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Article

Scientific analysis of cut flowers: a review of the main technical issues developed

Análise científica de flores de corte: uma revisão das principais questões técnicas desenvolvidas

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Abstract: The cut flower sector is an area of horticulture that generates great economic and academic interest worldwide, the production of flowers represents a market segment that has aesthetic and sentimental purposes in many regions of the world. In recent years, a large amount of research has been generated that has promoted this sector, therefore, in this work we have proposed to develop a systematic review in this field of knowledge, with the objective of consolidating knowledge, guiding future research, and supporting informed decisions, thus contributing to the efficient use of resources and the continuous advancement of the cut flower industry. The systematic review process was divided into six stages, starting with the definition of the search equation and the collection of information from the prestigious Scopus database. Subsequently, a detailed quality and technical analysis of the 532 documents collected was conducted. These documents were grouped into 13 topics that are related to the production system, ranging from propagation techniques, genome study, genetic improvement to topics of current interest such as sustainability. Each of these topics was examined and the results of this analysis led to the preparation of this technical document, which includes relevant aspects that have contributed to the improvement of productivity and productive diversity in species and under different climatic conditions.
Keywords: crop management, flower production, genetic improvement, research topics, sustainability.

Resumo: O setor de flores de corte é uma área da horticultura que gera grande interesse econômico e acadêmico em todo o mundo. A produção de flores representa um segmento de mercado que possui propósitos estéticos e sentimentais em muitas regiões do mundo. Nos últimos anos, foi gerada uma grande quantidade de pesquisas que promoveram esse setor. Portanto, neste trabalho, propusemos desenvolver uma revisão sistemática nesse campo de conhecimento, com o objetivo de consolidar este conhecimento, orientar pesquisas futuras e apoiar decisões informadas, contribuindo assim para o uso eficiente de recursos e o avanço contínuo do setor de flores de corte. O processo de revisão sistemática foi dividido em seis etapas, começando com a definição da equação de pesquisa e a coleta de informações do prestigioso banco de dados Scopus. Em seguida, foi realizada uma análise técnica e de qualidade detalhada dos 532 documentos coletados. Esses documentos foram agrupados em 13 tópicos relacionados ao sistema de produção, desde técnicas de propagação, estudo do genoma, melhoramento genético até tópicos de interesse atual, como sustentabilidade. Cada um desses tópicos foi examinado e os resultados dessa análise levaram à elaboração deste documento técnico, que inclui aspectos relevantes que contribuíram para a melhoria da produtividade e da diversidade produtiva em espécies e sob diferentes condições climáticas.
Palavras-chave: gestão de culturas, melhoramento genético, produção de flores, tópicos de pesquisa, sustentabilidade.

Introduction

Undoubtedly one of the species most valued by mankind in recent years, due to their beauty and everything they generate emotionally around them are cut flowers (Lykas et al., 2023; Zheng et al., 2023). Although its aesthetic value is unquestionable, it must be recognized that this product plays a very relevant role in different national and international scenarios, being a key product for the decoration and celebration of relevant festivities in different places (Khatami et al., 2020; Villagrán et al., 2021). Therefore, its economic and cultural relevance is undeniable, which has generated that the cut flower sector is constantly evolving, being a highly competitive sector that can respond favorably to the demands of a globalized and dynamic market (Krigas et al., 2021; Lan et al., 2022).

In recent years, the production and marketing of cut flowers has undergone profound transformations, driven by technological advances, changes in consumer demand, environmental concerns, and even social and political issues between countries (Naing and Kim, 2020). This review article seeks to establish a technical baseline in the cut flower sector, exploring not only their value as decorative ornamental products, but also the technical, scientific and commercial complexities surrounding these products and their production chain (Ha and In, 2022; Kenanoğlu, 2023). Therefore, we aim to provide a comprehensive overview of the most recent developments and highlight key areas that have undergone technical and scientific evolution over the last 40 years, especially in areas such as breeding, genotyping, crop physiology and management, pest and disease management, irrigation and fertilization management, technological advances and sustainability of the sector.

This systematic review will not only provide a holistic view of recent advances but will also identify areas where there is a critical need for more focused research. This is especially relevant in the context of cut flowers, as the demand for high quality and sustainable products is a growing reality, and the pressure to address challenges such as sustainable pest management, natural resource conservation, as well as product quality and traceability is increasingly relevant in international markets. In summary, this systematic review will provide a document that will allow researchers, growers and decision-makers to guide future research and practices in the cut flower industry, thus promoting its successful development and sustainability in the coming years.

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Materials and methods

Information search and collection

A systematic review of the literature about cut flowers was carried out by analyzing the information obtained from articles published in scientific journals between January 1989 and August 2023. It should be noted that these publications were peer-reviewed to ensure impartiality and high scientific quality data (Drottberger et al., 2023). The systematic review is a tool that provides a global and unbiased vision of the existing body of knowledge on the field of cut flowers. On the other hand, this review allows to compile all the scientific and empirical evidence in a document that can be reviewed by decision-makers to project future studies based on trends and knowledge gaps (Haddaway and Westgate, 2019). Finally, systematic reviews are clearly presented and duly documented, which simplifies the reproduction of this type of work and even the verification of some results, thus promoting compliance with rigorous scientific standards (Torres-Carrión et al., 2018).

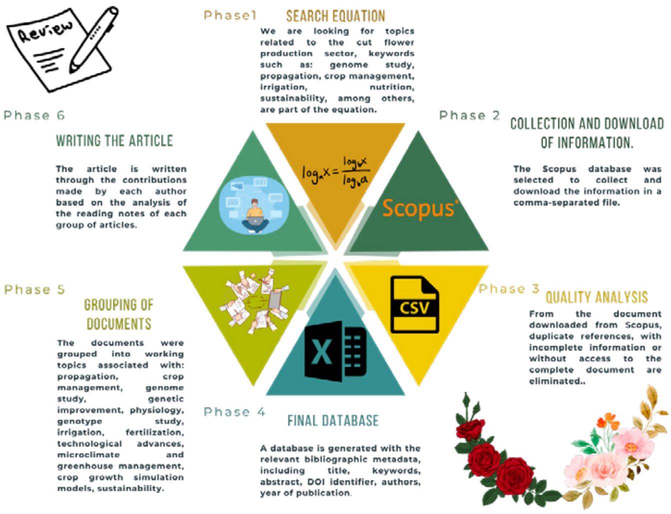

Fig. 1. Methodological process for the construction of the review document.

