

## **A Comprehensive Review of Strawberry (*Fragaria* × *ananassa*) Farming: Advancements, Challenges, and Sustainable Pathways**

**Pujarani Rath<sup>1\*</sup>, Naval Kishore Meena<sup>2</sup>, Nitu Kumari<sup>3</sup>, Satyam Singh<sup>4</sup>,  
Meena Yadav<sup>5</sup>, Sejal Kumawat<sup>6</sup>**

<sup>1</sup>Ph.D. Scholar, Department of Fruit Science and Horticulture Technology,  
College of Agriculture, OUAT, Bhubaneswar, Odisha

<sup>2,5</sup>Ph.D. Scholar, Department of Horticulture (Fruit Science), RCA, MPUAT, Udaipur-313001, Rajasthan

<sup>3,4</sup>Ph.D. Scholar, Department of Fruit Science,  
Rani Lakshmi Bai Central Agricultural University, Jhansi, Uttar Pradesh, 284003

<sup>6</sup>M.Sc. Scholar, Department of Fruit Science,  
Sardar Krushinaga Dantewada Agricultural University, Gujarat

\*Corresponding Author E-mail: [pujaranirath554@gmail.com](mailto:pujaranirath554@gmail.com)

Received: 16.03.2025 | Revised: 29.04.2025 | Accepted: 18.05.2025

### **ABSTRACT**

*Strawberry (*Fragaria* × *ananassa*) is one of the most economically significant soft fruit crops globally, valued for its rich nutritional profile and high market demand. Global production surpassed 9.7 million metric tonnes in 2023, with China, the United States, and Turkey being the leading producers. Despite remarkable advancements in breeding, cultivation technologies, and post-harvest management, strawberry farming continues to face formidable challenges, including fungal diseases such as *Botrytis cinerea* and *Colletotrichum acutatum*, pest infestations, climate change-induced thermal stress, soil degradation, and post-harvest losses. This review comprehensively examines the current state of strawberry farming worldwide, highlighting recent technological advancements including precision agriculture, hydroponics, vertical farming, and molecular breeding. It further evaluates sustainable pathways such as integrated pest management, biological control, nanotechnology applications, and climate-smart cultivation strategies. The synthesis of current literature aims to provide researchers, growers, and policymakers with an evidence-based framework for advancing resilient and sustainable strawberry production systems.*

**Keywords:** *Strawberry cultivation; Sustainable agriculture; Precision farming; Integrated pest management; Climate-smart agriculture.*

**Cite this article:** Rath, P., Meena, N. K., Kumari, N., Singh, S., Yadav, M., & Kumawat, S. (2025). A Comprehensive Review of Strawberry (*Fragaria* × *ananassa*) Farming: Advancements, Challenges, and Sustainable Pathways, *Curr. Rese. Agri. Far.* 6(3), 37-46. doi: <http://dx.doi.org/10.18782/2582-7146.271>

This article is published under the terms of the [Creative Commons Attribution License 4.0](https://creativecommons.org/licenses/by/4.0/).

## INTRODUCTION

The cultivated strawberry (*Fragaria × ananassa* Duch.) is a widely cultivated perennial fruit crop belonging to the family Rosaceae, recognized for its distinctive flavour, vibrant colour, and exceptional nutritional value (Giampieri et al., 2012). Strawberries are rich sources of vitamin C, folate, manganese, dietary fibre, and an array of bioactive phytochemicals including anthocyanins, ellagic acid, and quercetin, which confer significant antioxidant and anti-inflammatory health benefits (Afrin et al., 2016). The modern cultivated strawberry is an octoploid hybrid ( $2n = 8x = 56$ ) that originated in the 18th century from the accidental hybridization of *Fragaria virginiana* and *Fragaria chiloensis* in European botanical gardens (Darrow, 1966).

Globally, strawberry production has witnessed a remarkable upward trajectory over the past two decades. According to FAOSTAT (2024) data, worldwide production reached approximately 9.7 million metric tonnes in 2023, with China dominating at over 4.2 million tonnes, followed by the United States (1.25 million tonnes), Egypt (731,000 tonnes), Turkey (677,000 tonnes), and Mexico (642,000 tonnes). This growth has been driven by consumer demand, breeding innovations, expanded cultivation into subtropical and tropical regions, and the adoption of advanced agricultural technologies (Samtani et al., 2019). Initially limited to temperate climates, strawberry cultivation has expanded

significantly due to the development of day-neutral cultivars that rely solely on temperature cues rather than photoperiod, enabling production across a broader geographic range at temperatures between 4–29°C (Hernández-Martínez et al., 2023).

