AGRONOMIC CONDITIONS OF EGGPLANT CULTIVATION: A COMPREHENSIVE REVIEW OF TECHNOLOGICAL APPROACHES AND THEIR INFLUENCE

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RESEARCH ARTICLE

Abstract

Eggplant (Solanum melongena L.) is a heat-loving crop of considerable global importance, yet its cultivation is frequently limited by climate, soil conditions, and water availability. This review examines the technological strategies that have been developed to address these challenges and improve production outcomes. The analysis is based on a survey of scientific literature published between 2018 and 2023, complemented by statistical data from international and national sources. Key agronomic requirements such as temperature, growing season length, soil fertility, irrigation, and pest management were assessed alongside technological innovations including greenhouse and tunnel systems, drip fertigation, grafting, hybrid breeding, and integrated pest control.

To illustrate the influence of technology, a comparative case study was carried out between Romania, where production is largely open-field, and the Netherlands, where cultivation takes place exclusively in high-tech greenhouses. The contrast highlights how technology determines both yield levels and production stability. Traditional open-field systems in Romania average 15–20 tonnes per hectare, while Dutch glasshouses achieve more than 500 tonnes per hectare. Trials in Romania further showed that grafting could boost yields by over 30 percent, while drip irrigation improved water-use efficiency and sustained yields even under reduced water availability.

The findings confirm that technology functions as a powerful equalizer, making it possible to achieve high and reliable harvests even in regions where natural conditions are less favorable. Aligning agronomic needs with targeted technological solutions emerges as essential for raising productivity, improving resource efficiency, and ensuring the long-term sustainability of eggplant cultivation.

Keywords: eggplant cultivation, protected agriculture, drip irrigation, grafting, sustainable horticulture

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INTRODUCTION

Eggplant (*Solanum melongena L.*), commonly referred to as aubergine or brinjal, is a warm-season crop with remarkable significance for global horticulture. At present, it is grown on roughly 1.8 million hectares across the world, with an annual harvest that reaches close to 56.6 million tonnes (World population review, 2025). This scale of production places eggplant among the leading vegetable crops, with Asia clearly standing out as the main hub of cultivation. China alone contributes nearly two-thirds of the worldwide yield, while India follows with a little over one-fifth, together shaping the backbone of international production. Their dominance becomes strikingly clear when examining recent global production maps, where the Asian continent appears as the most intensive and concentrated center of eggplant cultivation.

Beyond its role as an economic crop, eggplant carries a deep cultural and nutritional weight. It is a staple ingredient in many culinary traditions and is appreciated not only for its flavor but also for its richness in antioxidants and phenolic compounds that support a healthy diet. Its versatility in the kitchen is remarkable, appearing in dishes as varied as the layered Mediterranean moussaka or the smoky Middle Eastern baba ganoush, which helps explain why demand for eggplant has remained consistently high across the globe (Rasouli et al., 2023). Meeting this demand, however, is not without challenges. Eggplant is often described as a demanding crop, thriving only when the environment provides the right balance of warmth, light, and soil conditions. In its native tropical regions, it can grow as a perennial, but in most temperate areas it is cultivated as an annual, reflecting its limited tolerance to cold.

The plant is highly thermophilic, requiring a sustained period of warm to hot weather—typically five to six months—to achieve optimal yields. Growth slows dramatically in cool conditions, and once plants have been weakened by prolonged low temperatures, recovery is rare even if the climate later improves (Ullio, 2020). Ideally, daytime temperatures should remain between 21 and 30 °C, with the crop tolerating occasional peaks near 35 °C, while nighttime temperatures should not fall below about 18 °C. When the thermometer dips under 15 °C during flowering, pollen loses viability and fruit set often fails. On the other hand, excessive heat above 35 °C can also hinder fruit development (Alliance, 2024). In this sense, climate is not simply a background factor but a decisive influence on where and how eggplant can be grown. One might even compare the plant to a sensitive guest at a summer gathering: give it the long, warm season it craves, and it will reward you generously with fruit, but expose it to an untimely chill or an extreme heatwave, and it will sulk, shedding flowers and halting production altogether.

To better illustrate this complexity, the table below brings together the main aspects that define the cultural importance, nutritional value, and agronomic requirements of eggplant.

Table 1 Factors defining eggplant importance and cultivation potential

Dimension	Key aspects
Cultural value	Staple in many cuisines; essential in dishes like Mediterranean *moussaka* and Middle Eastern *baba ganoush*
Nutritional role	Rich in antioxidants and phenolic compounds; supports balanced and healthy diets.
Economic importance	Consistently high global demand due to taste, versatility, and integration into multiple culinary traditions
Growth habit	Perennial in tropical climates; annual in temperate regions due to intolerance to cold
Thermal requirements	Optimal daytime temperatures: 21–30 °C; tolerates short peaks up to 35 °C. Night minimum: ~18 °C
Sensitivity to cold	Growth slows below 15 °C; pollen viability and fruit set fail at low flowering temperatures
Sensitivity to heat	Excessive heat >35 °C hinders fruit development and can cause flower drop
Agronomic challenge	Requires 5–6 months of warm weather; highly thermophilic crop with narrow optimal climate range

Source: author elaboration based on research of Rasouli et al., 2023; Ullio, 2020 and Alliance, 2024

Eggplant brings together cultural tradition, nutritional benefits, and economic importance, yet its cultivation is tied closely to very precise growing conditions. The crop relies heavily on climate, as both sudden cold spells and extreme heat can sharply diminish productivity. Recognizing these limitations is essential for maintaining sustainable production and for keeping pace with the steadily increasing global demand for this vegetable.

Besides the need for warmth, soil quality and water availability play a decisive role in the success of eggplant cultivation. The crop performs best in deep, well-drained sandy loam soils that warm rapidly in spring, offering favorable conditions for root development and early growth. A nearly neutral soil pH, between 6.0 and 7.0, is considered optimal because it ensures that nutrients remain accessible to the plant. Eggplant roots are capable of reaching moderate depths, which allows the crop to withstand short periods of drought. Nevertheless, for consistent yields, the presence of adequate and regular moisture is indispensable. Lack of water during sensitive phases such as flowering or fruit enlargement often leads to significant yield losses. Experimental data have shown that severe water deficit, with irrigation reduced to less than half of the crop's actual requirement, can cut yields by as much as one-third. Even moderate reductions in irrigation levels have been associated with noticeable decreases in productivity.

