International Research Journal of Innovations in Engineering and Technology (IRJIET)

ISSN (online): 2581-3048
Volume 10, Issue 9, pp 100-109, September-2026
https://doi.org/10.47001/IRJIET/2026.109011

Analysis of the Physiological Performance and Productive Yield of Cucumber (*Cucumis sativus* L.) in Smart Greenhouses

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***Abstract* - This study was conducted during the 2025 growing season at the protected-cultivation facility of Sham University, northern Syria, to evaluate the efficiency of an integrated smart greenhouse system in improving the physiological and productive performance of cucumber (*Cucumis sativus* L., cv. UZDE F1) relative to a conventional protected-cultivation system. A randomized complete block design (RCBD) with four replicates was used to compare two systems: an integrated smart system with environmental sensors and automated control of ventilation, cooling and irrigation, and a conventional system managed by routine manual practices. The results revealed a marked superiority of the smart system across all measured growth indicators. Plants in the smart system reached a mean height of 3.5 m versus 2.6 m, with longer leaves (29 vs 18 cm) and wider leaves (21 vs 15 cm), which gives a derived leaf area of 445 vs 197 cm². This is attributed to precise control of critical climatic factors, with temperature held within 25–30 °C and relative humidity within 85–90%. For yield, the smart system produced 126 fruits per plant versus 70, with greater fruit length (13.9 vs 12.28 cm), diameter (2.9 vs 2.53 cm), volume (97.3 vs 72.15 cm³) and weight (98.9 vs 79.8 g). Total productivity reached 12.462 kg per plant versus 5.586 kg, a 123% increase. The smart house also reached first harvest seven days before the control. These findings confirm smart-agriculture technologies as a strategic solution for improving crop productivity and quality under climatic and water-resource constraints.**

Keywords: Smart Greenhouses, Cucumber (*Cucumis sativus* L.), Productivity, Fruit Quality, Sustainable Agriculture, Environmental Control, Climate Change.

I. INTRODUCTION

In recent decades, the agricultural sector has undergone a radical transformation driven by the Fourth Industrial Revolution, in which digitalisation and automation have become essential pillars for confronting pressing global challenges, including climatic stresses, scarcity of water resources, and the escalating demand for food. Within this framework, smart agriculture emerges not as a luxury but as a strategic necessity for re-engineering agricultural production processes to achieve sustainable efficiency. One of the most prominent manifestations of this qualitative shift is the emergence and development of integrated smart greenhouse systems, which represent a genuine leap that greatly surpasses the capabilities of conventional protected cultivation.

These systems are defined as closed or semi-closed agricultural environments equipped with intelligent sensors, automated control units (actuators), and platforms for real-time data analysis. They are designed to monitor and regulate the microclimate within the protected structure with high precision, through the control of a complex set of biotic and abiotic factors, including temperature, relative humidity, light intensity and spectrum, carbon-dioxide concentration, and fertigation. This precise intervention allows the creation of an optimal, tailored environment that adapts dynamically to the physiological requirements of each crop throughout its different growth stages, transforming agriculture from a traditional craft into a precise, data-driven science.

In this regard, cucumber (*Cucumis sativus* L.) is a sensitive, high-value economic crop that is greatly affected by climatic fluctuations, requiring stable and moderate environmental conditions for optimal growth and fruiting. This environmental sensitivity makes it an ideal candidate for cultivation within these advanced systems, where the constraints of seasonality can be overcome and the abiotic stresses that weaken the quantitative and qualitative yield of the crop in open-field or even conventionally protected cultivation can be avoided.

Beyond improving productivity and quality, the fundamental benefits of these systems extend to enhancing environmental sustainability: they maximise water- and nutrient-use efficiency and reduce dependence on chemical inputs such as pesticides, by creating a physical barrier against pests and limiting conditions favourable to disease. Most importantly, these smart platforms enable the collection of

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vast quantities of data (big data) on plant-growth dynamics, which makes it possible to develop predictive models and intelligent algorithms that support proactive decision-making, thereby reducing the risks of cultivation and maximising long-term economic returns.

Proceeding from this importance, the present study aims to provide a comprehensive, quantitative analysis of the effect of applying smart protected-cultivation systems on the physiological, morphological, and productive indicators of the cucumber crop. It focuses in particular on assessing the efficiency of this technology in improving vegetative growth rates, the marketable quality of the fruits, and total productivity. Ultimately, this research seeks to provide a scientific and practical framework on which researchers, farmers, and policymakers alike can rely in order to generalise and develop this advanced model as a practical solution for sustainable agriculture in the twenty-first century.