Despite these advancements, strawberry farming faces multifaceted challenges. The crop is highly susceptible to soil-borne pathogens, foliar diseases, and arthropod pests, necessitating intensive chemical inputs that raise environmental and food safety concerns (Koike & Bolda, 2016). Climate change further compounds these issues through increased frequency of thermal extremes, altered precipitation patterns, and shifting pest dynamics (Dara, 2019). Soil degradation resulting from the phase-out of methyl bromide fumigation, water scarcity, and the highly perishable nature of the fruit add additional layers of complexity to sustainable production (Fennimore & Goodhue, 2016).

This review aims to provide a comprehensive synthesis of the current state of strawberry farming, examining recent advancements in cultivation technologies, persistent challenges, and emerging sustainable pathways. By integrating findings from diverse disciplines including agronomy, plant pathology, genetics, and environmental science, this paper seeks to offer an evidence-based framework for guiding future research and practice toward resilient strawberry production systems.

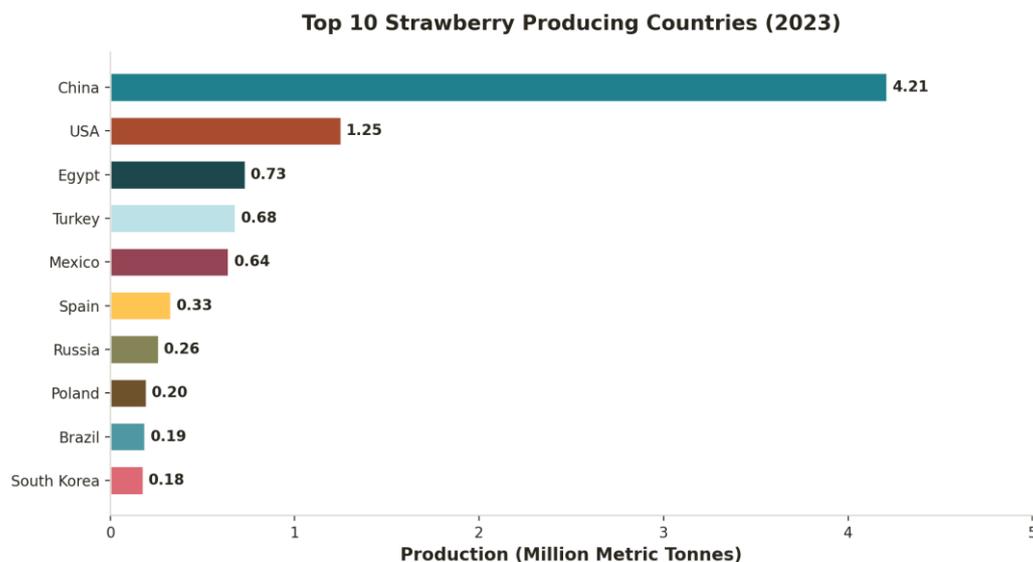


Figure1. Open-field strawberry cultivation with raised beds, plastic mulch, and drip irrigation system  
Copyright © May-June, 2025; CRAF

## 2. Global Production and Economic Significance

The global strawberry industry represents a multi-billion dollar sector with production concentrated in a few key countries. China has maintained its position as the world's leading producer since 1994, with three provinces—Hebei, Shandong, and Liaoning—accounting for over 60% of national production (FAOSTAT, 2024). In the United States,

California is responsible for approximately 90% of the national crop, with Florida, Oregon, North Carolina, and Michigan contributing the remainder (USDA, 2023). The European Union, led by Spain, Poland, and Germany, represents another significant production bloc, while Turkey and Egypt have emerged as major producers in the Mediterranean region (Eurostat, 2023).



**Figure2. Top 10 global strawberry-producing countries by production volume (2023). Data source: FAOSTAT (2024)**

The economic value of strawberry cultivation extends beyond fresh market sales to encompass processed products including frozen berries, jams, juices, and flavouring extracts. The crop provides substantial employment opportunities, particularly during the labour-intensive harvesting season, and plays a vital role in rural livelihoods in many developing countries. In subtropical nations such as Bangladesh, India, and several African countries, strawberry cultivation is emerging as a profitable horticultural enterprise, offering faster returns on investment compared to many perennial fruit crops (Hossain et al., 2021).

