

DISSERTATION

EVALUATING THE U.S. EDIBLE FLOWER MARKET AND CULTIVATION PRACTICES,  
AND IMPLEMENTING VIRTUAL REALITY INTO A HORTICULTURE COURSE

Submitted by

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## ABSTRACT

### EVALUATING THE U.S. EDIBLE FLOWER MARKET AND CULTIVATION PRACTICES, AND IMPLEMENTING VIRTUAL REALITY INTO A HORTICULTURE COURSE

Edible flowers can be defined as any flower material that is safe for human consumption and has potential health benefits. They have long been consumed, dating back to Ancient Egyptian, Ancient Roman, and Victorian societies. More recently, there has been a surge of public interest as consumers look for new and innovative food products to add to their diets. With this new surge of interest, there is both a need and an opportunity for producers and scientists to meet demand and help the market continue to grow and innovate. Recent research has primarily focused on post-harvest strategies, such as extending the limited shelf life, and analyses of phytochemical profiles. Two research areas with limited information concern the demographics of edible flower markets and the production methods for edible flowers.

Characteristics of the global and United States (US) edible flower markets are largely unknown, and market sizes are currently determined solely by third-party market reports. To address these gaps, this dissertation integrates three applied research studies spanning market characterization, production strategies, and horticultural education.

Our first study surveyed farmers' market managers in the US to assess if their markets sold edible flowers and, if so, what characteristics were associated with those sales (e.g., US region, regional land-use classification, market style classification). We found that markets located in urban and western areas were more highly associated with edible flower sales. The most commonly sold flower species were nasturtium (*Tropaeolum majus*), calendula (*Calendula*

*officinalis*), marigolds (*Tagetes* spp.), and pansies (*Viola x wittrockiana*). When asked about what other products edible flower vendors sold, those who sold vegetables alone (47.7%) and those who sold fruit and vegetables (32.6%) were the most common. Another important piece of information learned was the challenges to market expansion. These challenges include a lack of public knowledge, struggling with marketability, and a need for species-specific growing information. These results are important for researchers and producers alike, as they inform future research directions.

A second study was performed to begin addressing the need for species-specific and general production methods for edible flowers. A cultivation study was conducted from June to September 2025 comparing outdoor and greenhouse cultivation of four edible flower species: buzz button (*Acmella oleracea*), dahlia (*Dahlia x hybrida*), dianthus (*Dianthus chinensis*), and zinnia (*Zinnia elegans*) with concurrent replications. The objectives were to test whether the location treatments affected plant size, flower yield, and the levels of total antioxidant content (TAC) and total polyphenol content (TPC) for each of the species which can have potential health benefits. We observed that, for the final plant vegetative dry weight and total season flower yields, at least one greenhouse location was not statistically different from the outdoor treatments in biomass. Dianthus and zinnia plants in the Greenhouse Two location yielded significantly lower flower biomass, likely due to pest challenges such as thrips. Phytochemical content did not differ significantly between cultivation environments for any species. TPC averages for our species were expressed in GAE  $\text{mg} \cdot \text{g}^{-1}$  DW: buzz button  $6.63 \pm 3.51$ , dahlia  $71.21 \pm 18.02$ , dianthus  $31.06 \pm 8.10$ , and zinnia  $26.35 \pm 7.77$ . The TAC averages for our species were expressed in Trolox equivalents (TE)  $\mu\text{mol} \cdot \text{g}^{-1}$  DW: buzz button  $34.22 \pm 13.58$ , dahlia  $544.54 \pm 99.15$ , dianthus  $58.15 \pm 12.28$ , and zinnia  $98.87 \pm 26.73$ . The similarity in flower yields

and phytochemical levels between cultivation locations demonstrates that greenhouses may be a viable option for local production of edible flowers. These strategies would be beneficial for small to medium-sized producers and help reduce the associated costs of edible flowers' short shelf life.

Our final study looked to use virtual reality (VR) resources to connect online students to a laboratory exercise in a plant propagation course. The growing acceptance of online degrees has expanded program offerings, yet online learners often lack hands-on resources for courses that include laboratory activities. VR applications are tools that can bridge this gap. Prior horticultural research has evaluated VR for understanding greenhouse spaces, but little is known about its use to support greenhouse design-based decision-making. This study evaluated whether non-immersive VR materials enhanced online student engagement and comprehension during a mist-system design assignment in the undergraduate plant propagation course. Students viewed mist system designs using two media types: first, using static images, and second, with annotated 360° VR images. After each media type, students completed quizzes on key concepts and provided feedback on their experience. The media type did not significantly affect comprehension scores, even though 62% of students self-reported that VR images improved their understanding of the material. One insightful comment noted that static images help with detail, but VR images help with perspective, which is important in a design assignment. Students expressed interest in expanded, higher-quality VR integration and access to multiple media formats rather than relying on a single source. These findings suggest that VR can increase perceived accessibility of course content and warrant continued development as educational technologies evolve. Collectively, these studies demonstrate how horticultural research can

generate directly applicable insights for producers, educators, and researchers, strengthening the connection between academic studies and real-world practice.

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# CHAPTER 1. AN OVERVIEW OF THE EDIBLE FLOWER INDUSTRY, RESEARCH FOCUSES, AND VIABLE PRODUCTION METHODS

## **Abstract**

Edible flowers (EF) represent a long-standing yet understudied component of global food systems. This crop has been historically valued for its culinary, cultural, and medicinal uses. Contemporary research has expanded rapidly, particularly in the areas of phytochemical analysis. EF contain diverse bioactive compounds, including phenolics, flavonoids, carotenoids, anthocyanins, and volatile aromatics. These phytochemicals contribute to both sensory qualities and potential health benefits. However, the concentration of these compounds varies widely by species, cultivar, and production environment, underscoring the need for continued agronomic and postharvest research.

Despite scientific advances, the EF industry remains constrained by limited and inconsistent market data. Existing global market estimates rely heavily on proprietary reports that differ substantially in valuation, methodology, and transparency, leaving growers and researchers without reliable information. In the United States (U.S.), the absence of federal tracking further obscures production trends, supply chains, and consumer demand. Most domestic producers integrate EF as supplemental income sources to more conventional or specialty crops. Market opportunities exist in fresh, dried, and value-added products, particularly within culinary, craft beverage, and online retail sectors. Further market growth is hindered by short shelf life, distribution challenges, and the lack of standardized quality metrics.

With the aid of social media and a desire to try new foods, the public has a high interest in incorporating EF into their diets despite knowledge gaps, safety concerns, and challenges in acquiring products. Collectively, these factors reveal an emerging industry with strong potential

but limited cohesion. Addressing gaps in market data, production research, and consumer understanding will be essential for supporting broader commercialization and guiding the development of a more informed and productive edible flower industry.

## **Introduction**

Edible flowers (EF) can be broadly defined as the inflorescent portion of a plant that is safe for human consumption, with edibility often determined by the presence of alkaloid content and type (Jadhav et al., 2023). They are commonly categorized into three groups: fruit flowers, vegetable flowers, and medicinal or aromatic flowers (Zhao et al. 2019). Fruit and vegetable flowers, such as broccoli, squash blossoms, and artichokes, have long been integrated into the human diet through domestication and crop improvement. In contrast, aromatic flowers have historically been valued for ornamental purposes, including landscape bedding and decorative use, and are often referred to as edible ornamentals.

A renewed public interest in edible ornamentals has stimulated research into how these flowers can be produced and utilized at larger scales, particularly for culinary and beverage applications (Fernandes et al., 2020a). EF serve two primary roles: culinary and medicinal. While culinary uses tend to be consumer-driven, academic research has increasingly focused on their medicinal potential (Carboni et al., 2025, Rivas-García et al., 2021). Several reviews have synthesized the diverse applications of EF across culinary, nutritional, and medicinal domains (Husti et al., 2013; Santos and Reis, 2021).

While their uses are established in culinary fields, recent interest has focused on EF as “nutraceuticals”. Nutraceuticals are functional foods that aid in the prevention or treatment of a disease (Kalra, 2015), offering a myriad of medical benefits (Kandylis, 2022; Carboni et al.,

2025; Benvenuti and Mazzoncini, 2021). The concentration and composition of these compounds are influenced by production methods, underscoring the need for further agronomic research. At the same time, consumer demand remains insufficiently understood, creating a bottleneck for industry expansion. Progress in phytochemical characterization, production methods, and understanding of market characteristics will be key to expanding EF consumption.

### *Background*

EF use spans thousands of years, with historical records documenting their role in enhancing both the flavor and visual appeal of food (Fernandes et al., 2020a; Mlcek and Rop, 2011). Ancient Romans incorporated roses (*Rosa* spp.) into purees, omelets, and desserts to take advantage of their sweetness and aroma (Guiné et al., 2020). During the Middle Ages, the French commonly added calendula (*Calendula officinalis*) to salads and other dishes (Mlcek and Rop, 2011). In Central Europe, dandelion (*Taraxacum officinale*) syrups have been used as honey replacements, and elderflower blossoms (*Sambucus nigra*) have been served deep-fried (Rop et al., 2012). The historical uses demonstrate that EF are not a novel crop but rather one following waves of interest.

Ethnobotanical studies have further illuminated the cultural roots of EF consumption. In the Xishuangbanna prefecture of China, for example, local communities consume 212 different taxa of EF, most commonly prepared as vegetables or included in stir-fries (Zhang et al., 2023). A Mediterranean review documented 251 different taxa used across the region, with *Asteraceae* as the most frequently cited family, *Viola* as the most cited genus, and elderflower as the most cited species. Italy reported the highest diversity with 83 species used, followed by Spain with 56 (Motti et al., 2022). In Mexico, flowers from plants such as yucca

(*Yucca* spp.), dahlias (*Dahlia* spp.), marigolds (*Tagetes erecta*), and agave species (*Agave* spp.) are referred to as endemic edible flowers, have been incorporated into traditional dishes for centuries (Mulik et al., 2024). The rooted presence of EF in cultures across the globe highlights community interest and routes for further production opportunities.

### *Health Benefits*

The use of EF extends beyond culinary purposes to potential nutritional and medicinal applications. Global research trends indicate increasing scientific interest in EF composition and bioactivity. EF content analysis studies first emerged in the mid-1980s and have expanded rapidly, with China and Western Europe leading publication output (Ragasová et al., 2025). Rose species represent the most extensively studied EF, followed by dianthus (*Dianthus* sp.), allium (*Allium* sp.), and calendula (*Calendula* sp.) (Ragasová et al., 2025).

EF nutritional composition varies considerably depending on species, cultivar, and growing conditions. Water accounts for much of the flower weight, typically ranging from 70 to 90% (Jadhav et al., 2023). The remaining dry matter is composed of several nutritional components, including proteins, carbohydrates, lipids, fiber, and mineral content. Protein levels have been reported to range from 2% to 23% of dry weight (Carboni et al., 2025). Much of the protein associated with EF is in pollen; however, pollen consumption is often discouraged due to its potential to negatively impact flavor such as adding bitterness (Fernandes et al., 2018). Among the evaluated species, borage (*Borago officinalis*) has demonstrated some of the highest reported protein levels at 22.7 g per 100 g of dry flower weight (Fernandes et al., 2020b).

Dietary fiber is another nutritional contribution of EF. Crude fiber content ranges from approximately 0.4% to 20.5% of dry weight, with total dietary fiber values

reported between 17.2% and 75.9% (Carboni et al., 2025). Cornflower (*Centaurea cyanus*) and calendula species have been identified as particularly rich sources, with reported values of 62.3 g · 100 g<sup>-1</sup> and an average of 65.5 g · 100 g<sup>-1</sup> total dietary fiber, respectively (Carboni et al., 2025).

Lipid content is generally low, ranging from 0.1% to 15%, and includes nutritionally relevant fatty acids such as mono- and polyunsaturated fatty acids (Jadhav et al., 2023). Marigold species have been observed to contain some of the highest proportions of unsaturated fatty acids, reaching approximately 59% (Pires et al., 2017).

Carbohydrates represent another major component of EF dry matter. The carbohydrate profile includes sugars such as glucose, fructose, sucrose, maltose, arabinose, rhamnose, xylose, and galactose (Aremu and Van Staden, 2013). Depending on the species, Carboni et al. (2025) reported concentrations range between 3.3% to 90%. Variation in sugar composition contributes directly to the EF flavor profiles and higher sugar content may increase consumer acceptance even among species with otherwise pungent characteristics, such as allium flowers (Marchioni et al., 2023).

Ash content, representing the mineral fraction of EF, typically ranges from 3.8% to 22% of dry weight (Carboni et al., 2025). Identified minerals include calcium, sodium, potassium, iron, manganese, zinc, phosphorus, magnesium, and copper. Rop et al. (2012) analyzed 12 species and found that EF can be beneficial sources of potassium and phosphorus, with potassium occurring in the highest concentrations ranging from 1,842.61 to 3,964.84 mg per kg of fresh weight (FW). A study examining buzz button (*Acmella oleracea*) have reported significant concentrations of minerals, including iron, manganese, zinc, potassium, and strontium, along with a strong positive correlation between phenolic content and antioxidant

activity (González-Barrio et al. 2018). Collectively, these nutritional components support the idea that EF can contribute modestly to dietary nutrient intake while also providing color, texture, and flavor in culinary applications.

Beyond basic nutritional composition, EF are notable for having high concentrations of phytochemicals, particularly polyphenolic compounds. These secondary metabolites play important roles in plant defense, pigmentation, and environmental stress tolerance, while also contributing to potential health benefits when included in the human diet (Kandylis, 2022). Major phytochemical groups identified in EF include phenolic compounds, flavonoids, carotenoids, anthocyanins, and volatile aromatic compounds (Pires et al., 2019).

Among these groups, phenolic compounds represent the most extensively studied phytochemicals in EF. A meta-analysis of EF research reported that phenolic content accounted for approximately 56% of all compositional studies conducted in this field (Ragasová et al., 2025). Phenolics include two primary classes: phenolic acids and flavonoids. Phenolic compounds contribute to plant pigmentation and protection against environmental stressors and exhibit strong antioxidant properties through their ability to scavenge free radicals and chelate metal ions (Manach et al., 2004). A study by Rop et al. (2012) provided a summary of phenolic content of vegetables including cabbage, cucumber, and onion content compared to the high values observed in some EF. For example, *Rosa chinensis* (284.8 gallic acid equivalents (GAE) per g of dry weight (DW) and marigolds (89.2 GAE·g<sup>-1</sup> DW) have been reported to contain particularly high total phenolic content along with strong antioxidant capacity (Kandylis, 2022).

Antioxidant capacity represents the second most frequently investigated aspect of EF composition (Ragasová et al., 2025). Polyphenols, flavonoids, carotenoids, and anthocyanins contribute synergistically to antioxidant activity by neutralizing reactive oxygen species and

reducing oxidative stress in biological systems (Manach et al., 2004). Extracts from species such as hibiscus (*Hibiscus* spp.), viola (*Viola* spp.), marigold, and rose have demonstrated strong antioxidant activity in vitro, in some cases exceeding the activity of commonly consumed antioxidant-rich foods (Kandylis 2022). These findings have led to growing interest in EF as potential functional food ingredients that may help prevent oxidative stress-related diseases (e.g., cardiovascular diseases, cancer, and diabetes) (Carboni et al., 2025).

Flower pigmentation is closely connected to antioxidant potential. Pigments originally evolved to attract pollinators but also serve as indicators of phytochemical content. Anthocyanins, responsible for red, purple, and blue flower coloration, are amongst the most powerful antioxidant compounds present in EF (Grotewold, 2006; Stintzing & Carle, 2004). Species such as roses, hibiscus, and violas are particularly rich sources of these compounds. In addition to their antioxidant capacity, anthocyanins have been associated with cardioprotective and anti-inflammatory effects in human health studies (Kandylis, 2022).

Carotenoids are another important pigment group present in EF, influencing yellow, orange, and red coloration (Fernandes et al., 2017). These compounds play essential roles in plant photosynthesis and photoprotection and function as precursors to vitamin A in the human diet (Eggersdorfer and Wyss, 2018). Marigold species are particularly rich in carotenoids, lutein, and zeaxanthin, which are widely extracted for use in food and dietary supplements (Fernandes et al., 2017; Pavelková et al., 2020). In contrast, calendula petals contain a broader carotenoid profile, including  $\beta$ -carotene and lycopene, which contribute to their characteristic orange coloration (Fernandes et al., 2018). Variation in pigmentation intensity often reflects differences in carotenoid concentration; for example, darker colored pansy cultivars have been reported to contain higher carotenoid levels (Fernandes et al., 2020b).

In addition to polyphenols and pigments, edible flowers contain volatile compounds that contribute to aroma and biological activity. These volatile components include terpenoids, aldehydes, and esters, commonly found in essential oils (Bakkali et al., 2008). Beyond their sensory properties, many of these compounds demonstrate antimicrobial, anti-inflammatory, and neuroactive activities in experimental studies (Bakkali et al., 2008; Carboni et al., 2025).

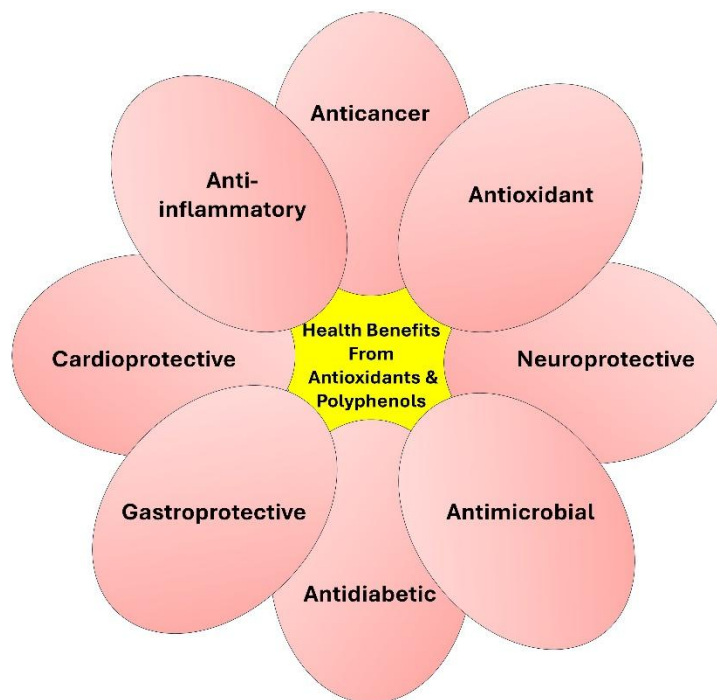


**Figure 1.1:** A variety of health benefits attributed to the antioxidant and polyphenol content of edible flowers.

The bioactive compounds present in EF have been associated with a range of physiological effects, largely attributed to their antioxidant and anti-inflammatory properties (Figure 1.1). Polyphenols may contribute to improved cardiovascular health by modulating oxidative stress and endothelial function (Manache et al., 2004). Polyphenolic compounds may also influence metabolic and gastrointestinal health by modulating the composition of the gut microbiota and improving nutrient absorption (González-Barrio et al., 2018; Kumari et al.,

2021). Hibiscus species, which are particularly rich in anthocyanins, have demonstrated the ability to lower blood pressure of pre- and mildly hypertensive adults in clinical studies evaluating hibiscus tea consumption (McKay et al., 2010). Historically, many EF have been used in traditional medicine systems to treat inflammation, infections, respiratory conditions, and skin disorders. Examples include lavender (*Lavandula angustifolia*) for calming effects, calendula and chamomile (*Matricaria* spp.) for inflammatory skin conditions, and elderflowers for respiratory ailments such as coughs and colds (Książkiewicz et al., 2025). Additionally, calendula has been shown to reduce inflammation and promote wound healing in experimental models, supporting their traditional medicinal uses (Preethi et al., 2009; Parenti et al., 2012). The wide range of nutraceutical benefits of EF make them a worthy crop of continued interest.

### *The Edible Flower Market*

The edible flower industry continues to face a fundamental challenge: the absence of reliable, transparent, and consistently reported market data. While scientific interest in EF has grown substantially, particularly in areas such as phytochemistry, food safety, and production practices, research into economic and consumer market characteristics remains relatively lacking. As a result, growers, researchers, and policymakers lack a clear understanding of the market's size, structure, and long-term potential. This gap complicates decision-making at every level, from farm-level production planning to national-scale policy development.

Existing estimates of the global EF market size illustrate the extent of the uncertainty connected to this industry. Very limited peer-reviewed published information is available which quantifies the EF market, and the two analyzed below relying on private market research firms. Pires et al. (2023) reported the value of the packaged EF market at \$331 million in 2023, while Jimenez-Sanchez et al. (2025) listed the valuation of the same year at \$421

million. Jimenez-Sanchez et al. attributes its estimate to Market Research Future, but Pires et al. do not clearly identify the origin of their data beyond a brief reference to Fact.MR when discussing growth rates. As the review by Pires et al. continues to be widely cited, their market values have become embedded in the literature despite their uncited origins, leaving the industry unknowingly dependent on potentially unreliable third-party reports.