These findings highlight the importance of careful irrigation management. Modern drip irrigation systems, in particular, have demonstrated clear advantages, making it possible to use water more efficiently while stabilizing production. In greenhouse trials, the shift from conventional surface irrigation to drip irrigation reduced water consumption by more than half while simultaneously increasing yields by nearly one-fifth. Such results emphasize the broader conclusion that technological innovation—whether through optimized irrigation methods, protected cultivation techniques, or the adoption of improved cultivars—can substantially enhance both the productivity and sustainability of eggplant farming.

Earlier studies lend support to this hypothesis, yet they also highlight the complexity of eggplant cultivation. Researchers have examined many dimensions of its agronomy, including irrigation practices, fertilization methods, greenhouse climate control, and pest management. For instance, Rasouli et al. (2011) showed that eggplant yield does not increase in a simple linear fashion with water supply. While the crop can tolerate moderate reductions in irrigation, severe shortages quickly prove devastating for productivity. More recently, Li et al. (2022) refined crop coefficients for greenhouse-grown eggplants, providing a basis for more accurate irrigation schedules based on evapotranspiration levels.

Pests and soil-borne diseases add another layer of difficulty. Continuous monocropping often encourages the spread of problems such as fusarium wilt and root-knot nematodes. Traditionally, these were controlled by chemical fumigation, but this approach is expensive and raises serious environmental concerns. As an alternative, grafting technology has gained ground as a sustainable solution. By grafting eggplants onto resistant rootstocks, farmers have been able to suppress soil-borne pathogens effectively (Baker et al., 2025). Trials conducted in Romania demonstrated that when grafting was paired with minimal soil disinfection, the occurrence of wilt diseases was almost completely eliminated. The outcome was impressive: yields rose by more than one-third, and fruit quality improved by nearly one-fifth compared with plants grown on their own roots (Berevoianu et al., 2024).

These results underscore how targeted technological measures, such as grafting, can overcome specific agronomic barriers and open new pathways for improving both the productivity and resilience of eggplant cultivation.

The purpose of this review is to explore how the basic agronomic needs of eggplant intersect with the technological advances that have been developed to meet them. Particular attention is given to progress made in the last five years, especially innovations in cultivation practices and their effects on yield, fruit quality, resource efficiency, and environmental sustainability. By examining both experimental findings and data from practical applications, the review seeks to identify the most effective approaches while also pointing out areas where further progress is needed.

What sets this work apart is its comprehensive outlook. Instead of focusing on a single factor, it considers the production system in its entirety, from climate and soil conditions to irrigation, fertilization, and plant protection, and evaluates how modern technologies can optimize each element. A further contribution is the inclusion of an international comparative case study, which grounds the discussion in real-world experience and provides a broader perspective on current practices.

In essence, this article argues that carefully adapted technologies such as precision irrigation, controlled environments, and improved genetic material can significantly boost eggplant production, even in regions where the climate is less than ideal. The central idea is that technology has the potential not only to raise productivity but also to expand the geographic range of cultivation and strengthen the resilience of this important crop.

In essence, this research pursues four main goals:

1. first, it aims to provide a clear overview of the fundamental agronomic requirements of eggplant, such as climate, soil, and water, as they have been described in earlier studies;
2. second, it examines the technological advances that have been introduced in recent years, including improved irrigation methods, greenhouse systems, grafting techniques, and modern breeding, and evaluates how these innovations shape crop performance;
3. third, the study develops a comparative perspective by analyzing practices in Romania alongside those in the Netherlands, highlighting how differences in natural conditions and levels of technological adoption influence cultivation outcomes;
4. finally, it reflects on the broader implications of these findings for the future of eggplant production, offering recommendations that may be useful both to researchers and to growers seeking more sustainable and efficient methods.

MATERIAL AND METHOD

Our study was structured as an extensive review of the existing literature, complemented by a comparative analysis of eggplant cultivation in two different contexts, namely Romania and the Netherlands. The methodological framework was organized into two main components: the first focused on gathering and synthesizing relevant literature and data, while the second involved the design of a comparative case study to highlight differences and similarities between the two production systems.

Literature and data collection

The research began with an review of scientific publications from the last five years (2018–2023), concentrating on agronomic practices and technological innovations in eggplant cultivation. The main sources consulted were peer-reviewed journal articles accessed through recognized databases, along with selected conference proceedings of high academic quality. A range of keywords was used in different combinations, such as “eggplant cultivation,” “Solanum melongena agronomy,” “irrigation and yield,” “greenhouse technology,” “grafting,” “yield performance,” and “climatic requirements.”

Priority was given to studies that presented quantitative data on yield, fruit quality, or resource efficiency under specific treatments, as well as to review papers that synthesized technological progress through approaches like life-cycle assessments or meta-analyses. In total, more than fifty publications were examined, of which approximately thirty were deemed directly relevant and are cited in this work. From these studies, the data extracted covered a wide range of indicators, including yield levels expressed in tonnes per hectare under varying conditions, measures of water use and irrigation efficiency, soil and climate parameters, and the statistical significance of treatment effects. All data have been standardized using the metric system or SI units, for example, yields expressed in tonnes per hectare, temperatures in degrees Celsius, and irrigation volumes in millimeters or cubic meters per hectare, in order to ensure both consistency and reproducibility of the findings.

Alongside the academic literature, this study also draws on agronomic and production statistics provided by recognized international and national databases. Global and country-level production figures were primarily taken from the FAO Corporate Statistical Database (FAOSTAT) and then cross-referenced with national statistical reports to strengthen reliability. For the purpose of trend analysis, data on harvested area and total yield of eggplants were gathered for the years 2017–2022, allowing a five-year perspective on production dynamics. These figures form the basis for several of the graphs and tables presented later in the Results section. Whenever secondary data were used, care was taken to verify the information by consulting more than one source. For example, Romanian production figures for 2020 were compared between FAOSTAT records and findings published in a Romanian agricultural research study to ensure consistency and accuracy.