## 3. Advancements in Cultivation Technologies

### 3.1 Precision Agriculture and Smart Farming

Precision agriculture has revolutionized strawberry production through the integration

of Internet of Things (IoT) sensors, unmanned aerial vehicles (UAVs), and artificial intelligence-based decision support systems. Modern strawberry farms employ sensor networks for real-time monitoring of soil moisture, temperature, humidity, and nutrient levels, enabling data-driven irrigation and fertilization decisions that optimize resource use and reduce waste (Shamshiri et al., 2018). Weather-based advisory systems, such as the Strawberry Advisory System (SAS) developed in Florida, utilize temperature and leaf wetness duration models to predict disease development and recommend precisely timed fungicide applications, significantly reducing unnecessary chemical inputs while maintaining effective disease control (Pavan et al., 2011).

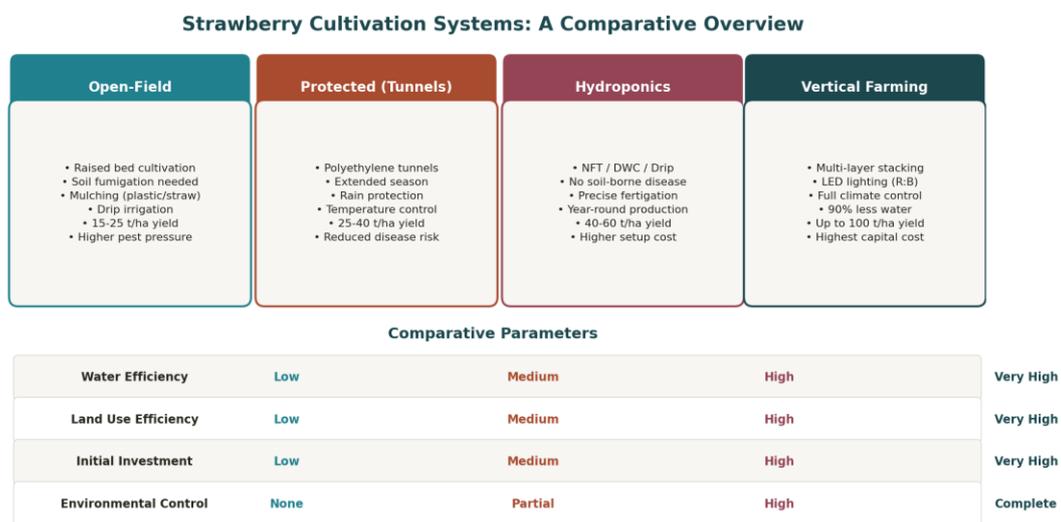
Robotic harvesting systems represent another frontier in strawberry technology.

Companies like Oishii have pioneered indoor vertical strawberry farms equipped with state-of-the-art robotics, multi-million-dollar water purification systems, and custom sensor packs that control humidity, temperature, and CO<sub>2</sub> levels with unprecedented precision (Koga, 2024). These systems can supplement specific light wavelengths using LED lighting to optimize fruit quality and sweetness.

### 3.2 Soilless Cultivation and Hydroponics

Soilless cultivation systems have gained considerable traction in strawberry production, offering solutions to soil-borne disease problems and enabling precise control over the

root zone environment. The primary hydroponic systems employed include Nutrient Film Technique (NFT), Deep Water Culture (DWC), and substrate-based drip irrigation systems using media such as coconut coir, perlite, and rockwool (Sharma et al., 2021). Research comparing these systems has demonstrated that coir-based substrate culture generally outperforms water-culture systems for total marketable yield and resource-use efficiency, making it the safer choice for commercial producers prioritizing productivity (Whitaker et al., 2025).



**Figure3. Comparative overview of strawberry cultivation systems: open-field, protected tunnels, hydroponics, and vertical farming**

Stage-specific nutrient management has emerged as a critical factor in soilless strawberry production. Research indicates that implementing a two-phase potassium-to-nitrogen (K:N) balance strategy—higher K:N ratios during vegetative growth followed by lower ratios during fruit production—can increase yields by up to 30% while simultaneously improving fruit firmness and shelf life (Hernandez-Apaolaza, 2024). Vertical farming systems, exemplified by Oishii’s Amatelas Farm spanning over 237,500 square feet, demonstrate the potential for year-round production with up to 90% less water consumption compared to conventional open-field systems (Koga, 2024).