Private market research firms including Fact.MR, Market Research Future, Verified Market Research, and Emergen Research publish market size estimates, but access to their full reports typically costs in excess of \$4,000. These reports differ dramatically in their valuations, with 2025 projections ranging from \$363 million (Stratview Research) to \$1.8 billion (Emergen Research) (Table 1.1). Such discrepancies reflect not only differences in data sources and modeling approaches, but also the lack of standardized reporting for EF as a commodity. Because EF are not tracked by U.S. federal agencies, growers and researchers must rely on these proprietary reports despite their limited transparency.

| <b>Table 1.1</b> Comparison of Estimated Market Size, Compound Annual Growth Rate (CAGR), and Report Pricing Across a Sampling of Third-Party Sources. |                                  |                 |                         |                                                                                                                                                                   |
|--------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------|-----------------|-------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Market Website</b>                                                                                                                                  | <b>Estimated 2025 Value (\$)</b> | <b>CAGR (%)</b> | <b>Report Cost (\$)</b> | <b>Report Link</b>                                                                                                                                                |
| Fact.MR                                                                                                                                                | 365.8 M                          | 4.7             | 2,900                   | <a href="https://www.factmr.com/report/2979/edible-flowers-market">https://www.factmr.com/report/2979/edible-flowers-market</a>                                   |
| Market Research Future                                                                                                                                 | 465 M                            | 5.2             | 4,950                   | <a href="https://www.marketresearchfuture.com/reports/edible-flowers-market-6634">https://www.marketresearchfuture.com/reports/edible-flowers-market-6634</a>     |
| Mordor Intelligence                                                                                                                                    | 420 M                            | 5.1             | 4,750                   | <a href="https://www.mordorintelligence.com/industry-reports/edible-flowers-market">https://www.mordorintelligence.com/industry-reports/edible-flowers-market</a> |
| Technavio                                                                                                                                              | NA                               | 5.8             | 2,500                   | <a href="https://newsroom.technavio.org/packaged-edible-flower-market">https://newsroom.technavio.org/packaged-edible-flower-market</a>                           |

|                          |         |     |       |                                                                                                                                                                                                                                                                                           |
|--------------------------|---------|-----|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Stratview Research       | 363.2 M | 4.7 | 4,790 | <a href="https://www.stratviewresearch.com/2674/package-edible-flower-market.html">https://www.stratviewresearch.com/2674/package-edible-flower-market.html</a>                                                                                                                           |
| Emergen Research         | 1.8 B   | 5.9 | 5,450 | <a href="https://www.emergenresearch.com/industry-report/edible-flowers-market?srltid=AfmBOoohM1jiWSTcfVTW9btkfYpeFrZTgBtUl2ohuEekGSB00r81I0gR">https://www.emergenresearch.com/industry-report/edible-flowers-market?srltid=AfmBOoohM1jiWSTcfVTW9btkfYpeFrZTgBtUl2ohuEekGSB00r81I0gR</a> |
| Verified Market Research | 1.2 B   | 9.9 | 3,950 | <a href="https://www.verifiedmarketreports.com/product/package-edible-flower-market/">https://www.verifiedmarketreports.com/product/package-edible-flower-market/</a>                                                                                                                     |

A closer look at the reports by Market Research Future, selected for its use in Jimenez-Sanchez et al. (2025), highlights the magnitude of the market report inconsistencies. On its public website, the company lists the projected 2025 market size at approximately \$465 million. However, after obtaining a sample report, the projected value for the same year was listed as \$1.8 billion, a difference of more than \$1.3 billion. This example underscores the broader challenge: without peer-reviewed economic research, stakeholders cannot confidently assess market size, growth potential, or regional distribution. The variability among reports raises concerns about their reliability as data sources for growers, researchers, and policymakers.

Despite these inconsistencies, several patterns appear across the third-party analyses. Most reports anticipate a compound annual growth rate (CAGR) between 4% and 6%, suggesting steady, moderate expansion (Market Research Future; Fact.MR; Technavio). North America, Asia-Pacific, and Europe are consistently identified as the largest regional markets, with the U.S and Asia-Pacific often highlighted as dominant contributors. Rose and hibiscus frequently appear as the species sold at larger volumes due to their widespread use in teas, beverages, and confectionery products. Beverage applications are repeatedly cited as the largest market segment, reflecting broader consumer trends toward botanical and visually

appealing food and drink products. Mordor Intelligence (2026) estimates that fresh EF account for approximately 63% of the global market share, emphasizing the importance of culinary and restaurant demand. This also indicates opportunities for fresh, local EF production to minimize costs and challenges with short post-harvest timelines.

The high cost of proprietary reports places meaningful market information out of reach for many academic researchers and small-scale growers. As a result, stakeholders often rely on secondary summaries or media interpretations rather than primary datasets. This reliance introduces additional uncertainty, as summaries may omit methodological details or selectively highlight favorable projections.

Published information on U.S. EF growers remains limited, but data for cut flowers, a possible vendor of EF, suggests that most producers operate on one to five acres (Curtis and Stock, 2023; Ford et al., 2012). EF production can be incorporated into these operations as a secondary crop rather than serving as a primary revenue source (Lee & Miller, 2026). Like conventional cut flower production, profitability is shaped by seasonal availability and limited post-harvest shelf life. EF also face a unique challenge due to the lack of a clearly defined sensory identity within the culinary market, which can make consumer adoption inconsistent and highly context-dependent.

North America has been estimated to produce 24% of the global packaged EF market, with production dominated by species such as lavender, hibiscus, rose, violas, marigolds, and dahlias (Pires et al., 2023). Many growers rely on EF as a supplemental income stream, paired with microgreens, herbs, or specialty vegetables (Fernandes et al., 2020a). This strategy reflects broader trends in specialty crop agriculture, where growers integrate high-value niche products

alongside more stable commodities to diversify farm income and market opportunities (USDA ERS, 2023).

Opportunities for market expansion exist, particularly through the diversification of small- and medium-scale farms. Extension research from the University of Florida in the early 1990s explained that EF could be successfully marketed through farmers' markets and high-end restaurants (Tardivo and Meru, 2018). These findings remain relevant today, especially as consumer preferences increasingly favor foods and beverages that offer aesthetic appeal and experiential value (Prinyawiwatkul, 2023). However, broader commercialization remains constrained by postharvest shelf life, distribution limitations, and the absence of standardized quality metrics (Pires et al., 2023; Fernandes et al., 2020a).

The U.S. EF market shares many of the same structural challenges seen globally: limited data availability, inconsistent reporting, and a fragmented distribution network. These issues are often amplified at the domestic scale. Because EF are not tracked as a distinct commodity by federal agencies, there is no centralized system for monitoring production volume, pricing trends, or regional supply chains. As a result, the U.S. market is shaped largely by individual producers, specialty distributors, and niche retail channels rather than by coordinated industry infrastructure.

The U.S. retail landscape can be broadly divided into three categories: producers selling fresh flowers, producers specializing in dried or preserved products, and wholesale suppliers serving chefs and restaurants. Fresh flower producers generally rely on seasonal outdoor production unless supported by greenhouse or controlled-environment agriculture systems (Heuvelink et al., 2024). Producers offering dried, freeze-dried, or pressed flowers can maintain year-round availability due to their extended shelf life, making them well-

suited for online retail platforms and value-added product lines. U.S. produced EF are rarely ever sold alone (3.5%), and have more been observed as being sold alongside other crops like vegetables and fruit (Lee and Miller, 2026).

Approximately 16 U.S.-based EF producers maintain an online storefront or grocery store presence (Table 1.2). These producers sell to three main audiences: direct to the public, direct to culinary companies such as catering and restaurants, and wholesale to grocery stores. This number is likely an underestimation, as many small-scale growers sell directly to local restaurants or farmers' markets without maintaining a formal online presence. Among major grocery retailers, Whole Foods (Austin, TX, U.S.A) is currently the only chain consistently carrying edible flowers in the northern Colorado region, typically sourced from Jacob's Farm and Rock Garden Herbs.

| <b>Table 1.2.</b> Current major retailers that sell edible flowers in the United States. This is not an exhaustive list of retailers, but those that have a large internet and market presence. |                 |                     |               |                 |                        |                                                                                                                                                                                     |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|---------------------|---------------|-----------------|------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Retailer</b>                                                                                                                                                                                 | <b>Products</b> | <b>Headquarters</b> | <b>Timing</b> | <b>Audience</b> | <b>Growing Methods</b> | <b>Website</b>                                                                                                                                                                      |
| Gourmet Sweet Botanicals                                                                                                                                                                        | Fresh           | San Marcos, CA      | Seasonal      | Public          | San Diego Growers      | <a href="https://gourmetsweetbotanicals.com/">https://gourmetsweetbotanicals.com/</a>                                                                                               |
| Cherry Valley Organics                                                                                                                                                                          | Dried           | Pittsburgh, PA      | Year-Round    | Public          | In-House               | <a href="https://cherryvalleyorganics.com/pages/editable-flowers">https://cherryvalleyorganics.com/pages/editable-flowers</a>                                                       |
| Chef's Warehouse                                                                                                                                                                                | Fresh           | Ridgefield, CT      | Seasonal      | Culinary        | Distributes others     | <a href="https://www.chefswarehouse.com/search/?q=edible%2520flowers">https://www.chefswarehouse.com/search/?q=edible%2520flowers</a>                                               |
| Flavour Fields                                                                                                                                                                                  | Fresh           | Riverhead, NY       | Year-Round    | Culinary        | In-House; Greenhouse   | <a href="https://flavourfields.com/flowers-and-leaves/editable-flowers-and-editable-leaves/">https://flavourfields.com/flowers-and-leaves/editable-flowers-and-editable-leaves/</a> |
| Fresh Origins                                                                                                                                                                                   | Fresh           | San Marcos, CA      | Seasonal      | Culinary        | In-House               | <a href="https://www.freshorigins.com/categories/editable-flowers/">https://www.freshorigins.com/categories/editable-flowers/</a>                                                   |

|                                    |                     |                    |            |                   |                      |                                                                                                                                                                           |
|------------------------------------|---------------------|--------------------|------------|-------------------|----------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Freshly Preserved                  | Dried and pressed   | North Royalton, OH | Year-Round | Public            | Partner Farms        | <a href="https://www.freshlypreserved.com/products?category=Edible%20Flowers">https://www.freshlypreserved.com/products?category=Edible%20Flowers</a>                     |
| Melissa's                          | Fresh               | Los Angeles, CA    | Seasonal   | Public            | NA*                  | <a href="https://www.melissas.com/">https://www.melissas.com/</a>                                                                                                         |
| Marx Food                          | Fresh               | Seattle, WA        | NA*        | Culinary          | NA*                  | <a href="https://www.marxfoods.com/edible-flower-guide">https://www.marxfoods.com/edible-flower-guide</a>                                                                 |
| Magnolia's Yarden                  | Fresh and preserved | Clovis, CA         | Seasonal   | Public            | In-House             | <a href="https://www.magnoliasyarden.com/">https://www.magnoliasyarden.com/</a>                                                                                           |
| Great Day Gardens                  | Fresh               | Forest, VA         | Seasonal   | Public            | In-House             | <a href="https://greatdaygardens.com/product/edible-flowers/">https://greatdaygardens.com/product/edible-flowers/</a>                                                     |
| Suncore Foods                      | Freeze dried        | Irvine, CA         | Year-Round | Public            | NA*                  | <a href="https://www.suncorefoods.com/">https://www.suncorefoods.com/</a>                                                                                                 |
| Eat Your Flowers                   | Dried, pressed      | Montecito, CA      | Year-Round | Public            | In-House             | <a href="https://eatyourflowers.com/collections/%F0%9F%92%90-flowers-%F0%9F%92%90">https://eatyourflowers.com/collections/%F0%9F%92%90-flowers-%F0%9F%92%90</a>           |
| Planted Detroit                    | Fresh               | Detroit, MI        | By request | Public by request | In-House; CEA        | <a href="https://planteddetroit.com/products/25-count-edible-flower-mix-addon">https://planteddetroit.com/products/25-count-edible-flower-mix-addon</a>                   |
| Jacob's Farm                       | Fresh               | Pescadero, CA      | Year-Round | Wholesale         | In-House             | <a href="https://www.jacobsfarmdelcabo.com/products/product/edible-flowers">https://www.jacobsfarmdelcabo.com/products/product/edible-flowers</a>                         |
| The Chef's Garden                  | Fresh               | Huron, Ohio        | Year-Round | Public; Culinary  | In-House; Greenhouse | <a href="https://chefs-garden.com/product-category/chef-products/edible-flowers-chefs/">https://chefs-garden.com/product-category/chef-products/edible-flowers-chefs/</a> |
| Rock Garden Herbs                  | Mixed fresh         | Miami, Florida     | Year-Round | Wholesale         | In-House             | <a href="https://www.rockgardenherbs.com/growspecialties">https://www.rockgardenherbs.com/growspecialties</a>                                                             |
| *This information is not available |                     |                    |            |                   |                      |                                                                                                                                                                           |

Online marketplaces such as Etsy (Brooklyn, NY, U.S.A) have become increasingly important distribution channels for preserved EF. Sellers on these platforms frequently market their products for use in cocktails, baking, and tea, highlighting aesthetic qualities such as color retention, petal shape, and visual appeal. Value-added products that include preserved flowers inside lollipops, baking kits, and infused sugars are frequently marketed, illustrating the potential for EF to serve as inputs for broader value-added industries. These platforms also allow small-scale producers to reach national audiences without the logistical challenges associated with shipping fresh flowers.

The U.S. market also intersects with broader trends in value-added food and beverage industries. One particularly promising avenue for market growth is the integration of EF into the craft beverage sector, where producers increasingly incorporate novel botanical ingredients to enhance sensory complexity and nutraceutical value (Pereira et al., 2026; Carboni et al., 2025). As consumer preferences increasingly emphasize botanical complexity, aesthetic presentation, and experiential dining, EF have gained traction in craft cocktails, artisanal beverages, and specialty desserts. This trend aligns with the growth of small- and medium-scale craft producers who prioritize unique ingredients and regional sourcing. EF such as lavender and hibiscus are already widely used in teas and syrups, and their incorporation into craft spirits and cocktail programs represents a promising avenue for expanding domestic demand (Fernandes et al., 2017; Jadhav et al., 2023).

Despite these opportunities, fresh EF have a high-water content that contributes to rapid post-harvest deterioration and short shelf life. This creates logistical challenges for shipping, storage, and retail sales. Producers must balance the superior flavor and aromatic expression of fresh flowers with the practical advantages of dried or preserved forms, which have a more stable

and longer shelf life. Additionally, the lack of standardized sensory descriptors or quality metrics complicates marketing efforts, as consumers may be unfamiliar with the flavor profiles or culinary applications of many EF species.

Overall, the U.S. EF market remains small, but has potential, that can be driven by culinary innovation, consumer interest in visually appealing foods, and the growth of value-added industries. Continued development of controlled-environment production, improved distribution networks, and clearer sensory and quality standards could help strengthen the domestic market and support broader commercialization.

### *Public Perception of Edible Flowers*

Public perception of EF reflects a mix of high curiosity, knowledge gaps, and growing culinary interest across the globe. Guiné et al. (2020) reported that while a large majority of studied participants had heard of EF, nearly all believed that available information was insufficient. About one-third of participants perceived any risks with EF consumption, and those concerns centered primarily on toxicity and pesticide exposure. These perceptions align with broader food safety concerns surrounding ornamental species and highlight the importance of clear guidance on safe cultivation and handling practices (Carboni et al., 2025). Despite these uncertainties, consumer attitudes remain largely positive; most participants find the use of EF in gastronomy appealing (80-89%), even if fewer believe they should be consumed more frequently (20-35%) (Guiné et al., 2020).

Cultural context plays a significant role in shaping how EF are used and perceived. In a multinational comparison, Slovenian participants most often used EF for decoration or dish presentation, whereas participants in Portugal and Brazil tended to incorporate them into salads

(Guiné et al., 2021). In the study by Guiné et al. (2021) chamomile emerged as the most frequently consumed species across the three surveyed countries, though preferences varied regionally, with rose, pumpkin flowers (*Cucurbita pepo*), sunflower (*Helianthus annuus*), and pansy (*Viola xwittrockiana*) also commonly used, but location dependent (Guiné et al. 2021). Ethnobotanical research further illustrates the diversity of traditional uses; in the Valais region of Switzerland, EF were commonly prepared as teas, cooked as vegetables, jams, or raw snacks (Abbett et al., 2014). These patterns demonstrate that familiarity and cultural food traditions strongly influence consumer acceptance.

Positive prior experiences appear to be a strong predictor of acceptance. Mulík et al. (2024) found that most participants reported favorable experiences with EF, suggesting that exposure may reduce hesitation and increase willingness to try new species. However, accessibility remains inconsistent. In one study, nearly half of respondents were unsure whether EF were easy to obtain, and the remaining responses were split between those who found them difficult and those who found them easy to access (Guiné et al., 2021). This uncertainty reflects the limited visibility of EF in mainstream retail settings and highlights an opportunity for growers and retailers to improve consumer access.

Consumer purchasing decisions are strongly influenced by visual appeal, safety assurances, and demographic characteristics. Kelley (2001) found that flower color was the most influential factor in purchasing decisions, with multicolor packages receiving the highest preference and pesticide-free labeling being viewed favorably. Additional work by Kelley et al. (2002a) showed that packages containing nasturtium were most preferred, followed by viola. Demographic trends also shape purchasing likelihood: consumers with higher education levels were more likely to buy and consume EF, women were more likely than men to use them, larger

households were more likely to grow them, and higher income households were more likely to purchase them (Kelley et al., 2002b). These patterns suggest that EF currently appeal most strongly to consumers with higher food literacy and disposable income.

Recent increases in EF use are closely tied to broader trends in gastronomy, including gourmet dining, craft beverages, and specialty food markets. Their resurgence has been linked to the growing emphasis on visual presentation, novelty, and natural ingredients in contemporary cuisine (Benvenuti and Mazzonocini, 2021; Fernandes et al., 2017). Social media such as Instagram (Menlo Park, CA, U.S.A.) has further amplified these trends by promoting visually striking food and beverage presentations, thereby reinforcing consumer demand for aesthetically enhanced products such as EF (Contois and Kish, 2022). Therefore, social media can help increase consumer exposure and normalize EF as part of modern culinary aesthetics.

### *Edible Flower Production Systems and Challenges*

Despite rising demand of EF as previously discussed, they remain one of the most challenging horticultural products to produce, handle, and commercialize. Production systems range from traditional field cultivation to advanced controlled environment agriculture (CEA). Each of these production systems is limited by constraints such as labor, shelf life, environmental control, and regulatory ambiguity. These factors create major impacts that limit scalability and consistency. For the EF market to succeed, additional work is needed to develop guidelines and regulations that support informed production systems.

High production costs are a defining feature of EF systems. Fernandes et al. (2020a) noted that the cost of organic EF production is high due to flower quality requirements, with all stages of production requiring larger amounts of labor. Prices can range widely. For example, 20

g of fresh calendula may cost between 2.40 and 39.0 euros (\$2.81 and \$45.68 USD) (Fernandes et al., 2020a). Jadhav et al. (2023) shared that EF are often sold by the unit, with prices varying by species. Regulatory frameworks further complicate production. There are no government-issued lists of EF species; in Europe, flowers must instead appear on the Novel Foods and Ingredients list (Fernandes et al., 2020a). Consumer awareness of EF species and their potential uses also plays a role in the success of production.

Shelf life is one of the most significant barriers to EF market expansion. Most species maintain quality for only 5–10 days under ideal conditions, and they are highly sensitive to temperature, humidity, and handling. Cornflower has been observed to have the longest shelf life at 12 days, with pansies and camellias (*Camellia* spp.) having the lowest at 6 days (Carboni et al., 2025). With such a short timeline, minimizing the time between harvest and reaching the consumer is essential. This narrow logistical window necessitates overnight shipping, increasing costs, and restricting market reach. Post-harvest improvement research has explored temperature management, modified atmosphere packaging, moisture absorbing pads, edible coatings, microbial control strategies, high-hydrostatic pressure, and irradiation, however species-specific responses remain a challenge (Fernandes et al., 2019b).

Production systems vary widely in scale and technological sophistication. Small and medium-sized growers have historically supplied local markets, often using field or greenhouse systems (USDA ERS, 2022). Extension efforts, such as those by Hochmuth and Cantliffe (1990), encouraged growers to treat EF as a specialty crop for high-end restaurants, though they emphasized that shelf-life constraints limit broader expansion. In the U.S., CEA has emerged as a promising approach for improving consistency and extending production seasons. CEA systems, including hydroponics such as nutrient film technique (NFT), deepwater

culture (DWC), and aeroponics, allow growers to manipulate environmental variables to optimize yield and quality (Gómez et al., 2019). These systems reduce water and land use, improve nutrient efficiency, and can shorten production cycles (Wahome et al., 2011; Eveleens and Blok, 2014). For example, aeration in DWC can increase chrysanthemum (*Chrysanthemum* spp.) fresh weight by 10% (Eveleens and Blok, 2014), and chrysanthemums grown in DWC have also shown superior stem quality and flower production (Villagran et al., 2024). Aeroponics, while higher risk due to root exposure and system sensitivity, has demonstrated increased biomass, flower number, and quality in carnations (Metwally et al., 2017) and higher yields in chrysanthemums compared to soil systems (Eveleens and Blok, 2014).