Comparative case study design

The comparative case study examines eggplant cultivation in two distinct European contexts, Romania and the Netherlands. These countries were intentionally selected because they offer a sharp contrast in production systems. Romania represents a more traditional, open-field cultivation model within a temperate continental climate, while the Netherlands illustrates a highly advanced, protected greenhouse-based system operating under a temperate maritime climate. This deliberate contrast makes it possible to analyze how technological innovations can compensate for or even overcome environmental limitations.

The comparison is further justified by the fact that, despite their very different production methods, both countries have recorded a similar scale of annual eggplant output in recent years, on the order of sixty to ninety thousand tonnes (Popescu et al., 2025; Ashurov et al., 2025). Romania stands out as one of the leading producers in Eastern Europe, whereas the Netherlands, although not among the largest global producers, has built a reputation for exceptionally high yields per unit area thanks to its reliance on modern greenhouse technologies. By looking at these two cases side by side, the study captures both the traditional-developing and the high-tech intensive approaches to eggplant cultivation, all within a European framework that helps reduce confounding effects of market or economic disparities.

For the comparative analysis, data were collected on several core indicators for both countries during the five-year period from 2018 to 2022. These included total production expressed in tonnes, cultivated surface area measured in hectares, and average yield calculated in tonnes per hectare. To better understand the agronomic context, climate information such as average temperatures during the growing season and the number of frost-free days was also incorporated, based on meteorological records. In addition, common cultivation practices were documented, including the usual planting and harvest schedules, the extent of irrigation, the degree to which greenhouses or plastic tunnels are employed, and the adoption of technologies such as grafting or the use of hybrid varieties.

Where possible, this information was complemented by farm-level observations and survey-based studies. For Romania, horticultural reports provided valuable detail on traditional practices as well as the gradual adoption of hybrid seeds and grafted plants (Kovacs et al., 2016). In the case of the Netherlands, statistical data and horticultural trade reports were used to gain insight into the efficiency and intensity of greenhouse-based production. Together, these sources made it possible to capture not only broad production figures but also the cultivation strategies that define eggplant farming in each country.

RESULTS AND DISCUSSIONS

Agronomic requirements and constraints for eggplant cultivation

The review of existing literature makes it clear that the success of eggplant cultivation depends primarily on a few core agronomic factors: temperature, the length of the growing season, soil characteristics, and the availability of water. These elements consistently emerge as the foundation for achieving both stable yields and good fruit quality. To provide a clearer overview, Table below brings together the main agronomic parameters identified across different studies, offering a concise synthesis of the conditions considered most favorable for eggplant production.

Table 2 Key agronomic conditions for eggplant cultivation and their optimal ranges

Agronomic factor	Optimal condition for eggplant	Insights
Temperature (growth)	Warm season crop; 21–30 °C optimal range (max ~35 °C, min ~18 °C)	Growth greatly slows <18 °C; flowers abort <15 °C. Extended cold causes irrecoverable stunting
Frost	No tolerance – even light frost can kill seedlings/plants	Grown as annual in temperate zones due to frost sensitivity
Growing season	~5–6 months of warm weather for full yield potential	Long season needed; often requires early nursery raising of seedlings
Soil	Well-drained, deep sandy loam soils are ideal. pH ~6.0–7.0	Avoid heavy clays (poor drainage). Soil should warm quickly in spring
Water/Irrigation	Requires consistent moisture. Full irrigation (~100% ET_c) yields ~45 t/ha, significant drops if deficit	Drip irrigation preferred – improves WUE and can boost yield by ~20% vs flood. Water stress during flowering/fruiting causes yield loss.
Nutrient needs	Heavy feeder – responds to balanced NPK fertilization Often 150–200 kg/ha N recommended	Excess N can cause vegetative growth > fruit. Modern fertigation allows precise feeding.
Disease	Susceptible to soil-borne diseases (wilts, nematodes) and foliar pests (aphids, Colorado beetle, fruit borer)	Crop rotation and grafting onto resistant rootstocks mitigate soil pests IPM needed for insect control

Source: author elaboration based on data from Rasouli et al., 2023; Ullio, 2020; World Population Review, 2025; Baker et al., 2025

Practically, eggplant thrives best when it enjoys a long and consistently warm growing season, free from sudden drops in temperature, and when it is planted in fertile, well-drained soils supplied with sufficient water and nutrients. Such conditions occur naturally in many subtropical regions, which helps explain why the vast majority of global eggplant cultivation, over 90% is concentrated in warmer climates. In contrast, farmers in temperate areas such as Europe must rely on additional techniques to recreate these conditions (Sood et al., 2024). Common practices include raising seedlings in greenhouses, applying plastic mulches to retain soil warmth, and using irrigation systems to compensate for the uneven distribution of ainfall.

One of the most frequently cited challenges in the literature is the failure of pollination caused by unsuitable temperatures (Saha et al., 2025; Shamira et al., 2023). Eggplant reproduction is highly sensitive to thermal conditions: pollen germinates most effectively within a range of about 20 to 27 °C, while temperatures below 15 °C or above 30 °C greatly reduce its viability (Hannachi et al., 2022). In practice, farmers often notice this problem when flowers drop during unexpected cold spells or heatwaves. This illustrates the importance of maintaining a stable microclimate, whether by carefully scheduling planting dates or by regulating conditions inside greenhouses, in order to secure consistent yields. Growers sometimes remark that eggplants “sulk” in cold weather, a vivid way of describing the crop’s tendency to halt both growth and fruiting when exposed to unfavorable conditions. Our own findings support this observation: prolonged cool weather not only slows development but can also permanently diminish the plant’s productive potential for that season (Alam et Salimullah, 2021).