### 3.3 Breeding and Genetic Improvement

Strawberry breeding has entered a transformative era with the integration of molecular tools and genomic approaches. The octoploid nature ( $2n = 8x = 56$ ) of cultivated strawberry presents unique challenges for genetic analysis, but recent advances in quantitative trait locus (QTL) mapping and genome-wide association studies (GWAS) have facilitated the identification of markers linked to important traits including fruit quality, disease resistance, and abiotic stress tolerance (Edger et al., 2019). Marker-assisted selection (MAS) enables breeders to efficiently introgress desirable genes from wild relatives into elite cultivars, accelerating

the development of improved varieties (Pott et al., 2023).

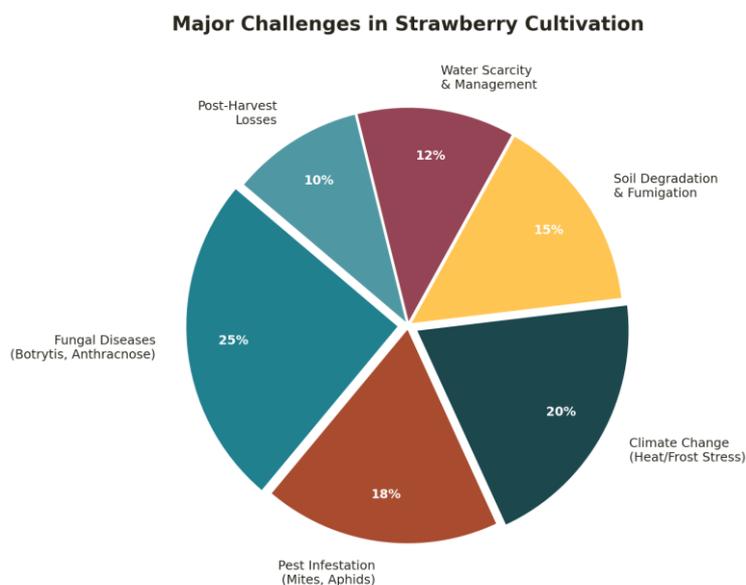
Genomic prediction models and CRISPR/Cas9 genome editing technologies offer promising avenues for accelerating breeding cycles and precisely modifying traits related to flavour, disease resistance, and shelf life. Breeding programmes worldwide are increasingly focusing on developing cultivars with enhanced resistance to grey mould (*Botrytis cinerea*), anthracnose (*Colletotrichum* spp.), and improved tolerance to heat and drought stress (Porter et al., 2023). Day-neutral cultivars that produce fruit throughout the growing season, independent of photoperiod, have expanded cultivation into non-traditional subtropical and tropical regions (Hernández-Martínez et al., 2023).

#### 4. Challenges in Strawberry Farming

##### 4.1 Diseases and Pest Management

Strawberry crops are highly vulnerable to a complex of fungal, bacterial, and viral diseases

that can cause devastating yield losses. Grey mould caused by *Botrytis cinerea* is the most economically important post-harvest disease, capable of causing losses exceeding 50% under favourable conditions of high humidity and moderate temperatures (Petrasch et al., 2019). Anthracnose fruit rot caused by *Colletotrichum acutatum* is particularly destructive in warm, humid climates, while soil-borne pathogens including *Phytophthora* spp., *Verticillium dahliae*, and *Fusarium oxysporum* cause crown rot, wilt, and root diseases (Koike & Bolda, 2016). Major arthropod pests include two-spotted spider mites (*Tetranychus urticae*), aphids, thrips, and spotted wing drosophila (*Drosophila suzukii*), which directly damage fruit and can serve as vectors for viral pathogens (Dara, 2019).



**Figure4. Distribution of major challenges affecting strawberry cultivation globally**

##### 4.2 Climate Change Impacts

Climate change poses an escalating threat to strawberry production through multiple mechanisms. Rising temperatures disrupt vernalization requirements, alter flowering patterns, and reduce fruit set and quality (Heide et al., 2013). Research on thermal vulnerability of strawberry cultivars has

revealed that flowers exhibit significantly lower freezing tolerance than leaves, suggesting that freeze-induced damage during spring frosts may increasingly constrain production in traditional growing regions (González-Villagra et al., 2025). Niche modelling under warming scenarios projects a poleward shift in suitable cultivation areas,

with decreased suitability in subtropical regions of North America, Europe, eastern Asia, and southeastern Australia (González-Villagra et al., 2025). Increased climate variability, including irregular rainfall patterns and more frequent extreme weather events, further complicates production planning and pest management strategies (USDA, 2016).