A review by Munyanont (2025) highlights the growing relevance of advanced CEA systems, particularly plant factories with artificial lighting (PFALs), which offer full environmental control and year-round production potential. PFALs allow precise manipulation of light intensity, spectrum, and photoperiod, factors known to influence flowering, morphogenesis, and secondary metabolite accumulation (e.g., phenolics, flavonoids, carotenoids). A study by Munyanont et al. (2024a) demonstrated that prolonging photoperiods can increase calendula polyphenolic content and antioxidant content for some cultivar like ‘Orange Gem’, but not another ‘Citrus Orange’, showing that phytochemical reaction can be species and cultivar dependent. Lighting can also play a part in calendula flowering as specific red and far-red light combinations were found to regulate calendula flowering (Munyanont et al., 2024b). Nasturtium grown under PFAL conditions exhibits optimal seedling performance at an electrical conductivity of 1.0 dS m<sup>-1</sup> (Xu et al. 2021a), and yields increase with rising daily light integral (DLI) under 24 hr lighting without inducing stress (Xu et al., 2021b). French marigold

cultivars also show differential performance in PFALs, with ‘Red’ producing the highest flower number and biomass (Kwak et al., 2024). These findings illustrate the potential of PFALs to standardize production and enhance quality, though species-specific protocols remain limited and operational costs remain high.

Despite technological advances, EF production continues to face substantial biological and regulatory challenges. Pest management is particularly difficult because EF lack federally approved pesticides in the U.S., forcing growers to rely on cultural practices, biological control, and contact-limited organic products such as neem oil and insecticidal soap. Greenhouse pests, including thrips (*Thysanoptera*), aphids (*Aphididae*), fungus gnats (*Sciaridae*), whiteflies (*Trialeurodes vaporariorum*), and mites (*Tetranychus urticae*), can cause cosmetic damage that renders flowers unsellable. Outdoor systems face additional insect and disease pressures, including earwigs (*Forficula 22uricularia*), weevils (*Attelabidae*), grasshoppers (*Orthoptera*), and aster yellows (*Candidatus Phytoplasma asteris*), with general crop losses reaching up to 26–40% due to pests (Chadfield, 2022).

Pesticide use on greenhouse herbs is highly restricted because these crops are classified as specialty food commodities, and only a limited number of products have established residue tolerances or pre-harvest intervals (EPA, 2023; USDA IR-4 Project, 2022). As a result, growers rely heavily on cultural and biological controls, since many conventional insecticides labeled for ornamentals cannot be legally applied to edible herbs. This regulatory framework directly parallels the situation for EF, which are also consumed fresh and therefore lack approved pesticides for most key pests. Consequently, even moderate pest pressure can cause disproportionate economic losses in EF production due to the absence of legally permissible chemical interventions.

Environmental benefits associated with intercropping and diversified production systems offer promising avenues for sustainable EF cultivation. Intercropping with flowers and EF can increase pollinator abundance (Balmer, 2014), improve fruit yield and quality in vegetable crops (Pinero, 2015; Mallinger, 2019), and reduce pest pressure through volatile-mediated repellence or masking effects (Togni et al., 2010; Jadhav et al., 2023; Mir, 2022). Aromatic species such as marigolds attract beneficial insects and have been widely used as companion plants in tomato (*Solanum lycopersicum*) systems (Conboy, 2019; Chaturvedi, 2024; Gong, 2024). However, while the benefits of EF for vegetable crops are increasingly documented, far less is known about how intercropping affects the flowers themselves, especially when looking into the impacts on yield, quality, and pest resilience. With further research, intercropping EF with traditional or specialty crops may become an important way to support their use as a supplementary crop.

Taken together, the literature reveals a production landscape shaped by high labor demands, short shelf life, pest management constraints, and inconsistent environmental conditions across systems. While CEA and PFAL technologies offer promising solutions for year-round, high-quality production, their economic feasibility and species-specific optimization remain underdeveloped. Similarly, intercropping diversification strategies show potential to reduce pest pressure and enhance sustainability, yet their direct impacts on EF productivity remain poorly understood. These gaps highlight the need for integrated research that connects production efficiency, environmental control, and informed policy making to support the development of scalable, resilient EF production systems.

## *Conclusion*

Edible flowers offer a unique mixture of cultural tradition, nutritional potential, and emerging commercial opportunity. Historical and ethnobotanical records demonstrate that their use is neither novel nor geographically isolated. Currently, interest has accelerated as consumers seek foods that offer aesthetic value, sensory novelty, and perceived health benefits. Scientific research has expanded rapidly in response, particularly in the areas of phytochemical composition, antioxidant capacity, and medicinal properties. These findings demonstrate that EF are more than decorative ingredients; they are complex nutraceuticals whose profiles vary widely by species, cultivar, and production environment.

Despite this growing scientific foundation, the EF industry remains constrained by structural and informational gaps. Market data are inconsistent, proprietary, and often vague in their collection methodologies. This leaves growers and researchers without reliable estimates of market size, growth trajectories, or regional sales characteristics. Production systems share these uncertainties. Most U.S. growers operate at small scales, integrate EF as supplemental crops, and navigate challenges related to shelf life, distribution, and the absence of standardized quality metrics. At the same time, consumer interest is evident but uneven. While many individuals express curiosity and positive attitudes toward EF, knowledge gaps, safety concerns, and limited availability continue to shape public perception and purchasing behavior.

Together, these patterns reveal an industry with clear potential but many knowledge gaps that must be addressed first. Scientific research has outpaced economic and consumer understanding, resulting in a fragmented industry where growers, retailers, and consumers operate with incomplete information. Strengthening the EF market will require efforts that connect production practices, phytochemical research, market data, and consumer behavior.

Addressing these gaps is essential for supporting growers, informing policy, and guiding the development of a more transparent, resilient, and accessible EF market. The following chapters build on this foundation by examining the U.S. market landscape and production system considerations in greater depth, with the goal of contributing to steppingstones to an industry ready for continued growth.

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## CHAPTER 2. THE U.S. EDIBLE FLOWER MARKET THROUGH THE FARMERS' MARKET LENS <sup>1</sup>

### **Abstract**

Consumers' desires for new culinary experiences have provided avenues for the resurgence of less commonly known food crops such as edible flowers. With historical uses in civilizations such as Ancient Rome and the Victorian era, this specialty crop has followed waves of popularity with a current increase in public interest. Edible flower research has largely focused on understanding the health benefits and increasing shelf life. General information about the edible flower markets and trends, especially in the US, is limited. Edible flowers have the potential to be a profitable supplementary crop, so understanding the characteristics of the US edible flower market is key to assisting growers make informed decisions related to production and marketing. A national survey of US farmers' market managers was conducted in the summer of 2025. The survey asked managers to share their market demographics, the perceived status of the edible flower industry in their area, and opinions regarding the edible flower market characteristics. About 1000 farmers' markets were contacted with 229 responses for a 22.9% response rate. Respondents located in urban (62.8%) and western (52.1%) regions were more likely to sell edible flowers in their market. Southern (25%) and rural (25.9%) were less likely to sell them. The most sold edible species by markets were nasturtium, calendula, marigolds, and pansies. Vendors who sold edible flowers species alone accounted for only 3.5%

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<sup>1</sup> This research was originally published in HortTechnology Journal by Lee MK, Miller CT. 2026. The U.S. Edible Flower Market Through the Farmers' Market Lens. *HortTechnology*.

with vendors who primarily sold vegetables (47.7%) and vegetables and fruit (32.6%) as the most common vendor type, thus supporting claims of edible flowers sales primarily as supplemental income. When asked about the largest barriers to the edible flower market, managers shared that public knowledge (72.5%) and marketability (63.8%) were the biggest barriers to the expansion of this industry. The results of this study provide more insight into the US edible flower market. Moreover, it highlights areas of future research that can support producers interested in growing and expanding edible flowers sales and supplementing their current practices.

## **Introduction**

Edible flowers are known for their medicinal and culinary uses. They are not a new crop; however, their market often follows cycles of popularity. The earliest documented edible flower use can be traced back to Ancient Egypt and Ancient Rome, when they were used in drinks and purees (Kumar 2022). In modern times, edible flowers have been popular in culinary dishes such as rose in Turkish delight and fried squash blossoms in Italian cuisine (Kumar 2022). While their uses are established in culinary fields, recent interest has focused on edible flowers as “nutraceuticals”. Nutraceuticals are functional foods that aid in the prevention or treatment of a disease (Kalra 2015), with a myriad of medical benefits (Kandylis 2022; Carboni et al. 2025; Benvenuti and Mazzoncini, 2021). For instance, marigolds (*Tagetes* spp.) have been documented to benefit eye health, chrysanthemum (*Chrysanthemum × morifolium*) can have anti-obesity effects, and hibiscus (*Hibiscus* spp.) can act as an anti-inflammatory (Kandylis 2022; Benvenuti and Mazzoncini, 2021; Carboni et al. 2025). Some of these nutraceutical benefits originate from naturally derived components such as fiber, antioxidants, and polyphenols (Jadhav et al. 2023;

Pires et al. 2023). The wide breadth of edible flower health benefits, as a food crop, makes them worthy of investigation.

Global market estimates are currently only available through private market research companies (e.g., Fact.MR 2025; Market Research Future 2025; Verified Market Research 2025), and full access to them requires payment. As such, there is a large range of market size estimates, with values of \$141 million (360iResearch 2025), \$440 million (Singh 2025), and \$1.2 billion (Verified Market Research 2025). One similarity in these reports is an anticipated compound annual growth rate between 4% and 6%, with North America, Asia-Pacific, and Europe considered the largest market areas (Verified Market Research 2025). Despite this projection, there is a lack of research and publicly available market data, and our understanding of the US edible flower market is limited. One reason for this is that edible flowers are not a tracked commodity by the US Department of Agriculture (USDA), leaving growers dependent on these paid reports. Researchers in other countries facing similar issues have looked into other ways to address this gap. For example, there is an effort in Portugal to expand public knowledge on edible flowers and their market. For instance, Fernandes et. al. (2020) in their review of the Portuguese market, establishes possible pathways to make edible flower market details accessible. This review noted that restrictions such as the short shelf life of edible flowers means that understanding local sources for this crop is exceptionally important which is in agreement with findings by Jadhav et al. (2023).

Farmers' markets are a community market that allows farmers to sell their products locally to consumers (Brown and Miller 2008; Török et al. 2024). There are an estimated 7,000 farmers' markets in the US, according to the USDA Local Food Directory (US Dept Agric 2025). While the size of the market can vary, consistent attributes are open spaces, booths or

stands, and a market manager who organizes, conducts, and advertises the event. Market managers can be employees of the market alone, a private market company, or part of a government system such as Extension. They can function as a liaison between producers and consumers, who can go to them for information and to find the goods they need. Market managers can be important sources of local market information and logistics, aiding producers by connecting them with resources and following consumer trends.

The objective of our study was to survey farmers' markets about edible flowers to better understand the US edible flower market. More specifically, our goals were to gain insight into which market variable(s) influenced edible flower sales and what barriers might exist that impede the edible flower market expansion. We had two hypotheses for this study: 1) the existence of edible flowers sales is impacted by the market type and location, and 2) the limited amount of currently available data and information could be a major barrier to increasing sales. Fernandes et al. (2020) discussed how edible flowers are often sold as a secondary source of income. This additional revenue stream could be beneficial to US cut flower growers and other producers looking for local sources of income. With a better understanding of the US edible flower industry, growers and marketers of edible flowers will be able to tailor their production to meet the desires of the consumers, overcome barriers, and expand the edible flower market.

## **Materials and Methods**

### *SURVEY DESIGN*

A survey was developed based on preliminary consumer edible flower survey results and feedback from Extension specialists. The survey was distributed electronically (Qualtrics LLC, Provo UT USA). The survey questions included: (1) zip code associated with the market; (2) regional land-use classification of the market location (i.e., rural, suburban, or urban); (3) market

style classification (i.e., traditional, producers' only, year-round, pop-up, hybrid, virtual); (4) estimated percentage range of vendors who sold any type of flowers (e.g. 0 to 20%, 20 to 40%); (5) presence of vendors who intercrop food crops and any flowers; (6) level of perceived edible flower market interest; (7) and if edible flowers are sold at that market. In Questions 2, 4, 5, 6, and 7 were multiple choice questions, allowing respondents to provide a single choice. For Question 3, market classifications were created based on observed market classification trends and definitions were not provided to the respondents and they were allowed to select more than one classification. Question (7) was a skip logic question; if the respondent answered "no" to edible flowers being sold, they were directed to the final three survey questions. The first required question asked which barriers impact the presence of edible flower sales. The second and third questions were optional, asking respondents to rank edible flowers of interest and an optional free-response feedback opportunity. If the respondents answered "yes" that edible flowers were sold at their market, they were surveyed as to what specific edible flower species were sold and what other crops the edible flowers vendors sold. After answering these two questions, the "yes" respondents were also directed to the last three questions that the "no" respondents were asked. With the exception of the market's zip code, all the responses were self-identified by the survey respondents. The survey was between 10 and 12 questions depending on the skip logic question (7).

The survey was distributed on 15 June 2025 and closed on 30 Sep 2025. Farmers' market managers were chosen as the recipients for our survey due to their central role in market operation and connections with both vendors and consumers. The survey was distributed to individual farmers' markets in each state, by contacting through direct emails or website contact forms which were only used in cases where an email address was not available. Unique farmers'

markets were contacted until we reached a minimum of two responses per state. Larger states (e.g., California and Florida) received more contacts in an attempt to capture the different areas of that state. Follow-up emails were not sent. This study was reviewed and approved by the Colorado State University (CSU) Institutional Review Board #7032.

## *DATA ANALYSIS*

The zip code provided with each response was used to categorize the market region to one of four regions (Midwest, Northeast, South, and West), based on the US Census classification page (US Census Bureau, n.d.). Descriptive summaries were conducted to determine frequencies and create contingency tables. Chi square tests, z scores, and residuals were conducted using R Studio (Posit Software, PBC, Boston, MA, USA).

## **Results and Discussion**

### *SURVEY RESPONDENT DEMOGRAPHICS*



**Figure 2.1.** A Qualtrics survey was distributed nationwide to farmers' markets seeking information about edible flower sales at their market, with a response rate of 229 out of 1000

inquiries. The figure shows the 89 locations of respondent markets that sold edible flowers and the flower species sold in the markets in that state. States with a marker but no flowers did not or were not able to provide specific flower species sold in their market.

Of the nearly ~1000 individual farmers' markets organizations contacted, a total of 225 complete surveys were returned, with an average completion time of 4.5 min. Completed surveys were reviewed and processed for irregularities and any that were completed in a very short time. We did not observe any surveys that would indicate they needed to be excluded from the data analysis. Three respondents personally corresponded via email and indicated that they were the managers of multiple markets and provided multiple zip codes. The responses for these participants were duplicated to represent each market they oversaw, yielding a final dataset of  $n = 229$ .

**Table 2.1.** Demographics of participating farmers' markets by region, location type, percent of flower vendors at the market, and by market classification. A Qualtrics survey was distributed nationwide to farmers' markets, with a response of 229 out of 1000.

|                                           | Count | Percentage |
|-------------------------------------------|-------|------------|
| <b>Region<sup>i</sup></b>                 |       |            |
| West                                      | 73    | 31.9       |
| Midwest                                   | 61    | 26.6       |
| Northeast                                 | 35    | 15.3       |
| South                                     | 60    | 26.2       |
| <b>Location Type</b>                      |       |            |
| Rural                                     | 85    | 37.1       |
| Suburban                                  | 65    | 28.4       |
| Urban                                     | 79    | 34.5       |
| <b>% Flower Vendors Present</b>           |       |            |
| 0-20%                                     | 207   | 90.4       |
| 21-40%                                    | 20    | 8.7        |
| 41-60%                                    | 2     | 0.9        |
| 61-80%                                    | 0     | 0          |
| 81-100%                                   | 0     | 0          |
| <b>Market Classification<sup>ii</sup></b> |       |            |
| Traditional                               | 155   | 67.7       |
| Producers Only                            | 66    | 28.8       |
| Year Round                                | 66    | 28.8       |
| Hybrid                                    | 46    | 20.1       |
| Pop-up                                    | 9     | 3.9        |
| Virtual                                   | 1     | 0.4        |

<sup>i</sup>Regions based on the US Census Classification (U.S. Census Bureau, n.d.).

<sup>ii</sup>Markets could self-identify as multiple classifications

Respondents identified with a series of demographics related to survey questions 2 to 4 (Table 2.1). The most respondents were from the Western region (31.9%), while the Northeastern region had the least representation (15.3%). Our market representation was in contrast of Schupp (2016) who found that the Northeast had the highest farmers' market density per 1000 people, while the Southern region had the lowest density. In our study, most of the respondents self-identified as rural markets (37.1%) and the suburban were the lowest, accounting for 28.4%, whereas Schupp (2016) observed higher concentrations of farmers' markets in metropolitan areas to rural areas. These comparisons demonstrate that the

demographics of farmers' market responses used in our study may not be an accurate representation of the US farmers' market climate, but this is likely due to the survey methodology used.

Of the 229 responses, traditional markets represented the majority (68%). Producers' only markets and year-round markets were equally represented at around 29%, with hybrid markets slightly lower at 20%. Only nine respondents identified as pop-up markets, and one identified as a virtual-only market.

Question 4 was in relation to what percentage of vendors sold any flowers in their market. The majority of the participants ( $\approx 90\%$ ) indicated that 0 to 20% of their vendors sold some kind of flowers. Only two respondents indicated that 41 to 60% of their vendors were selling flowers. No participating markets reported 61% or higher of vendors selling any type of flowers.

When asked in Question 7 if edible flowers were sold in their market, a total of 90 farmers' markets across 39 states indicated that they were sold there. Eleven states did not have participating farmers' markets that sold edible flowers (Figure 1). These included Alabama, Delaware, Kentucky, Maine, Missouri, Mississippi, New Jersey, North Dakota, Oklahoma, South Dakota, and West Virginia.

## EDIBLE FLOWER MARKET PERCEPTION AND SALES

**Table 2.2.** Perceptions and percentage of farmers' markets with edible flowers. A Qualtrics survey was distributed nationwide to farmers' markets seeking information about edible flower sales at their market, with a response of 229 out of 1000. The remaining categories were self-characterized by respondents.

|                                     | #   | Percentages<br>Is there a market for edible flowers in your area? |                           |                        |                 |          | Percentages<br>Are edible flowers sold? |      |
|-------------------------------------|-----|-------------------------------------------------------------------|---------------------------|------------------------|-----------------|----------|-----------------------------------------|------|
|                                     |     | Yes, Thriving                                                     | Yes, Room for Improvement | No, but there is space | No, no interest | Not sure | Yes                                     | No   |
| All Markets                         |     | 4.8                                                               | 45.0                      | 26.2                   | 10.5            | 13.5     | 39.3                                    | 60.7 |
| Region <sup>i</sup>                 |     |                                                                   |                           |                        |                 |          |                                         |      |
| West                                | 73  | 8.2                                                               | 56.2                      | 12.3                   | 9.6             | 13.7     | 52.1                                    | 47.9 |
| Midwest                             | 61  | 4.9                                                               | 42.6                      | 27.9                   | 13.1            | 11.5     | 34.4                                    | 65.6 |
| Northeast                           | 35  | 0.0                                                               | 45.7                      | 28.6                   | 11.4            | 14.3     | 45.7                                    | 54.3 |
| South                               | 60  | 3.3                                                               | 33.3                      | 40                     | 8.3             | 15       | 25                                      | 75   |
| Location Type                       |     |                                                                   |                           |                        |                 |          |                                         |      |
| Rural                               | 85  | 0                                                                 | 36.5                      | 25.9                   | 14.1            | 23.5     | 25.9                                    | 74.1 |
| Suburban                            | 65  | 4.6                                                               | 47.7                      | 33.8                   | 7.7             | 6.2      | 30.8                                    | 69.2 |
| Urban                               | 79  | 10.1                                                              | 51.9                      | 20.3                   | 8.9             | 8.9      | 60.8                                    | 39.2 |
| % Flower Vendors Present            |     |                                                                   |                           |                        |                 |          |                                         |      |
| 0-20%                               | 207 | 4.3                                                               | 44.4                      | 28.0                   | 10.6            | 12.6     | 36.7                                    | 74.1 |
| 21-40%                              | 20  | 5                                                                 | 50                        | 10                     | 10              | 25       | 60                                      | 40   |
| 41-60%                              | 2   | 50                                                                | 50                        | 0                      | 0               | 0        | 100                                     | 0    |
| 61-80%                              | 0   | 0                                                                 | 0                         | 0                      | 0               | 0        | 0                                       | 0    |
| 81-100%                             | 0   | 0                                                                 | 0                         | 0                      | 0               | 0        | 0                                       | 0    |
| Market Classification <sup>ii</sup> |     |                                                                   |                           |                        |                 |          |                                         |      |
| Traditional                         | 155 | 4.5                                                               | 49.0                      | 23.9                   | 11.6            | 11.0     | 39.4                                    | 60.6 |
| Producers Only                      | 66  | 10.6                                                              | 42.4                      | 24.2                   | 12.1            | 10.6     | 57.6                                    | 42.4 |
| Year Round                          | 66  | 13.6                                                              | 54.5                      | 16.7                   | 6.1             | 9.1      | 65.2                                    | 34.8 |
| Hybrid                              | 46  | 2.2                                                               | 43.5                      | 30.4                   | 6.5             | 17.4     | 23.9                                    | 76.1 |
| Pop-up                              | 9   | 11.1                                                              | 55.6                      | 11.1                   | 11.1            | 11.1     | 44.4                                    | 55.6 |
| Virtual                             | 1   | 0.0                                                               | 50.0                      | 0.0                    | 0.0             | 0.0      | 100.0                                   | 0.0  |

<sup>i</sup>Regions based on the US Census Classification (U.S. Census Bureau, n.d.).