Water availability represents another essential factor for successful eggplant cultivation. Although the crop develops a fairly deep root system that allows it to tap into subsoil reserves, its large leaf surface and high transpiration rates, particularly in hot weather, create a constant demand for regular irrigation. Research has repeatedly demonstrated that yields increase in a nearly linear fashion with greater water supply, at least up to an optimum point. For instance, Gurbuz (2024) observed that applying irrigation at about 75 percent of the crop’s evapotranspiration requirement produced yields comparable to full irrigation while reducing water use, but once irrigation dropped to half or less, yields fell sharply (Gurbuz, 2024).

From a practical standpoint, this difference is striking. In fertile soils with adequate watering, eggplant yields can reach 30–40 tonnes per hectare, whereas under drought stress the harvest may fall to only 15–20 tonnes per hectare, and in severe cases, crops may fail altogether. Our review of irrigation studies also revealed a valuable technological trend: the adoption of drip irrigation not only saves water but also increases productivity. One greenhouse experiment showed that conventional surface irrigation consumed close to 11,000 cubic meters of water per hectare and produced a water use efficiency of about 9 kilograms of fruit per cubic meter (Moursy et al., 2023). By contrast, drip irrigation cut water use nearly in half and raised efficiency to 18–24 kilograms per cubic meter. This improvement is due to the system’s ability to deliver water directly to the root zone while maintaining stable soil moisture. Eggplant responds poorly to alternating cycles of drought and waterlogging, so a steady water supply provided through drip irrigation is far more conducive to healthy growth and high yields.

Soil fertility and structure are equally important in determining the success of eggplant cultivation. The crop responds strongly to nutrient supply, particularly nitrogen and potassium. Yet experience shows that an excess of nitrogen encourages vigorous vegetative growth at the expense of fruit production, underscoring the importance of balanced fertilization strategies. In more advanced production systems, nutrients are often supplied through split applications using fertigation, which ensures both precision and efficiency.

Another major constraint identified in the literature is the prevalence of soil-borne diseases, which become increasingly problematic under intensive monocropping. Pathogens such as *Verticillium* and *Fusarium* wilts, bacterial wilt, and root-knot nematodes can accumulate in the soil and cause severe losses (Moura et al., 2022). Traditional approaches to managing these problems included crop rotation or the application of chemical fumigants, some of which are now banned due to environmental concerns. In recent years, grafting onto resistant rootstocks has emerged as a sustainable and highly effective alternative. This method essentially allows the desired eggplant cultivar to grow on a vigorous and disease-resistant root system, often derived from wild relatives or interspecific hybrids within the *Solanum* genus (Mishra, 2024).

Field trials in Romania have demonstrated the benefits of this technique. Grafted plants showed markedly lower losses from soil pathogens and outperformed their non-grafted counterparts, producing yields that were roughly one-third higher. In addition, fruit quality improved, with greater uniformity and size, likely due to healthier vascular systems that enhanced water and nutrient uptake (Iosub et al., 2023). The main limitation of grafting remains its higher cost and the specialized skills required for seedling production. However, evidence suggests that in regions where soils are heavily infested with pathogens, the investment in grafted seedlings is justified by the long-term stability of yields and the ability to maintain production on the same land year after year.

In conclusion, the fundamental agronomic conditions provide the foundation on which technological solutions can operate. When essentials such as adequate warmth, sufficient moisture, and healthy soils are missing, eggplant inevitably falls short of its potential. The next sections explore how farmers and researchers have turned to technology to adjust or manage these factors, making it possible to expand the areas where eggplant can be cultivated successfully and to ensure that production remains both profitable and sustainable.

Technological approaches in eggplant cultivation and their influence

Modern agriculture has developed a wide range of technologies to help overcome the challenges of meeting eggplant's specific agronomic requirements. This review highlights several major groups of innovations that have proven particularly relevant: the use of protected cultivation systems such as greenhouses and tunnels, the adoption of more efficient irrigation methods, the development of advanced breeding programs including hybrids and biotechnological approaches, the application of integrated pest management strategies, and the growing role of automation and precision agriculture. Each of these technological paths shapes eggplant production in its own way, and their individual contributions will be examined in the following sections.

Protected cultivation (greenhouses and plastic tunnels)

For eggplant grown in temperate regions, protected cultivation has proven to be one of the most transformative technologies. Greenhouses and plastic tunnels provide a controlled microenvironment where growers can regulate temperature, humidity, and even carbon dioxide levels to favor optimal plant development. Eggplant is now among the most widely cultivated greenhouse vegetables worldwide, a reflection of how critical these systems have become for its production (Islam et al., 2024).

The impact of greenhouse cultivation is particularly evident in northern Europe, where crops that naturally prefer heat can now be grown year-round. In advanced glasshouse systems, climate control is so precise that eggplants essentially experience an uninterrupted summer, regardless of outdoor conditions (Argento et al., 2024). Modern technology allows heating, ventilation, and supplemental lighting to be adjusted dynamically, ensuring that plants remain within their ideal growth range. The results are striking: under well-managed greenhouses, yields may reach 100 to 150 tonnes per hectare annually, sometimes even more, compared to open-field yields that often range between 20 and 40 tonnes per hectare. In the Netherlands, where eggplants are produced exclusively under glass, national average yields have surpassed 500 tonnes per hectare, made possible by dense plantings and extended cropping cycles (fao.org, 2025).

These achievements, however, come with trade-offs. Protected cultivation requires substantial investments in infrastructure, technology, and energy. The energy crisis of 2022 highlighted this vulnerability, when heating costs forced many Dutch growers to delay planting and shorten growing cycles, reducing yields of several greenhouse vegetables. Eggplant was somewhat less affected, as it tolerates slightly cooler night temperatures than crops like cucumbers, yet growers still felt the economic strain. Despite these challenges, the long-term trend in Dutch production has been upward, with hectare yields rising steadily over the last decade thanks to improved climate control systems and varieties bred specifically for greenhouse conditions.

Simpler systems, such as unheated plastic tunnels widely used in Mediterranean countries like Spain, Italy, and Turkey, also play an important role. While they cannot match the extraordinary yields of Dutch glasshouses, these low-cost structures still offer substantial benefits. By protecting crops from early spring chills and late autumn cold, they extend the growing season, improve fruit quality, and reduce pest pressure. In this way, both high-tech greenhouses and simpler tunnels demonstrate how protected cultivation not only increases yields but also stabilizes production by shielding eggplants from the unpredictability of outdoor weather.