#### 4.3 Soil Health and Chemical Dependency

The phase-out of methyl bromide as a soil fumigant under the Montreal Protocol has created significant challenges for strawberry growers who relied heavily on this broad-spectrum biocide for controlling soil-borne pathogens, nematodes, and weeds (Fennimore & Goodhue, 2016). Alternative chemical fumigants and non-chemical approaches, including anaerobic soil disinfestation, biofumigation with brassica cover crops, and soil solarization, have been developed but often provide inconsistent or inferior control compared to methyl bromide (Samtani et al., 2019). The excessive reliance on chemical fertilizers, which account for approximately one-third of strawberry cultivation costs, further degrades soil health by disrupting microbial communities and reducing organic matter content (Rahman et al., 2025).

#### 4.4 Post-Harvest Losses and Perishability

Strawberries are among the most perishable of commercially important fruits, with a typical shelf life of only 5–7 days under optimal refrigeration at 0–1°C and 90–95% relative humidity. Rapid pre-cooling through forced-air systems is essential, as it can remove field heat within approximately 90 minutes compared to 9 hours for conventional refrigeration (Cornell University, 2020). Post-harvest losses can be substantial, particularly in developing countries where cold chain infrastructure is inadequate, resulting in significant economic losses and food waste throughout the supply chain.

### 5. Sustainable Pathways for Strawberry Production

#### 5.1 Integrated Pest Management

Integrated Pest Management (IPM) represents a cornerstone of sustainable strawberry production, combining cultural, biological, and

chemical strategies to maintain pest populations below economically damaging thresholds while minimizing environmental impact (Dara, 2019). Cultural practices including crop rotation, use of resistant cultivars, optimization of planting dates, and sanitation measures form the foundation of IPM programmes. Biological control agents, particularly predatory mites (*Phytoseiulus persimilis* and *Neoseiulus californicus*) for spider mite control, and bumblebees for pollination enhancement, have become essential components of commercial strawberry production (Biobest, 2023). Innovative Breeding for Integrated Pest Management (B-IPM) approaches are being developed that combine cultivar resistance with enhanced facilitation of biological control agents (Menz et al., 2025).

#### 5.2 Organic and Integrated Nutrient Management

The combined application of organic and inorganic fertilizers offers a sustainable approach to maintaining soil health while optimizing strawberry productivity. Research conducted in Bangladesh demonstrated that applying 3 tonnes per hectare of poultry manure combined with 125% of the recommended inorganic NPKSZnB fertilizer dose produced the highest yield (10.9 t/ha), improved fruit quality attributes including vitamin C content and total soluble solids, and enhanced soil health indicators (Rahman et al., 2025). Organic amendments including vermicompost, cattle manure, and poultry manure gradually release nutrients, promote beneficial soil microbial activity, improve soil structure and water retention, and enhance disease suppression capacity (Singh et al., 2020).

#### 5.3 Nanotechnology Applications

Nanotechnology is emerging as a promising frontier for enhancing strawberry production sustainability. Nano-formulated fertilizers improve nutrient uptake efficiency by providing controlled-release nutrient delivery directly to plant roots and foliage, reducing overall fertilizer requirements and environmental contamination (Kumar et al.,

2025). Nano-biopesticides based on materials such as chitosan nanoparticles offer targeted pest and disease control with reduced environmental persistence compared to conventional pesticides. Post-harvest applications of chitosan and glycine betaine nanoparticle coatings have demonstrated significant effectiveness in reducing fruit decay, minimizing weight loss, and preserving firmness and biochemical quality, extending shelf life considerably (Abdelrahman et al., 2024).

**5.4 Climate-Smart Strategies**

Adapting strawberry production to climate change requires a multi-pronged approach encompassing varietal development, cultivation system modification, and management practice optimization. Breeding programmes are targeting enhanced heat and drought tolerance, with a focus on developing cultivars with broader thermal tolerance

breadth (González-Villagra et al., 2025). Protected cultivation systems, including high tunnels and controlled environment agriculture, buffer crops against climate extremes while enabling season extension and improved water use efficiency (Salamone et al., 2021). The integration of arbuscular mycorrhizal fungi, plant growth-promoting rhizobacteria, and other beneficial microorganisms enhances plant resilience to both abiotic and biotic stresses, offering biological solutions to climate adaptation (Singh et al., 2019). Decision support tools such as the CROPGRO-Strawberry model within DSSAT facilitate simulation of growth and yield under variable environmental conditions, enabling growers to optimize planting schedules and management strategies for changing climatic conditions (González-Villagra et al., 2025).