This systematic review was developed through the process summarized in Fig. 1, starting with phase 1 where the search equation was determined for the capture of published documents, in phase 2 the collection and downloading of information from the Scopus database was performed. In phase 3, the quality analysis of the database was conducted, eliminating duplicate elements or those with incomplete references; in phase 4, the final database was generated, with the relevant bibliographic metadata. In phase 5, the articles reviewed were grouped and classified according to a set of identified sub-themes associated with various stages of the cut flower production system. Once phase 5 was developed and seeing the research relevance of the post-harvest area, it was decided to eliminate this topic from the review discussed in this document, so that the 443 documents dedicated to this topic could be analyzed in depth in an independent review article. Therefore, the review and discussion proposed in this document was conducted on a total of 532, equivalent to 54.5% of the total number of documents collected. Finally, in phase 6 we proceeded to write the literature review based on the relevant reading notes for each group of articles.

Results and discussion

Distribution of documents

The 532 articles were grouped into the 13 production system topics summarized in Fig. 2. The number of articles per group varied from a maximum of 82 for pest and disease management to a minimum of 6 for crop growth modeling and simulation. Each of these topics will be analyzed below.

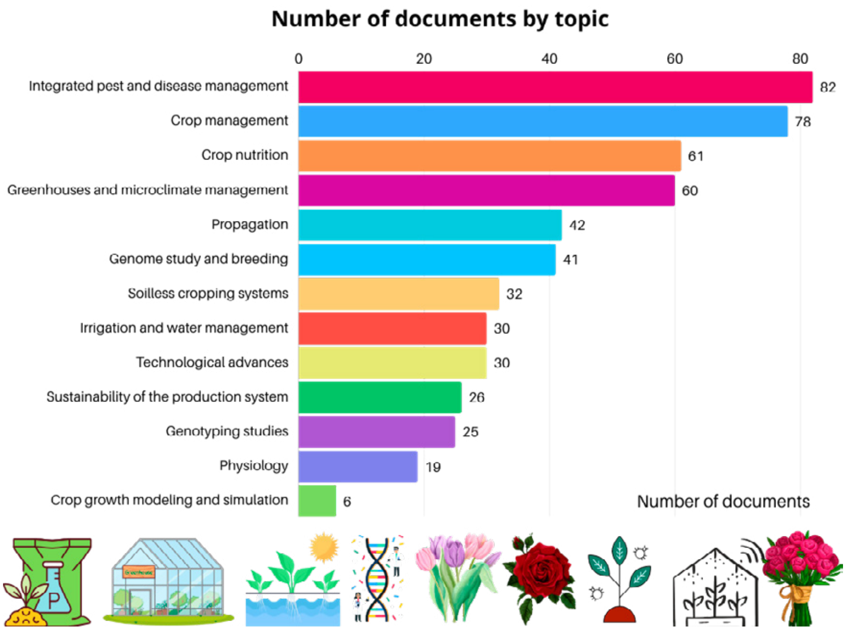

Fig. 2. Thematic grouping of the documents collected.

Propagation

In floriculture, different methods of propagation of plant material are used, being the in vitro tissue culture technology the most used for large-scale clonal multiplication, applied to diverse types of species, as a response to the high demand of farmers worldwide to obtain planting material with new innovative attributes that conquer this demanding market. This biotechnological tool has also been used to accelerate genetic improvement programs and to obtain new hybrids through rapid propagation systems, producing virus-free mother plant reserves (Ruffoni et al., 2008). Large-scale multiplication of exquisite and rare hybrids using tissue culture techniques has helped orchids occupy a position among the top ten cut flowers in the world today (Chugh et al., 2009). Micropropagation is also the main system used to clonally propagate orchids, gerberas and lilies, due to the high economic value they represent in the floriculture industry, either as cut flowers or potted plants worldwide, being a fast way to supply the industry by producing millions of plants each year (Balilashaki et al., 2014).

In some cases, conventional propagation methods are slow due to the low multiplication rate of the plants, as is the case of *Strelitzia spp*, therefore, an efficient and safe large-scale propagation is needed to take advantage of all the potential that this species represents in the industry. Therefore, the development of a successful micropropagation protocol represents a fast and efficient alternative for large-scale plant production (North et al., 2010). The industry works daily in the development of new micropropagation protocols to make its clonal production systems more efficient and global of plant material with health and that preserves the phenotypic characteristics of the mothers, which in many cases come from conventional breeding programs or using techniques such as the use of colchicine. The large-scale production of seedlings in the industry by means of plant tissue culture allows to obtain as a result homogeneity in crop growth, thus improving cutting times and optimizing production management programs, which leads to greater profitability at each stage of production. Research ranges from seed disinfection methods to seed introduction, as in the case of a study on *Lilium longiflorum* cv. Dozzel, where different treatments for the disinfection of bulbs prior to in vitro establishment are evaluated (Ghoreyshi et al., 2008); studies of the effect of the use of different growth regulators in the multiplication stage and the use of different types of explants and evaluation of their response to their establishment in vitro (Hernández-Mendoza et al., 2021); acclimatization of laboratory-grown plant material (da Silva et al., 2017), the latter being a crucial stage for the establishment of seedlings at the greenhouse stage, as they may die due to sudden changes in environmental conditions to which they may be exposed.

Genome study and genetic improvement

The studies that worked in the field of genetics and genomics have contributed significantly to both the horticultural industry and to the scientific understanding of flower genetics. Among these works are genetic studies of Kalanchoe where the aim is to expand the vegetative and reproductive characteristics (Smith and Shtein, 2022), the LiMYB305 gene was also identified as a relevant regulator in the synthesis of monoterpenes in Lilium 'Siberia' (Yang et al., 2022). Transcription factors, such as DcWRKY33 and DcERF-1, that regulate wilting and genes related to ethylene and ABA have also been identified in Carnation (Wang et al., 2023; Zhu et al., 2023). An additional study revealed how DcEIL3-1 and DcWRKY75 coactivate ethylene biosynthetic genes and senescence-related genes, accelerating petal senescence in carnation in the presence of ethylene (Xu et al., 2022). In this context, the negative regulation of DcERF-1 on the wilting of carnation cut flowers has also been investigated (Ren et al., 2016). Additionally, the mutual regulation between DcEBF1/2 and DcEIL3-1 in carnation has been investigated to understand their influence on ethylene-induced petal wilting (Zhu et al., 2023).

Among the advances highlighted is also the development of the gerbera variety Joyful, which has become a valuable resource in the industry (Chung and Lee, 2019). In addition, reproductive growth in 'Yuuka' chrysanthemum was found to be influenced by its response to photoperiod, which has provided valuable information on gene regulation in this species (Ren et al., 2016). In oriental lily 'Sorbonne', the regulation of carbohydrate metabolism genes and sucrose transport has been analyzed (Gu et al., 2020). In gerbera, genetic improvements have been made in the lignin biosynthesis pathway to solve problems of curvature in cut flower stems (Jaberian Hamedan et al., 2019). On the rose side, the variety To Dios, with greater resistance to high temperatures, was developed (Heo et al., 2016). Genetic tools also made it possible to describe significant morphological and genetic differences between buttercup genotypes (Baran et al., 2023), as well as the identification of key genes and proteins related to petal senescence in chrysanthemums (Yao et al., 2021).