<sup>ii</sup>Markets could self-identify as multiple classifications

The aim of survey questions 6 and 7 was to understand the farmers markets directors perceptions on their edible flower market interest and the number of markets that sold edible flowers, respectively. Responses that reported a thriving market accounted for the smallest proportion across all survey respondents (Table 2.2). Urban and Western markets had a higher proportion of participants who felt their edible flower markets were thriving or existed and had room to grow. Farmers' markets that didn't perceive that a market existed and there was no interest represented the second lowest proportion. If we consider future edible flower

opportunities (i.e., markets that are thriving, have room for improvement, have space for one, etc.), 76.2% of the markets surveyed believed the markets had growth potential. Moreover, 13.5% of participating markets, across all four regions were unsure of how they would classify the edible market in their area, which could indicate an opportunity for edible flower sales expansion or a lack of knowledge of edible flower species. Pop-up and Year-Round markets had a higher proportion of respondents who perceived that a market existed and had room for improvement. Rural market locations reported the highest lack of interest in edible flowers.

The majority of the market respondents (60.7%), across the four regions, did not report edible flower sales (Table 2.2). Significant associations were observed (Chi square tests) between edible flowers being sold by location type ( $\chi^2=11.33$ ,  $p = 0.01$ ) and regions ( $\chi^2 = 23.65$ ,  $p = <0.0001$ ). Rural markets were less likely to sell edible flowers ( $z = -3.19$ ), while those in urban areas were more likely to sell them ( $z = 4.82$ ). The Southern region had a lower proportion of markets that sold edible flowers ( $z = -2.64$ ), and the Western region had a significantly higher proportion ( $z = 2.70$ ). Market classifications also had significant associations ( $\chi^2 = 25.10$ ,  $p = <0.0001$ ). Hybrid markets had a lower proportion of markets selling edible flowers ( $z = -3.23$ ). Producers Only ( $z = 2.12$ ) and Year-Round ( $z = 3.50$ ) markets had a higher proportion of edible flower sales. Interestingly, the one virtual market that participated sold edible flowers. The four markets that had 41-60% of vendors selling flowers also sold edible flowers.

The insight gained in this survey can be useful for marketers looking to add and expand their markets, with the inclusion of edible flowers. Areas looking to expand, such as Southern markets, can incorporate strategies used by urban and Western markets to be successful. Additionally, these data suggest future studies into specific market classifications and their impacts on edible flower sales would be insightful.

## EDIBLE FLOWERS SPECIES SOLD

**Table 2.3.** Edible flower species sold by region and market location at participating farmers' markets. A Qualtrics survey was distributed nationwide to farmers' markets seeking information about edible flower sales at their market, with a response of 229 out of 1000. Location type was self-characterized by respondents. 89 respondents indicated they sold edible flowers, and 14 of the 90 did not know or share which species were sold.

|                                                           | #  | Percentages         |         |           |       | Percentages   |          |       |
|-----------------------------------------------------------|----|---------------------|---------|-----------|-------|---------------|----------|-------|
|                                                           |    | Region <sup>i</sup> |         |           |       | Location Type |          |       |
|                                                           |    | West                | Midwest | Northeast | South | Rural         | Suburban | Urban |
| All Respondents <sup>ii</sup>                             | 90 | 39.5                | 25.0    | 19.7      | 15.8  | 23.7          | 21.0     | 55.3  |
| Species                                                   |    |                     |         |           |       |               |          |       |
| Nasturtium ( <i>Tropaeolum majus</i> )                    | 56 | 42.9                | 21.4    | 23.2      | 12.5  | 23.2          | 21.4     | 55.4  |
| Calendula ( <i>Calendula officinalis</i> )                | 35 | 40.0                | 25.7    | 17.1      | 17.1  | 25.7          | 17       | 57.1  |
| Marigold ( <i>Tagetes</i> spp.)                           | 34 | 38.2                | 26.5    | 17.6      | 17.6  | 20.6          | 20.6     | 58.8  |
| Pansy ( <i>Viola x wittrockiana</i> )                     | 32 | 46.9                | 28.1    | 18.8      | 6.3   | 28.1          | 18.8     | 53.1  |
| Butterfly Pea ( <i>Clitoria ternatea</i> )                | 20 | 30.0                | 25.0    | 10.0      | 35.0  | 10.0          | 35.0     | 55.0  |
| Viola ( <i>Viola</i> spp.)                                | 18 | 33.3                | 27.8    | 16.7      | 22.2  | 11.1          | 0        | 88.9  |
| Cornflower ( <i>Centaurea cyanus</i> )                    | 15 | 40.0                | 13.3    | 13.3      | 33.3  | 13.3          | 13.3     | 73.3  |
| Dahlia ( <i>Dahlia</i> spp.)                              | 14 | 50.0                | 35.7    | 7.1       | 7.1   | 7.1           | 28.6     | 64.3  |
| Snapdragon ( <i>Antirrhinum majus</i> )                   | 14 | 50.0                | 28.6    | 14.3      | 7.1   | 7.1           | 14.3     | 78.6  |
| Squash Blossom ( <i>Cucurbita pepo</i> ) <sup>iii</sup>   | 12 | 33.3                | 33.3    | 16.7      | 16.7  | 25.00         | 25.0     | 50.0  |
| Rose ( <i>Rosa</i> spp.)                                  | 10 | 50.0                | 20.0    | 0         | 30.0  | 20.0          | 20.0     | 60.0  |
| Lilac ( <i>Syringa vulgaris</i> )                         | 7  | 14.3                | 71.4    | 14.3      | 0     | 28.6          | 0        | 71.4  |
| Carnation ( <i>Dianthus caryophyllus</i> )                | 6  | 66.6                | 16.7    | 0         | 16.7  | 33.3          | 16.7     | 50.0  |
| Borage ( <i>Borago officinalis</i> ) <sup>iii</sup>       | 5  | 40.0                | 60.0    | 0         | 0     | 60.00         | 0        | 40.0  |
| Hibiscus ( <i>Hibiscus</i> spp.) <sup>iii</sup>           | 5  | 20.0                | 60.0    | 0         | 20.0  | 40.0          | 40.0     | 20.0  |
| Buzz Button ( <i>Acmella oleracea</i> )                   | 4  | 75.0                | 0       | 0         | 25.0  | 0             | 25.0     | 75.0  |
| Chrysanthemum ( <i>Chrysanthemum x morifolium</i> )       | 4  | 50.0                | 0       | 0         | 50.0  | 25.0          | 25.0     | 50.0  |
| Lavender ( <i>Lavandula angustifolia</i> ) <sup>iii</sup> | 4  | 0                   | 100     | 0         | 0     | 50.0          | 0        | 50.0  |
| Bee Balm ( <i>Monarda didyma</i> ) <sup>iii</sup>         | 2  | 0                   | 100     | 0         | 0     | 100           | 0        | 0     |
| Chamomile ( <i>Matricaria chamomilla</i> ) <sup>iii</sup> | 2  | 0                   | 100     | 0         | 0     | 100           | 0        | 0     |
| Dandelion ( <i>Taraxacum officinale</i> ) <sup>iii</sup>  | 2  | 0                   | 100     | 0         | 0     | 100           | 0        | 0     |
| Cherry Blossom ( <i>Cerasus</i> sp.) <sup>iii</sup>       | 1  | 100                 | 0       | 0         | 0     | 0             | 100      | 0     |
| Elderflower ( <i>Sambucus nigra</i> ) <sup>iii</sup>      | 1  | 0                   | 100     | 0         | 0     | 0             | 0        | 100   |
| Magnolias ( <i>Magnolia</i> spp.) <sup>iii</sup>          | 1  | 100                 | 0       | 0         | 0     | 0             | 100      | 0     |

<sup>i</sup>Regions based on the US Census Classification (U.S. Census Bureau, n.d.).

<sup>ii</sup>Markets that sold edible flowers

<sup>iii</sup>Species that were mentioned in the "Other" response form

Respondents provided information about the specific edible flower species that were sold in their markets. Nasturtium (*Tropaeolum majus*) was the most common edible flower reported as being sold at participating markets, with 56 (62%) of the 90 markets selling the edible flower. Calendula (*Calendula officinalis*), marigolds, and pansies (*Viola* × *wittrockiana*) were the next

most reported species sold (Table 2.3). Respondents were permitted to list “Other” edible flower species not pre-populated in the survey. The most common “Other” response was squash blossoms (*Cucurbita pepo*), which 12 market respondents indicated were sold in their markets. “Other” edible flowers provided by respondents were borage (*Borago officinalis*), hibiscus, lavender (*Lavandula angustifolia*), bee balm (*Monarda didyma*), chamomile (*Matricaria chamomilla*), dandelions (*Taraxacum officinale*), cherry blossom (*Cerasus* spp.), clovers (*Trifolium* sp.), danieli (*Erigeron denali*), elderflower (*Sambucus nigra*), and magnolias (*Magnolia* spp.).

Lilac (*Syringa vulgaris*) was mostly sold in Midwest markets (71%). Dahlia (*Dahlia* spp.) and snapdragon (*Antirrhinum majus*) were sold more by Western and Midwestern markets. Western markets represented a higher proportion of carnation (*Dianthus caryophyllus*) and buzz button (*Acmella oleracea*) sales and rural markets had higher borage sales. Of the 90 markets that sold edible flowers (based on zip code; Figure 2.1), 14 markets were unsure of which edible flowers were sold. Edible flowers sold in the state are included within the state’s boundary, however, does not mean that every farmers’ market in that state sells all the flowers included. Of the 24 species reported by respondents, over 50% (13) of the species were identified in the 2024 Census of Horticultural Specialties report (USDA NASS 2024) as top annual/garden plants sold. With pre-established cultivation in the horticultural industry, the existence of edible flower sales of these species shows that producers can diversify their income sources by utilizing these species in multiple sectors.

The most popular species reported in our study were similar to observed sales of pansies, nasturtium, borage, and squash blossom in the Portuguese edible flower market (Fernandes et al. 2020). Surprisingly, rose and hibiscus were less commonly sold species despite being noted as

the most popular species in third-party market reports (Fact.MR 2025; Market Research Future 2025). Our results show that there is limited diversity of edible flowers species sold in the US compared to the consumption in other areas of the world. In the Xishuangbanna prefecture of China, for example, local communities consume 212 different taxa of edible flowers (Zhang et al. 2023), while in the Mediterranean there has been use of 251 different taxa documented across the region (Motti et al. 2022). The limited taxa sold in U.S. highlights advantages such as easier producer adaptations and consumer recognition, while also identifying opportunities for market expansion into other consumable species.

### *VENDOR SALES CHARACTERISTICS*

**Table 2.4.** Primary revenue source for vendors who sell edible flowers by region, location type, and market classification. A Qualtrics survey was distributed nationwide to farmers' markets seeking information about edible flower sales at their market, with a response of 229 out of 1000. Location type was self-characterized by respondents.

|                                     | #  | Percentages          |                      |             |              |             |                     |
|-------------------------------------|----|----------------------|----------------------|-------------|--------------|-------------|---------------------|
|                                     |    | Vegetables primarily | Fruit and veggie mix | Cut flowers | Plant Starts | Microgreens | Only edible flowers |
| All Markets                         | 86 | 47.7                 | 32.6                 | 16.3        | 7.0          | 5.8         | 3.5                 |
| Region <sup>i</sup>                 |    |                      |                      |             |              |             |                     |
| West                                | 36 | 55.6                 | 25                   | 16.7        | 8.3          | 11.1        | 5.6                 |
| Midwest                             | 20 | 50                   | 40                   | 15          | 10           | 0           | 5                   |
| Northeast                           | 15 | 5.3                  | 33.3                 | 6.7         | 0            | 0           | 0                   |
| South                               | 15 | 20                   | 40                   | 26.7        | 6.7          | 6.7         | 0                   |
| Location Type                       |    |                      |                      |             |              |             |                     |
| Rural                               | 21 | 52.4                 | 23.8                 | 19          | 0            | 0           | 0                   |
| Suburban                            | 18 | 55.6                 | 22.2                 | 27.8        | 16.7         | 16.7        | 11.1                |
| Urban                               | 47 | 42.6                 | 40.4                 | 10.6        | 6.4          | 4.3         | 2.1                 |
| % Flower Vendors Present            |    |                      |                      |             |              |             |                     |
| 0-20%                               | 73 | 47.9                 | 32.9                 | 16.4        | 6.8          | 6.8         | 4.1                 |
| 21-40%                              | 11 | 54.5                 | 27.3                 | 9.1         | 9.1          | 0           | 0                   |
| 41-60%                              | 2  | 0                    | 50                   | 50          | 0            | 0           | 0                   |
| 61-80%                              | 0  | 0                    | 0                    | 0           | 0            | 0           | 0                   |
| 81-100%                             | 0  | 0                    | 0                    | 0           | 0            | 0           | 0                   |
| Market Classification <sup>ii</sup> |    |                      |                      |             |              |             |                     |
| Traditional                         | 57 | 49.1                 | 28.1                 | 22.8        | 10.5         | 7           | 5.3                 |
| Producers Only                      | 38 | 44.7                 | 31.6                 | 15.8        | 5.3          | 5.3         | 0                   |
| Year Round                          | 40 | 35                   | 47.5                 | 12.5        | 5            | 10          | 2.5                 |
| Hybrid                              | 11 | 54.5                 | 45.5                 | 18.2        | 9.1          | 9.1         | 18.2                |
| Pop-up                              | 3  | 33.3                 | 33.3                 | 66.6        | 0            | 0           | 0                   |
| Virtual                             | 1  | 100                  | 0                    | 0           | 0            | 0           | 0                   |

<sup>i</sup>Regions based on the US Census Classification<sup>(U.S. Census Bureau, n.d.)</sup>.

<sup>ii</sup>Markets could self-identify as multiple classifications

<sup>iii</sup>Vendor type that was mentioned in the "Other" response form

Respondents who indicated they sold edible flowers at their market (n=90), were also asked if they sold other products. Of the 86 respondents who provided feedback, 47.7% indicated that edible flower vendors sold primarily vegetables, followed by fruit and vegetables (32.6%), and cut flowers (16.3%) (Table 2.4). Similar findings were reported by Fernandes et al. (2020), as they found vegetable growers often use edible flowers as a supplemental source of income. Edible flowers have also been noted to be grown primarily alongside herbs and ornamental flowers (Jadhav et al. 2023), but only 5 respondents in our study noted through the “other” option, that vendors also sold herbs or microgreens (data not shown).

### PERCEIVED BARRIERS

**Table 2.5.** Perceived barriers to the edible flower market by region, location type, percent of flower vendors at the market, and by market classification. A Qualtrics survey was distributed nationwide to farmers’ markets seeking information about edible flower sales at their market, with a response of 229 out of 1000.

|                                     |     | Percentages <sup>iii</sup> |                                      |                      |                 |                  |
|-------------------------------------|-----|----------------------------|--------------------------------------|----------------------|-----------------|------------------|
|                                     | #   | Marketability              | Species Specific Growing Information | Pest Management/ IPM | Plant Nutrition | Public Knowledge |
| All Markets                         | 229 | 63.8                       | 18.8                                 | 8.3                  | 7.4             | 72.5             |
| Region <sup>i</sup>                 |     |                            |                                      |                      |                 |                  |
| West                                | 73  | 63                         | 17.8                                 | 5.5                  | 9.6             | 61.6             |
| Midwest                             | 61  | 62.3                       | 18                                   | 4.9                  | 4.9             | 78.7             |
| Northeast                           | 35  | 71.4                       | 2.9                                  | 5.7                  | 2.9             | 68.6             |
| South                               | 60  | 61.7                       | 30.0                                 | 16.7                 | 10.0            | 81.7             |
| Location Type                       |     |                            |                                      |                      |                 |                  |
| Rural                               | 85  | 67.1                       | 20.0                                 | 10.6                 | 9.4             | 74.1             |
| Suburban                            | 65  | 53.8                       | 18.5                                 | 9.2                  | 7.7             | 72.3             |
| Urban                               | 79  | 68.4                       | 17.7                                 | 5.1                  | 5.1             | 70.9             |
| % Flower Vendors Present            |     |                            |                                      |                      |                 |                  |
| 0-20%                               | 207 | 90.4                       | 63.3                                 | 19.3                 | 8.2             | 72.5             |
| 21-40%                              | 20  | 8.7                        | 70.0                                 | 15.0                 | 10.0            | 70.0             |
| 41-60%                              | 2   | 0.9                        | 50.0                                 | 0                    | 0               | 0                |
| 61-80%                              | 0   | 0                          | 0                                    | 0                    | 0               | 0                |
| 81-100%                             | 0   | 0                          | 0                                    | 0                    | 0               | 0                |
| Market Classification <sup>ii</sup> |     |                            |                                      |                      |                 |                  |
| Traditional                         | 155 | 62.6                       | 16.1                                 | 8.4                  | 5.8             | 72.3             |
| Producers Only                      | 66  | 68.2                       | 9.1                                  | 7.6                  | 6.1             | 71.2             |
| Year Round                          | 66  | 63.6                       | 18.2                                 | 3.0                  | 3.0             | 54.5             |
| Hybrid                              | 46  | 56.5                       | 23.9                                 | 10.9                 | 10.9            | 73.9             |
| Pop-up                              | 9   | 66.7                       | 33.3                                 | 33.3                 | 22.2            | 77.8             |
| Virtual                             | 1   | 100                        | 0                                    | 0                    | 0               | 0                |

<sup>i</sup>Regions based on the US Census Classification<sup>(U.S. Census Bureau, n.d.)</sup>

<sup>ii</sup>Markets could self-identify as multiple classifications

<sup>iii</sup>Markets could select multiple barriers

Market managers were asked about what they perceived as barriers to the edible flower market in their area. Public knowledge (72.5%) and marketability (63.8%) were the two most mentioned barriers to the presence of an edible flower market (Table 2.5). Southern markets had the highest proportion (81.7%) of markets indicating that public knowledge was a barrier. Benvenuti and Mazzoncini (2021) reported similar issues, in that overcoming neophobia, a fear of new food, and improving consumer nutrition education will aid edible flower agricultural potential. Education, household income, and gender were found to impact the likelihood of purchasing edible flowers (Kelley et al. 2002), so these characteristics should also be considered.

When looking at barriers to the edible flower market, one aspect for consideration is production barriers. In our survey, species-specific growing information (i.e., the lack thereof) was the most reported (18.8%), while pest management practices (8.3%) and plant nutrition (7.4%) were less of a concern. Southern farmers' markets were more concerned with species-specific growing information and pest management, while Northeastern markets were less concerned with species-specific information and plant nutrition. Uncertainty over growing new specialty crops due to lack of production information is not a new story, as the cut flower industry faced similar challenges when US sales began to rise (Kelly 1991).

Respondents also provided valuable insight through the free response survey question, particularly in relation to barriers. For example, logistics, which includes legislation and production costs, were described. Another important edible flower production barrier noted was the concern over increased time and labor for edible flower production, specifically as it relates to packaging. Another group of free responses were clustered around environmental conditions and production concerns concerning heat, short growing seasons, and the effects of the farmers' market environment. One limitation with fresh products, including edible flowers, is the post-

harvest and short shelf life, which is short at seven to ten days depending on the species (Fernandes et al. 2020). Pires et al. (2023) noted that coupling increased marketing initiatives while providing additional cultivation and post-harvest information can reduce production barriers. Other notable responses received were that edible flowers can be viewed as niche products, only applicable to fine dining; limited grower interest in marketing and sales; and the notion that customers would likely grow them at home instead of purchasing them. These responses further support the general need for additional information, from growing to marketing, in all market segments from production to marketing for edible flowers.

## **Conclusions**

Our study provides further insight into the US edible flower market. Urban and Western markets had higher interest in and reported sales of edible flowers compared to rural and Southern markets. The mostly commonly selected vendor type for those who sold edible flowers were those who sell vegetables alone or vegetables and fruit together.

As with any developing industry, overcoming perceived barriers is paramount to success. With our survey, marketability and public knowledge were documented as the biggest barriers and provide direction for critical work that can be done by educating the public on edible flowers to facilitate industry expansion.