Figure 3: Sustainable Pathways for Modern Strawberry Farming

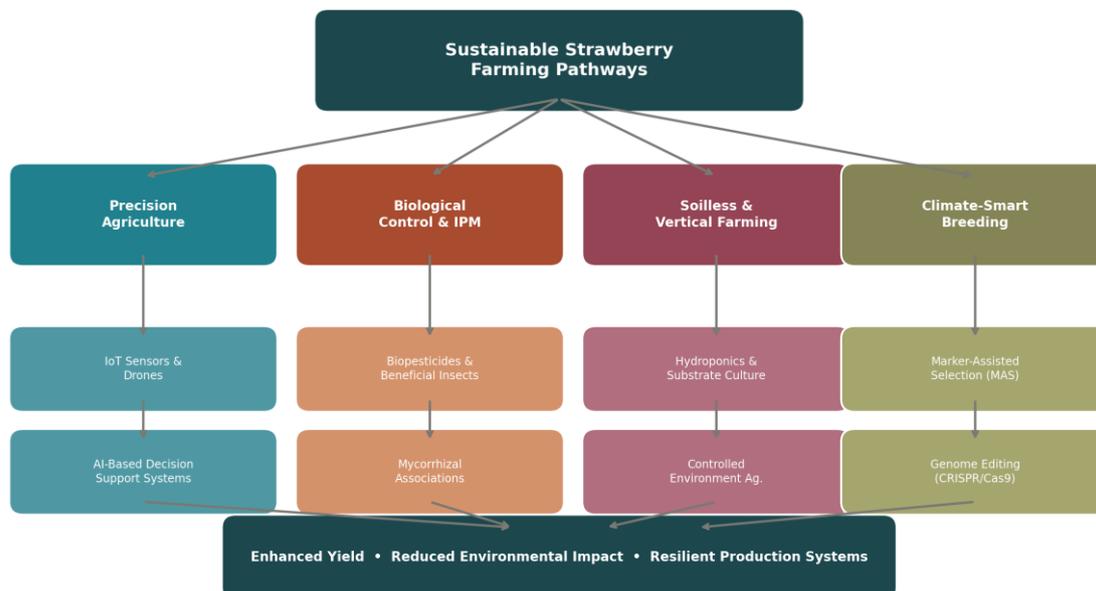


Figure5. Conceptual framework of sustainable pathways for modern strawberry farming systems

**CONCLUSION**

Strawberry farming stands at a critical juncture where the intersection of technological innovation and environmental stewardship will determine the future trajectory of this globally important horticultural industry. This review has highlighted the remarkable advancements achieved in precision agriculture, soilless

cultivation systems, molecular breeding, and post-harvest technologies that have expanded production capabilities and improved fruit quality and consistency. Simultaneously, the persistent challenges of disease pressure, climate variability, soil degradation, and post-harvest losses demand continued attention and innovative solutions.

The sustainable pathways identified in this review—including integrated pest management, organic-inorganic nutrient integration, nanotechnology applications, and climate-smart strategies—offer viable frameworks for transitioning toward more resilient and environmentally responsible production systems. The convergence of genomic tools, artificial intelligence, and controlled environment agriculture holds particular promise for developing next-generation strawberry cultivars and production platforms that can meet growing consumer demand while minimizing ecological footprints.

Future research priorities should focus on developing climate-resilient cultivars through accelerated breeding programmes leveraging genomic selection and genome editing technologies, advancing economically viable biological alternatives to chemical pest and disease management, optimizing soilless and vertical farming systems for broader commercial adoption, and strengthening post-harvest cold chain infrastructure in developing countries. Collaborative efforts among breeders, agronomists, plant pathologists, engineers, and policymakers will be essential to realize the full potential of sustainable strawberry production in an era of unprecedented environmental and demographic change.

#### **Acknowledgement:**

I would like to sincerely thank my co-authors for their support and kind gesture to complete this manuscript in time.

**Funding:** NIL.

#### **Conflict of Interest:**

There is no such evidence of conflict of interest.

#### **Author Contribution:**

All authors have participated in critically revising of the entire manuscript and approval of the final manuscript.

