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Climate-Smart Floriculture: Strategies for Sustainable Flower Production Under a Changing Climate

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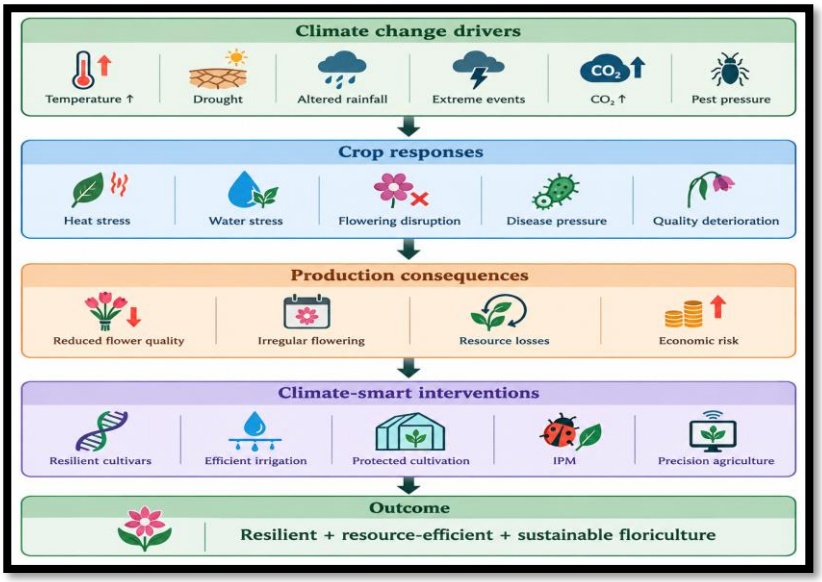
Abstract

Floriculture is a high-value horticultural sector comprising cut flowers, potted flowering plants, foliage plants, ornamental bulbs and nursery plants. The sector is increasingly exposed to climate variability through rising temperature, drought, irregular rainfall, extreme weather events, elevated atmospheric CO_2 and changing pest and disease pressure. These stresses can influence vegetative growth, flowering, flower quality, production scheduling and postharvest performance, thereby affecting the economic value of ornamental crops. Climate-smart floriculture provides an integrated framework for improving resilience while maintaining productivity and resource-use efficiency. Key strategies include climate-resilient cultivar selection, efficient irrigation, soil-moisture conservation, protected cultivation, microclimate regulation, integrated pest management and precision technologies. Genetic improvement offers a long-term approach for developing cultivars capable of maintaining desirable ornamental traits under environmental stress, whereas protected cultivation can buffer crops against external climatic fluctuations. Efficient irrigation, rainwater harvesting and improved soil management can reduce vulnerability to water scarcity, while integrated pest management can address climate-associated changes in pest and disease pressure. Precision agriculture, controlled-environment agriculture and machine-learning-based decision systems offer additional opportunities for real-time monitoring and resource optimisation. However, technological adoption is influenced by investment costs, knowledge availability, extension services, market access and supportive policies. This article discusses the major climate-related risks to floriculture and evaluates integrated strategies for developing productive, resource-efficient and climate-resilient flower production systems.

Keywords: Climate change, Climate-smart floriculture, Heat stress, Drought, Protected cultivation, Water management.

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1. Introduction



Over the years, floriculture has transformed from a largely ornamental pursuit into a specialised commercial industry, covering the production, handling, marketing, and distribution of cut flowers, potted plants, foliage plants, bulbs, and nursery crops. Commercial flower production is closely linked with consumer preferences and therefore depends on characteristics such as flower size, colour, shape, fragrance, freshness and vase life. These quality requirements make ornamental crops particularly sensitive to environmental fluctuations. Climate change is becoming an important constraint to sustainable floriculture. Rising temperatures, altered precipitation, drought, flooding and changing pest and disease pressure can affect crop growth and flowering and can increase the difficulty of maintaining consistent commercial quality. Recent horticultural assessments similarly identify increasing temperature, changing rainfall, drought and flooding as major pressures affecting crop performance and postharvest quality. Climate-smart horticulture aims to improve productivity and resilience while encouraging efficient use of natural resources and reducing climate-related risks. In floriculture, this concept must be adapted to the specific requirements of ornamental crops, where productivity alone does not determine commercial value. A plant may exhibit good growth and flower production, yet its flowers may have limited marketability if environmental stresses adversely affect important quality attributes such as colour, size, shape, fragrance, or vase life.