Future research can build on this study by surveying growers (e.g., cut flower, herb, and vegetable) to determine their opinions on edible flower production and the market in their area. Ideally, an economic research study should occur to determine the exact values of the US market and sales trends across regions and sectors in a study on the edible flower production challenges. Understanding these values will allow the edible flower market to expand, and growers to make informed production and marketing decisions.

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### CHAPTER 3. COMPARING OUTDOOR AND GREENHOUSE PRODUCTION METHODS OF SELECT EDIBLE FLOWER SPECIES ON FLOWER YIELDS AND PHYTOCHEMICAL CONTENT

#### **Abstract**

Edible flowers are a crop of increasing interest among producers and consumers alike. Edible flower species also grown for ornamental purposes (edible ornamentals), can be a possible supplemental source of income for growers. Fresh sources of edible flowers have a limited shelf life or postharvest, so local production is very important for reducing the impacts of shipping on flower quality and consumer prices. These challenges highlight the need for year-round local production and utilization of controlled environments, such as greenhouses, in areas with short growing seasons. This study was designed to test whether greenhouse production is viable for edible flower species and to assess its impact on the phytochemical profile by comparing production across two locations; outdoor and greenhouse. Four edible flower species were grown in this study: buzz button (*Acmella oleracea*), dahlia (*Dahlia x hybrida*), dianthus (*Dianthus chinensis*), and zinnia (*Zinnia elegans*). Flowers were harvested weekly and assessed for flower number and flower fresh weights. Plants were destructively harvested after 14 weeks, and the final vegetative biomass was recorded. Dahlia tuberous root dry weights were also recorded. Zinnia and buzz button plants were significantly larger in the outdoor treatments, whereas dahlia and dianthus plants did not differ significantly between the outdoor and greenhouse environments. No statistical difference was observed in flower yields between growing environments for any of the species. At three points in the season, flowers were sampled and assessed for total polyphenol content (TPC) and total antioxidant content (TAC).

Phytochemical content did not differ significantly between cultivation environments for any species. TPC averages for our species were expressed in GAE  $\text{mg}\cdot\text{g}^{-1}$  DW: buzz button  $6.63 \pm 3.51$ , dahlia  $71.21 \pm 18.02$ , dianthus  $31.06 \pm 8.10$ , and zinnia  $26.35 \pm 7.77$ . The TAC averages for our species were expressed in Trolox equivalents (TE)  $\mu\text{mol}\cdot\text{g}^{-1}$  DW: buzz button  $34.22 \pm 13.58$ , dahlia  $544.54 \pm 99.15$ , dianthus  $58.15 \pm 12.28$ , and zinnia  $98.87 \pm 26.73$ . Consistent flower yields and phytochemical content across our location treatments indicate that greenhouses can serve as a production site for these edible flower species. Further work is needed to test the feasibility of year-round production.

## **Introduction**

Edible flowers represent a historic, yet understudied component of global food systems, valued for their culinary, cultural, and medicinal uses. Recent consumer interest in edible flowers has spurred research into how these crops can be produced and utilized on a larger scale, particularly for culinary and beverage applications (Fernandes et al., 2020). This increase in consumer interest is reflected in the market's projected compound annual growth rate of 4 to 6% over the next several years (Singh 2025; Verified Market Research 2025). Despite this growing demand, edible flowers remain one of the most challenging horticultural products to commercialize.

Shelf life is one of the most significant barriers to edible flower distribution. Most species maintain quality for only 5 to 10 d under ideal conditions, and some, such as pansies and camellias, last as few as 6 d (Carboni et al., 2025). Their sensitivity to temperature, humidity, and postharvest handling necessitates rapid, temperature-controlled distribution to maintain quality which increases costs and limits market reach (Kelley et al., 2003; Fernandes et al.,

2020). Expanding local, year-round production is one strategy to reduce these logistical constraints and improve product availability.

Production challenges extend beyond perishability. Edible flowers are labor-intensive, costly to produce, and highly vulnerable to pests due to the lack of federally approved pesticides for edible use (Pires et al. 2023). Greenhouse pests, including thrips (Thysanoptera), aphids (Aphididae), fungus gnats (Sciaridae), whiteflies (*Trialeurodes vaporariorum*), and mites (*Tetranychus urticae*), can cause cosmetic damage that renders flowers unsellable. Outdoor systems face additional insect and disease pressures, including earwigs (*Forficula auricularia*), weevils (Attelabidae), grasshoppers (Orthoptera), and aster yellows (*Candidatus Phytoplasma asteris*). These vulnerabilities underscore the need for production systems that can improve consistency and reduce losses.

Controlled environment agriculture (CEA) has emerged as a promising approach for addressing these challenges. Production systems range from traditional field cultivation to high tunnels, greenhouses, and advanced plant factories with artificial lighting (PFALs). Previous work comparing indoor and outdoor systems demonstrates that protected cultivation can improve yield, shorten time to harvest, and enhance stem quality for several floriculture species (Ortiz et al. 2012; Owen et al. 2016). More technologically advanced CEA systems offer even greater environmental control. PFALs allow precise manipulation of light intensity, spectrum, and photo period, factors known to influence flowering, morphology, and secondary metabolite accumulation. Studies have shown that prolonged photoperiods can increase calendula yield and antioxidant activity (Munyanont et al., 2024a). At the same time, specific combinations of red and far-red light regulate flowering (Munyanont et al., 2024b). Similar improvements in growth

and yield have been reported for nasturtium and French marigold under PFAL conditions (Xu et al., 2021; Kwak et al., 2024).

In addition to crop yield, production practices influence phytochemical composition. Edible flowers can contain high concentrations of polyphenolic compounds, including phenolics, flavonoids, carotenoids, and anthocyanins, which contribute to pigmentation, stress tolerance, and antioxidant capacity (Pires et al., 2019; Manach et al., 2004). The amount of total polyphenolic content (TPC) present is variable amongst species. For example, *Rosa chinensis* has an observed TPC of 284.8 gallic acid equivalents (GAE) per g of dry weight (DW)) and marigolds was observed at 89.2 GAE·g<sup>-1</sup> DW, giving these species particularly high TPC along with strong antioxidant capacity (Kandylis, 2022). The concentration and composition of these compounds can vary with production methods and is also impacted by the shelf life (Marchioni et al. 2020), so understanding how greenhouse and outdoor environments shape phytochemical profiles is essential for evaluating product quality.

Given the short shelf life, high production costs, and sensitivity of edible flowers to environmental conditions, CEA cultivation may offer growers a viable pathway to consistent, local, year-round production. However, species-specific data remains limited, particularly regarding how greenhouse systems influence biomass, flower yield, and phytochemical content. The objective of this study was to compare greenhouse and outdoor production methods for four edible flower species. Specifically, we aimed to 1) determine whether greenhouse production affects plant biomass and flower yield between cultivation systems, and 2) assess effects on TPC and total anthocyanin content (TAC) with the production method. Understanding these relationships is essential for determining whether indoor production can reliably supply marketable edible flowers and serve as a supplemental crop option for horticultural producers.

## Materials and Methods

The experiment was conducted at the Colorado State University (CSU) Horticulture Center [Fort Collins, CO, USA (40.564697, -105.084832)]. The greenhouse was actively controlled by a combination of venting, heating, and cooling technologies (Veristep Multistep control system; Wadsworth; Arvada, CO, USA). The plants were grown on rolling metal benches, with temperature set points at 18.33/23.89 °C and 15.56/21.11 °C (day/night). Data loggers (Hobo Pendant MX; Onset Computer Corporation; Bourne, MA, USA) recorded light intensity and air temperature throughout the experiment (Table 3.1). The data loggers were placed within blocks on the benches. Plants were grown outdoors underneath a structure covered with shade cloth. The data loggers were positioned at plant level.

**Table 3.1.** Average daily air temperatures and average daylight interval observed during 14 weeks in 2025 in two cultivation environments; greenhouse and outdoors. Each cultivation environment had two location replicates. The air temperature and light levels were recorded at 5 minute intervals throughout the study.

|                                           | Cultivation Environment |              |              |              |
|-------------------------------------------|-------------------------|--------------|--------------|--------------|
|                                           | Outdoor                 |              | Greenhouse   |              |
|                                           | Rep 1                   | Rep 2        | Rep 1        | Rep 2        |
| Average Air Temperature (°C)              | 21.87 ± 8.48            | 20.77 ± 7.88 | 25.67 ± 7.55 | 23.66 ± 5.34 |
| Day Light Interval (mol·m <sup>-2</sup> ) | 9.77 ± 3.82             | 9.24 ± 3.29  | 13.64 ± 4.18 | 10.91 ± 3.54 |

*Edible Flowers Propagation and Production*

The species evaluated in this study included ‘Lemon Drop’ buzz button (*Acmella oleracea*), ‘Venti Parfait Crimson’ dianthus (*Dianthus chinensis*), ‘Figaro™ Red Shade’ dahlia (*Dahlia xhybrida*), and ‘Zesty™ Scarlet’ zinnia (*Zinnia elegans*). These species were selected to represent different flower morphologies and to capture a range of possible phytochemical profiles which may respond to growth conditions differently based on the measured outcomes of total polyphenols and total antioxidant capacity.

Seeds were sown in 2025 April into 98-cell plug trays filled with a commercial peat-based growing medium (ProMix BX; Premier Tech; Quebec, CA) and grown in the CSU Plant Growth Facility greenhouse, where they were hand-watered as needed. The greenhouse was set to 70/65 °F (day/night). The photoperiod in the greenhouse was set to 16 hrs, with supplementary high pressure sodium lighting used when light levels fell below 300 W/m<sup>2</sup>.

Seedlings were transplanted to 3.25” pots that were filled with peat-based growing medium 3 wks after sowing dates. After 4 wks, small plants were transplanted into 0.75 gal containers and were moved to the appropriate treatment location. Containers in the greenhouse and under the shade structure were watered using one drip emitter per plant from a central dripline. The outdoor drip emitters provided each plant with 200 mL of water every day. The greenhouse drip emitters were calibrated to deliver 200 mL of water per plant daily at 10 AM. Fertilization occurred 7 d after transplant by a topdressing of 11 g of a 17N–6P<sub>2</sub>O<sub>5</sub>–12K<sub>2</sub>O controlled-release fertilizer was applied, providing 1.87 g N, 0.29 g P, and 1.10 g K per container (Harrells 17–6–12 Plus, 3- to 4-month formula; Harrell’s, Lakeland, FL).

### *Experimental Design*



**Figure 3.1.** Edible flowers were grown in the Summer of 2025 to compare cultivation environments outdoors and in a greenhouse. Four species (buzz buttons (*Acmella oleracea*), dahlia (*Dahlia xhybrida*), dianthus (*Dianthus chinensis*), and zinnia (*Zinnia elegans*) were grown in two location replicates for each cultivation treatment. Each location featured 12 block replicates, with each block containing one of each species. Shown above are Greenhouse Two (left) and Outdoor Two (right).

The experiment was conducted in both greenhouse and outdoor settings during the 2025 growing season, from June to September. Two concurrent replications were set up in each greenhouse and in the outdoor setting, for a total of 4 locations. Each location consisted of 12 blocks, each containing 1 replicate of each species as the experimental unit (Figure 3.1). Each container contained one plant. A randomized complete block design was used for the plot design.

### *Harvest and data collection*

Flowers were harvested every 7 d in the mornings throughout the growing season. Flowers of zinnias, dianthus, and dahlias were harvested when fully open and near peak bloom (Jadhav et al., 2023). The harvest point of buzz button is more difficult to pinpoint. As this species is a capitula, a dense cluster of many small flowers (Lee 2026), the inflorescence was considered harvestable when at least 70% of the flowers were open and the top florets were visible.

Harvested flower numbers were recorded by plant and then pooled for phytochemical analysis. Pooling was assigned groups 1-4, 5-8, and 9-12 for a total of 3 plants per pool for a harvest. Each pooled group was stored for phytochemical analysis at three points throughout the season to test for changes over time. Stored pooled samples were immediately stored in a walk-in cooler set to 4.4 °C until they were transported to an –80 °C freezer before analysis.

Plants were harvested at the end of the experiment at the media surface, and FW was recorded. The plants were placed in paper bags and dried in an oven at 70 °C, and DW recorded after 48 hrs.

### *Phytochemical Analysis*

After harvest, pooled flower samples were stored at -80 °C for a minimum of 48 hrs before lyophilization. Samples were then lyophilized (LabConco Freezone; Labconco, Kansas City, MO, USA) for 48 hrs to halt physiological activity (Maisl et al., 2023). Flower material

was homogenized and then extracted by utilizing methanol. Dried flower tissue (100 mg) was extracted in 3 mL of methanol, and antioxidant capacity and total phenolics were quantified from the extract and expressed on a DW basis. Total polyphenol content (TPC) was analyzed using the Folin-Ciocalteu assay (Singleton and Rossi 1965), with each sample measured in triplicate, and results were expressed as mg of gallic acid per g of flower material. The total antioxidant content (TAC) was analyzed using a 2,2-Diphenyl-1-picrylhydrazyl (DPPH) assay, with each sample measured in triplicate and results expressed as  $\mu\text{mol}$  of Trolox (TE) per g of flower material (Blois 1958).

### *Statistical Analysis*

Data were analyzed using R Studio (Posit Software, PBC, Boston, MA, USA). Games-Howell ANOVA tests and a Welch's post hoc analysis were used to account for unequal variances. We analyzed the effects of the cultivation environment (greenhouse vs. outdoors) and location (e.g., Greenhouse One vs. Greenhouse Two) on the total harvested flower count, final harvested flower biomass, vegetative fresh weight (FW), vegetative dry weight (DW), TPC, and TAC. Total harvested flower count was calculated by adding the weekly harvests of each plant during the study. Flower species were analyzed separately to allow for species-specific recommendations.

## **Results and Discussion**

### *Morphological effects of the growing environment during production*

#### ***PLANT BIOMASS***

After 14 weeks of growth, the FW and DW of buzz button and zinnia plants was significantly greater in outdoor cultivation locations compared to greenhouse environments

(Table 3.2). *Dianthus* exhibited location specific responses: Greenhouse-cultivated plants had lower biomass than both outdoor locations, but Greenhouse One did not differ significantly from Outdoor One. *Dahlia* biomass did not follow a consistent pattern, though one outdoor location produced larger plants than one greenhouse location.

**Table 3.2.** Four edible flower species (buzz button, dianthus, dahlia, and zinnia) were grown for 14 weeks in 2025 in two cultivation environments: inside a greenhouse and outdoors. The growing environments each had two location replicates. Flowers were harvested weekly, with counts recorded for each plant. Plants were destructively harvested at the end of the season. Average plant vegetative fresh weight, dry weight, and tuber dry weight were recorded. Welch's ANOVA with Games–Howell post hoc tests was used to compare locations. Compact letter displays denote significant differences across cultivation environment for each variable.

|                                                                       | Cultivation Environment |                       |                       |                        |
|-----------------------------------------------------------------------|-------------------------|-----------------------|-----------------------|------------------------|
|                                                                       | Outdoor                 |                       | Greenhouse            |                        |
|                                                                       | Rep 1                   | Rep 2                 | Rep 1                 | Rep 2                  |
| <b>Lemon Drop' Buzz Button (<i>Acmella oleracea</i>)</b>              |                         |                       |                       |                        |
| Vegetative Fresh Weight (g)                                           | 129.8 ± 30.3 <b>b</b>   | 138.2 ± 30.5 <b>b</b> | 91.7 ± 8.4 <b>a</b>   | 99.4 ± 13.2 <b>a</b>   |
| Vegetative Dry Weight (g)                                             | 18.5 ± 4.2 <b>b</b>     | 19.9 ± 2.8 <b>b</b>   | 19.0 ± 2.0 <b>a</b>   | 17.1 ± 5.7 <b>a</b>    |
| Harvested Flower Number                                               | 61.8 ± 13.1 <b>a</b>    | 59.4 ± 9.9 <b>a</b>   | 57.0 ± 9.6 <b>a</b>   | 46.9 ± 7.7 <b>a</b>    |
| <b>Figaro<sup>TM</sup> Red Shade' Dahlia (<i>Dahlia xhybrida</i>)</b> |                         |                       |                       |                        |
| Vegetative Fresh Weight (g)                                           | 131.6 ± 49.2 <b>ab</b>  | 159.8 ± 22.9 <b>b</b> | 94.1 ± 58.3 <b>a</b>  | 133.7 ± 41.1 <b>ab</b> |
| Vegetative Dry Weight (g)                                             | 19.2 ± 7.0 <b>ab</b>    | 23.5 ± 4.3 <b>b</b>   | 17.0 ± 6.5 <b>a</b>   | 21.9 ± 5.8 <b>ab</b>   |
| Tuber Biomass Dry Weight (g)                                          | 16.4 ± 8.7 <b>a</b>     | 15.4 ± 7.7 <b>a</b>   | 11.0 ± 8.1 <b>a</b>   | 13.9 ± 6.3 <b>a</b>    |
| Harvested Flower Number                                               | 78.3 ± 32.2 <b>a</b>    | 97.3 ± 23.3 <b>a</b>  | 65.5 ± 34.6 <b>a</b>  | 66 ± 34.1 <b>a</b>     |
| <b>Venti Parfait Crimson' Dianthus (<i>Dianthus chinensis</i>)</b>    |                         |                       |                       |                        |
| Vegetative Fresh Weight (g)                                           | 111.5 ± 26.4 <b>b</b>   | 122.6 ± 11.6 <b>b</b> | 78.1 ± 30.9 <b>a</b>  | 69.1 ± 20.4 <b>ab</b>  |
| Vegetative Dry Weight (g)                                             | 18.5 ± 4.2 <b>b</b>     | 19.9 ± 2.8 <b>b</b>   | 15.4 ± 5.4 <b>ab</b>  | 12.3 ± 3.6 <b>a</b>    |
| Harvested Flower Number                                               | 39.7 ± 9.9 <b>ac</b>    | 47.1 ± 9.3 <b>c</b>   | 35.6 ± 9.3 <b>a</b>   | 19.8 ± 7.6 <b>b</b>    |
| <b>Zesty<sup>TM</sup> Scarlet' Zinnia (<i>Zinnia elegans</i>)</b>     |                         |                       |                       |                        |
| Vegetative Fresh Weight (g)                                           | 77.0 ± 22.3 <b>b</b>    | 69 ± 26.1 <b>b</b>    | 131.4 ± 14.0 <b>a</b> | 117.8 ± 15.6 <b>a</b>  |
| Vegetative Dry Weight (g)                                             | 26.7 ± 2.8 <b>b</b>     | 24.8 ± 2.9 <b>b</b>   | 17.2 ± 3.4 <b>a</b>   | 13.1 ± 4.1 <b>a</b>    |
| Harvested Flower Number                                               | 48.8 ± 11.2 <b>a</b>    | 49.4 ± 10.4 <b>ab</b> | 45.8 ± 7.7 <b>a</b>   | 32.8 ± 7.7 <b>b</b>    |



**Figure 3.2.** Beneficial insects, including pollinators and predatory insects, were observed in the Outdoor treatment.

Pest pressure likely contributed to these differences in plant biomass. Outdoor plants experienced minimal insect damage and benefitted from natural predators (Figure 3.2), whereas greenhouse plants were subject to persistent thrips, fungus gnats, and fungal issues (Figure 3.3). Pest control was minimal in the greenhouse treatments, with only two pesticide applications and the use of sticky traps, similar to that observed in previously observed edible flower production. Greenhouse systems are known to be vulnerable to pest outbreaks, also reported in another reviews, Pires et al. (2023), which noted the need for government-approved pesticides for edible flower crops.



**Figure 3.3.** Presence of thrips (Thysanoptera) damage on dianthus plants in the Greenhouse Two treatment.

The final biomass data recorded in this study were the dahlia tuberous root biomass. Dahlia tubers can serve as propagation material for future crop production and as nutritious food products high in Vitamin C and fiber (Costa et al., 2022). Dahlia tuber dry weight did not differ between environments, indicating that the production system did not influence storage organ development. This result differs from the findings of Brondum and Heins (1993), where tuber weight decreased with increasing temperatures, but the observed temperature differences between the treatments may not have been sufficient to detect a significant difference in biomass.

### ***FLOWER YIELDS***

Weekly flower harvests included the flower count and fresh flower biomass, both recorded for each plant. Dry weight was not taken as most of the collected flowers were used in

the phytochemical analyses. Most recorded edible flower sales (63%) are estimated to be on a fresh-weight basis (Mordor Intelligence 2026), so this value reflects how the market would likely sell them. When looking at the average number of flowers collected, neither buzz buttons nor dahlias showed significant differences across growing environments (Table 3.2). Dianthus and zinnia plants did not differ between the Outdoor treatments and Greenhouse One, but the season flower biomass yields were significantly lower in Greenhouse Two. The Greenhouse Two location was in proximity to the evaporative cooling pads and had higher fungal and thrip pressure, which may explain this difference.