In orchids, the biosafety of genetically modified plants was evaluated, specifically by RNA interference of phytoene synthase hormone genes (Ko et al., 2019). The evaluation of genetic variability in gladiolus cultivars also yielded important results (Singh et al., 2016). While in chrysanthemums, the studies focused on the analysis of the overexpression of genes related to flower initiation (Shulga et al., 2011). Genetic transformation in carnations using the rolC gene and its effects on cuttings production was also explored (Zuker et al., 2001) and emphasis was placed on plant breeding through the introduction of new genes to confer desirable traits. Finally, genetic engineering has been a useful tool for modifying commercial aspects such as color and vase life of gerberas (Huang et al., 1995), roses, carnations and chrysanthemums (Zuker et al., 1998).

Greenhouses and microclimate management

The use of greenhouses is quite common in the production of cut flowers. Within these structures and depending on their technological level, it is possible to partially or totally manage the micro-climatic conditions [temperature, relative humidity, *Vapor Pressure Deficit* (VPD), CO_2 concentration and luminosity] (Villagran et al., 2018). In this area, we highlight works related to microclimatic optimization and the study of natural ventilation of passive greenhouses used in Colombia, as well as the analysis of night climate and passive climate control strategies to prevent thermal inversion and condensation phenomena (Villagrán And Bojacá, 2020; Villagran and Bojacá, 2019). Likewise, works where geostatistical tools are used to predict the spatial variability of microclimatic variables of relevance for plant growth and development have been carried out (Villagrán et al., 2022; Villagran and Bojacá, 2020).

On the other hand, there are the studies developed in high-tech greenhouses, where one of the most interesting factors is the optimization of supplementary light, which plays an important role in the growth and development of several long-day flowering species (Spall and Lopez, 2022). In this area there are papers comparing the effects of different lighting systems, such as high pressure sodium (HPS) and light emitting diode (LED) devices (Spall and Lopez, 2023). In works with LED light it has been found that red light favors the growth and flowering of ranunculus, in Alstroemeria it is blue light that improves the quantitative and qualitative traits of cut flowers and in gerberas with treatment with 85% red and 15% blue light it is possible to extend the vase life by approximately 3 days (Anvari et al., 2022; Llewellyn et al., 2019; Sugawara et al., 2023). In rose is the work developed by Lee et al. (2021), who evaluated lighting systems of sulfur plasma lamps (PLS) and high pressure sodium lamps (HPS), finding that with the use of PLS it was possible to increase the length, fresh and dry weight of cut flowers, as well as the length of vase life. For rose, there are also other authors who indicate that treatment with light management can be a method to control flower opening and water absorption in cut flowers, in order to prolong their vase life (Horibe et al., 2020).

Another way to manage luminosity, but in a passive way, is the use of shading or photo-selective nets, e.g. Sousa et al. (2021), evaluated the vegetative growth, flowering and vase life of some gladiolus cultivars exposed to full sun conditions and under a 70% shade system. The results reported show that under shade the plants exhibited greater height and larger stem diameter, although a shorter vase life compared to plants exposed to direct sun. In the same sense Almeida et al. (2021), demonstrated that the use of blue and red photo-selective nets change pigment and chlorophyll b contents in lisianthus, although the intensity and magnitude of the change depended on each of the four cultivars evaluated. Previously Rodrigues et al. (2016), had reported that the lisianthus crop under the use of red photo-selective nets, presented a greater precocity in harvest, greater stem thickness and a superior height of 12.6 cm, with respect to the treatment under blue photo-selective nets.

Another microclimate variable that is generally controlled in high-tech greenhouses is CO_2 concentration, Yang et al. (2017), developed a work where they evaluated concentrations of 700, 1000 and 1300 Mmol mol^{-1} sec^{-1} and a control environment without fertilizer injection in an anthurium crop in a solar greenhouse. The results showed that plants in enriched environment had a higher photosynthetic rate, intercellular concentration of CO_2 and water use efficiency, as well as a higher quality of commercial parameters of the flower, however the environment that generated the greatest gain was the 1000 Mmol mol^{-1}, with which the authors conclude that environments with this level of concentration are the most suitable for the production of anthuriums in winter. However, it should be mentioned that each species needs in-depth analysis and experiments in this aspect, since CO_2 concentration must also be related to other microclimatic variables and its effects are diverse in each species and cultivar (Carvalho and Heuvelink, 2001). Finally, another factor is vapor pressure deficit (VPD), which not only affects crops not only in pre-harvest, but also becomes noticeable in post-harvest. In floriculture, plants are produced in high humidity or low DPV environments, which sometimes results in uncontrolled transpiration and a decrease in water content in the postharvest stage, affecting the vase life of the species (Aliniaeifard and Van Meeteren, 2017). In this regard Lim et al. (2017), demonstrated that dehumidification resulted in cut roses with higher fresh weight, thicker stem diameter and longer vase life compared to roses cut from high-humidity greenhouses.

Crop management

The introduction of new cut flower cultivars is a common practice mainly due to market demands (Altman et al., 2022). Multiple studies document the introduction of wild materials such as *Ranunculus lyallii* (Evans et al., 2002) and leucadendron (Littlejohn and Robyn, 1999) and others that are the product of plant breeding such as *Gerbera jamesonii* (Shan et al., 2017) and the orchid *Ionocidium* ‘Cerrado 101’ (Cardoso, 2017). Some authors have studied in depth the morphological characteristics (Karsten et al., 2012), physiological (Lv et al., 2011) and crop management (Sharma et al., 2016).

Parallel to the development of materials, the optimal environmental conditions to produce ornamentals and cut flowers have been studied. Each species and, in many cases, each variety has specific requirements. In the case of temperature, Chon et al. (2013), report that plant height and fresh weight of roses under greenhouse misting increased in the range of 10-20%, although these conditions increased the number of malformed flowers and decreased the vase life. On the other hand, Katsutani and Ikeda (1997), found an acceleration of the process of flower bud differentiation and improved seedling formation when the temperature was above 20 °C. In Australian bluebell and carnation, bud emergence and flowering were promoted by a short-term cooling pulse followed by warmer conditions (Higashiura et al., 2021), while under Mediterranean conditions it was possible to produce allelis flowers in unheated greenhouses (Scuderi et al., 2012).