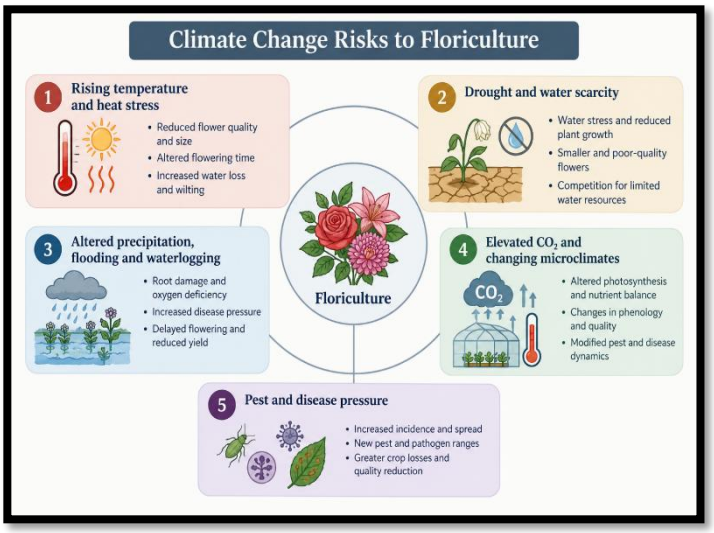
2. Climate Change Risks to Floriculture:

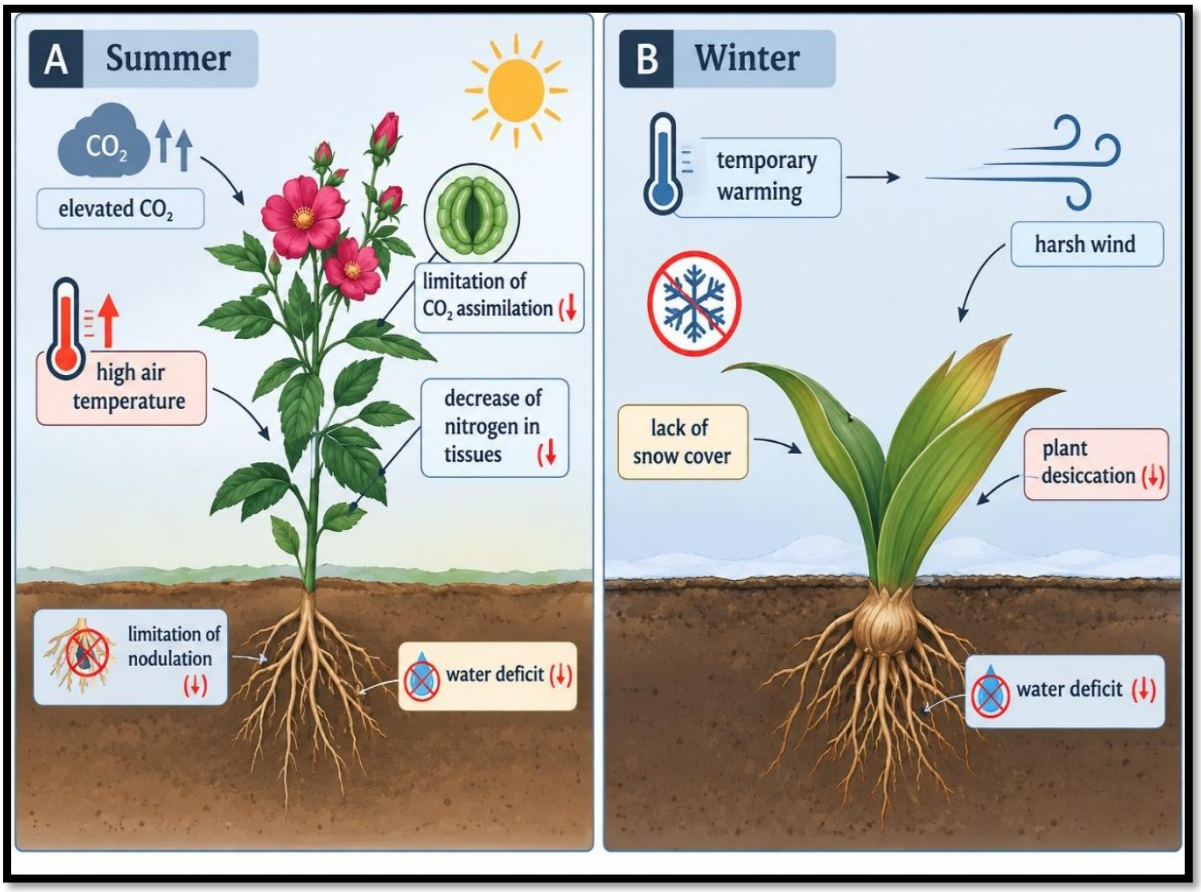
Rising temperature and heat stress

Temperature strongly influences vegetative growth, flowering and reproductive development. Increasing temperature can disturb crop phenology and reduce flower quality when conditions exceed the optimum range for a particular crop. In sensitive ornamental crops, heat

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stress can influence flower initiation, flower size, colour development and the duration of flowering. The effects are particularly important in commercial floriculture because even relatively small changes in flower characteristics can reduce market value. Temperature variability can also make flowering and harvesting less predictable, creating difficulties for growers supplying markets with fixed dates and quality requirements.





➢ **Drought and water scarcity**

Water scarcity is an important component of climate vulnerability. Reduced soil moisture increases plant water stress and may lead to stomatal closure, reduced photosynthesis, impaired

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nutrient uptake and reduced growth. The problem becomes more important where flower production depends on irrigation and where climatic conditions increase evapotranspiration. Efficient irrigation is essential for climate-smart floriculture, as it helps use water wisely and maintain healthy crop growth under changing climatic conditions. Drip and micro-irrigation can improve water-use efficiency by delivering water directly to the root zone, while mulching and soil-moisture conservation can reduce evaporative losses. Rainwater harvesting provides an additional opportunity for reducing dependence on irregular external water supplies.

- **Altered precipitation, flooding and waterlogging**

Climate variability may result in both prolonged dry periods and intense rainfall. Excessive rainfall can cause waterlogging, erosion, nutrient losses and root-zone problems. Raised beds, improved drainage and appropriate planting systems can reduce the effects of excess water. The importance of water management therefore extends beyond irrigation. Climate-smart floriculture requires a balanced approach in which water is efficiently supplied during dry periods while excess rainfall is rapidly removed during wet periods.

- **Elevated CO_2 and changing microclimates**

Increasing atmospheric CO_2 can stimulate photosynthetic activity and vegetative biomass in some crops, but the response does not necessarily translate into improved flower quality. Changes in carbon allocation between vegetative and reproductive growth may influence commercially important floral characteristics. Similarly, changes in humidity and light can affect flower development and disease incidence. High humidity can favour fungal diseases, while changes in light conditions may influence photoperiod-sensitive ornamental crops. These interactions highlight the importance of maintaining an appropriate crop microclimate rather than considering individual climatic factors independently.

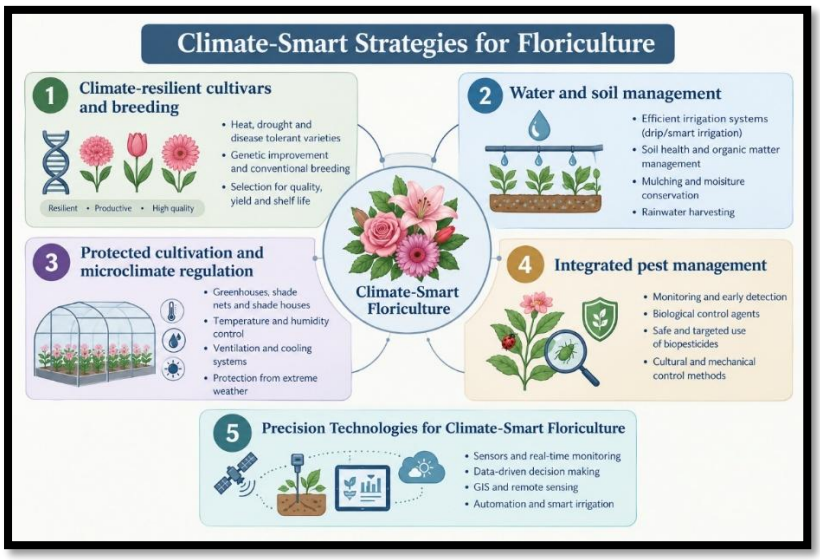
- **Pest and disease pressure**

Climate change can alter insect pest biology, distribution and population dynamics. Warmer conditions may shorten pest developmental periods and increase the potential for additional generations, while altered humidity can influence disease development. Consequently, pest management strategies need to consider both current infestation and climatic conditions favouring future outbreaks.