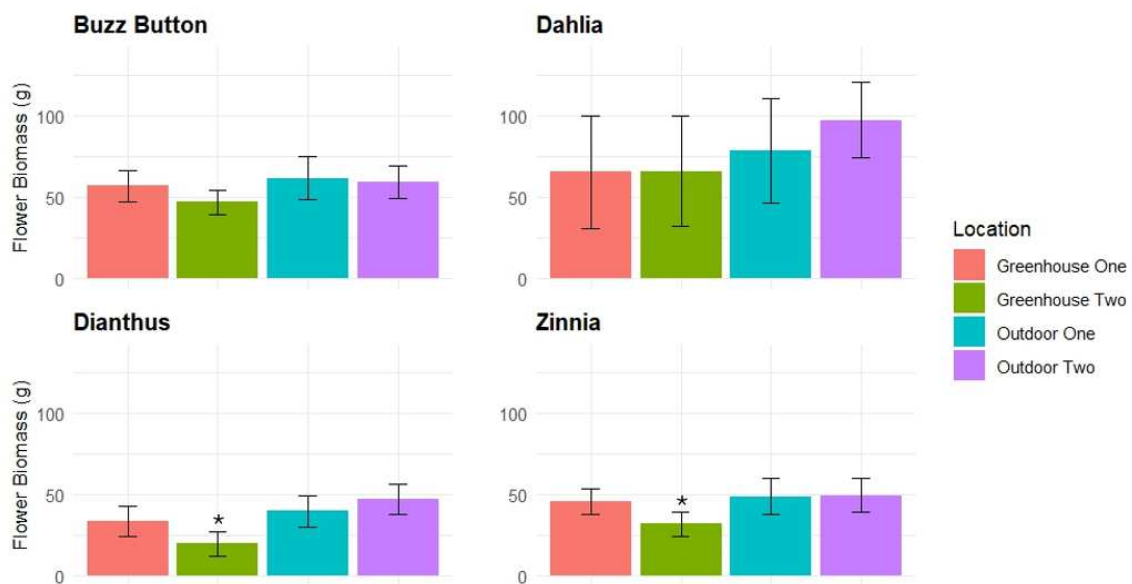


**Figure 3.4.** Average final harvested flower biomass. Edible flowers were grown from June to September (14 wks) to compare cultivation environments outdoors and in a greenhouse. Four species (buzz buttons (*Acmella oleracea*), dahlia (*Dahlia xhybrida*), dianthus (*Dianthus chinensis*), and zinnia (*Zinnia elegans*) were grown in two location replicates for each cultivation treatment (greenhouse or outdoor). Flowers were harvested weekly, and biomass was recorded

for each plant throughout the season. Location treatments with significance from other treatments were indicated by a star (\*).

The final flower harvest biomass yields followed similar trends to the flower counts. Buzz button and dahlia yields did not differ significantly among growing environments (Figure 3.4). Dianthus treatment Outdoor One did not differ significantly between Greenhouse One and Outdoor Two ( $p=0.406$ ;  $0.264$ ). Zinnia plants grown in the Outdoor treatments were not significantly different from Greenhouse One ( $p=0.884$ ;  $p=0.796$ ). The presence of at least one Outdoor and Greenhouse treatment that does not show a statistical difference indicates that greenhouse production is a viable means of achieving flower yields and may offer potential for season extension and year-round production.



**Figure 3.5.** Observed image of thrips (Thysanoptera) damage on edible zinnia flowers. The thrips-damaged flower (right) shows stippling and stunted growth compared to the healthy flower (left).

The final edible-flower product form may, however, influence the production method. Pest damage from insects such as thrips can ruin the aesthetic appeal of the flowers due to

stippling (petal color peeling) and flower stunting (Figure 3.5). For fresh-flower products, stippling may render the flowers below marketable quality. If selling dried or as a powder, pest damage may be less of a concern. In a similar field, such as herbs, the quality of dried products is defined by phytochemical and sensory attributes rather than by visual appearance (Al-Hamdani et al., 2022).

### ***Physiological effects of the growing environment during production***

TPC was measured by the Folin-Ciocalteu assay using gallic acid as the standard, and the results were expressed as gallic acid equivalents (GAE). When comparing the four treatment locations, no significant differences were found among treatments for any species. Dahlia flowers had the highest polyphenol levels, with an average range of  $71.21 \pm 18.02$  GAE mg per g of dry dahlia material (Table 3.3). A previous study by Costa et al. (2022) reported the flower phenolic content as 111.99 mg per 100 g of fresh material using high-performance liquid chromatography. Other studies evaluating dahlia species using the Folin-Ciocalteu method for GAE are not currently available, so our work provides a starting point for understanding TPC levels. Extraction methods and flower color also play a role in TPC, with red flowers measuring lower than purple ones (Costa et al., 2022).

Polyphenols and other antioxidants are phytochemicals that contribute to plant secondary defenses. One case relevant to this study is the connection between phytochemicals in response to pest predation. Polyphenols, such as tannins, produce bitter tastes that act insect herbivory deterrents (War et al., 2012). Another area of secondary defense is in response to climatic conditions. Plants growing outdoors experience different stresses than those grown in a greenhouse, outdoor plants may have higher UV light exposure and more extreme temperature

fluctuations. As consumers, we can benefit from these stress conditions, as they lead to higher levels of phytochemicals, which make them better for human nutrition.

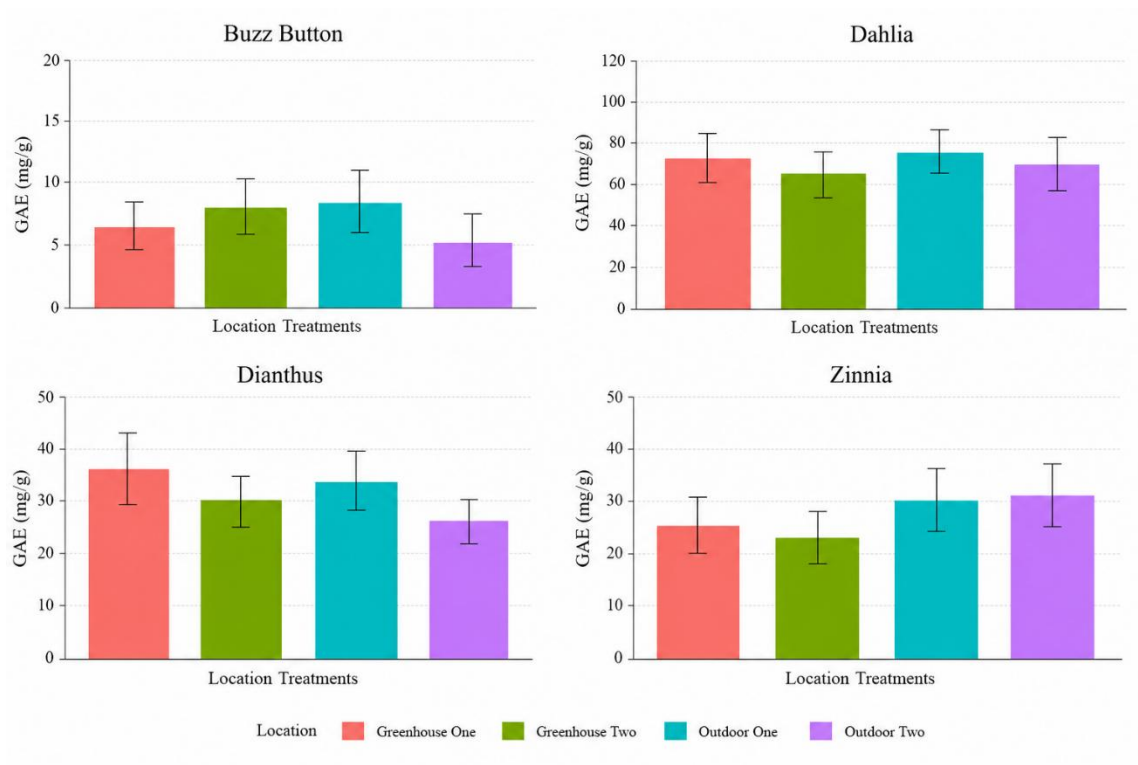


**Figure 3.6.** Four edible flower species were grown for 14 weeks in 2025 in two cultivation environments, inside a greenhouse and outdoors. The cultivation environments each had two location replicates. Flowers were harvested throughout the season, and extracts were made from the edible portions. Total polyphenol content (Folin-Ciocalteu assay) was analyzed. Welch's ANOVA with Games–Howell post hoc tests was used to compare locations. Compact letter displays (CLDs) denote significant differences between table rows that are independent of one another.

Dianthus had the next-highest polyphenol levels,  $31.06 \pm 8.10$  GAE  $\text{mg} \cdot \text{g}^{-1}$ . The TPC in *Dianthus* varies among species, and a study by Stefaniak and Grzeszczuk (DATE) found that *Dianthus chinensis* flowers produced  $12.26$  GAE  $\text{mg} \cdot \text{g}^{-1}$  of fresh weight. Given that edible

flowers are, on average, 70-90% water (Jadhav et al., 2023), this value is close to the observed range in this study. Zinnia was next highest with a range of  $26.35 \pm 7.77$  GAE  $\text{mg}\cdot\text{g}^{-1}$ . Previous studies on *Zinnia elegans* have reported the presence of phenolic-rich methanolic extracts and fractions; however, total phenolic content values, expressed as GAE, are primarily reported on a per-fraction or per-extract basis rather than standardized to whole-flower dry weight making the data observed hard to compare across studies (Burlec 2019 et al., 2019). The lowest polyphenol levels were observed in buzz button inflorescences,  $6.63 \pm 3.51$  GAE  $\text{mg}\cdot\text{g}^{-1}$ . Lower phenolic levels in *Acmella* species have previously been attributed to metabolic allocation toward spilanthol production, with flowers having lower TPC than leaves, 5.34 GAE  $\text{mg}\cdot\text{g}^{-1}$  and 7.59 GAE  $\text{mg}\cdot\text{g}^{-1}$ , respectively (Abeyasinghe et al., 2013).

Trolox was used as our standard, and flower TAC was expressed in Trolox equivalents (TE). Across treatments, there was no statistically significant difference between the buzz button ( $p=0.68$ ), dahlia ( $p=0.72$ ), or dianthus plants ( $p=0.38$ ). Zinnia plants grown in Outdoor One had statistically lower antioxidant content than those in Greenhouse Two ( $p=0.02$ ), but zinnia in the Outdoor Two treatment did not differ statistically in TAC from plants in Greenhouse One

and Two.

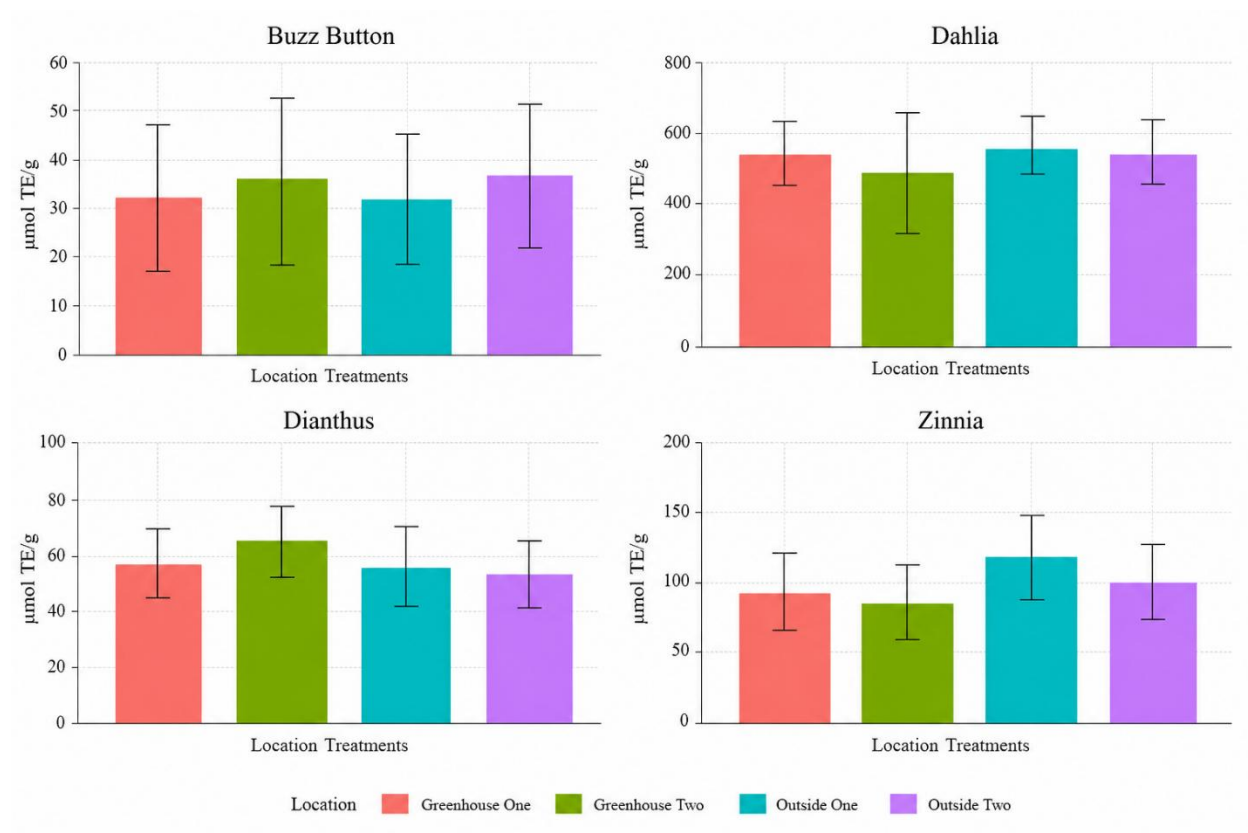


**Figure 3.7.** Four edible flower species were grown for 14 weeks in 2025 in two cultivation environments, inside a greenhouse and outdoors. The cultivation environments each had two location replicates. Flowers were harvested throughout the season, and extracts were made from the edible portions. Total antioxidant content (DPPH assay) were analyzed. Welch’s ANOVA with Games–Howell post hoc tests was used to compare locations. Compact letter displays (CLDs) denote significant differences between table rows that are independent of one another.

Dahlia flowers had the highest antioxidant levels with an average  $544.54 \pm 99.15 \mu\text{mol TE per gram of dry material}$ . Petrova et al., (2020) observed higher levels for decorative dahlias levels at  $3.74 \text{ mmol TEg}^{-1} \text{ FW}$  and  $77.19 \text{ mmol TE} \cdot \text{g}^{-1} \text{ extracted DW}$ . Zinnia plants had the next-highest TAC, with an average  $98.87 \pm 26.73 \mu\text{mol TE} \cdot \text{g}^{-1} \text{ DW}$ . Although antioxidant capacity is

commonly quantified using assays such as ABTS), no published studies to date report TE-expressed antioxidant values for zinnia species. Existing phytochemical analyses confirm the presence of phenolic acids and flavonoid glycosides in *Zinnia elegans*, but antioxidant capacity has not been quantified using TE-based assays. Dianthus was the next lowest, at  $58.15 \pm 12.28 \mu\text{mol TE} \cdot \text{g}^{-1}$ . This was higher than the observed values of  $28.91 \text{ mM TE} \cdot \text{g}^{-1} \text{ DW}$  in garden pink (*Dianthus plumaris*) (Petrova et al., 2020). The buzz button was at its lowest again in the TAC with  $34.21 \pm 13.58 \mu\text{mol TE} \cdot \text{g}^{-1}$ . This is higher than the recorded values of  $10.75 \mu\text{mol TE} \cdot \text{g}^{-1}$  (Weintraub et al., 2020) and  $3.42 \mu\text{mol TE} \cdot \text{g}^{-1}$  (Abeyasinghe et al., 2013), but differences in extraction method or cultivar may have contributed to the higher values observed in this study.

While comparing with previous findings on flowers is helpful, using a widely known antioxidant-rich berry provides perspective. Blueberry (*Vaccinium* spp.) for example, typically containing between 200–600 mg (GAE) per 100 g fresh weight and approximately 20–60  $\mu\text{mol TE}$  per g dry weight (Stevenson and Scallzo 2012). In addition to the species in this study, many edible flower species, including pansies and snapdragons (*Antirrhinum majus*), have been reported to exceed 100 mg GAE  $\cdot \text{g}^{-1}$  dry weight (Bao et al., 2018; González-Barrio et al., 2018). Edible flowers can serve as concentrated sources of bioactive compounds, with TPC and antioxidant capacities comparable to or exceeding those of blueberries when expressed on a dry-weight basis but the serving size is a limiting factor. While there are no existing suggested serving sizes for flowers, recipes often use one to two flowers per dish serving. The average dahlia flower weight of our study was 3.87 g per flower whereas the average dianthus flower weight of our study was 0.44 g per flower. For this reason, it should be acknowledged that while edible flowers are a good antioxidant and polyphenol source that limited gram consumption differentiates it from other sources like blueberries.

The final point of interest in the TPC and TAC for our study was whether there was a shift in the content levels over the cultivation season. Flower material was collected at two or three points over the season to determine whether phytochemical levels changed over time, especially considering harvesting of flowers and whether growers would need to consider implementing succession plantings. No significant changes in content levels occurred across the season (data set not shown) for any of the species grown. One provided example is Block 3 in the dianthus Outdoor Two treatment. The sample from 1 July had a TPC level of  $33.9 \text{ mg} \cdot \text{g}^{-1}$ , 31.5 in the 16 July sample, and 35.7 in the 3 September sample. The same samples had TAC levels of 56.2, 67.6, and  $63.2 \text{ } \mu\text{mol TE} \cdot \text{g}^{-1}$  for the sample dates. Consistency in phytochemicals across the season is better for producers, as they can produce consistent flowers throughout the growing season.

The TPC and TAC data observed in our study contribute to the growing body of work on the phytochemical profiles of these edible flower species. The nonsignificant impact of location treatments on phytochemical content is important, as growers do not need to worry about sacrificing it if they were to grow these species in a greenhouse.

## **Conclusions**

The edible flower market is expected to expand in the next several years, necessitating increased production. Fresh product fragility, which leads to a limited shelf life, makes understanding practices for local year-round production vital. Currently, the industry lacks information on cultivation practices for edible applications, as the priority for plant tissue allocation differs: more flowers and less stem than in the cut flower industry. This study sought

to address the knowledge gap by comparing greenhouse and outdoor production to assess impacts on flower yields and the phytochemical content of harvested flowers. Except for final plant biomass in zinnia and buzz button plants, there were no observed statistical differences between cultivation environments for flower counts, flower biomass yields, or the phytochemical content of the sampled flowers. The phytochemical content of the species in this study was within range and higher than in previous studies for their production. The lack of significant differences between these data shows that, at a minimum, these edible flower species may be grown in a greenhouse without affecting yield or phytochemical content. Further work will be needed to demonstrate the potential for season extension and year-round greenhouse production. Some unique challenges should be accounted for in production, especially in greenhouses, as this environment is favorable to pests. IPM practices that focus on cultural and biological controls should be implemented to address the lack of federally approved edible-flower pesticides. Organic sprays such as neem oil and insecticidal soap may be used, but as a contact agent, they are likely less effective. Overall, greenhouses are a suitable way to provide consumers with locally grown edible flowers.

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## CHAPTER 4. USING VIRTUAL REALITY FOR MIST SYSTEM IRRIGATION DESIGN CONCEPTS IN A PLANT PROPAGATION COURSE<sup>2</sup>

### **Abstract**

The growing acceptance of online degrees has expanded program offerings, yet online learners often lack hands-on resources for courses that include laboratory activities. Virtual reality (VR) applications are tools that can bridge this gap. Prior horticulture research has evaluated VR for understanding greenhouse spaces, but little is known about using VR to support design-based decision-making. This study evaluated whether non-immersive VR materials enhance online student engagement and comprehension during a mist system design assignment in an undergraduate plant propagation course. Students viewed mist system designs using two media types: first using static images and second, with annotated 360° VR images. After each media type, students completed quizzes on key concepts and provided feedback on their experience. The media type did not affect comprehension scores even though 62% of students self-reported that VR images improved their understanding of the material. One insightful feedback comment shared that static images help with detail, but VR images helped with gaining perspective, which is important in a design assignment. Students expressed interest in expanded and higher-quality VR integration, as well as access to multiple media formats rather than reliance on a single source. These findings suggest that VR can increase perceived

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accessibility of course content and warrant continued development as educational technologies evolve.

## **Introduction**

Virtual reality (VR) is a digitally simulated environment that enables users to interact with three-dimensional content at varying levels of immersion—non-, semi-, and fully immersive formats (Espinoza Castro et al., 2025). VR environments can evoke a sense of presence and embodiment and allow learners to gesture, manipulate objects, and engage spatially with content (Johnson-Glenburg, 2018). While not considered a form of virtual reality, augmented reality (AR) can be another method for environment simulation. AR overlays digital elements onto real-world settings. Both VR and AR share the potential to enhance experiential learning. VR systems are accessible through a range of devices, including portable units, monitors, and head-mounted displays (Anastasiou et al., 2023).