On the other hand, salinity is considered one of the main factors limiting crop production, due to its negative effect on plant growth and nutrition, and has been extensively studied in lupine, calla lilies and daffodils (Maren et al., 2019; Niu et al., 2007; Veatch-Blohm et al., 2012) and together with the effects of water deficit on rose crops by authors such as Bolla et al. (2010). Among the most studied cultural practices in ornamental species is planting density (Chopde et al., 2015), the overwhelmed or bent in rose crops (Kim et al., 2004), shape and structure of beds for greenhouse production (Niedziela et al., 2005). In addition, on the use of substances to improve crop performance, there is work related to the use of silicon to promote lignin accumulation in peonies (Zhao et al., 2021), H_2 that improves growth, development, stress tolerance and post-harvest storage of roses, carnations and lilies (Li et al., 2021) and CO_2 that can improve the vase life of phalaenopsis orchids (Endo and Ikushima, 1997).

In terms of soil management, work has been done to analyze the use of microorganisms such as the fungus *Phanerochaete chrysosporium*, which allows the degradation of phenolic acids deposited on land continuously planted with chrysanthemums, with the aim of improving the microbial structure of the soil (Liu et al., 2016); also the application of mycorrhizae, trichoderma, *Azospirillum brasilense* and *Bacillus subtilis* have increased plant height, chlorophyll intensity, N, P and K absorption and the duration in bloom of gerberas (Rakbar et al., 2022) and gladiolus (Ahmmad and Abdullatif, 2020).

Commercially, the use of growth regulators has also become widespread in different crops to homogenize harvest dates, accelerate flowering, and improve the rooting of cuttings or, on the contrary, inhibit the growth of undesired organs such as lateral shoots or blind stems. This is the case of auxins, gibberellins, cytokinins, jasmonates and abscisic acid (Rhie et al., 2020), uniconazole (Adil et al., 2021), organic acids such as malic acid and citric acid (Ghazijahani et al., 2018), among others. Finally, research has also been conducted in postharvest of cut flowers focused on the prolongation of vase life. The use of ethylene inhibitors such as 1-methylcyclopropane (1-MCP) is common (Asil et al., 2013), spermine and limonene in gerberas (Mohammadi et al., 2020), alstroemeria (Langroudi et al., 2019), Wax flowers (Abdalghani et al., 2018) and Snapdragon (Heffron and Korban, 2022). The use of preservatives such as oligosaccharins, 8-hydroxyquinoline citrate (8HQC) and sucrose is also reported to show higher percentages of bud opening and flower pigmentation, as well as maintenance of appearance, color and overall size of lisianthus flowers (López-Guerrero et al., 2021), clematis (Rabiza-Świder et al., 2017) and tulips (Hwang et al., 2014).

Physiology

The research was focused on the study of the quality of the lily (Al-Ajlouni et al., 2023; Inamoto et al., 2022) and its post-harvest durability (Huo et al., 2018; Zhang et al., 2021), through the use of different products and/or techniques. Inamoto et al., (2022) found that under high concentrations (2000 ppm) of CO_2 the lily plants showed an increase in photosynthetic rate that was twice as high as that shown with the ambient concentration (380 ppm CO_2), which improved flower size and quality. Another research to improve the quality of the lily found that, under greenhouse conditions in Brazil, bulbs with diameters between 3.2 - 3.8 cm stored for 25 days in a cooling chamber were the ones that allowed a higher flower production and longer stem length, factors that end up favoring the increase of its price in the market (Almeida et al., 2017).

In other species, some of the findings are also related to postharvest quality and shelf life, Shabanian et al. (2019) found that Salicylic Acid applications contribute to delay gerbera flower senescence. However, they clarify that these applications can have more or less prolonged effects according to the variety worked. Elansary (2020), analyzed the role of tree bark extracts of *Magnolia acuminata* and *Taxus cuspidata* as a natural antioxidant preservative, extending the longevity of gladiolus in vase up to 18 days with doses of 50 mg L^{-1} of *M. acuminata*. This is explained by the role played by the antioxidant mechanism in controlling flower senescence and activating enzymes such as superoxide dismutase (SOD) and catalase (CAT) that antagonize reactive oxygen species. Finally, in chrysanthemums, the role that pretreatment with nitrogen compounds could play in the duration of the cut flower was analyzed, finding that pretreatment with ammonium sulfate at low concentrations or with moderate to high concentrations of potassium nitrate or calcium nitrate can significantly improve the useful life and quality of chrysanthemums in postharvest (Souri et al., 2018).

Genotyping study

In this line of work, In and Lim (2017), observed that rose plants, cultivated under greenhouse conditions, of the variety Lovely Lidia had different vase life time’s depending on the time of the year in which they were produced. Thus, flowers cultivated in spring had an average vase life of 12.2 days, while winter flowers had an average vase life of 9.2 days. On the other hand, these studies have also been focused on the adaptation of cultivable plants to adverse conditions; in California, USA, the performance of Rosa Mistica (*Zinnia elegans*), a species selected for its economic value and the resistance of its wild relatives to salinity conditions, was evaluated; the cultivars “Salmon Rose” and “Golden Yellow” showed a potential adaptation to salinity conditions, having in their metabolic pathway a priority of K over Na (Carter and Grieve, 2010). Other studies have evaluated the adaptation of materials to conditions different from those in which they were developed; in Kuwait, Al-Menaie et al. (2005), evaluated the ideonity of eleven varieties of rose (*Rosa indica*) introduced from the Netherlands, with good results since, with the exception of the Elfe variety, the other ten varieties produced excellent flowers for commercial bouquets. Another condition for the evaluation of genotypes was the evaluation under cover; in India, ten gerbera materials were evaluated for growth, yield and cut flower quality; as a remarkable result, the genotypes Naike and Kyllian produced the highest number of cut flowers and quality, showing statistical differences with the other eight genotypes evaluated (Taj and Naik, 2013).

Integrated pest and disease management

Flower production worldwide has always involved the control of pests and diseases due to the susceptibility of the different plant species grown, planting density, among other factors that favor the establishment and multiplication of pathogens that reduce yields (Wegulo and Vilchez, 2007) and generate productive and commercial restrictions. For this reason, pathogen management has focused mainly on the use of chemically synthesized agrochemicals (Radosevich et al., 2020; Solmaz et al., 2020). However, it has been demonstrated that some of the active ingredients generate harmful effects for the environment and the health of producers and even consumers, especially when several pesticides are mixed (Cloyd and Raudenbush, 2014). For this reason, other types of pests and disease management have been implemented in commercial cut flower crops for several decades.