II. LITERATURE SURVEY

Cucumber (*Cucumis sativus* L.) is one of the most important vegetable crops worldwide, ranking fourth among vegetable crops in terms of cultivated area and productivity, according to the statistics of the Food and Agriculture Organization [1]. Data indicate that world production exceeds 90 million tonnes annually, with a continuous upward trend in demand owing to changes in dietary consumption patterns. Cucumber is distinguished by a high nutritional value that makes it a basic component of a healthy diet, containing a distinctive set of vitamins, minerals, and antioxidants. According to the database of the United States Department of Agriculture [2], every 100 g of fresh cucumber provides about 20% of the daily requirement of vitamin K, 5% of vitamin C, and 2% of vitamin A, in addition to notable proportions of potassium and magnesium. It is also characterised by a low caloric content and a high water content, which makes it an ideal choice for dietary regimes [3].

Cucumber requires precise environmental conditions for optimal growth and high productivity. Studies have shown that the optimal temperature range lies between 25–30 °C during the day and 18–20 °C at night [4], [5], with the need to maintain the soil temperature around 20–25 °C [6]. As for relative humidity, the optimal range lies between 70–85% during the day and 80–90% at night [7]. Deviations from these ranges lead to negative effects on pollination, fruit set, and increased incidence of fungal diseases [8]. Cucumber also requires a high light intensity ranging between 600–800 μmol m^{-2} s^{-1} to achieve the maximum rate of photosynthesis [9], and studies have shown that the use of supplementary lighting with blue- and red-spectrum LED lamps can increase fruit productivity by up to 25% [10]. The optimal photoperiod ranges between 14–16 hours per day for ideal vegetative growth [11]. Cucumber production faces multiple challenges, including sensitivity to extreme environmental conditions, susceptibility to a number of diseases such as powdery mildew and blight, and sensitivity to water and salt stress [12]; these challenges underline the importance of using advanced protected-cultivation technologies to ensure high productivity and excellent quality.

Smart greenhouses represent a qualitative leap in the field of protected cultivation, combining advanced technologies with scientific agricultural practices to achieve the maximum degree of efficiency and productivity. These systems have become a pressing necessity in light of increasing climatic challenges and the escalating demand for food. Recent studies confirm that the integration of real-time monitoring and intelligent control provides an ideal environment for plant growth, which is reflected positively in quality and productivity.

With regard to the technological foundations of these systems, the study of Katzin *et al.* [13] showed that the Internet of Things (IoT) constitutes the backbone of smart greenhouses, working to link the various elements in an integrated manner. This system consists of an advanced network of sensors that continuously monitor environmental factors such as temperature, humidity, light intensity, carbon-dioxide concentration, and soil-moisture levels, collecting data regularly and transmitting it to a central control unit for processing and analysis.

The importance of these systems lies in their ability to provide accurate, real-time data, enabling farmers to make informed decisions based on reliable information. Zhang *et al.* [14] indicated that automated control systems (actuators) represent the executive element of this integrated system, carrying out the commands issued by the central control unit; these systems include advanced equipment such as automated cooling and heating systems, lighting-control systems, smart irrigation and fertigation systems, and ventilation-control devices.

The artificial-intelligence platforms addressed in the study of Elijah *et al.* [15] represent the thinking mind of this system, analysing the big data received from the sensors and using advanced algorithms to predict future conditions and take appropriate decisions. These platforms work to improve resource-use efficiency and reduce losses of agricultural inputs, which is reflected positively in the economic and environmental dimensions.

In the field of precise control of the internal environment, the study of Alvarez *et al.* 5 °C leads to a substantial improvement in the physiological processes of the plant,

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allowing optimal growth and avoiding the heat stress that adversely affects productivity. The study also confirmed that precise control of relative humidity within margins of ±3% contributes to reducing fungal diseases and facilitating pollination.

The study of Liu *et al.* [16] focused on the importance of controlling carbon-dioxide concentration, showing that reducing the daily variation in concentration to less than 100 parts per million improves the efficiency of photosynthesis. Carbon dioxide acts as a fundamental element in photosynthesis, and the presence of a balanced concentration of it ensures the optimal continuity of the plant's vital processes.

In the area of the physiological responses of cucumber, specialised studies have revealed a marked improvement in photochemical efficiency under smart greenhouse conditions. The study of Papadopoulos *et al.* [17] showed that plants grown in these greenhouses recorded a quantum efficiency of photosynthesis (ΦPSII) of up to 0.83 compared with 0.68 in conventional greenhouses, reflecting a substantial improvement in the plant's ability to convert light energy into chemical energy and, consequently, in growth and productivity rates.

From another perspective, the study of Hao *et al.* [9] showed that the use of advanced lighting techniques with custom-spectrum LED lamps increased chlorophyll-a content by 27%. As chlorophyll-a contributes fundamentally to the absorption of light energy and its conversion into chemical energy, this increase reflects an overall improvement in photochemical efficiency.

At the level of hydraulic dynamics and water transport, the study of Gonzalez-Dugo *et al.* 35 to 0.21 mol H_2O m^{-2} s^{-1}, reflecting improved efficiency of gas exchange and water transport through the plant, with positive effects on transpiration and nutrient uptake. In addition, the study of Medrano *et al.* 15 MPa as a result of precise control of humidity levels, reflecting greater efficiency in regulating the plant's water balance.