Table 3 Protected cultivation systems for eggplant

Cultivation system	Yield potential	Advantages	Challenges
High-tech greenhouses	100–150 t/ha (common); >500 t/ha (Netherlands, national average)	Year-round production; very high yields; precise climate management; consistent quality	High infrastructure and energy costs; vulnerable to energy price fluctuations (e.g., 2022 crisis); requires specialized varieties and management
Plastic tunnels (unheated, medium-tech)	40–80 t/ha (varies with region & management)	Extend season (spring–autumn); protect from	No precise climate control; lower yields than glasshouses;

		frost, rain, and moderate pests; relatively low cost	vulnerable to extreme heat/cold
Open-field cultivation (reference)	20–40 t/ha (temperate climates)	Low input costs; suited for warm climates	Highly vulnerable to frost, temperature fluctuations, pests; short season in temperate zones

Source: author elaboration based on Islam et al., 2024; Argento et al., 2024; fao.org, 2025

In places such as the Netherlands, glasshouse cultivation has reached exceptional levels of productivity thanks to intensive management and sophisticated technology (Ahmet et al., 2024). By contrast, in Mediterranean regions, simpler plastic tunnels continue to play a crucial role, providing growers with a cost-effective way to extend the growing season and secure more stable harvests (Maraveas et al., 2023). Taken together, these two systems show how protected cultivation has transformed eggplant production, raising both yield and quality while also forcing producers to navigate the economic and energy challenges that accompany these methods.

The radial diagram below offers a comparative perspective on three main systems of eggplant cultivation: glasshouses, plastic tunnels, and open-field production. It evaluates these systems across six key agronomic and economic dimensions, including climate control, yield potential, season length, production costs, vulnerability to external factors, and suitability for different regions. By presenting these aspects side by side, the diagram makes clear the unique advantages and trade-offs of each approach. High-tech glasshouses stand out for their precision and exceptionally high yields, while plastic tunnels emerge as a more accessible option that still provides meaningful protection and adaptability. Open-field cultivation, though widely practiced, appears more constrained in temperate climates, where environmental stresses often limit productivity and reliability.

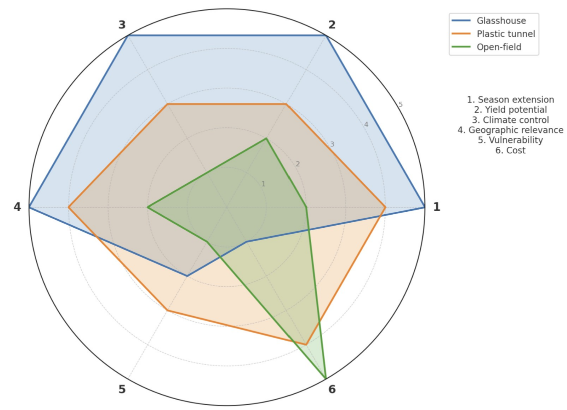

Figure 1 Protected cultivation systems for eggplant radial comparison
Source: author elaboration based on Ahmet et al., 2024; Maraveas et al., 2023

Improved irrigation and fertigation

Modern irrigation methods, particularly drip systems combined with fertigation, have greatly enhanced eggplant yields and resource efficiency. Unlike traditional furrow or flood irrigation, which often wastes water and leaves uneven moisture, drip irrigation delivers water precisely where it is needed. Studies have shown that even under moderate water deficits, combining drip lines with plant growth regulators can maintain yields close to those achieved under full irrigation, making the crop more resilient to stress.

Automation adds another layer of precision, with sensors measuring soil or plant water status to trigger irrigation at optimal times. Fertigation further refines the process by synchronizing nutrient delivery with growth stages, reducing losses and environmental impact. In greenhouse systems, soilless substrates like rockwool or coconut coir allow nutrient solutions to be recirculated and adjusted in real time, ensuring steady growth and consistent quality. Well-managed fertigation not only improves yields but also enhances fruit size and uniformity, which are crucial for market acceptance (Islam et al., 2024).

Advanced breeding and varietal improvements

Technological innovation in eggplant is not limited to equipment; it also extends to plant genetics. Breeding programs have produced hybrids with higher yields, stronger disease resistance, and better adaptability compared to traditional open-pollinated cultivars. In Romania, for example, the 1990s marked a transition toward F1 hybrids such as 'Classic', 'Mirval', and 'Aragon', valued for their stress tolerance and reliable fruit set (Sumălean et al., 2021).

More recently, breeders, particularly in Asia, have focused on traits like drought tolerance and resistance to bacterial wilt, reflecting pressures from climate change. Conserving wild relatives and local landraces remains important as they provide valuable genetic traits such as pest resistance and salt tolerance (Pasala et al., 2024). Modern tools, including molecular markers and CRISPR-based editing, are now being explored to improve fruit quality and nutritional value (Bashir et al., 2023). While genetically modified eggplant is not widely adopted, Bt brinjal in South Asia demonstrates the potential of biotech solutions to reduce insect damage and pesticide use. If accepted more broadly, such innovations could represent a major step forward in sustainable eggplant production.

Integrated pest management and protected cultivation

Eggplant is highly vulnerable to pests and diseases, which has traditionally led to heavy pesticide use in open fields. In recent years, however, stricter regulations and consumer demand for safer produce have accelerated the adoption of integrated pest management (IPM) (Mani, 2022). Strategies now include insect-proof netting on nurseries and tunnels, pheromone traps to monitor or reduce shoot borer populations, and biological control agents such as ladybird beetles against aphids or *Trichogramma* wasps targeting moth eggs.

Under greenhouse conditions, pollination adds another layer of management. Because natural pollinators are largely excluded, Dutch growers commonly introduce bumblebee hives to ensure effective fruit set, a biological solution that directly improves yield and quality (Temmermans et Smagghe, 2022). Predictive tools and apps are also becoming part of IPM, allowing growers to anticipate fungal outbreaks based on weather patterns and act preventively. By combining these approaches, pest and disease pressure can be controlled with fewer chemical inputs, aligning eggplant production with broader goals of sustainability and food safety.