### **REFERENCES**

- Abdelrahman, S. H., El-Mogy, M. M., & Fahmy, K. (2024). Enhancing postharvest quality and shelf life of strawberries through chitosan-glycine betaine nanoparticle coatings. *Plants*, *13*(8), 1128. <https://doi.org/10.3390/plants13081128>
- Afrin, S., Gasparrini, M., Forbes-Hernández, T. Y., Reboredo-Rodríguez, P., Mezzetti, B., Varela-López, A., Giampieri, F., & Battino, M. (2016). Promising health benefits of the strawberry: A focus on clinical studies. *Journal of Agricultural and Food Chemistry*, *64*(22), 4435–4449. <https://doi.org/10.1021/acs.jafc.6b00857>
- Biobest Group. (2023). Biological control and pollination: Strawberry crop. <https://www.biobest.com/crops/strawberry>
- Cornell University. (2020). Strawberry harvest and storage/shipping considerations. Cornell Cooperative Extension. [https://rvpadmin.cce.cornell.edu/uploads/doc\\_98.pdf](https://rvpadmin.cce.cornell.edu/uploads/doc_98.pdf)
- Dara, S. K. (2019). A sustainable way of producing strawberries using the new IPM model. University of California Agriculture and Natural Resources. <https://ucanr.edu/blog/e-journal-entomology-and-biologicals/article/sustainable-way-producing-strawberries-using-new>
- Darrow, G. M. (1966). The strawberry: History, breeding and physiology. Holt, Rinehart & Winston.
- Edger, P. P., Poorten, T. J., VanBuren, R., Hardigan, M. A., Colle, M., McKain, M. R., Smith, R. D., Teresi, S. J., Nelson, A. D. L., Wai, C. M., Alger, E. I., Bird, K. A., Yocca, A. E., Pumplin, N., Ou, S., Ben-Zvi, G., Brober, A., Baruch, K., Swale, T., & Knapp, S. J. (2019). Origin and evolution of the octoploid strawberry genome. *Nature Genetics*, *51*(3), 541–547. <https://doi.org/10.1038/s41588-019-0356-4>

- Eurostat. (2023). Agricultural production data: Strawberries. European Commission. <https://ec.europa.eu/eurostat>
- FAOSTAT. (2024). Food and Agriculture Organization of the United Nations statistical database: Strawberry production data. <https://www.fao.org/faostat>
- Fennimore, S. A., & Goodhue, R. E. (2016). Soil disinfection with steam: A review of economics, engineering, and soil pest control in California strawberry. *International Journal of Fruit Science*, 16(S1), 71–83. <https://doi.org/10.1080/15538362.2016.1195312>
- Giampieri, F., Tulipani, S., Alvarez-Suarez, J. M., Quiles, J. L., Mezzetti, B., & Battino, M. (2012). The strawberry: Composition, nutritional quality, and impact on human health. *Nutrition*, 28(1), 9–19. <https://doi.org/10.1016/j.nut.2011.08.009>
- González-Villagra, J., Reyes-Díaz, M., & Bravo, L. A. (2025). Thermal vulnerability and potential cultivation areas of four day-neutral strawberry varieties. *Plants*, 14(20), 3083. <https://doi.org/10.3390/plants14203083>
- Heide, O. M., Stavang, J. A., & Sønsteby, A. (2013). Physiology and genetics of flowering in cultivated and wild strawberries: A review. *Journal of Horticultural Science and Biotechnology*, 88(1), 1–18. <https://doi.org/10.1080/14620316.2013.11512930>
- Hernández-Martínez, N. R., Blanchard, C., Wells, D., & Pérez-Ruiz, M. (2023). Challenges of climate change to strawberry cultivation: A review. *Scientia Horticulturae*, 307, 111531. <https://doi.org/10.1016/j.scienta.2022.111531>
- Hernandez-Apaolaza, L. (2024). Recent findings in hydroponic and soilless strawberries: A data-first approach. *Scientia Horticulturae*, 329, 113642.
- Hossain, M. M., Rabbani, M. G., & Rahaman, E. H. M. S. (2021). Strawberry cultivation in South Asia: Prospects and challenges. *HortScience*, 56(8), 894–901. <https://doi.org/10.21273/HORTSCI15861-21>
- Koga, H. (2024). Oishii: Combining time-honored growing techniques with the ingenuity of vertical farming. <https://oishii.com/pages/our-farms>
- Koike, S. T., & Bolda, M. P. (2016). Charcoal rot of strawberry in California caused by *Macrophomina phaseolina*. *Plant Disease*, 100(12), 2537. <https://doi.org/10.1094/PDIS-06-16-0835-PDN>
- Kumar, A., Singh, R., & Sharma, P. (2025). Nanoagrochemicals: Ensuring sustainable productivity through nutrient and pest management in strawberry. *Biocatalysis and Agricultural Biotechnology*, 63, 103452. <https://doi.org/10.1016/j.bcab.2025.103452>
- Menz, L., Strauss, G., & Stenberg, J. A. (2025). Breeding for integrated pest management (B-IPM): A new concept applied to strawberry. *Frontiers in Plant Science*, 16, 1478532. <https://doi.org/10.3389/fpls.2025.1478532>
- Pavan, W., Fraisse, C. W., & Peres, N. A. (2011). Development of a web-based disease forecasting system for strawberries. *Computers and Electronics in Agriculture*, 75(1), 169–175. <https://doi.org/10.1016/j.compag.2010.10.013>
- Petrusch, S., Knapp, S. J., Van Kan, J. A. L., & Blanco-Ulate, B. (2019). Grey mould of strawberry, a devastating disease caused by the ubiquitous necrotrophic fungal pathogen *Botrytis cinerea*. *Molecular Plant Pathology*, 20(6), 877–892. <https://doi.org/10.1111/mpp.12794>