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3. Climate-Smart Strategies for Floriculture:

- **Climate-resilient cultivars and breeding**



The development and adoption of climate-resilient cultivars provide one of the most sustainable approaches to adaptation. Selection should consider tolerance to heat, drought and other environmental stresses while retaining commercially important characteristics. Future breeding programmes can integrate conventional selection with molecular tools and improved phenotyping. Importantly, tolerance should not be evaluated only in terms of plant survival or biomass. In floriculture, a useful climate-resilient cultivar should maintain desirable flower colour, size, form, fragrance and postharvest quality under stress.

- **Water and soil management**

Water management should combine efficient irrigation with soil-moisture conservation. Drip and micro-irrigation, rainwater harvesting, mulching, organic amendments and improved soil structure can contribute to efficient water use. These measures should be integrated according to local climatic conditions. In drought-prone areas, priority should be given to reducing water losses and improving root-zone moisture availability. In high-rainfall regions, drainage and raised beds become equally important.

- **Protected cultivation and microclimate regulation**

Greenhouses, polyhouses and shade structures provide an important buffer against external climatic fluctuations. Controlled environments can regulate temperature, humidity, radiation and water availability and are particularly useful for high-value ornamental crops. Controlled-environment agriculture is increasingly recognised as an important research area within horticultural production. However, protected cultivation can require substantial investment and energy inputs. Therefore, the choice between simple structures and advanced climate-control systems should be based on crop value, local climate, energy availability and economic feasibility.

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➢ **Integrated pest management**

Integrated pest management combines cultural, biological and chemical approaches and provides a more sustainable response to changing pest pressure. Resistant cultivars, sanitation, biological control, monitoring and targeted pesticide use can reduce dependence on repeated chemical applications. Climate information can further improve IPM by helping identify periods favourable for pest development. Such approaches can shift pest management from a reactive system towards preventive and timely intervention.

➢ **Precision Technologies for Climate-Smart Floriculture**

Precision agriculture can improve the monitoring and management of crop environments. IoT-based sensing, data analytics and machine learning can support decisions involving irrigation, environmental control and crop monitoring. In protected floriculture, sensors can continuously monitor temperature, humidity, soil moisture and other environmental variables. These data can be used to trigger irrigation, ventilation or cooling according to crop requirements rather than fixed schedules. Controlled-environment agriculture can further reduce exposure to external climatic variability. However, technological approaches should complement rather than replace basic agronomic management. The most appropriate system will depend on crop requirements, production scale, infrastructure and economic resources.

Table 1. Major climate risks to floriculture and potential responses

Climate stress	Major consequences for floriculture	Climate-smart response
Rising temperature	Heat stress, flowering disturbance, reduced flower quality	Heat-tolerant cultivars, shading, cooling and protected cultivation
Drought	Reduced growth, water stress, lower flower quality	Drip irrigation, mulching, rainwater harvesting, water-efficient scheduling
Heavy rainfall	Waterlogging, nutrient loss, root damage	Raised beds, drainage and improved soil management
High humidity	Greater disease pressure	Ventilation, microclimate regulation and IPM

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Changing light	Altered flowering and crop scheduling	Protected cultivation and photoperiod management
Changing pest pressure	Increased infestation and crop damage	Monitoring, resistant cultivars and IPM
Climate variability	Irregular flowering and production scheduling	Climate information, forecasting and precision management

4. Climate-Smart Management Across the Floriculture Value Chain

Climate adaptation should not be restricted to crop production. Flowers are highly perishable and therefore vulnerable throughout harvesting, packaging, transportation, storage and marketing. Recent horticultural research also emphasises that climate-related deterioration can continue after harvest, increasing losses during storage, transportation and marketing. A climate-smart value chain should therefore combine resilient production with efficient postharvest handling. Improved temperature management, appropriate packaging, efficient transportation and cold-chain systems can help maintain flower quality.

