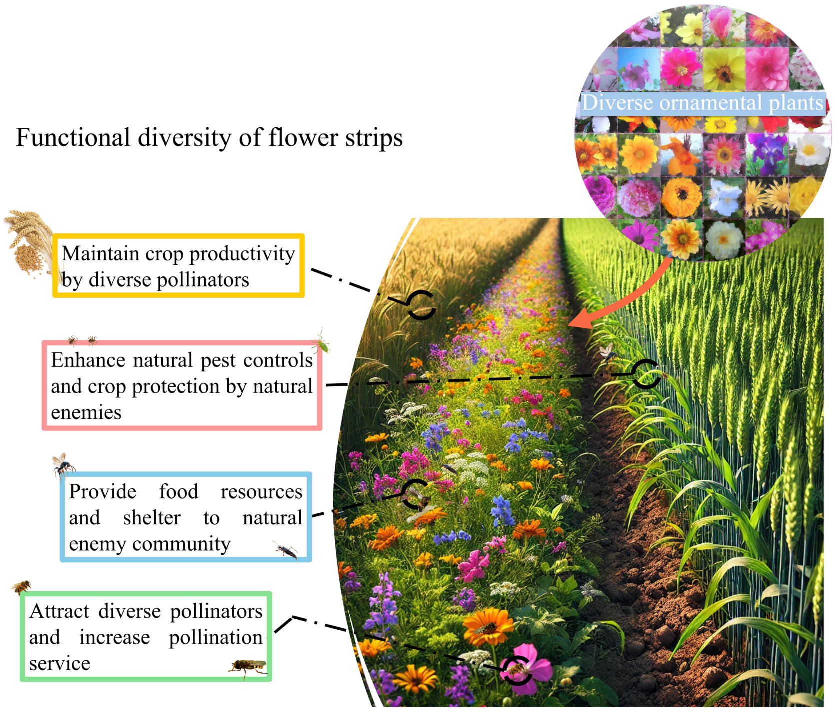

Fig. 1 **A graphic illustration of functional diversity applying ornamental plants in flower strips in agroecosystems.**

hyperaccumulators have been extensively investigated for their practical applications in the phytoremediation of contaminated agricultural soils such as *Sedum alfredii* or *Sedum plumbizincicola*[40,41].

According to the online Global Hyperaccumulator Database (http://hyperaccumulators.smi.uq.edu.au/collection/) and HALOPH database (https://ehaloph.uc.pt), there are a total of 1202 halophytes and around 1000 hyperaccumulators recorded worldwide. Besides their practical implementations in saline or contaminated soil, many halophytes and hyperaccumulators can produce attractive flowers which also have high potential for landscaping in degraded soils[42,43]. For instance, Cassaniti & Romano[44] investigated native halophytes in the Mediterranean region and listed 42 species with ornamental potentials. Similar works have been investigated in Turkey with more than 80 species utilized in landscape design for soil conservation and erosion prevention[45]. Some candidate halophyte and hyperaccumulator species with attractive flowers are presented in Fig. 2. Pictures are cited from the Plants of the World Online (https://powo.science.kew.org), Flora of Victoria (https://vicflora.rbg.vic.gov.au), and Plant Plus of China (https://ppbc.iplant.cn). Flower meadows comprising these halophytes and hyperaccumulators with attractive traits can increase the aesthetic appeal of abandoned degraded landscapes and may help to support sustainable floriculture marketing strategies[21]. This provides an attractive solution for economic utilization and ecological remediation of these degraded and often abandoned land such as mining areas or polluted agricultural fields.

Roadmap to an ecologically significant floriculture industry

We are meeting at a time of immense challenges to sustainable development with natural resource depletion and adverse impacts of environmental degradation including biodiversity loss and land degradation ('Transforming our world: the 2030 Agenda for Sustainable Development', United Nations). Among the 17 SDGs (sustainable development goals), goal 15 specifically depicts a vision of protecting, restoring, and promoting sustainable use of terrestrial ecosystems, sustainably managing forests, combating desertification, and halting and reversing land degradation, and halting biodiversity loss. Although the current floriculture industry is still under debate regarding its sustainability, it has great potential in realizing its ecological importance in restoring degraded land, conserving biodiversity, and promoting sustainable agricultural production. Much more work needs to be done, however, to fully realize this potential and advocate its ecological significance. In this context, a three-step roadmap is proposed that the R&D of the floriculture industry can undertake to transform service provision and accelerate sustainable development (Fig. 3).

Firstly, implementing ornamental plants in both flower strips and degraded soil remediation requires screening for flower species with high potential. For the implementation in flower strips, a database should be established based on the known important traits in attracting pollinators and natural enemy communities given that there are hundreds of ornamental species, each comprising many cultivars with different colors, fragrances, sizes, and nectar quality[46]. This also includes laboratory and field experiments assessing the effective interactions between flowers and focal insect communities (e.g., relationship between nectar quality and attracted insects abundance and diversity) to quantify the attractiveness and screen for the potential flower species. Regarding the database for the utilization of floral halophytes and hyperaccumulators in degraded soil remediation and landscaping, less work may be required as there are limited choices when considering both the aesthetical traits and their respective elemental hyperaccumulating and tolerance abilities. The second step is to assess their practicability by quantifying their actual performances in the field. For the implementation in flower strips, a systematic investigation of the ecological effects of flower compositions and land management on the abundance and diversity of attracted focal insects, pest control efficiency, and crop yield to scrutinize the most suitable formula for each crop. As for the utilization in degraded soil remediation, the focus is on soil quality improvement, land recovery, biodiversity gain, and human aesthetical enjoyment. Based on the knowledge acquired from the first two steps, the species can then be target-designed with precise traits implemented in flower strips or phytoremediation fields to improve the performance by modern breeding biotechnology such as CRISPR/Cas9 and smart breeding driven by big data technology and artificial intelligence (AI)[47−49]. With the improvement in the focal functional traits, the application of novel functional floral plants can then be applied in more delicate scenarios with better performance.