- Porter, S. S., Acharya, C. B., Colquhoun, T. A., & Vance, C. P. (2023). Strawberry breeding for improved flavor. *Crop Science*, 63(4), 1964–1981. <https://doi.org/10.1002/csc2.21012>
- Pott, D. M., Vallarino, J. G., Cruz-Rus, E., Willmitzer, L., Sánchez-Sevilla, J. F., Amaya, I., & Valpuesta, V. (2023). Molecular bases of strawberry fruit quality traits: Advances, challenges, and future directions. *Plant Physiology*, 192(3), 1857–1878. <https://doi.org/10.1093/plphys/kiad243>
- Rahman, M. S., Hossain, M. M., & Kareem, A. (2025). Organic and inorganic fertilizers influence the productivity, fruit quality, and nutrient uptake of strawberry. *Scientific Reports*, 15, 24891. <https://doi.org/10.1038/s41598-025-24891-x>
- Salamone, F., Rosso, L., & Ferrara, C. (2021). Smart protected cultivation: Concepts, tools, and trends for the future. *Sustainability*, 13(9), 4783. <https://doi.org/10.3390/su13094783>
- Samtani, J. B., Rom, C. R., Friedrich, H., Fennimore, S. A., Finn, C. E., Petran, A., Wallace, R. W., Pritts, M. P., Fernandez, G., Chase, C. A., Kubota, C., & Bergfeld, B. (2019). The status and future of the strawberry industry in the United States. *HortTechnology*, 29(1), 11–24. <https://doi.org/10.21273/HORTTECH04135-18>
- Shamshiri, R. R., Weltzien, C., Haghghi, A. K., Balasundram, S. K., Yamin, M., & Ibrahim, A. (2018). Research and development in agricultural robotics: A perspective of digital farming. *International Journal of Agricultural and Biological Engineering*, 11(4), 1–14. <https://doi.org/10.25165/j.ijabe.20181104.4278>
- Sharma, N., Acharya, S., Kumar, K., Singh, N., & Chaurasia, O. P. (2021). Hydroponics as an advanced technique for vegetable production: An overview. *Journal of Soil and Water Conservation*, 17(4), 364–371. <https://doi.org/10.5958/2455-7145.2018.00056.5>
- Singh, M., Kumar, A., Singh, R., & Pandey, K. D. (2019). Endophytic bacteria: A new source of bioactive compounds. *3 Biotech*, 7(5), 315. <https://doi.org/10.1007/s13205-017-0942-z>
- Singh, M., Dotaniya, M. L., Mishra, A., Dotaniya, C. K., Regar, K. L., & Lata, M. (2020). Role of biofertilizers in conservation agriculture. In *Conservation agriculture: An approach to combat climate change in Indian Himalaya* (pp. 113–134). Springer. [https://doi.org/10.1007/978-981-13-9282-5\\_4](https://doi.org/10.1007/978-981-13-9282-5_4)
- USDA. (2016). Climate, weather and strawberries. USDA Climate Hubs. <https://www.climatehubs.usda.gov/sites/default/files/Climate,%20Weather%20and%20Strawberries.pdf>
- USDA. (2023). United States Department of Agriculture National Agricultural Statistics Service: Strawberry production data. <https://www.nass.usda.gov>
- Whitaker, V. M., Guan, Z., Wu, F., & Peres, N. A. (2025). Comparison of hydroponic and substrate-based strawberry production systems. *HortScience*, 60(2), 145–153. <https://doi.org/10.21273/HORTSCI17541-24>