With respect to productive yield, studies have shown tangible results that support the feasibility of adopting these technologies. The study of Sánchez-Molina *et al.* [18] indicated that the use of smart greenhouses increased the total yield by between 45–60% depending on the cultivar, attributed to the improvement in environmental conditions and the precise care that the plants receive throughout the growth cycle. The study of Dannehl *et al.* 2 fruits m^{-2} in intensive cropping cycles, reflecting greater efficiency in the management of agricultural operations and the use of available space.

Regarding qualitative indicators, the study of Zhao *et al.* 8% in fruits produced in smart greenhouses, contributing to improved taste and sensory quality and thus to greater market value and consumer acceptance. In parallel, the study of Wang *et al.* [19] confirmed an increase in fruit firmness of about 12% in smart greenhouses compared with conventional systems, reflecting improved keeping and storage characteristics that reduce losses during handling and transport. The study of Tüzel *et al.* [20] recorded a notable reduction in cellular-deformation cases to less than 3% compared with 15% in conventional systems, attributed to the stable and suitable environmental conditions provided by smart greenhouses.

In the field of advanced environmental control, the study of Hemming *et al.* [21] showed that integrated sensing systems are capable of monitoring 15 environmental variables simultaneously and with high accuracy, enabling comprehensive management of the internal environment and its complex interactions. The study of Li *et al.* [22] developed intelligent algorithms capable of predicting plant diseases 72 hours before their appearance, relying on the analysis of environmental and plant data models for the early detection of any anomalies that may indicate the likelihood of infection.

In the field of nutrient management, the study of Savvas *et al.* [23] clarified that smart irrigation systems reduce fertiliser consumption by 35% while improving the plant's uptake of nutrients, by delivering nutrients precisely according to the plant's needs and at the appropriate time. On the economic and sustainability side, the study of Vox *et al.* [24] showed that the integration of solar-energy systems with smart technologies reduces energy consumption by 35%, lowering operating costs and the carbon footprint of the system, while the study of Pardossi *et al.* [25] showed that the smart irrigation system reduces water consumption to 45% while maintaining comparable productivity. The economic models developed by van Os *et al.* [26] indicated that the return on investment in these technologies can reach 22% annually after the third year of application.

In the field of climate adaptation, the study of Campen *et al.* In the field of marketable quality, the study of Nicola *et al.* Finally, in the field of future applications, the study of Körner and van Straten [27] predicted that advanced artificial-intelligence techniques will lead to further improvements in the efficiency of these systems, while Baeza and van't Ooster [28] predicted that these technologies will become a basic standard in protected cultivation within the coming decade as their costs decline and farmers' awareness of their benefits grows. The growing scientific evidence indicates that smart greenhouses represent the future of protected cultivation, providing an integrated solution to environmental and

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economic challenges and contributing to the achievement of sustainable food security.

III. PROBLEM DEFINITION AND OBJECTIVES

Amid the worsening global climatic challenges, conventional protected-cultivation systems face unprecedented pressures, represented by sharp fluctuations in temperature and relative humidity, which in turn are reflected negatively in production stability and the qualitative specifications of crops. In the face of this dilemma, advanced technical solutions represented by integrated smart protected-cultivation systems emerge as a promising platform for precise environmental control, capable of providing the optimal microclimate for plant-growth dynamics.

Accordingly, the fundamental justifications of this study lie in bridging the knowledge and applied gap by conducting a comprehensive evaluation of the use of smart greenhouse technologies against conventional systems, and measuring the extent of their effect on the physiological, morphological, and productive indicators of the cucumber crop. The research also aspires to provide an evidence-based analytical framework through which decision-making processes for farmers and agricultural planners can be strengthened, advancing the pathways of smart and sustainable agriculture.

In line with the justifications above, this study seeks to achieve the following main objectives:

1. To study and analyse the integrated effect of the smart greenhouse system on the vegetative growth rates, total yield, and qualitative traits of the cucumber cultivar UZDE.
2. To conduct a precise statistical comparison of the quantitative and qualitative productivity of the crop between the smart management pattern (the experimental variable) and the conventional management pattern (the control).
3. To assess the efficiency of the automated control systems (ventilation, cooling, and smart irrigation systems) in maintaining the stability of the internal environmental conditions within the optimal range for growth.
4. To establish a database that supports the adoption and generalisation of smart-agriculture technologies in order to ensure stable, high-quality production consistent with the requirements of food security under climate-change scenarios.

IV. MATERIALS AND METHODS

a) Study Site and Climatic Conditions

The experiment was carried out at the agricultural protected-cultivation facility of Sham University, located close to the Syrian–Turkish border between the Syrian city of Azaz and the Turkish city of Kilis (Figure 1). The region is characterised by a hot, dry climate in summer, when temperatures reach about 28.5 °C on average, and a cold, humid winter, when temperatures fall to about 5 °C on average. The mean annual rainfall is around 377 mm, concentrated mainly in the winter months.