Fig. 2 Some halophytes and hyperaccumulators with attractive floral traits. (a)−(c) halophytes; (d)−(h) hyperaccumulators.

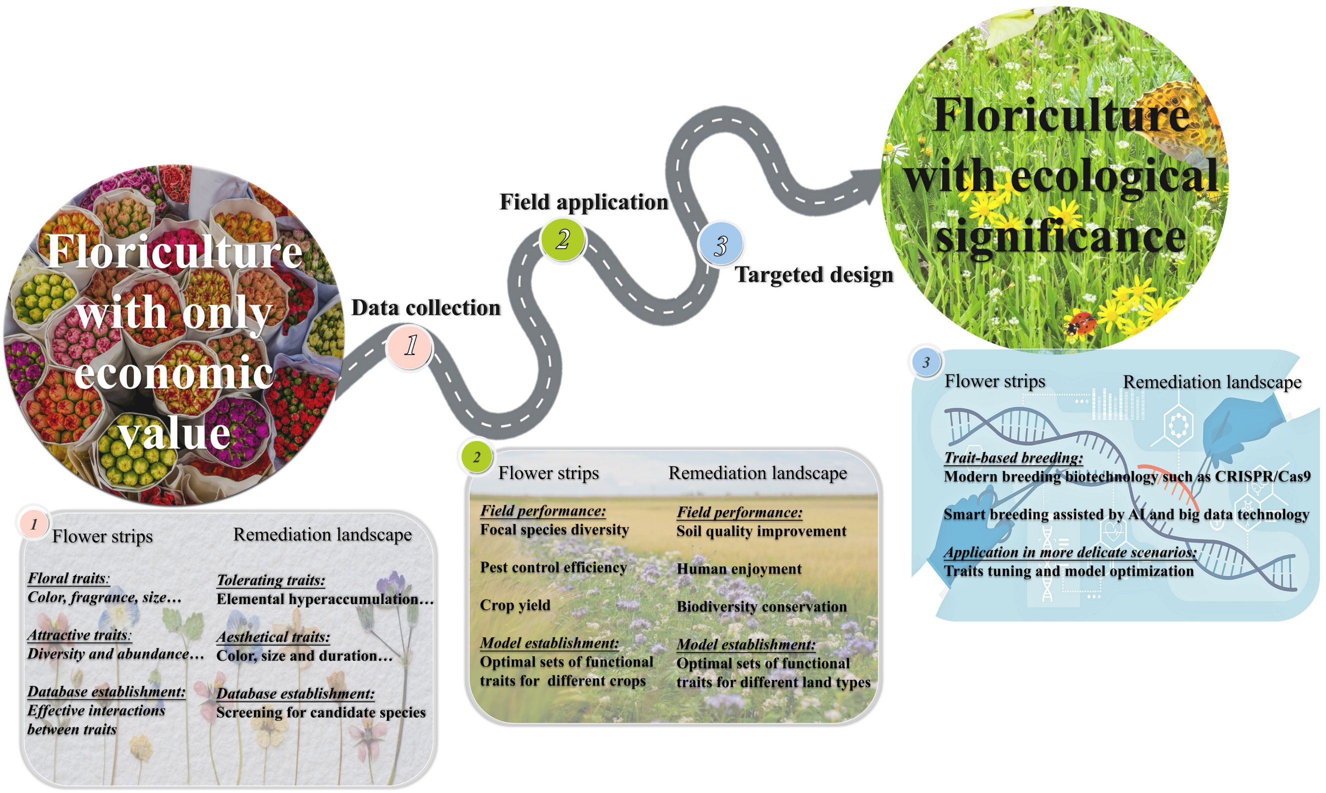

Fig. 3 Roadmap to realize the functional diversity of floral plants in agroecosystems.

Conclusions

The ecological service provided by today's floriculture industry is mainly to human beings based on their aesthetical needs. As a consequence, the market for ornamental plants is subjected to periodic trend-driven changes based on consumer preference which ultimately determines its economic value. In the meantime, the quality production of flower products is at the cost of huge environmental impact to meet the increasingly restricted standards of the market. In the present situation of global change, the paradoxical situation between quality production and environmental protection induces a dilemma for the sustainable development of floriculture. In this context, the ecological importance of floral plants in their functional services to other key components in the terrestrial ecosystem is advocated, and two potential applications proposed (i.e., flower strips and phytoremediation) of floral plants in the agricultural systems and degraded landscapes. This may provide alternatives to relieve the floriculture industry from the current dilemma towards a future with sustainability and applicability. Nevertheless, substantial work is urgently required regarding the database of the candidate species, field performances, and interactive functional traits to fully realize these ecological functions.

Author contributions

The authors confirm contribution to the paper as follows: study conception and design: Zhang P, Li F; draft manuscript preparation: Zhang P; data collection and organization: Zhou J, He D, Yang Y; manuscript revision and editing: Li F. All authors reviewed the results and approved the final version of the manuscript.

Data availability

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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Conflict of interest

The authors declare that they have no conflict of interest.

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