Within these lines of work, the propagation of plant material has been investigated as an alternative to control pathogens such as arthropods and microorganisms. Asjes (2000), evaluated lily propagation methods to reduce the incidence of asymptomatic and spotted viruses. This included storage conditions and early virus detection to make early decisions in managing vectors such as aphids and aphids, using integrated strategies with mineral oil and pyrethroid-based insecticides. Likewise, Wegulo and Vilchez (2007) evaluated the resistance of lisianthus cultivars to the fungus *Botrytis cinerea*, by defining methods for resistance evaluation, and particularly for causing lesions of healthy Lisianthus stems. With this study, it was possible to obtain reliable results and select commercially available cultivars that can be used for the improvement of this crop. Authors such as Gautam et al. (2017), have also demonstrated another strategy and that is the use of chemotherapy on gerbera plants *in vitro* for the management of Cucumber Mosaic Virus (CMV), obtaining also an increase in plant growth, leaf lamina length and leaf width.

Biological control is one of the strategies that have been used for pest and disease management in flower crops, under glass. One of the examples of biological control strategies was implemented for the management of white rust (*Puccinia horiana*) of chrysanthemum. Torres et al. (2017) , showed that there are fungi of the *Cladosporium* genus that have potential as biological controllers for the control of this disease. Some of the strategies that involve the use of complementary methods to biological control are the application of essential oils, plant extracts or even the application of plant material substrates for pest and disease management. Oliveira et al. (2012), evidenced that the use of *Piper aduncum* essential oil showed potential for the management of insects of the order Hemiptera on heliconium bracts. In addition, authors such as Numa et al. (2015), Numa et al. (2018), demonstrated that the use of ethanolic extracts of *Cnidoscolus aconitifoluis, Copaifera oficinalis and Anadenanthera peregrina* have potential for the management of *Tetranychus urticae* adults in rose crops, reporting mortalities above 60% and reduced fecundity in the laboratory.

Another interesting example is the use of plant bark for pathogen management, such as the work of O'Neill and Mason (2014), where they found that soil incorporation of pine and spruce bark (three days before planting) reduces the incidence of wilt in flower crops caused by *Fusarium oxysporum f. sp. mathiolae*. However, the authors recommend initial testing to verify that there is a significant reduction in disease incidence according to the crop, and an evaluation of the bark to be applied to confirm that it is free of any pathogens. On the other hand, there is the release of arthropods as parasitoids and predators, among them the flower bug (*Orius insidiosus*) known as a predator of larvae and adults of the flower thrips and its compatibility with the use of the insecticide spinosad as a complementary strategy for the management of *Frankliniella occidentalis* in chrysanthemum crops, without affecting the survival or the predation capacity of the flower bug (Herrick et al., 2021). Similar cases are found in the literature, such as the use of predators such as the mites *Phytoseiulus persimilis* and *Neoseiulus californicus* for the management of the mite *Tetranychus urticae* in rose crops (Naher and Haque, 2007) and the compatibility of these biological controllers with entomopathogenic fungi (Bugeme et al., 2009) or plant extracts (Vergel et al., 2011), and even the compatibility of entomopathogenic fungi with plant extracts as integrated strategies for pest management.

Another strategy used for insect management is ethological control in flower crops with the use of colored and light traps, Johansen et al. (2018), showed that blue sticky traps with light attract more adults of *F. occidentalis* in alstroemeria crops compared to the use of yellow traps. Molecular tools are now available that allow the identification of different pathogens that affect crop production and quality, which is crucial when evaluating management practices to reduce losses in cut flower production (Sert Çelik et al., 2019). The strategies mentioned above are just some of the works done over the years in several countries, and many of these strategies have already been implemented on a commercial flower crop scale with results that favor the use of "environmentally friendly" strategies or complementary to the use of chemical synthesis products.

Irrigation and water resource management.

Plants in general require water for their physiological processes; within them, the cut flower sector has acquired relevance in the international market, becoming a dynamic sector that contributes to the economic dynamics of the countries that develop this activity at a commercial level. In order to increase the value of the product, research has been carried out on the efficient use of water (Piroli et al., 2022) and irrigation alternatives with water of lower quality than that commonly used in this productive sector (Rauter et al., 2021; Vera-Puerto et al., 2020), waters that generally, due to their salt content, complicate their use in horticultural crops or for human consumption, but can be used in the floricultural sector. Irrigation should not only be considered as a water source (Martins et al., 2021), but also as a technological alternative to increase the harvest and post-harvest quality of flowers (Santos et al., 2020; 2021), through irrigation management, water quality management and fertilizer supply control (Tsirogiannis et al., 2010). Different forms of cultivation are proposed for the use of water, both in open spaces and in protected environments, with soil, substrates or cultivated in both hydroponic and aeroponic solutions. The use of reclaimed water in cut flower production is a current issue, so that recent research has designed production systems using saline water, while analyzing the use of root inoculums (Al-Maamory et al., 2018; Bernstein et al., 2008).

The production of cut flowers coupled with the water crisis has driven the implementation of efficient irrigation systems, both in open field and in greenhouses. For this, applied research is being the necessary tool to find the appropriate water management for each type of crop, relating it both to the physiology and to an economic optimum (Piroli et al., 2022). Water requirements are linked to climate and production system, for example, it has been noted that in tropical climates roses show stem thickening and water stress problems, which can be mitigated under greenhouse conditions. Some authors recommend maintaining water content in soil stresses close to 3 kPa (Almeida et al., 2012; Oki et al., 2001), this also results in better flower quality, but the worst results were observed for stresses above 15 kPa (Al-Hammouri et al., 2017). We have also experimented with the use of low quality water (saline), evaluating the quality of roses (Rosa indica, Rosa canina and Natal Briar) and carnations Voyore, Diana and Chad, with promising and not very limiting results from the production point of view (Tsirogiannis et al., 2010). In this same research, the authors emphasize the importance of the irrigation schedule and soil as a salinity buffer. Similarly, adverse effects have been found in the rose when supplementary light is applied mainly at night, the results indicated that if 90 $\mu mol\ m^{-2}\ s^{-1}$ PPFD of artificial light is applied, it is necessary to apply irrigation every hour to ensure the formation of the button, otherwise it will generate a malformation of the flower (Shi and Kim, 2014).

Research has also been conducted on the cultivation of Asiatic lily 'Brunello', specifically evaluating irrigation in zeolite and a mixture of treated water (Al-Hammouri et al., 2017). The results indicated that the concentration of treated water for irrigation, depending on the concentration, has an effect on crop development, however, it is possible to achieve quality standards when a balance of concentrations is found. On the other hand Jinfen et al. (2022), conducted an experiment where lilies collected in greenhouses were treated with 2,4-epibrasinolide (EBR) 10-7 M and then subjected to a drought treatment to evaluate changes in wilting time, malondialdehyde (MDA) and total phenol (TP) content. The results obtained allowed them to provide information on the exogenous application of EBR as a mechanism to reduce the damage caused by water stress, since it reduces the MDA content and improves the TP content, which translates into a prolongation of plant life. flowers.