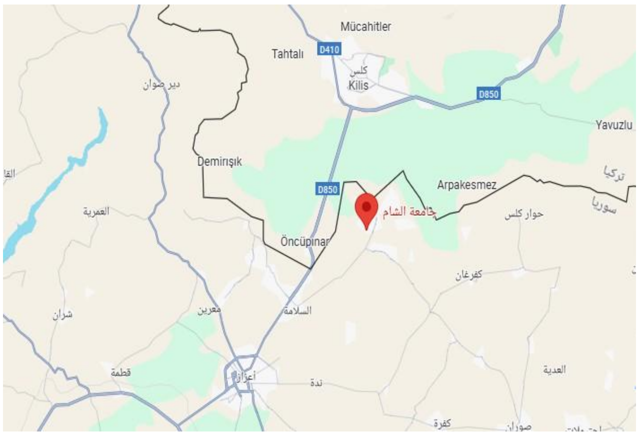

Figure 1: Location of the experimental site at the protected-cultivation facility of Sham University, near Azaz, northern Syria

b) Plant Material

The plant material used in the experiment was cucumber seedlings of the cultivar UZDE, a Turkish F1 hybrid of vigorous growth, distinguished by high productivity and well suited to cultivation in greenhouses for both winter and spring production (Figure 2).

Figure 2: The cucumber cultivar UZDE F1 used in the experiment (seed package and plant in the greenhouse)

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c) Experimental Treatments

The effect of controlling the environmental factors inside the greenhouse was tested through a smart cultivation system that allows the regulation of temperature, air humidity, ventilation, and soil irrigation, in comparison with the control, namely a conventional greenhouse in which the environmental conditions are adjusted manually. The two treatments were therefore the smart agricultural greenhouse and the conventional agricultural greenhouse (control).

d) Greenhouse Structure and Soil Preparation

Preparation of the greenhouse began with the installation of a sturdy metal frame, engineered to resist wind and the various weather factors, with due regard to material-strength standards and fixing angles to ensure the stability of the structure and its endurance of harsh climatic conditions.

The frame was then covered with a layer of high-quality agricultural plastic of 150–200 µm thickness, ensuring that the cover was stretched uniformly to prevent the formation of air pockets; this cover provides the required thermal insulation while allowing the passage of the light spectrum suitable for plant growth. Doors and side windows were then installed tightly to ensure optimal ventilation while preventing the entry of pests and insects, with the ventilation openings designed by precise calculation proportional to the total area of the greenhouse to ensure regular air renewal. Retractable shade nets were then fitted, controllable manually or automatically to adjust the internal light intensity and protect the plants from direct sunlight during peak hours, using durable, UV-resistant materials to ensure a long operational life.

Soil preparation began with perpendicular ploughing to ensure ideal loosening and aeration, followed by the removal of plant residues and harmful weeds that could form a suitable environment for the spread of pests and diseases. Fully decomposed organic fertiliser was then added at a rate of 4–5 m^3 per dunum, homogeneously mixed with the soil using mechanical mixers to ensure a uniform distribution of organic matter throughout the cultivated area. The soil was then sterilised with steam under high pressure, together with suitable soil sterilants, in full compliance with environmental and safety standards, in order to eliminate pathogens, nematodes, and weed seeds. After preparation, the soil was levelled precisely and laid out into straight planting rows at regular spacings of 90 cm, with lateral drainage channels established to prevent water accumulation. An integrated drip-irrigation system equipped with a central control unit was then installed, comprising multi-stage sand and screen filters to prevent emitter clogging, together with precise pressure regulators to ensure a uniform distribution of irrigation water; a thorough inspection of all emitters and a full efficiency test of the system were carried out before the start of the season.

e) Environmental Control Systems

The preparation and operation of the environmental-control systems began with the installation of an integrated ventilation system comprising high-efficiency external exhaust fans and internal circulation fans to ensure a uniform distribution of air throughout the greenhouse, with precise engineering calculations for the installation locations based on the volume of the structure and its ventilation capacity.

An advanced evaporative (Pads & Fans) cooling system was then installed, consisting of highly absorbent cellulose cooling pads and exhaust fans capable of achieving a suitable air-pressure differential, with a balanced water-distribution design to ensure uniform wetting of the cooling pads; this system lowers the temperature by up to 10–15 °C under hot climatic conditions. An integrated network of precise electronic sensors was then installed to monitor temperature, relative humidity, and light intensity, linked to an intelligent electronic control unit capable of processing data in real time and taking automated decisions to adjust the environmental conditions.