VR technology integration into educational settings has accelerated, with improved affordability and accessibility (Cook et al., 2019; Freina and Ott, 2015). VR materials may require substantial initial development, but once they are created, they can be easily shared and reused across courses and institutions (Bailensen et al., 2008). Educational VR applications span interactive scenarios, training modules, and game-based learning. In recent years, VR use has expanded across various academic subject areas (Lamb and Etopio 2019). Early implementations centered on educational games with 3D environments, but contemporary approaches emphasize immersive and realistic, and fluid learning experiences (Krajčovič et al., 2021; Lamb and Etopio, 2019). VR supports open-ended exploration and can improve retention of course material (Tandon et al., 2024). Its use has broadened into libraries, field trips, and other experiential learning contexts (Cook et al., 2019; Rojas-Alfaro, 2023; Bailensen et al., 2008; Dede, 2009).

VR has demonstrated benefits for student comprehension and engagement across disciplines. Exposure to VR simulations can improve students' ability to write in discipline-specific styles (Lamb et al., 2019), enhance self-efficacy during spatial analytic tasks (Lischer-Katz et al., 2018), and increase understanding of abstract concepts when learners actively manipulate content (Johnson-Glenburg, 2018). When paired with traditional instruction, VR can strengthen cognitive recall and learning experiences (Carruth et al., 2020). These advantages are especially relevant in fields where depth, scale, and spatial reasoning are central to design-based learning (Cook et al., 2019).

Online education has expanded substantially in university settings (Gleason and Greenhow, 2017). In 2023, 53% of postsecondary students were enrolled in at least one online course, compared to 35% in 2019 (USDE, 2023). For example, at Colorado State University (CSU; Fort Collins, CO, USA), the Horticulture and Landscape Architecture Department (HLA) has experienced significant growth and expansion in online student enrollment especially in the Horticulture Business degree program (CSU Institutional Research, Planning, and Effectiveness).

As online enrollments increase, instructors are challenged to adapt laboratory-based and hands-on courses to ensure equitable access for remote learners. Following the COVID-19 pandemic, further technology integration and use is expected and adaptable learning models are becoming necessary to meet student needs and expectations (Imran et al. 2023). Agriculture disciplines, including horticulture and plant science programs, face unique challenges in this regard.

Although VR and AR applications for greenhouse and horticulture education are emerging, the field remains in its early stages. Carruth et al. (2020) demonstrated potential AR greenhouse applications to address students' limited access for training in controlled

environment agriculture (CEA) systems but did not assess user experiences. In that study, an example was provided of how AR systems can be used to provide job training in spaces with sensitive plant material and minimal risk to the CEA setup but did not survey student experiences. Kim et al. (2024) developed a horticulture therapy VR simulation that allowed users to water plants, remove pests, and manipulate greenhouse environmental conditions like temperature, lighting, humidity, etc. resulting in increased participant physiological stability and a sense of accomplishment. Gamified AR greenhouse environments have been shown to increase student excitement and immersion (Raman et al., 2021). Additionally, instructors at Texas Tech University (Lubbock, TX, USA) developed and have integrated the iVisit program to provide guided virtual greenhouse tours for online students (iVisit, n.d.). Despite these developments, opportunities remain to integrate VR into horticulture curricula and evaluate its impact on student learning, particularly for online learners.

HORT 260 Plant Propagation is a core curriculum course at CSU, required for all horticulture majors and minors. The four-credit course is taught in-person and online in both spring and fall semesters. There is an accompanying weekly laboratory component for both modalities with the in-person section participating in a guided 2 h sessions and the online section able to perform the lab component at their own pace within their weekly timeframes. The average enrollment is 45 to 60 students each semester for the in-person section and 40 students for the online section. One unit in HORT 260 focuses on the propagation environment and mist system unit. In that unit, in-person and online students complete an assignment in which they design an intermittent mist system using lecture materials and information from a preliminary assignment. In this preliminary assignment, online students viewed a video guiding them through mist system components and indicate they watched the video by submitting the word

“completed”. Based on previous end-of-the-semester evaluations, students described frustrations or challenges with the design assignment; namely, expectations of understanding, using only a video, and lacking the in-person opportunity.

Given the potential of VR to enhance spatial understanding and engagement, we identified an opportunity to incorporate annotated 360° VR images into this assignment. The objective of this study was to evaluate student learning and experiences using annotated 360° VR images of the mist systems and system components compared to static images for the online section of the course. We hypothesized that the VR media would improve student comprehension of mist system design concepts and influence their perception of readiness to complete the design assignment. The results of this study will help to inform instructor decision making for future inclusion of VR materials in horticulture courses.

## **Materials and Methods**

The research was conducted by altering the instructional video format previously used in the original mist system assignment. The newly designed assignment was administered in two parts, Part A and Part B. Both were administered at the same time with the same due date through the course learning management system (Canvas; Instructure, Salt Lake City, UT, USA). For Part A, students were provided with a digital slide set (PowerPoint™; Microsoft Corporation, Redmond, WA, USA) depicting annotated static images of different mist system parts and mist systems operating with different mist nozzle types. After reviewing the slide set, students completed a multiple-choice quiz on Canvas, to assess their conceptual understanding on the output of the three mist nozzles.

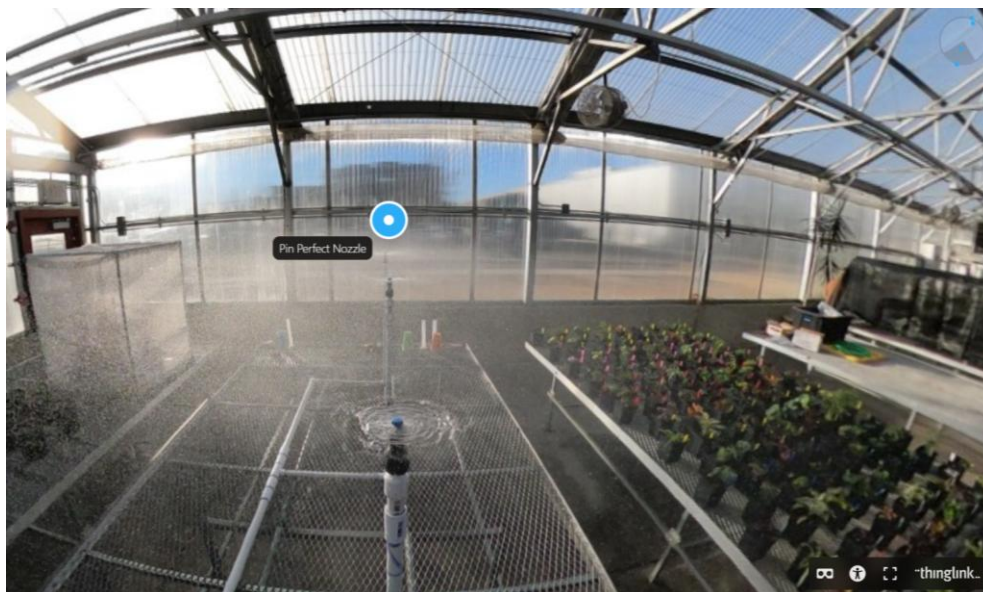


**Figure 4.1.** A screen capture of a 360° image and a tag in the ThingLink platform (Thinglink, Palo Alto, CA, USA) used for Part B. The central icon demonstrates the annotation feature in which hovering over the icon reveals the tag “Pin Perfect Nozzle”.

For Part B, students were provided with a link to the online VR software platform (Thinglink, Palo Alto, CA, USA), where they were required to view VR 360° images (Figure 4.1) of the same mist system components and the same mist systems running with various nozzle heads that were presented in Part A. The images within the Thinglink platform places students on a central point from which they can pivot around and view what is around them. The mist system component images with each part of the system around them were annotated. The active mist systems images were labeled with nozzle types and riser heights. Students were not provided with any instructions or training before using the software. After students engaged in the VR activity, a second quiz, comprised of the same questions as Part A, was administered. Additional questions were also included in Part B, which solicited student feedback on the media forms and asked about their general experience(s) with VR. Students received all assignment points if they

fully completed the quizzes disregarding their accuracy. However, quiz answers were graded internally for accuracy and for purposes of this research. The study was conducted in the third week of the Spring and Fall 2024 semesters. This study was reviewed and approved by the CSU Institutional Review Board #5385.

Student assessment surveys (Parts A and B) contained 5 multiple-choice paired questions that were asked in both. In two additional questions that were in both surveys, students were asked to self-evaluate their comprehension by selecting “Yes” or “No” for the following statements: “I can visualize why head-to-head nozzle spacing is important.” and “I could use the photos of the nozzles running to help me design my own mist system.”

The Part B quiz contained additional questions to compare the different media. The first question of this section asked to evaluate the media for their comprehension by selecting “Yes” or “No”: “I could use the virtual reality of the nozzles running to help me design my own mist system.” Two questions asked students to directly compare the media provided for the quizzes: “Which viewing system was easier for you to visualize the mist system design pieces?” and “Which viewing system was easier for you to visualize how the mist nozzles were spraying water?” Two “Yes” or “No” questions asked students about their experiences with VR: “Have you had previous experience using VR in your classes?” and “Would you like more VR to be integrated into your courses?” The final question was an open-ended, free-response question to gather general feedback: “Do you have any feedback for this assignment? Put N/A if you do not want to say anything.”

Student responses were anonymized, utilizing the Canvas code generation program. This program provides a unique code for each student, which is provided when quiz responses are downloaded from the course site. Quiz A results and Quiz B results were compared using

McNemar's test ( $p \leq 0.05$ ) using R-Studio (Posit Software; PBC, Boston, MA, USA) to show whether the types of assignment media form were significant. Welch's t test was performed to analyze if differences were observed between our semesters, and when no significance was found the results between semesters was pooled.

## Results and Discussion

### PAIRED QUESTIONS

The enrollment for the Fall 2023 and Spring 2024 online sections was 42 and 11, respectively, with 40 and 7 students completing the assignment, for a total of 47 responses used in this study.

Table 4.1. Post-activity self-assessment quizzes were used to evaluate the impact of media type (static vs. VR 360 images) on student comprehension of propagation mist system concepts for the HORT 260 Plant Propagation course at CSU. Students received a quiz after interacting with each of the media types. Five questions appeared in both quizzes, and student answers were analyzed for media influence on accuracy by performing McNemar's Test.<sup>i</sup>

| Paired Quiz Questions                                                                                                          | Answer Accuracy       |                   | P Value |
|--------------------------------------------------------------------------------------------------------------------------------|-----------------------|-------------------|---------|
|                                                                                                                                | Part A: Static Images | Part B: VR Images |         |
| Q1. Which rise height had a larger spray radius?                                                                               | 93.6                  | 91.5              | 1       |
| Q2. Which nozzle type produces the most GPM (gallons per minute)?                                                              | 59.6                  | 61.7              | 1       |
| Q3. Which nozzle type would be most influenced by greenhouse airflow (evaporative cooling system or horizontal air flow fans)? | 42.6                  | 31.9              | 0.18    |
| Q4. Which nozzle has a larger water droplet size?                                                                              | 68.1                  | 70.2              | 1       |
| Q5. Which nozzle has the smallest radius of mist, aka mist remains closest to the riser?                                       | 42.6                  | 40.4              | 1       |

<sup>i</sup>The activity was implemented for 2 semesters (Spring and Fall 2024). Data were analyzed and no significant difference was observed between semesters; therefore, the data were pooled (n=47).

For the five paired questions on the quizzes for Part A (static images) and Part B (VR images), we did not observe an increase in accuracy or understanding between the two media (Table 4.1). We observed a decrease in accuracy (10.7%) for Question 3 however it was not statistically significant ( $p = 0.18$ ). In our personal observation, the lighting and visibility of the mist sprays in the VR images may have been the cause for the decrease which indicates an opportunity for activity improvements.

### *MIST SYSTEM CONCEPT VISUALIZATIONS*

**Table 4.2.** Post-activity self-assessment quizzes were used to evaluate the impact of media type (static vs. VR 360 images) on student comprehension of propagation mist system concepts for the HORT 260 Plant Propagation course at CSU. Additional questions outside of the 5 paired questions were asked in the Part B quiz to assess student preferences and feedback.<sup>i</sup>

| Part B Questions                                                                                    | Responses      |            |
|-----------------------------------------------------------------------------------------------------|----------------|------------|
| <b>Q8.</b> Which viewing system was easier for you to visualize the mist system design pieces?      | Static (36.2%) | VR (63.8%) |
| <b>Q9.</b> Which viewing system was easier for you to visualize how the mist nozzles were spraying? | Static (38.3%) | VR (61.7%) |
| <b>Q10.</b> Have you had VR experience in the classroom?                                            | Yes (42.6%)    | No (57.4%) |
| <b>Q11.</b> Would you like more VR to be integrated into your courses?                              | Yes (80.9%)    | No (19.1%) |

<sup>i</sup>The activity was implemented for 2 semesters (Spring and Fall 2024). Data were analyzed and no significant difference was observed between semesters; therefore, the data were pooled ( $n=47$ ).

Students were asked which system they thought was better for visualizing important course concepts. They were separated into two questions (Questions 8 and 9) based on how they

related to the course. The ability to visualize design pieces is important for understanding what goes into a design, while the ability to visualize how the nozzle was spraying was important for understanding how different designs affect the system's effectiveness. Results for the two questions were similar in terms of the outcome, as VR material was better for visualization despite not having a statistical impact on scores (Table 4.2). Most students indicated they thought the VR 360 images provided easier visualization of the mist system design pieces (63.8%) and the nozzles spraying water (61.7%). In a study by Lischer-Katz et al. (2018), it was observed that spatial analysis abilities can statistically improve when VR material is utilized in an anthropology course, but these results can be course and activity dependent as they did not observe any improvement in the observed chemistry course. This study combined with the results we observed showcase that the effectiveness of the VR activity may only as good as how the activity is designed.

#### *VIRTUAL REALITY EXPERIENCE AND INTEREST*

Of the students who participated, 42.6% had previously experienced VR use in the classroom (Table 2). One student in the Fall 2024 semester shared feedback that they experienced VR in the greenhouse management course taught at CSU (Craver et al. 2023); *"We utilized ThingLink for our labs and other assignments, and it proved to be extremely beneficial. The virtual platform provided a remarkable experience by offering various views and angles, enhancing the learning process. Combined with Echo360, it enhances my engagement in the course, providing a more immersive and dare I say fun learning experience."*

Of the students who participated, 80.9% indicated that they would like more VR experiences in the classroom (Table 4.2). The students who did not want more VR expressed through the open response question, an apprehension of technology costs, particularly if the

added cost was for VR goggles. While VR technology options are becoming more accessible and more cost effective, the reality is true there may be added costs for the students, especially with more advanced and technical VR methods. Students in the manual therapy field shared similar concerns of cost being a barrier to adoption (Sampath et al., 2023). This trend highlights the importance of utilizing programs where the associated cost is with the instructor or institution and not the students. ThingLink did not require students to create an account or any special tools, so it can serve well for this purpose. VR imaging or digital twin creation through spatial mapping devices (e.g., Matterport, Sunnyvale, CA, USA) can also work well. Additionally, the use of browser-based virtual environments and 360° imagery can further reduce student costs by eliminating the need for specialized hardware (e.g., VR headsets) and paid software licenses, which have been identified as key barriers to adoption in immersive learning environments (Radianti et al., 2020).

### *COMMON FEEDBACK THEMES*

We observed some common themes in the free-response question in the Part B assignment. The first theme was that students would like the VR images to be videos. The 360° images only captured one point in time, so the opportunity to navigate while the system was running was intriguing to them.

A second identified theme centered around the images. Students felt that image quality was an issue, in that, some photos appeared blurry and there were lighting issues. Due to time constraints, some of the systems were captured at different times of day, resulting in different light levels and angles, which led to perception of blurry photos, along with general challenge of visualization of the active mist system. Students expressed that they preferred the images captured at “golden hour” when mist droplets were more visible. Another way to ensure more

accurate depictions, would be altering the coloring or contrast in the images prior to uploading them. Students also thought images capturing multiple angles would be helpful. The camera positioning was set above the running mist nozzles. They felt that images and videos below the system and level with the system would be helpful. This feedback would require careful planning to execute, as cameras below the system or in the path of the system would be exposed to water. Utilizing a waterproof camera would assist with this, but care should be taken to avoid accumulation of the mist droplets blocking the camera lens.

Students also expressed appreciation that the Thinglink images were tagged with details of the mist systems. We chose to incorporate a select number of tags to avoid overwhelming students, but they expressed that they would be open additional tags. The final and most important theme is that students wanted all forms of media. Some students shared that they felt they were able to understand different concepts better from using both media types. One student shared the feedback: *“I liked the static photos for detail as this helped me understand the different nozzle types and spray radius. The VR gave me perspective on the practical use and how they are oriented within a greenhouse or propagation setting, especially with nozzle spacing.”* This insight tells us that how students interact with virtual material may be influenced by the students’ learning styles, i.e., visual, auditory, and kinesthetic (VAK). Students in a plant identification course who self-identified as visual learners, found the virtual plant walk resource very useful (Wilson et al. 2017). Psychology students who participated in a study by Tautz et al. (2021) shared a variety of experiences with their provided online tools but ultimately ranked online lectures higher while using the other digital tools like the VR material as lecture enrichment. These examples demonstrate that VR tools should be used as supplements or extra tools rather than a replacement for traditional media and student use will vary.

## *ACTIVITY IMPROVEMENT*

There are several considerations to improve the course activity. First, all imaging should occur at once to ensure consistent image quality. The ideal time to capture images of activated mist systems would be during “golden hour” or overcast lighting. Image capturing should also include multiple angles so students can observe from different perspectives. Videos should also include the very beginning of the mist system activation for each of the nozzles. If a VR video is not achievable, utilizing spatial mapping devices (e.g., MatterPort) in which the videos can be, embedded in a tag would be beneficial. Image tags should be used readily and include any components that are important to the course concept or the mist system design. However, over tagging could be overwhelming, so instructors should use them sparingly to avoid observed information overload in VR settings and increase student comprehension (McNamara et al. 2019). Additionally, to increase student engagement, the instructor could provide partial annotations and active learning prompts within and also by tasking the students to create their own tags and videos, to demonstrate the content knowledge.

## **Conclusions**

Online instruction is an educational modality on the rise due to its increased flexibility, acceptance, and accessibility, especially after the COVID-19 pandemic. A challenge for online courses is making them more personal and providing experiential learning opportunities, like in-person settings. Between 2000 and 2021, 50% of published VR studies related to agriculture industries were focused on VR use for educational purposes (Anastasiou et al., 2023), but little has been published on integration into horticultural courses. Our study looked to test a possible way that VR technology can be integrated into a horticultural plant propagation course.

In our study, student quiz scores comparing use of static images and VR 360 images on mist system design concepts, were not statistically different. However, students shared that the VR images were easier for visualizing the mist system components and the mist nozzles spray patterns. Most students wanted more VR in the classroom and also shared their thoughts on ways that the media could be improved. These suggestions are important to further improve and develop relevant and effective course curriculum. By incorporating VR as an additional tool into horticultural courses, we can provide students with additional study tools and better connect with online students.

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## APPENDIX ONE. EVALUATION OF INTERCROPPING ZUCCHINI AND MARIGOLDS: THE IMPACTS ON PHYTOCHEMICALS AND SENSORY PERCEPTION

### **Abstract**

Companion planting and intercropping are emerging cultivation practices due to their association with sustainability and pest management practices. Companion plants are often not a commodity, so exploring edible flowers as an intercrop rather than just a companion crop can provide another revenue stream for farmers. This study explored whether intercropping a known fragrant edible flower, marigold (*Tagetes patula*), influenced the flavor profiles of zucchini (*Cucurbita pepo*), and phytochemical content (antioxidants and polyphenols) of the marigold flowers. Utilizing a sensory tetrad test, this research illustrated that participants could distinguish intercropped produce from those grown in monocultures. Crops grown in monoculture maintained their traditionally associated flavors. Zucchini grown intercropped were lighter in taste and more sour rather than sweet. Intercropped marigolds were noted to have lighter, herbal flavors. None of the impacts on crop flavor notes were perceived as negative, indicating that intercropping vegetables with edible flowers may be a viable way to grow produce. Methanolic extracts of marigold petals exhibited total antioxidant capacity values ranging from 450 to 550  $\mu\text{mol}$  Trolox equivalents (TE)  $\text{g}^{-1}$  DW and total phenolic content ranging from 67–74 mg gallic acid equivalents (GAE)  $\text{g}^{-1}$  DW with no significant effect from the cultivation method. Intercropping with edible flowers, such as marigolds, offers a promising way to generate additional income in a growing market.

### **Introduction**

Intercropping, growing two or more crop species together, is a popular sustainable cultivation practice. Intercropping crops can have benefits such as reducing pest prevalence, increasing pest predation by recruiting beneficial predators, and attracting pollinators to our crops (Mallinger et al., 2019). This cultivation method is considered more sustainable and affordable than monoculture, the most labor- and resource-intensive form of crop production globally (Mir et al., 2022). New intercropping relationships are being proposed regularly, with marigolds often selected for observed companion plant benefits to zucchini and tomatoes (Chadfield et al., 2022), Intercropping with edible flowers may increase market diversity and market opportunities for local agriculture.