Table 2. Climate-smart interventions across the floriculture production chain

Production stage	Major climate-related risk	Recommended intervention
Site selection	Increasing climatic variability	Climate suitability assessment
Cultivar selection	Heat and drought	Climate-resilient cultivars
Crop establishment	Water stress	Efficient irrigation and soil-moisture conservation
Crop growth	Heat and humidity	Shade, ventilation and protected cultivation
Pest management	Changing pest and disease pressure	IPM and climate-based monitoring
Flowering	Irregular crop phenology	Environmental regulation and forecasting
Harvest	Heat-induced quality loss	Timely harvesting and rapid cooling
Transportation	Temperature fluctuation	Efficient cold-chain management

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Storage	Accelerated deterioration	Temperature and humidity management
Marketing	Quality loss and supply disruption	Improved logistics and value-chain coordination

5. Socioeconomic Considerations and Adoption Challenges

The technical effectiveness of climate-smart practices does not automatically guarantee their adoption. Initial investment, access to credit, technical knowledge, extension services, market access and availability of climate information influence the ability of producers to implement new technologies. This issue is particularly important for small and resource-constrained growers. Climate-smart technologies should therefore not be limited to high-cost automated systems. Affordable irrigation systems, mulching, shade structures, rainwater harvesting, improved cultivars, and basic environmental monitoring can serve as practical and accessible measures for climate-smart floriculture. Knowledge sharing and capacity building are also important. Effective extension services can help producers understand the economic benefits of climate-smart practices and select approaches appropriate for their local conditions. Supportive government policies, financial incentives and improved market access can further encourage adoption. Climate -smart agriculture research also shows that adoption is influenced by economic, institutional, demographic, climatic and sociocultural factors, indicating that technological interventions need to be accompanied by appropriate institutional support.

Table 3. Climate-smart floriculture strategies: benefits and limitations

Strategy	Main benefit	Major limitation/consideration
Resilient cultivars	Long-term adaptation	Breeding must retain ornamental quality
Drip/micro-irrigation	Improved water-use efficiency	Installation cost and maintenance
Mulching	Reduced evaporation and improved soil moisture	Material availability and management
Protected cultivation	Buffering against climatic extremes	Capital and energy requirements
IPM	Reduced chemical dependence	Requires monitoring and technical knowledge

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Precision agriculture	Real-time management	Sensors, data and technical expertise
Controlled environments	Greater environmental control	High infrastructure and energy requirements
Climate forecasting	Better production decisions	Requires reliable local data
Extension and training	Improves adoption	Requires sustained institutional support

6. Future Perspectives and Research Priorities

The future of climate-smart floriculture lies in integrating biological adaptation with technological and socioeconomic solutions. Research should focus on developing ornamental cultivars capable of maintaining commercial quality under combined heat, drought and humidity stresses. Greater attention is also required for interactions among temperature, water availability, CO_2 and pest pressure. Climate responses should be evaluated under realistic combinations of stresses rather than under individual stress conditions. Precision technologies offer another major research opportunity. IoT-based environmental monitoring, machine learning and controlled-environment production can provide more precise crop management. However, floriculture-specific datasets remain important for developing reliable decision-support systems. Future research should also examine the entire flower value chain. Production resilience will have limited value if flowers subsequently experience substantial losses during transportation or marketing. Integrated climate-smart systems should therefore connect production, postharvest management, logistics and market requirements. A further opportunity is the use of ornamental plants within climate-resilient urban landscapes. Ornamental plants can contribute to urban greening, environmental improvement and human well-being, extending the role of floriculture beyond commercial flower production.

7. Conclusions

Climate change presents a multidimensional challenge to floriculture by influencing temperature, water availability, rainfall, humidity, pests, diseases and production stability. Because ornamental crops are marketed primarily according to quality attributes, climate stress can have economic consequences even when plants remain alive and productive. Climate-smart floriculture should therefore combine climate-resilient cultivars, efficient irrigation, soil-moisture conservation, protected cultivation, microclimate management and integrated pest management. Precision agriculture, controlled-environment agriculture and machine-learning-based decision

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systems can strengthen these approaches by improving monitoring and resource-use efficiency. The most effective strategy will not be a single technology but an integrated, crop-specific and economically feasible production system. Research, extension services, producers, policymakers and technology developers need to work together to ensure that climate-smart innovations are accessible and adaptable. Such integration can help maintain flower quality and productivity while improving the environmental and economic sustainability of floriculture under a changing climate.

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