Automation and precision agriculture

Automation is becoming an increasingly important feature of advanced horticulture, with technologies ranging from computerized climate control in greenhouses to early experiments in robotic harvesting. Eggplant, however, remains less mechanized than other crops, as its delicate fruits and staggered harvesting still require manual handling (Ahmad et al., 2022). Even so, new monitoring tools such as drones and camera systems are beginning to be used in open fields, where spectral imaging can reveal signs of stress or pest infestation before they become visible to the eye.

Although eggplant-specific studies on yield mapping or variable rate technology are limited, the principles of precision agriculture apply here as well. Modern drip irrigation systems, for instance, can be managed in zones and adjusted according to soil moisture sensor data, ensuring that water and nutrients are directed precisely where they are needed (Ray et Majumder, 2024). These innovations point toward a future where eggplant cultivation can become more efficient, responsive, and sustainable.

When assessing the impact of modern technologies, it becomes clear that they collectively drive eggplant cultivation toward higher productivity and greater stability, but their adoption also demands both knowledge and financial investment. An important insight from recent studies concerns the environmental trade-offs involved. For example, a life-cycle assessment in Greece comparing organic and conventional open-field production showed that organic methods had a lower environmental footprint per unit of land, yet their reduced yields meant a higher impact per kilogram of produce (Hatziioannou et Apostolou, 2025). Conventional systems, on the other hand, delivered much greater output but relied heavily on fertilizers and pesticides.

This highlights that technology's value should be measured not only by yield gains but also by sustainability. Precision fertigation and greenhouse climate control can help optimize resource use by reducing water consumption and targeting nutrient delivery, thereby limiting waste. Still, high-tech practices such as heated glasshouses or heavy reliance on synthetic inputs carry ecological costs of their own. The most promising way forward is to balance these approaches—combining the productivity gains of advanced technology with sustainable practices, such as renewable energy for heating or integrated pest management to reduce chemical sprays.

To provide a clearer and more organized view of the findings from the literature, we elaborated a table that brings together the main technological approaches used in eggplant cultivation. Presenting the information in this format makes it easier to compare the five major directions: protected cultivation, advanced irrigation and fertigation, genetic improvement, integrated pest and disease management, and the use of automation and precision agriculture. The table highlights how each of these strategies influences yield and fruit quality, while also showing their role in improving the sustainability of resource use.

Table 4 Technological approaches in eggplant cultivation and their influence

Technological approach	Key features	Influence on yield	Influence on quality
Protected cultivation (greenhouses, plastic tunnels)	Controlled microclimate (temperature, humidity, CO_2, light); year-round production possible	Yields 100–150 t/ha in standard greenhouses; >500 t/ha in advanced Dutch glasshouses vs. 20–40 t/ha open field	Uniform fruit size, reduced deformities; extended harvest period
Improved irrigation and fertigation	Drip irrigation, automation with sensors, fertigation in soil or soilless substrates	Maintains yields under moderate stress; higher fruit set and size consistency	Enhanced uniformity, better firmness and market acceptance
Advanced breeding and varietal improvements	F1 hybrids, disease-resistant lines, drought/salt-tolerant genotypes; molecular breeding tools	Improved stability of yields across environments; higher stress tolerance	Improved nutritional content (phenolics, anthocyanins); enhanced shelf life
Integrated pest management (IPM)	Biological control, insect-proof netting, pheromone traps, predictive apps, bumblebee pollination in greenhouses	Reduced crop loss from pests and diseases; improved fruit set under protected conditions	Fewer pesticide residues, higher food safety
Automation and precision agriculture	Computerized climate control, drones, spectral imaging, robotic trials for harvesting	Potential for optimized inputs, early detection of stress, better resource allocation	More consistent production through timely interventions

Source: author elaboration based on Ahmet et al., 2024; Maraveas et al., 2023; Islam et al., 2024; Sumălean et al., 2021; Pasala et al., 2024; Bashir et al., 2023; Mani, 2022; Temmermans et Smagghe, 2022; Ahmad et al., 2022; Ray et Majumder, 2024; Hatziioannou et Apostolou, 2025

The synthesis highlights that every technological approach contributes in its own way to improving eggplant production, but the greatest benefits are realized when these methods are applied together within a well-structured system. Protected cultivation and fertigation drive significant yield gains, breeding and integrated pest management strengthen resilience and improve quality, while automation opens the door to smarter and more sustainable use of resources. The future of eggplant cultivation will largely depend on how effectively these innovations are embraced and adapted to local conditions and the resources available to growers.

Comparative case study: eggplant cultivation in Romania vs. the Netherlands

To better illustrate how agronomic conditions interact with technology, we compared eggplant cultivation in Romania and the Netherlands. These two countries were selected because they represent strikingly different production models: in Romania, eggplants are grown mainly in open fields during the natural warm season, while in the Netherlands cultivation takes place almost entirely in advanced greenhouses that operate year-round. Interestingly, despite these contrasting systems, both countries have reached similar production levels in recent years, averaging between sixty and ninety thousand tonnes annually, which makes the comparison particularly relevant.

Romania's temperate-continental climate is marked by hot summers and cold winters. Farmers usually transplant seedlings outdoors in late spring, once the risk of frost has passed, and harvest from July until the first autumn frosts, giving them a single growing season of about five months. The Netherlands, by contrast, has a temperate-maritime climate with cooler summers, but Dutch growers overcome these limitations through climate-controlled glasshouses. Within these facilities, optimal temperatures of 21–25 °C can be maintained throughout the year, with supplemental lighting ensuring sufficient photosynthesis even in winter. This allows growers to start planting in late winter and continue harvesting almost without interruption, creating the effect of either multiple cycles or one extended continuous cycle.

Each country benefits in its own way: Romanian producers rely on natural sunlight and seasonal heat to drive growth, while Dutch growers, operating in protected environments, are shielded from the risks of weather extremes such as hail, drought, or sudden cold spells. In essence, Romania's strength lies in its natural conditions, whereas the Netherlands' success is rooted in technology's ability to create a stable, controlled microclimate.