The central control unit was programmed according to the optimal growth criteria for cucumber: the soil-moisture range was set between 80–85%, air humidity between 85–90%, and temperature between 25–30 °C, with the ventilation system set to operate automatically when these ranges were exceeded. A comprehensive test of all systems was carried out, including the automatic irrigation system and the cooling, heating, ventilation, and shading systems, monitoring the performance of each system individually and in integration; the test included measuring the response time, the accuracy of reaching the required values, and their stability. A final readiness test was conducted over 48 continuous hours to monitor the stability of the environmental conditions inside the greenhouse, with full documentation of all environmental readings and a review of the performance of the control systems.

f) Crop Establishment and Field Management

Two sections were partitioned within the previously equipped greenhouse at Sham University: one section provided with the smart environmental-control system, and the second (control) relying on personal, manual control of these conditions. Cucumber seedlings of the cultivar UZDE were planted on 29 April 2025 in the two experimental sections of the greenhouse, on four rows (100 cm apart), at a rate of 20 seedlings per house (5 seedlings per row), with 50 cm between one plant and the next within the row; a 1 m margin was left

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around the entire internal perimeter of the greenhouse for the necessary service operations. The performance of the environmental-control systems was monitored continuously through the real-time monitoring system, which recorded a marked stability of the optimal environmental conditions, maintaining operational accuracy within the programmed ranges for soil moisture (80–85%), air humidity (85–90%), and temperature (25–30 °C). The principal field operations were then carried out according to the following schedule:

1. On 8 May 2025, a foundational fertilisation programme was applied by adding a root-stimulant fertiliser high in phosphorus (10-52-10) to stimulate the development of the root system and enhance nutrient-uptake efficiency in the early stages of growth.
2. On 14 May 2025, an integrated preventive programme was implemented, comprising treatment of the seedlings with systemic fungicides (such as Rizolex) and insecticides (such as Confidor) together with foliar fertilisers containing micronutrients, after the appearance of early fungal-disease symptoms and insect infestations.
3. On 16 May 2025, the fertilisation programme was reinforced by adding a dose of balanced soluble fertiliser (20-20-20) fortified with amino acids through the drip-irrigation system, to meet the integrated nutritional needs of the plants during the active vegetative-growth stage.
4. On 22 May 2025, an infestation by spider mites and scale insects was recorded and treated immediately by spraying specialised pesticides (such as abamectin for mites and pyrethroids for insects); notably, these infestations appeared in the conventional house 48 hours before the smart house, confirming the effectiveness of the early-monitoring systems in smart greenhouses.
5. On 25 May 2025, the first fruit harvest took place in the smart greenhouse, where the plants had reached full maturity, while the fruits of the conventional house were still in the formation stage. From 1 June, periodic fruit harvesting from both houses began at a rate of one picking every three days, and regular harvesting continued until 20 August 2025.
6. On 9 June 2025, a second preventive programme was implemented, comprising treatment of the plants with miticides and insecticides together with foliar fertilisers containing silicon and potassium to enhance plant resistance, after the observation of scattered infestations.
7. On 12 June 2025, a dose of balanced soluble fertiliser fortified with amino acids was added through the irrigation system, to enhance fruit set and increase the solids content of the fruits.

Figure 3: Planting of cucumber seedlings (cv. UZDE) in the smart greenhouse

Figure 4: Growth and development of the cucumber plants (cv. UZDE) in the smart greenhouse

g) Measured Traits

The most important vegetative-growth and yield parameters were measured on the cucumber plants in all treatments and replicates. The recorded parameters were as follows:

1. Plant height (m): measured from the soil surface to the tip of the main stem.
2. Leaf length and leaf width (cm): measured on representative fully expanded leaves using a graduated ruler. Leaf area (cm^2) was then derived as length × width × 0.73, using the shape factor for cucumber leaves.
3. Fruit length (cm): measured using a 50 cm graduated ruler.
4. Fruit diameter (cm): measured using a 50 cm graduated ruler.
5. Fruit volume (cm^3): determined by the water-displacement method using a 1 L beaker.

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6. Single-fruit weight (g): determined using a sensitive balance (to four decimal places).
7. Number of fruits per plant: all fruits of every treatment and replicate were counted, and the average number of fruits per plant was calculated for each treatment.
8. Fruit weight per plant (kg): the productivity of a single plant was calculated by multiplying the number of fruits per plant by the mean single-fruit weight.

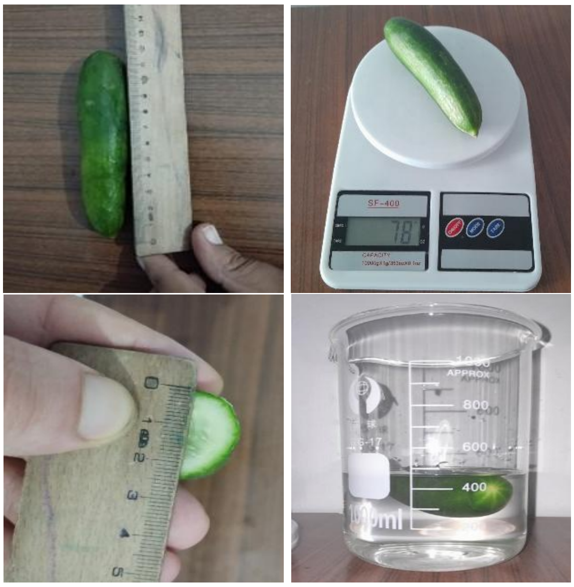

Figure 5: Taking the measurements on the fruits (length, weight, diameter, and volume)

h) Experimental Design and Statistical Analysis

The experiment was carried out according to a randomized complete block design (RCBD). Two treatments were adopted, namely the smart agricultural greenhouse treatment and the conventional agricultural greenhouse treatment (control); each treatment was represented by four replicates, and each replicate consisted of a row planted with five cucumber plants of the cultivar UZDE.