On the other hand, in crops such as cultivated *Alstroemeria* × hybrida, despite the quality and commercial interest of the flower, research is incipient in this species. In 2016 Girardi et al. (2016), carried out a study to estimate evapotranspiration and crop coefficient under greenhouse conditions for irrigation purposes. With the results obtained it was possible to determine that with water limitations the range of water consumption by the plant increases, in this case irrigation laminae from 47.6 mm to 207.8 mm were reported. Likewise, the average crop coefficient of *Alstroemeria* × hybrida grown under greenhouse conditions was 0.39 for the growth stages, 0.41 for the beginning of flowering, 0.95 for flowering, and 1.50 and 0.75 for full flowering and late flowering, respectively.

Crop nutrition

Integrated nutrition in cut flower crops is becoming a relevant area of impact in agronomic management (Savvas, 2019), showing positive physiological effects under abiotic stress conditions (Kumari et al., 2023), without relevant affectation in the growth rate in some species such as lisianthus (Seydmohammadi et al., 2020). In addition, plant nutrition is being complemented by the development of diagnostic techniques and the determination of fertilizer extraction curves for some species (Haussecker et al., 2023). Floral diversity is a strength of the sector that increases temporal relevance and maintains commercial dynamics. The impact of fertilization in cut flowers has had important technological advances not only in flower production but also in the use of nutrient solutions (Bose et al., 2019) both inorganic and inorganic, relating elements such as silica (Kumari et al., 2023), calcium and nitrogen (Milani et al., 2020, 2021), or zinc (Shaheen et al., 2015), as well as the use of organic solutions (Altaee and Alsawaf, 2021; Mancini and De Lucia, 2011).

Gerbera is among the floricultural species that have been studied. In order to improve quality, studies have been carried out to evaluate the phosphorus content, which influences plant nutrition but does not improve commercial quality (Mantovani et al., 2017). Studies of mineral and organic fertilization show that the use of reuse compounds (agro-industrial wastes), promise a feasibility in the use of a balanced combination of liquid organic fertilizers at the level of mineral fertilization (Santos et al., 2017). Cut flower nutrition has a specific incidence on the physiological factors of the plant depending on the type, but in general each element has its repercussion on the development stages of the crop. A study of Zerche (1997), estimated the amount of dry matter produced as a function of nitrogen content in chrysanthemums (*Dendranthema-Grandiflorum*-Hybrids). The relevant results of this study indicate that, due to the relationship between shoot production, dry matter or phenological stage, it is possible to infer nitrogen requirements as a function of the agronomic variables mentioned above.

Other species such as *Delphinium belladonna*, *Echinops ritro* and *Goniolimon tataricum* have been the subject of experiments to analyze the effect of nitrogen and potassium (Alt and Rehrmann, 1996). Regarding the species that occupy the commercial leadership in the cut flower sector, such as roses, carnations, lilies, alstroemerias and orchids, research has been conducted to determine the nutritional optimums with the transversal objective of improving the quality of the product according to market demands. In rose cultivation, research has been conducted with the use of reused water, either from agribusiness or treated wastewater. Since 1998, the effect of the use of organic amendments on soil properties and, consequently, on the productivity of 'Bridal Pink' roses has been measured. Although initially inconclusive results were not obtained, a line of research was established that has continued with the analysis between the weight and concentration of nutrients in rose plant tissues. For example, Bar-Yosef et al. (2009), stressed the importance of prior analysis of the element content in the soil and that there is a suggested stem diameter threshold, above which it is recommended to increase the fertilizer dose.

The use of UREA as a nitrogen source increases pH and inhibits calcium and phosphorus absorption, consequently increasing the content of reducing sugars in leaves and decreasing starch and sucrose. In roses, botrytis-related problems can be mitigated by dosing the amount of calcium, potassium and magnesium in the nutrient solution. Boztok and Cokuysal (2006) reported higher stem length, number of extra class flowers, number of first-class flowers, total yield, and yield from November to March, from the application of fertilizers with a higher K/Ca ratio (3/1). A study conducted by Singh et al. (2013), determined that rose vase life has a significant relationship with the rate of N-P-K application, which is used during crop development. On the other hand Baas et al. (1995), analyzed the effect of NaCl in the nutrient solution for carnation cultivation, noting that the shelf life is not important, but remarking that there is a reduction in the size of the peduncle when the concentration of sodium chloride reached 23 mM NaCl. Likewise Singh et al. (2015), in a foliar fertilization study developed in a greenhouse carnation crop tested fertilization systems in alternative growing media such as coco peat and soil. The results indicated that foliar fertilization once a week with 250 ppm of N and K helped to obtain better quality flowers. Finally Baracaldo et al. (2019), demonstrated that it is possible to maintain production and quality standards in carnation using a lower amount of nitrogen in the fertigation formula, which promotes greater efficiency in the use of this fertilizer and a lower environmental impact.

As for lilies, which are one of the most commercialized species in the international market, there are still visual defects that reduce their quality and shelf life, which have been attenuated with nutritional management, specifically calcium supplementation. The results of Álvarez-Sánchez et al. (2008), indicated that with an increase of 6.75 me l^{-1} over Steiner's solution, the maximum dry weight production (51.6 gr l^{-1}) was reached. Similarly Sajid et al. (2009), analyzed the use of foliar fertilizers and estimated nutrient uptake curves, finding that both nutrition and application mechanisms, such as pH and type of growing medium, condition the quality of nutrient uptake and consequently the transformation of dry matter into leaves and petals. Recently Beura et al. (2019), recommended the N-P-K fertilizer dosage based on an experimental design with lilies in which it was found that the maximum number of flowers and their length is achieved with the combined application of fertilizers with vermicompost, azotobacter, macros, micros and vitamins.

Soilless cultivation systems

One reason for shifting from soil to soilless cultivation of flowers is the efficiency of water and fertilizer use and the reduced likelihood of disease attack from the soil (Savvas and Gruda, 2018). For example, in rose crops, reductions in water consumption of up to 42% have been reported, while in fertilizers, reductions of up to 55% can be achieved (Rodríguez and Flórez, 2012). In soilless crops, the choice of substrate will depend on the type of crop and its properties, being necessary to satisfy the production needs of the plant driven by its biology and by the technification of the systems. One of the main advantages of using substrates is the improvement in root aeration compared to water systems and the ability to retain moisture providing a reserve in case of any technical failure (Savvas and Gruda, 2018).

The recycling of nutrient solution drainage in a soilless growing system can bring great benefits as they say Vélez Carvajal et al. (2023), who point out that recycling drainage for carnations can help maintain optimal levels of nitrogen, phosphorus and potassium in the growing medium. For their part Rodríguez and Flórez (2012) conclude that the use of substrates based on burnt rice husk and coconut fiber for roses produced a decrease in EC and pH of the drainage solution over time, indicating a higher consumption of mineral salts by the plant. Cabrera and Perdomo (2003), found that, for roses grown under intensive nutrient and water management practices, roses are not significantly affected by moderate salinity concentrations in irrigation water. However, salt concentrations affected electrical conductivity and chloride concentrations in the leachates; however, there were no significant effects on flower quality and quantity during four growth and flowering cycles.