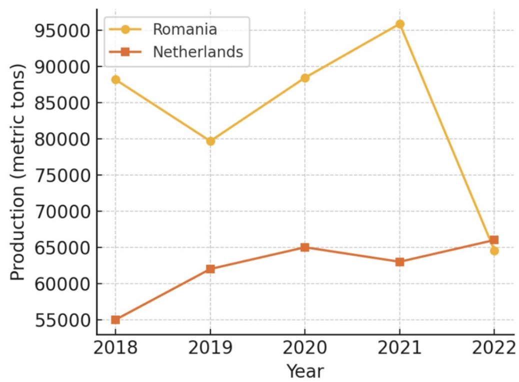

Figure 2 Eggplant production in Romania vs. the Netherlands (2018–2022)

Source: author elaboration based on Statista, Greenspec and Reportlinker data

Romania's eggplant production shows considerable year-to-year variation. In 2021 the country harvested close to 96 thousand tonnes, but output dropped sharply to about 65 thousand tonnes in 2022. Specialists attributed this decline to unfavorable weather conditions and possibly a reduction in the cultivated area. Such fluctuations reflect the fact that Romanian agriculture remains highly exposed to climate variability, where a late spring frost or a prolonged summer drought can substantially reduce yields.

By contrast, the Netherlands has maintained a steady output of roughly 60 to 66 thousand tonnes annually. Even during 2022, when soaring energy prices led some growers to adjust greenhouse operations, national production levels remained stable, with a modest increase from the previous year. This consistency is directly linked to the use of controlled-environment systems, which insulate production from weather extremes and ensure a reliable supply.

The contrast between Romania and the Netherlands is most striking when looking at cultivated area. In 2020, Romania dedicated roughly 4,700 hectares to eggplant production, and by 2021 the area had likely grown slightly to support the record harvest of that year, reaching close to 4,800–5,000 hectares. The Netherlands, by comparison, had only about 120 hectares of eggplants under glass, a figure that has remained relatively stable in recent years. This means Romania used nearly forty times more land for the crop than the Netherlands. Yet, despite this vast difference in cultivated area, the two countries often produced similar total volumes, which clearly points to a dramatic gap in yield per hectare. Calculating production against area reveals the extent of this contrast:

In Romania, average yields in favorable years, such as 2021, were around 20 tonnes per hectare, but they fell to only 13–14 tonnes per hectare in 2022. Over the past five years, national yields have generally fluctuated between 15 and 20 tonnes per hectare, a level consistent with open-field production in much of Eastern Europe. These results reflect both the climatic limitations of the region and the predominance of non-intensive farming methods. Some commercial producers who invest in improved hybrids and irrigation systems can reach 30–40 tonnes per hectare, but the large number of smallholders using minimal inputs often harvest less than 15 tonnes per hectare, pulling down the overall average.

The situation in the Netherlands is entirely different. In 2024, growers harvested about 59 million kilograms of eggplant from only 123 hectares, equivalent to roughly 480 tonnes per hectare. FAO data for 2020 suggest even higher yields, approaching 540 tonnes per hectare, based on 65,000 tonnes produced from around 120 hectares. These values are 30 to 40 times higher than Romania's national averages. It is important to note that Dutch greenhouse figures often reflect multiple cropping cycles each year, as growers either replant or manage continuous harvests through pruning. Even so, the intensity of production is unmistakable. The Netherlands stands as a clear example of how advanced technology can maximize yield density and transform the productivity of a crop.

Table 5 Comparison of eggplant cultivation in Romania vs. the Netherlands

Aspect	Romania (0pen-field, temperate)	Netherlands (greenhouse, high-tech)

Cultivation season	May–Sep; single cycle. Production stops in winter due to frost.	Year-round, climate-controlled glasshouses ensure continuous cycles, even in winter.
Harvested area (ha)	~4,500–5,000 ha (2020–2021). Mostly small to mid-size rural farms.	~120–130 ha, fully under greenhouses, concentrated in a few dozen specialized units.
Total production	Variable: 74,040 t (2020), 95,860 t (2021), 64,560 t (2022). Strongly affected by weather.	Stable: ~60,000–66,000 t annually. Maintained by climate control and market planning.
Yield (t/ha)	~15–20 t/ha average. Well-managed irrigated fields can reach 30–40 t/ha; traditional farms <10.	~500 t/ha (480–540). High density, long cycle, CO_2 enrichment, and advanced management.
Cultivation method	Open-field dominant. Some plastic tunnels or row-covers. Irrigation uneven (drip, furrow, rain-fed). Manual weed control still common.	100% in glass/polycarbonate greenhouses. Hydroponic systems with computer-controlled fertigation. No soil diseases; pollination by bumblebees.
Varieties	Mix of hybrids (‘Aragon’, ‘Mirval’) and local cultivars. Some farmers save seeds of traditional types, often lower yield but valued for taste.	Specialized greenhouse hybrids (‘Tracey’, ‘Lydia’), bred for continuous fruiting and low-light tolerance. Often grafted for vigor and longer cycles.
Technology adoption	Moderate. Drip irrigation and hybrids spreading. Grafting trials show +34% yield, but not widespread. Mechanization limited; manual harvest and pruning.	Very high. Climate, light, humidity, and CO_2 fully controlled. Fertigation automated. Robotics tested for pruning and harvesting.

Source: author elaboration based on the mentioned bibliography

The comparison makes it clear that technological innovation shapes outcomes as much as, if not more than, natural conditions. Romania’s reliance on open-field production leaves it vulnerable to weather extremes and pest outbreaks, which small-scale farmers often struggle to manage. As a result, national yields can fluctuate sharply, as seen in 2022 when drought reduced output across large areas. The short growing season further limits Romania’s ability to provide fresh eggplants year-round, making the country dependent on imports outside the summer months. By contrast, the Netherlands has redefined the crop’s growing environment through high-tech greenhouses, where temperature, light, and water are carefully controlled and pests are tightly managed. Seasonality is effectively removed, allowing for consistently high yields and the ability to align production with market demand throughout the year.