The total number of experimental plants was therefore: 1 cucumber cultivar × 2 treatments × 4 replicates × 5 plants = 40 plants. The results were analysed on the computer using the statistical analysis software Genstat-7, and the means were compared using the least significant difference (LSD) test at the 0.05 significance level.

V. RESULTS AND DISCUSSION

a) Effect of the Treatments on the Vegetative-Growth Parameters

The results presented in Table 1 show a clear qualitative and statistical superiority of the cucumber plants grown in the smart system compared with the conventional system across all measured vegetative-growth indicators. Plants in the smart greenhouses recorded a mean height of 3.5 m compared with 2.6 m in the conventional system, representing an increase of 34.6% — a statistically significant increase that exceeded the LSD value at the 0.05 level. This superiority in height growth can be attributed to the efficiency of the smart system in providing optimal environmental conditions, and in particular the precise control of carbon-dioxide concentration, which is a principal determining factor in photosynthesis and cell elongation [13].

As for the leaf traits, plants in the smart system recorded a marked superiority in leaf length (29 cm versus 18 cm) and leaf width (21 cm versus 15 cm), representing increases of 61.1% and 40% respectively. Applying the shape factor, this corresponds to a leaf area of 445 cm² against 197 cm². These large increases in leaf area reflect a substantial improvement in photochemical efficiency, as studies indicate that a larger leaf area allows greater absorption of light energy and leads to an increase in the net photosynthetic rate [9].

The overall superiority of 45% in total vegetative-growth traits can be explained by the ability of the smart system to provide an ideal, stable growth environment free of the environmental stresses normally experienced by conventional systems. These results are consistent with the findings of Papadopoulos et al. [17], who found that precise control of environmental factors inside smart greenhouses leads to an increase in plant vegetative growth of up to 50% compared with conventional systems; the study of Sánchez-Molina *et al.* [18] likewise confirms that smart-control systems provide ideal conditions for growth by maintaining the optimal balance between the various environmental factors.

Table 1: Effect of the Experimental Treatments on the Vegetative-Growth Parameters

Parameter	Smart Greenhouse	Conventional Greenhouse (Control)	LSD (5%)
Plant height (m)	**3.5**	2.6	0.3
Leaf length (cm)	**29**	18	2.1
Leaf width (cm)	**21**	15	1.7

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b) Effect of the Treatments on the Yield and Quality Parameters

The results in Table 2 constitute strong scientific evidence of the significant superiority of the smart cultivation system in improving the productive and qualitative indicators of the cucumber crop. With regard to fruit length and diameter, the results showed a clear significant superiority of the smart house, where the mean fruit length reached 13.9 cm compared with 12.28 cm in the conventional house, while the fruit diameter recorded 2.9 cm in the smart house against 2.53 cm in the conventional house. These differences are statistically significant, exceeding the LSD value at the 0.05 level, reflecting the positive effect of precise control of environmental factors through the sensing and real-time monitoring systems. These results are consistent with the findings of Sánchez-Molina *et al.* [18] regarding the effect of environmental stability on the physiological processes of fruit growth.

As for fruit volume, the smart house recorded a value of 97.3 cm³ against 72.15 cm³ in the conventional house, an increase of 34.9%, reflecting greater efficiency in cell division and the accumulation of carbohydrate materials.

For the quantitative indicators, a large significant superiority was observed in the number of fruits per plant, reaching 126 fruits in the smart house against 70 fruits in the conventional house, an increase of 80%. The fruit weight in the smart house was also superior, reaching 98.9 g compared with 79.8 g in the conventional house. These results agree with the findings of Papadopoulos *et al.* [17] regarding the effect of smart-agriculture systems on improving pollination efficiency and reducing flower drop.

With regard to total productivity, the smart house recorded a productivity of 12.462 kg per plant compared with 5.586 kg per plant in the conventional house, an increase of 123.1%. This qualitative leap in productivity reflects the integration of precise environmental control and the integrated management of agricultural operations, which was confirmed by the study of van Os *et al.* [26] in its analysis of the economic feasibility of smart greenhouses.

Through comparison with previous studies, these results coincide with the findings of Gonzalez-Dugo *et al.* Taken together, these results confirm that the smart cultivation system is not merely a technical upgrade but represents a qualitative shift in the agricultural production model, providing an ideal growth environment that simulates the optimal conditions for the plant, consistent with the vision of Körner and van Straten [27] on the future of smart agriculture in achieving sustainable food security.