Regarding irrigation management in substrate crops, it is important to know the effect of irrigation control methods on crop yield and quality since the results are contrasting. On one side Fascella et al. (2009), highlighted that, out of four irrigation methods, the combined method of substrate tension and substrate electrical conductivity brought better results in terms of longer and thicker stems in roses. In conclusion, the use of accurate and efficient irrigation control methods is important to produce high quality and profitable protected crops under soilless cultivation systems. However, Han et al. (2014), showed that irrigation frequency had no significant effect on the yield and quality of roses grown on different substrates.

To improve the yield and quality of soilless crops, it is necessary to analyze the effects of substrates on crop development and quality. Ikram et al. (2012), mentioned that mixtures of different soilless growing media can increase the leaf area index and increase the number of leaves of crops. They point out that, for spikenard, a combination of coconut fiber and poultry manure in a 1:1 ratio improves its leaf area and that, a combination of coconut fiber and leaf compost 1:1 produces the greatest plant height and the greatest number of flowers. In lilies, a combination of peat and pumice causes earlier flowering and increased plant height for the Siberia variety. Nevertheless, Merhaut and Newman (2005), in oriental lilies established that there was no significant difference in growth when using peat, coconut fiber and sandy soil substrates.

Some studies of Heliconia dedicated substrate crops established that coconut fiber can increase flower production and improve quality compared to volcanic tuff and that coconut fiber can cause excessive vegetative growth, which can affect flower bud production and crop renewal (Díaz et al., 2007). For its part, Restrepo-Díaz et al. (2011), used burned rice husk and coconut fiber for rose plants, highlighting that the coconut fiber substrate showed better performance in terms of growth and flower quality. In soilless Gerbera cultivation, the effect of different substrates on growth, yield and quality of the crops have been studied. The highest cost-benefit ratio was observed in coco peat, followed by rice husk (Panj et al., 2012). Mixtures of perlite and coconut fiber in 1:1 ratios with arbuscular mycorrhizal inoculations improved nutrient uptake, yield and postharvest quality of cut flowers (Nazari Deljou et al., 2013). The application of promoters and inhibitors of the enzyme phenylalanine ammonium-lyase in Gerberas can affect the inclination of the stem of cut flowers (Khalaj and Kanani, 2018), the use of pine bark substrate as well as nitrogen fertilization have no significant effect on yield and quality variation, while calcium fertilization has a significant positive effect on yield and quality (Milani et al., 2022).

To improve the yield and quality of flower crops, it is necessary to implement organic inputs such as worm humus and microorganisms such as Trichoderma in the substrates. In the case of Gladiola, it has been found that a combination of a commercial substrate and organic inputs favor the development and quality of flower stems (Cruz et al., 2018). In recent years, studies have shown that the particle size of substrates significantly affects water availability and aeration, which in turn impacts the growth and flower quality of lilies grown on volcanic substrate (Al-Ajlouni et al., 2017). It was also confirmed that perlite and degraded granite can be suitable substrates for growing Ornithogalum thyrsoides and that the choice of substrate is especially important for growing ornamentals in regions with poor or limited soils (Bonomelli et al., 2017).

Another option for growing flowers in soilless culture is to grow them in water or hydroponic systems. In deep water culture of chrysanthemums, it has been shown that maintaining a constant maximum water level can produce the best results in terms of stem quality and flower production. However, electrical conductivity and day length are among the variables that have the greatest impact on flowers. Recommending improved aeration of the water flow system to improve stem fresh weight production (Eveleens and Blok, 2013). Barbosa et al. (2012), established that the use of different N:K ratios in the nutrient solution of a hydroponic system significantly affects the production and postharvest quality of chrysanthemum flowers. The production of lilies in NFT systems allows greater control of plant nutrition and greater water use efficiency compared to other cropping systems (substrates and soil). However, quality seed and seedling selection are necessary for successful production.

Technological advances

Technological advances have had a profound impact on multiple aspects, from plant genetics to product commercialization, including environmental and chemical strategies to improve flower quality and longevity (Scariot et al., 2014). For example, in snowball and lily production, advanced techniques have been employed to control and accelerate plant development to obtain high quality flowers in a shorter period. In addition, the relevance of temperature in the cultivation process has been highlighted and genetic research has been conducted to improve flower production. These technological advances have great potential to benefit the cut flower industry by improving efficiency and product quality (Suh et al., 2013). In greenhouse chrysanthemum cultivation, an advanced prediction model based on thermal effectiveness and photosynthetical active radiation has been designed. This model offers exceptional accuracy in assessing quality, which has the potential to generate significant yield improvements (Yang et al., 2007). In addition, in the cultivation of other flowers, innovative technologies such as the functional-structural plant model (FSP) have been applied, allowing the simulation of three-dimensional plant growth, as in the case of lilies. Furthermore, 3D modeling has been implemented to optimize agronomic practices through a detailed analysis of accumulated photosynthetically active radiation (PAR) (Li et al., 2019).

In chrysanthemum production, smart farms using automation and information and communications technology (ICT) have been adopted to improve growth, reduce harvesting time and manage environmental factors such as light, temperature, humidity and CO_2 (Roh and Yoo, 2020). Intelligent systems based on thermal and visual cameras have been developed for the detection and control of plant diseases (Minaei et al., 2018). As well as mathematical models to predict the risk of gray mold outbreaks in greenhouse crops (Körner et al., 2014). Through nanofertilizers and nanosensors, crop efficiency has been improved and precise pest and disease control has been achieved (Rana et al., 2021). In addition, to combat the senescence of cut flowers, sensors based on nanoparticles and nanocomposites have been applied to detect and eliminate ethylene, improving the shelf life and quality of floral products (Scariot et al., 2014). In terms of water resource management, companies have implemented networks of wireless cellular nodes and sensors to monitor soil moisture and electrical conductivity, reducing water use without affecting crop yields (Lea-Cox et al., 2018). Vacuum cooling has been studied in research on the preservation of cut flowers (Sun and Zheng, 2006). At the same time, in the post-harvest classification of roses, progress has been made through the use of 3D image processing techniques and deep learning models, highlighting their superiority in speed and accuracy compared to other approaches (Fei et al., 2023). In addition, in flower production planning, an efficient system called “RoseTracker” has emerged, which employs computer vision techniques and a data set called “RoseBlooming” to improve the planning and monitoring of flower growth (Shinoda et al., 2023).