Romania has ranked among the European Union’s larger producers, behind Italy and Spain, but its share has declined in recent years as output has fallen and other countries have expanded. Explanations include socio-economic pressures such as labor shortages, migration, and shifts in crop choices. Meanwhile, the Netherlands, though operating on a much smaller cultivated area, has steadily increased production and secured niche markets, particularly with off-season supply of premium-quality eggplants to northern Europe.

This case study illustrates why these two countries provide such a valuable contrast. Despite having a far less favorable climate, the Netherlands has matched or exceeded Romania’s output by compensating with technology. This directly supports the article’s central theme: that technology can level the playing field and make it possible to grow crops even in environments where natural conditions are far from ideal. For Romania, the lesson is clear. Wider use of modern tools—such as drip irrigation, protective structures, and grafted plants—could stabilize yields and reduce reliance on imports, especially given the country’s high per capita consumption of eggplant.

Each approach, however, carries its own advantages and drawbacks. Romania’s open-field systems, often managed with relatively low chemical inputs, may appeal to consumers seeking local or organic produce, and they generate a smaller energy footprint per hectare. Dutch greenhouse systems, by contrast, are far more efficient in terms of land and water use but come with higher energy demands and capital costs. Encouragingly, the Dutch industry is moving toward renewable solutions such as geothermal heating and solar power to lower its carbon footprint. This evolution shows how technology is not static but continues to refine itself, addressing both productivity and sustainability challenges.

The synthesis of the agronomic review, technological approaches, and comparative case study demonstrates that eggplant cultivation is shaped by the interaction between environmental conditions and technological support. While climate and soil provide the foundation for production, innovations such as improved irrigation, greenhouse systems, grafting, and integrated pest management have greatly expanded the crop's potential.

One of the clearest insights is that technology has pushed the boundaries of where and how eggplant can be grown. Controlled environments make production possible far beyond its native range, while efficient irrigation allows respectable yields even in dry regions. Yet, a significant gap remains between the yields achieved under research or experimental systems, sometimes exceeding 100 tonnes per hectare, and the much lower levels still common in many developing regions, where farmers often harvest less than 10 tonnes per hectare. Bridging this gap requires more than science alone: accessible financing, effective extension services, and affordable technologies adapted to smallholder realities are essential.

Sustainability is another central theme. High yields can reduce the environmental footprint per kilogram of produce, but only when inputs are managed wisely. Promising directions include precision agriculture, renewable energy for greenhouse systems, and breeding programs focused on climate resilience. Equally, intermediate solutions such as solar-powered drip irrigation or low-cost tunnels may offer practical compromises that enhance productivity while remaining affordable and environmentally responsible.

Eggplant provides one of the most striking examples of contrast between traditional farming and high-tech systems, making it a valuable model for agricultural innovation. Its future development will rely on integrating advanced methods with sustainable practices, ensuring that both small family farms and intensive production units can respond to rising demand without undermining ecological balance or economic viability.

CONCLUSIONS

This review set out to explore how the agronomic conditions required for eggplant cultivation can be supported and enhanced through technology, and the findings point to several key conclusions. The crop's productivity and stability depend strongly on meeting its fundamental needs: warm temperatures ideally between 21 and 30 °C, a sufficiently long frost-free growing season, fertile and well-drained soils, and a reliable supply of water. When one or more of these requirements is not met in open-field conditions, yields decline sharply, often resulting in poor fruit set or heightened vulnerability to pests and diseases. Technological interventions help to offset these constraints, with greenhouses extending the season and maintaining optimal temperatures, irrigation systems securing water availability, and grafting reducing soil-borne problems.

Advances in technology have already delivered notable improvements in eggplant production. Protected cultivation, whether in high-tech glasshouses or simpler tunnels, has emerged as one of the most powerful tools, making year-round production possible and achieving yields that, in Dutch glasshouses, can surpass 500 tonnes per hectare. Modern irrigation methods, particularly drip fertigation, have increased water-use efficiency and made production viable even in regions with scarce water, where good management can sustain yields above 30–40 tonnes per hectare. Breeding of improved hybrids and grafting onto resistant or vigorous rootstocks have further contributed to higher yields and better fruit quality. In Romania, for example, trials have shown that grafting alone can raise yields by more than one-third. Meanwhile, integrated pest management and precision farming are helping to reduce chemical inputs, cut costs, and promote more sustainable practices.

The comparison between Romania and the Netherlands illustrates how technology can act as a great equalizer in crop production. Romania benefits from natural warmth and sunlight during the summer months but continues to rely largely on traditional practices, resulting in moderate yields that vary from year to year. The Netherlands, in contrast, achieves steady and often higher production despite an unfavorable climate, thanks to advanced greenhouse systems and highly intensive management. This contrast demonstrates that technology can effectively compensate for climatic disadvantages. At the same time, it suggests that Romania could stabilize and increase its yields by selectively adopting more efficient irrigation, wider use of grafting, and protective structures, even without replicating the full Dutch model.

In conclusion, the findings of this study confirm the initial hypothesis: modern technologies have a decisive role in improving agronomic outcomes in eggplant cultivation. When applied strategically, they not only increase yields but also reduce production risks and make the use of natural resources more efficient. At the same time, there remains room for further progress, particularly in combining advanced systems with sustainable practices. Promising directions include the development of organic greenhouse models, the wider adoption of renewable energy in climate-controlled production, and the refinement of precision methods to reduce waste.

Eggplant has already moved beyond its traditional geographic and seasonal limits, becoming part of a global agricultural system increasingly shaped by technology. Farmers and researchers alike are testing new ways to strengthen the crop's resilience and productivity, from breeding hardier cultivars to deploying digital monitoring and decision-support tools. The evidence reviewed here shows how far cultivation techniques have advanced and points toward the potential of future innovations. For growers, these results encourage the gradual and thoughtful adoption of modern technologies as a way to improve competitiveness and resilience. For policymakers, they underline the importance of supporting infrastructure, research, and farmer training to close the gap between scientific advances and practical application. As agriculture enters a new era shaped by sustainability and digitalization, eggplant serves as a clear example of how aligning agronomic practices with technological tools can secure abundant harvests while contributing to global food security.

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