Table 2: Effect of the Experimental Treatments on the Yield and Quality Parameters

Parameter	Smart Greenhouse	Conventional Greenhouse (Control)	LSD (5%)
Fruit length (cm)	**13.9**	12.28	0.4
Fruit diameter (cm)	**2.9**	2.53	0.12
Fruit volume (cm³)	**97.3**	72.15	3.7
Number of fruits per plant	**126**	70	5.4
Single-fruit weight (g)	**98.9**	79.8	2.1
Productivity (kg per plant)	**12.462**	5.586	0.264

c) Earliness of Production

The record of field operations gives a further result that the tables do not capture. The first picking was taken from the smart greenhouse on 25 May, at which point the fruits of the conventional house were still at the formation stage; periodic picking from both houses began on 1 June. The smart system therefore reached marketable maturity seven days ahead of the control. In protected cultivation this matters commercially as much as total yield, because the first pickings of the season meet the thinnest supply and the highest prices. The same environmental stability that produced the larger canopy also shortened the time to first harvest.

VI. CONCLUSION

The smart greenhouse system showed a clear, statistically significant superiority over the conventional system across all measured vegetative-growth indicators, with the differences in plant height (3.5 vs 2.6 m) and leaf traits exceeding the recorded LSD values. It also achieved a large superiority in fruit yield and quality, surpassing the control in fruit volume (97.3 vs 72.15 cm³), number (126 vs 70 per plant), weight

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(98.9 vs 79.8 g), and total productivity (12.462 vs 5.586 kg per plant; $P \leq 0.05$). The precise environmental stability provided by real-time control of temperature, humidity, light, and ventilation was the key factor behind this superiority, ensuring continuous growth free of the stresses that affected the conventional system. With productivity more than doubling (a 123% increase) and superior marketable quality, the smart model offers high economic feasibility, reaching first harvest seven days before the control and confirming its success as an integrated, sustainable solution that warrants wider adoption in the protected-cultivation sector.

VII. FUTURE SCOPE

1. Adopting and expanding the use of smart greenhouses, with a focus on the precise control of environmental factors (temperature, humidity, ventilation), to achieve the highest productivity and quality for the cucumber crop.
2. Developing integrated programmes for precise irrigation and fertilisation, and expanding the application of these technologies to other vegetable crops and larger areas to ensure the sustainability of production.
3. Adopting advanced environmental-programming technologies and training farmers in automated control systems, particularly in regions with a variable climate.
4. Supporting investment in the infrastructure of smart agriculture (energy, networks, communications) and encouraging applied research on other crops.
5. Establishing an integrated national platform to unify standards, transfer knowledge, and provide technical support to farmers, in order to ensure the success of the digital transformation in the agricultural sector.

ACKNOWLEDGEMENT

The author extends sincere thanks and appreciation to the Faculty of Agricultural Engineering, University of Idlib, and to the protected-cultivation facility of Sham University, for the scientific and logistical support provided, and to all who contributed to the implementation of the field experiment and the follow-up of its various stages.

REFERENCES

[1] Food and Agriculture Organization of the United Nations, "World Food and Agriculture – Statistical Yearbook 2022," *FAO, Rome, Italy*, 2022.

[2] United States Department of Agriculture, "FoodData Central: Cucumbers, raw, with peel," *USDA*, 2022. [Online]. Available: https://fdc.nal.usda.gov

[3] P. K. Mukherjee, N. K. Nema, N. Maity, and B. K. Sarkar, "Phytochemical and therapeutic potential of cucumber," *Fitoterapia*, vol. 84, pp. 227-236, 2013.

[4] A.P. Papadopoulos, "Growing Greenhouse Seedless Cucumbers in Soil and in Soilless Media," *Agriculture and Agri-Food Canada, Publication* 1902/E, 1994.

[5] J. C. Bakker, G. P. A. Bot, H. Challa, and N. J. Van de Braak, Greenhouse Climate Control: An Integrated Approach. *Wageningen, The Netherlands: Wageningen Academic Press*, 1995.

[6] R. Draie, Production of Vegetable Crops: Theoretical and Practical Part. *Idlib, Syria: Directorate of Books and Publications, University of Idlib Publications, Faculty of Agriculture*, 2019, 450 p.

[7] R. Draie, Protected Agriculture: Theoretical and Practical Part. *Idlib, Syria: Directorate of Books and Publications, University of Idlib Publications, Faculty of Agriculture*, 2022, 574 p.

[8] S. O. Grimstad, and E. Frimanslund, "Effect of different day and night temperature regimes on greenhouse cucumber young plant production, flower bud formation and early yield," *Scientia Horticulturae*, vol. 53, no. 3, pp. 191-204, 1993.

[9] X. Hao, J. Zheng, C. Little, and S. Khosla, "LED lighting for greenhouse cucumber production: Spectral effects on photosynthesis and growth," *Frontiers in Plant Science*, vol. 13, no. 4, pp. 830–845, 2022.

[10] S. W. Hogewoning, G. Trouwborst, H. Maljaars, H. Poorter, W. van Ieperen, and J. Harbinson, "Blue light dose–responses of leaf photosynthesis, morphology, and chemical composition of *Cucumis sativus* grown under different combinations of red and blue light," *Journal of Experimental Botany*, vol. 61, no. 11, pp. 3107–3117, 2010.