The edible flower market is fast-growing with a projected compound annual growth rate of 4 to 6% over the next several years (Singh 2025; Verified Market Research 2025). The market includes crops such as several herbs, lavender (*Lavandula* spp.), and other popular flowers, including violas (*Viola* spp.), marigolds (*Tagetes* spp.), and dahlias (*Dahlia* spp.). The previously mentioned flower species are more often grown for ornamental purposes (Benvenuti and Mazzoncini, 2021). Marigolds are among the most commonly sold edible flower species in the United States (Lee and Miller, 2026). Most growers who produce edible flowers use them to supplement their income and cultivate vegetables as their primary crops (Fernandes et al., 2019; Lee and Miller, 2026). However, intercropping edible flowers to improve both vegetable and edible flower cultivation for sustainability and profitability has been minimally explored. This intercropping approach can provide many benefits, making it an attractive option for farmers looking to enhance their practices.

Crop growing environments have been observed to influence the phytochemical profile and sensory quality in products like basil (*Ocimum basilicum*) and tomatoes (Korcok et al., 2021;

Arenas-Salazar et al., 2024). Tea (*Camellia sinensis*) intercropped with chestnuts (*Castanea mollissima*) had higher amino acid levels and lower bitter flavonoid levels (Wu et al. 2021). Coffee (*Coffea arabica*) plants intercropped with mahogany (*Khaya ivorensis*) and teak (*Tectona grandis*) yielded higher sensory notes, with greater body, flavor, and balance, compared to the monoculture treatment (Freitas et al. 2020).

This study had two objectives. The first was to determine whether cultivation environment (monoculture vs. intercropping) affects the sensory qualities of zucchini fruit and marigold flowers. The second was to assess how growing environment influences the total antioxidant content (TAC) and total polyphenolic content (TPC) of marigold flowers. Because intercropping has been shown to alter nutrient dynamics and secondary metabolite profiles in several crops and marigold is a highly aromatic species, we hypothesized that sensory panelists would be able to distinguish between samples grown in different environments. By clarifying how intercropping may affect edible flower quality, this work aims to support growers in optimizing production practices and expanding revenue opportunities.

## Materials and Methods

### *Growing Conditions*

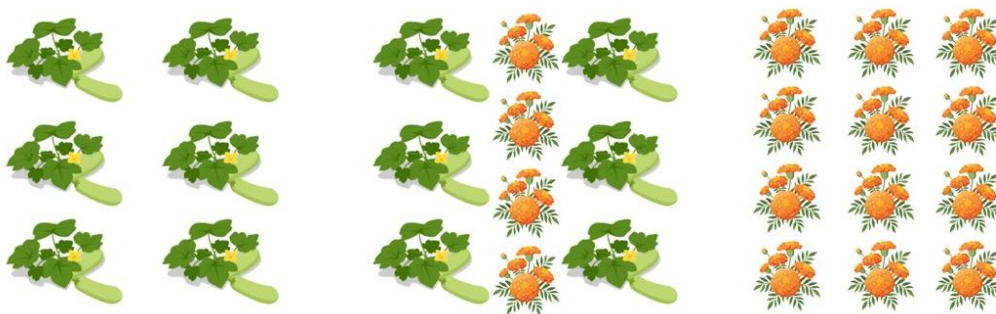


**Figure A1.1.** The field design for one of three research blocks used in this study. Each replication block had one monoculture zucchini section, one monoculture marigold section, and one intercropped section. The location of each section was randomized within each block.

‘Fordhook’ zucchini (*Cucurbita pepo*) and ‘Queen Sophia’ French marigold (*Tagetes patula*) plants were grown at Dandelion Farms in Fort Collins, CO. Plants were split between three 15’ x 5’ plots, which were divided into three treatments based on a randomized complete block design. The treatments included zucchini grown as a monoculture, marigolds grown as a monoculture, and zucchini intercropped with marigolds, with marigolds planted between zucchini plants (Figure A1.1). During the growing season, the field plots had an average high temperature of 29.0°C and an average low temperature of 12.6°C (Wunderground, Brookhaven, GA, USA). The humidity averaged 54.5%. Mushroom compost from Hazel Dell (Fort Collins, CO, USA) was applied to the plots the day before transplanting. The plants were irrigated using drip lines at a rate of 1 inch of water per week.

#### *Sensory Study Harvesting*

The zucchini fruit and marigold flowers were hand-harvested one day prior to sensory evaluation. Samples were collected from a variety of plants and homogenized. Zucchini were picked to ensure the fruit was of similar age and size, and were stored in separate plastic laboratory bags. Marigold flowers were cut from the plants, leaving a stem of 3-4”. The marigold stems were placed into designated treatment cups filled with water for transport. Marigolds and zucchini were kept separate during transport to avoid contamination. All harvested samples were kept in an ice chest until they were transferred to CSU SPUR, where they were placed in refrigeration until the study the next day.

#### *Sensory Sample Preparation*

All zucchini and marigold samples were rinsed with tap water before serving and allowed to dry on paper towels. Zucchini was served raw and sliced into 1 mm sections per sample. Raw preparation was selected to eliminate possible variability from cooking methods. Zucchini samples were served at room temperature in two-ounce plastic cups coded with a three-digit random number. Marigold petals were separated from the flower structure and placed in a tea infuser. The marigold tea recipe was one tablespoon (weight in grams) of fresh flower material per 237 mL of water, and the flowers were steeped in boiling water for 5 minutes before the infuser was removed. A hot-water infusion was selected because edible flowers reliably release their volatile and phenolic constituents into aqueous extracts, producing a stable and discriminable sensory profile suitable for tetrad testing. Marigold-containing floral teas have previously demonstrated distinct aroma and flavor attributes detectable by sensory panels (Baskey et al., 2015). The tea samples were served in two-ounce white paper cups coded with a three-digit random number. The tea was brewed three times during the sensory evaluation period, and temperature was maintained by placing the tea in a crock pot at the lowest setting to ensure all samples were served at a palatable temperature.

### *Participant Selection*

Untrained participants were recruited from the Greater Denver Metropolitan area. There was no financial incentive to participate in the study. All study procedures were approved by the CSU Institutional Review Board).

### *Sensory Evaluation*

A tetrad discrimination test was used to evaluate zucchini and marigold tea samples. The tetrad test was performed twice: first for the zucchini, then for the marigold tea. In each test,

participants were presented with four samples (two monoculture-produced and two intercropped) and asked to group them into pairs based on similarity. Crackers and distilled tap water were provided for palate cleansing. The tetrad has advantages because it decreases the effect size and reduces unexplained variations within the samples, therefore using fewer panelists and samples (O'Mahony, 2013). Participants completed their evaluations using Compusense (Compusense, Guelph, ON, CA) on touchscreen computers.

### *Phytochemical Analysis*

Marigold flowers were harvested twice during the experiment, once in July and again in September. Flowers from the plants within a replicate section were pooled to create control and minimize other sources of possible variability. After harvest, pooled flower samples were stored at -80 °C for a minimum of 48 hrs before lyophilization. Samples were then lyophilized (LabConco Freezone; Labconco, Kansas City, MO, USA) for 48 hours to halt biological pathways (Maisl et al., 2023). Flower material was homogenized and then extracted by utilizing methanol. Dried petal tissue (100 mg) was extracted in 3 mL of methanol, and antioxidant capacity and total phenolics were quantified from the extract and expressed on a dry weight basis. Total polyphenol content (TPC) was analyzed using the Folin-Ciocalteu assay (Singleton and Rossi 1965), with each sample measured in triplicate, and results were expressed as mg of gallic acid per g of flower material. The total antioxidant content (TAC) was analyzed using the DPPH assay, with each sample measured in triplicate and results expressed as  $\mu\text{mol}$  of Trolox (TE) per g of flower material (Blois 1958).

### *Statistical Analysis*

A binomial test was used for the sensory study portion, with the marigold tea and zucchini tested independently in RStudio (Posit Software, PBC, Boston, MA, USA). Participants' feedback was analyzed using clause-level coding. Responses were segmented into discrete clauses to capture specific sensory observations. Each clause was manually coded into descriptive categories (e.g., fragrance, appearance, taste). Code frequencies were then calculated to summarize how often participants reported each type of attribute. The categorized clauses were used to create word clouds using Microsoft CoPilot (Microsoft, Redmond, WA, USA). Phytochemical data were analyzed using R Studio to test the effects of the cultivation strategy on the TPC and TAC. ANOVA tests and Tukey's HSD post hoc analysis were used as the data had equal variances.

## Results

### *Zucchini Tetrad Results*



**Figure A1.2.** Word clouds of flavor notes of zucchini fruit samples, intercropped samples (left), and monoculture tea samples (right).

In total, 45 participants took part in the tetrad test, and 21 (47%) correctly paired the monoculture and intercropped treatment samples. The growing-environment treatments significantly influenced zucchini flavor ( $p = 0.044$ ), indicating that participants were able to perceive sensory differences between the two production systems.

Clause-level coding was applied to comments from participants who correctly paired the samples. Clauses describing little to no flavor appeared in ten comments (47.6%) for the intercropped samples, compared with four comments (19.0%) for the monoculture samples. Eight respondents indicated that monoculture-grown zucchini had more flavor or was sweeter, whereas two respondents reported stronger flavor in the intercropped samples. Monoculture samples were described as earthy, herbal, matcha-like, sweet, vegetable-like, and having a traditional zucchini flavor, whereas intercropped samples were more frequently characterized as buttery, green, sour, and vegetable-like (Figure A1.2).

These patterns suggest that marigold intercropping may influence zucchini sensory quality in addition to its well-documented effects on crop production and pest management. Previous research has shown that intercropping can alter plant resource acquisition, nutrient availability, and secondary metabolite accumulation through plant interaction changes and the growing environment (Brooker et al., 2015; Arenas-Salazar et al., 2024). Although the biochemical basis for these sensory differences was not investigated, the reduced flavor intensity and increased perception of green or sour notes in intercropped zucchini may reflect physiological responses associated with the intercropping system.

Texture differences also emerged from participant comments. Despite selecting zucchini of similar size, five participants described the intercropped samples as crunchier, whereas three described the monoculture samples as softer. Although these observations are exploratory, they suggest that the production system may also influence textural characteristics. Instrumental texture analysis would be needed to determine whether these perceived differences represent measurable treatment effects.

Overall, the sensory results indicate that participants were able to distinguish between monoculture and marigold-intercropped zucchini. Participant comments suggest that monoculture fruit generally had a stronger, sweeter, and more characteristic zucchini flavor, whereas intercropped fruit was more frequently described as having muted, green, or sour flavor notes. While these findings should be interpreted cautiously because of the qualitative nature of the comments and the limited number of responses, they provide evidence that intercropping may influence zucchini sensory quality and warrant future studies linking sensory perception with changes in fruit chemistry.

#### *Marigold Tea Tetrad Results*



**Figure A1.3.** Word clouds of flavor notes of marigold tea samples, intercropped samples (left), and monoculture tea samples (right).

In total, 45 participants took part in the tetrad test, and 24 (53%) correctly paired the monoculture and intercropped treatment samples. The growing-environment treatments significantly influenced marigold tea flavor ( $p = 0.004$ ), indicating that participants were able to perceive sensory differences between the two production systems.

Clause-level coding was applied to feedback comments from participants who correctly paired the samples. Five participants described the monoculture-derived tea as having more flavor, whereas two participants felt the intercropped tea was more flavorful. Reports of limited

or muted flavor occurred across both treatments, with half of respondents noting that the teas in general had little flavor.

Clauses describing specific flavor qualities differed between treatments. Monoculture samples were associated with buttery, floral, honey, smooth, and umami descriptors, whereas intercropped samples were described as floral, herbal, lemongrass, salty, warm, and characteristic of traditional tea (Figure A1.3). Similar changes in beverage quality have been reported in intercropped tea systems, where mixed-species production altered metabolite profiles associated with flavor, including amino acids, sugars, and flavonoids, resulting in measurable differences in tea quality (Wu et al., 2021; Lei et al., 2022). Although marigold flowers differ substantially from tea leaves, these findings suggest that intercropping can influence the chemical composition of plants used for beverages, providing a plausible explanation for the differences in flavor descriptors observed between monoculture and intercropped marigold tea. Additional chemical analyses would be needed to determine whether differences in volatile compounds, phenolics, or other metabolites contributed to the sensory responses observed in the present study.

Aromatics were mentioned by several participants, but no consistent trends emerged. Some participants noted that the intercropped tea was darker, while the monoculture samples were lighter. Because color can influence sensory expectations and sample discrimination, this visual difference may have contributed to correct pairing in the tetrad test. Participant comments and data showed that marigolds grown in monoculture had more traditional marigold flavor profiles, with umami and rich notes, while intercropped marigolds had a lighter, more herbal flavor.

As with the zucchini results, these sensory observations should be interpreted as preliminary impressions rather than definitive evidence of treatment-driven differences. Although participants detected differences between treatments, the qualitative nature of the comments and limited sample size constrain the extent to which conclusions can be drawn. Further controlled sensory work including trained panels, larger participant pools, and targeted volatile and non-volatile analyses is needed to determine whether intercropping consistently affects marigold flavor and to determine the mechanisms involved.

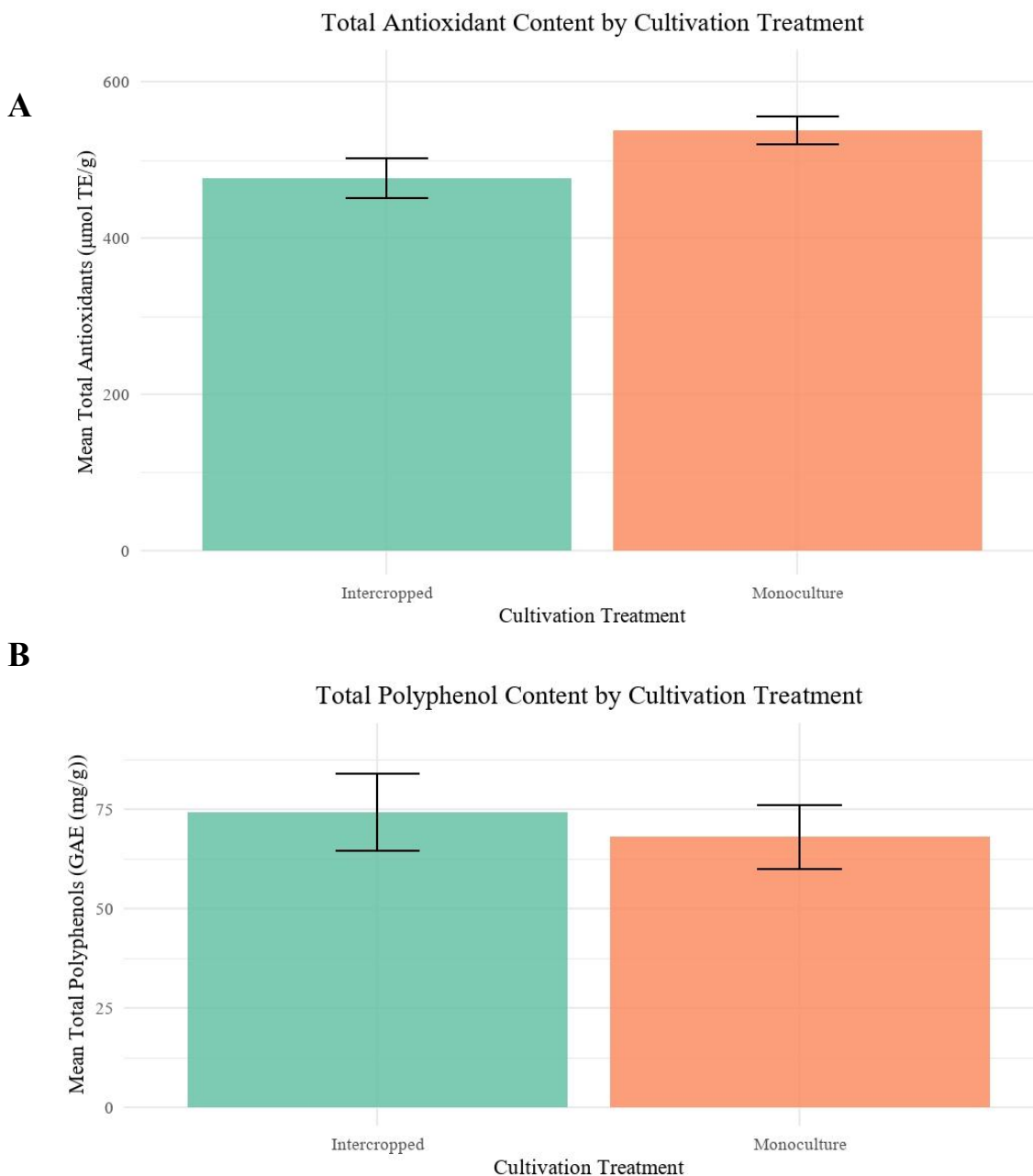


**Figure A1.4.** ‘Queen Sophia’ French marigolds (*Tagetes patula*) plants were grown in monoculture sections and sections that were intercropped with ‘Fordhook’ zucchini (*Cucurbita pepo*) to test the impact that cultivation practices had on the phytochemical content. A) The total antioxidant content of marigold flowers of each cultivation treatment. B) The total polyphenol content of marigold flowers of each cultivation treatment.

### *Phytochemical Content*

The antioxidant and polyphenolic content of methanolic extracts of marigold flowers produced by monoculture-grown and intercropped plants did not differ significantly from each other ( $p=0.056$ ;  $p=0.090$ ). Intercropped marigolds had an average TAC of  $476.9 \mu\text{mol TE g}^{-1} \text{ DW}$ , and the flowers from the monoculture plants had an average TAC of  $537.7 \mu\text{mol TE g}^{-1} \text{ DW}$  (Figure A1.4.A). The TPC of intercropped marigolds had an average of  $74.2 \text{ mg GAE g}^{-1} \text{ DW}$ , while monoculture flowers had an average of  $68.1 \text{ mg GAE g}^{-1} \text{ DW}$  (Figure A1.5.B). Comparable antioxidant activity has been reported in *Tagetes* species, although values are frequently expressed on an extract basis. For example, Sukhikh et al. (2025) reported antioxidant capacities of  $2.9\text{--}7.6 \text{ mmol TE g}^{-1} \text{ extract}$  across FRAP, DPPH, and ABTS assays for French marigolds, indicating substantial radical-scavenging potential, though direct comparison is limited by differences in reporting units. Similarly, phenolic concentrations of approximately  $35 \text{ mg GAE g}^{-1}$  in methanolic extracts of French marigolds have been documented, supporting the classification of this species as phenolic-rich.

When expressed on a dry weight basis, the values observed here align more closely with ranges reported for other high-antioxidant edible flowers, including species such as *Dahlia xhybrida.*, which have been reported to exhibit total antioxidant capacities in the range of  $479\text{--}679 \mu\text{mol TE g}^{-1} \text{ DW}$  (Lee et al. 2026). The relatively high phenolic content and antioxidant capacity observed in the present study, therefore, reinforce the potential of French marigolds as a functional edible flower crop. It should be noted that the values reported here reflect methanolic-extractable compounds, normalized to dry weight, and that variation among studies is likely influenced by the extraction solvent, the solvent-to-tissue ratio, and the assay type.

Intercropping systems have been shown to influence secondary metabolite accumulation, although responses are species- and system-dependent. For example, intercropping increased total phenolic content and antioxidant activity in buckwheat grown with fenugreek (Salehi et al. 2018). Similarly, intercropped tomato cultivation settings have indicated elevated levels of phenolics and flavonoids, as well as antioxidant capacity, relative to their monoculture counterpart (Santin et al., 2024). These responses may be attributed to shifts in plant secondary metabolism, as intercropping has been shown to upregulate flavonoid biosynthesis and other metabolite pathways (Wu et al., 2021).

The magnitude of the intercropping phytochemical effects is not universal. In one observed case, the cultivation system exerted only a minor influence on total phenolic content and antioxidant capacity compared with environmental and genetic factors (Anton et al., 2014). The limited differences observed between intercropped and monoculture marigolds in this study are therefore consistent with the broader literature, suggesting that while intercropping can enhance phytochemical accumulation, its effects are not guaranteed and may be subtle under certain production conditions.

## **Conclusions**

Intercropping vegetables and fruit with edible flowers may offer growers a sustainable way to generate a second source of income. Understanding the sensory and phytochemical impacts of intercropping is important for assessing the characteristics of produce sold to consumers. In two sensory tetrad tests, study participants were able to distinguish between cultivation environments for both zucchini and marigolds. Zucchini grown in monoculture settings were described as having a more traditional zucchini flavor, whereas intercropped zucchinis were characterized as lighter or comparatively flavorless. Marigolds grown in

monoculture were associated with stronger flavor profiles, while intercropped flowers were noted for lighter flavor notes. Together, these findings indicate that intercropping can subtly shift sensory perception in ways that growers should consider when marketing edible flowers and associated produce.

Additionally, when analyzing phytochemical content, the total antioxidant and polyphenol concentrations did not differ significantly between cultivation treatments. These results are promising for growers, as they suggest marigolds can be intercropped with zucchini without diminishing key health-related phytochemical attributes. Further research should confirm how intercropping edible flower species with other fruit and vegetable crops may mutually influence crop sensory quality and phytochemical content.

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