The use of liquid chromatography-mass spectrometry technology has enabled accurate analysis of plant hormones and antioxidants in flowers and fruits, providing valuable information on ripening processes and floral senescence (Lü et al., 2011). Also, infrared thermography has proven effective in monitoring the temperature of cut roses, predicting water stress and vase life, which benefits the cut rose industry (Ha et al., 2020). Electron microscopy and controlled illumination systems have been used to investigate stomatal distribution and transpiration mechanisms in cut gerbera flowers, providing useful information on their quality and durability (Huang et al., 2018). In addition, thermography technology has proven useful for estimating the rate of transpiration under dark conditions, which could be valuable for predicting the shelf life of cut flowers (In et al., 2016). Finally, on the commercial side, blockchain technology has been used to track and authenticate the provenance of flowers, providing consumers with transparent information about their products (De Carvalho et al., 2022). In addition, it emphasizes the importance of active monitoring and comprehensive mapping of the selection environment to design effective strategies for the commercialization of innovative products, especially those that are technologically controversial. This involves anticipating problems related to public acceptance and regulation (Enserink, 2000).

Crop growth modeling and simulation

The use of crop modeling and simulation tools has currently become one of the strategies for decision making, since through the use of these tools it is possible to analyze factors of the production system and their effect on plant yield (Flores-Velázquez et al., 2022). In this line of work, it is worth mentioning that there are very few studies, therefore, there are some investigations that began to be developed in the early 2000s, where at the time the development of models for the prediction of nutrient absorption in some cut flowers was promoted, to be able to integrate them in the future to growth models. Later, in 2010, the work of Chen et al. (2010), who used observations of leaf number accumulation rate and light integrals to develop a model predicting flowering time of a new *Limonium* hybrid. The results of this work revealed that, within the temperature and photoperiod limits used, growers can use the pre-sowing model to schedule planting dates and predict flowering time. They also proposed an adjusted model for the prediction of flowering time after planting.

In carnation, we should report the study developed by López et al. (2014), who developed a potential growth model, which considered photosynthetical active radiation (PAR) and temperature as input variables, and assumed that the plants were under optimal nutritional and irrigation conditions. The results showed that the daily increase in dry mass of flower stems was dependent on PAR, the fraction of light intercepted by the canopy and the efficiency of light use. Finally, in rose cultivation, we can highlight the work of Kim and Lieth. (2012), who developed and successfully validated a model for the prediction of shoot growth, root growth and nutrient uptake, this model was valid for both short flowering cycles, as well as for the development of the crop during a calendar year. The main results show that temperature is directly involved in flowering, but not in biomass accumulation and stem growth, which is why flower growth is rapid in the summer season and delayed in the winter season, while flower shoot length is shorter in summer than in winter.

Sustainability

Environmental deterioration is a reality in which we find ourselves immersed, together with the risks generated by climate change, which forces us to search for mechanisms to mitigate its consequences. As a result, the concept of sustainability has gained a relevant role in the last decade, especially when there is a need to ensure the survival and welfare, through a balance between humans and nature, through a systemic approach, where the problems can be recognized in an interconnected way (Zeng et al., 2022). Similarly, agriculture is one of the sectors with the greatest challenges in achieving this balance between environment, economy, and social equity. Global guidelines, through seals, certifications and governmental laws, seek to ensure that farmers apply sustainable initiatives (Yu and Wu, 2018). In the case of cut flowers, the review showed that sustainable initiatives are currently being applied in areas such as: a) energy efficiency and environment; b) environmental education, gender equity and labor welfare; c) integrated crop management; d) water resource management; e) post-harvest; and f) biotechnology.

In energy efficiency and environment, for example, a sample of 14 producers in Michigan (USA) showed interest in the use of battery electric tractors (BET), considering that maintenance costs and greenhouse gas emissions (GHGs) are ostensibly reduced; however, financial incentives are insufficient mainly for adoption by small producers (Bessette et al., 2022). However, several studies estimate the low efficiency in the life cycle of crops, from establishment to the distribution chain in automotive vehicles, which causes high emissions of carbon dioxide (CO_2) and methane (CH_4), primarily (Buryan and Buryan, 2020).

On the other hand, integrated crop management initiatives, such as the use of biomasses obtained as bioadsorbents for antibiotics or lead ions in water, have been developed (Sabri et al., 2021), as well as the application of green manures to maintain or improve the productive capacity of soils, in order to discourage the use of animal manures and chemical compounds (Almeida et al., 2017), can generate a higher level of crop sustainability. However, an adequate management of water resources, through the use of wastewater and industrial water, is an alternative for crop irrigation, since through treatment processes such as electrocoagulation, it can be used as a source of water for irrigation (Sakhel and Geissen, 2022), or the use of soil substrates with absorption capacity such as coconut fiber, can help to make a sustainable use of wastewater under the acceptable ranges for the products (Nirit et al., 2006). Beyond economics and the environment, equity or social responsibility is one of the main bases of sustainability, so it is important to develop school models of learning skills for organic agriculture, as well as policy proposals on social responsibility of producers in developing countries (Rasi et al., 2022).

Conclusions

Plant tissue culture technology, such as micropropagation, has revolutionized the floriculture industry by enabling more efficient and cost-effective production of high-quality plant material, thus contributing to the continued growth and development of this important industry. Likewise, genetics and genomics have enriched the diversity of cultivated species, also improving the post-harvest quality and commercial characteristics of flowers.

The management of micro-climatic conditions generated in greenhouses is fundamental to the success in cut flower production, research in this area along with physiological and genotype studies, soil management, water, fertilizers, have contributed to the diversification of the options available in the market and the continuous improvement of cut flower quality, providing innovative tools and approaches to maintain the freshness and quality of cut flowers for longer, thus satisfying market and consumer demands.

In recent years, with the sustainability of the production system in mind, there has been an evolution in pathogen management strategies in commercial flower crops. More sustainable and environmentally friendly approaches have been explored, such as the propagation of resistant plant material, biological control of pests and diseases, the use of essential oils, plant extracts and substrates, and ethological control strategies. In addition, molecular tools have been implemented to identify pathogens and evaluate management practices. In the area of sustainability, we are also exploring practices for efficient use of resources, circularity through environmental education, and even social impact strategies that address issues of salary and gender equity.

For future studies, it is recommended to further advance the integration of these sustainable practices, as well as to explore interdisciplinary approaches that address both environmental and social aspects. It is also critical to continue to research and develop innovative strategies that will boost the quality and longevity of cut flowers, thus meeting the changing demands of the market and consumers.

Author contribution

EV, GAOR, LM, JF-V, CEA, LG, DG, EA, SN: idea creation, data analysis and collection, data analysis, preparation of the manuscript, edition of the manuscript.

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Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability Statement

Data will be made available on request.

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