[11] L. F. M. Marcelis, E. Heuvelink, and J. Goudriaan, "Photosynthesis and production," in Plant Production in Closed Ecosystems, E. Goto, K. Kurata, M. Hayashi, and S. Sase, *Eds. Springer*, 2006, pp. 51–67.

[12] T. C. Wehner and D. N. Maynard, "Cucumbers, melons, and watermelons," in Encyclopedia of Food Sciences and Nutrition, B. Caballero, P. Finglas, and F. Toldrá, Eds. *Academic Press*, 2003, pp. 1697–1703.

[13] D. Katzin, L. F. M. Marcelis, and S. van Mourik, "Energy savings in greenhouses by transition from high-pressure sodium to LED lighting," *Applied Energy*, vol. 281, pp. 116019, 2021.

[14] H. Benyezza, M. Bouhedda, R. Kara, and S. Rebouh, "Smart platform based on IoT and WSN for monitoring and control of a greenhouse in the context of precision agriculture," *Internet of Things*, vol. 23, pp. 100830, 2023.

[15] O. Elijah, T. A. Rahman, I. Orikumhi, C. Y. Leow, and M. H. D. N. Hindia, "An Overview of Internet of Things (IoT) and Data Analytics in Agriculture:

ISSN (online): 2581-3048
Volume 10, Issue 9, pp 100-109, September-2026
https://doi.org/10.47001/IRJIET/2026.109011

Benefits and Challenges," *IEEE Internet of Things Journal*, vol. 5, no. 5, pp. 3758-3773, 2018.

[16] M. Nurmalisa, T. Tokairin, T. Kumazaki, and K. Takayama, "CO_2 distribution under CO_2 enrichment using computational fluid dynamics considering photosynthesis in a tomato greenhouse," *Applied Sciences*, vol. 12, no. 15, pp. 7756, 2022.

[17] H. A. Abdel Rahman, and H. S. Al-Wahaibi, "Water Use Efficiency and Yield of Cucumber (*Cucumis sativus* L.) Under Greenhouse and Field Conditions," *Journal of Agricultural and Marine Sciences [JAMS]*, vol. 9, no. 2, pp. 31, 2004.

[18] S. Engindeniz, and A. Gül, "Economic analysis of soilless and soil-based greenhouse cucumber production in Turkey," *Scientia Agricola*, vol. 66, no. 5, pp. 606-614, 2009.

[19] H. M. Kang, K. W. Park, and M. E. Saltveit, "Elevated growing temperatures during the day improve the postharvest chilling tolerance of greenhouse-grown cucumber (*Cucumis sativus*) fruit," *Postharvest Biology and Technology*, vol. 24, no. 1, pp. 49-57, 2002.

[20] J. C. Bakker, "Physiological Disorders In Cucumber Under High Humidity Conditions And Low Ventilation Rates In Greenhouses," *Acta Horticulturae*, no. 156, pp. 257-264, 1985.

[21] A.Ouammi, O. Choukai, D. Zejli, and S. Sayadi, "A Decision Support Tool for the Optimal Monitoring of the Microclimate Environments of Connected Smart Greenhouses," *IEEE Access*, vol. 8, pp. 212094-212105, 2020.

[22] Y. Li, X. Chen, L. Yin, and Y. Hu, "Deep Learning-Based Methods for Multi-Class Rice Disease Detection Using Plant Images," *Agronomy*, vol. 14, no. 9, pp. 1879, 2024.

[23] C. Lykas, P. Giaglaras, and C. Kittas, "Nutrient Solution Management Recirculating Soilless Culture Of Rose In Mild Winter Climates," *Acta Horticulturae*, no. 559, pp. 543-548, 2001.

[24] M. Santamouris, A. Argiriou, and M. Vallindras, "Design and operation of a low energy consumption passive solar agricultural greenhouse," *Solar Energy*, vol. 52, no. 5, pp. 371-378, 1994.

[25] R. Çakir, U. Kanburoglu-Çebi, S. Altintas, and A. Ozdemir, "Irrigation scheduling and water use efficiency of cucumber grown as a spring-summer cycle crop in solar greenhouse," *Agricultural Water Management*, vol. 180, pp. 78-87, 2017.

[26] S. Engindeniz, "Economic Feasibility of Organic Greenhouse Cucumber Production: The Case of Menderes," *Pakistan Journal of Biological Sciences*, vol. 5, no. 3, pp. 367-370, 2002.

[27] G. Chen, and F. You, "Energy-efficient greenhouse climate control with diffusion reinforcement learning," *Applied Energy*, vol. 409, pp. 127437, 2026.

[28] R. Al-Najadi, Y. Al-Mulla, and K. Goher, "Advances in intelligent and autonomous greenhouse systems," *Smart Agricultural Technology*, vol. 12, pp. 101670, 2025.

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Citation of this Article:

Prof. Dr. Rida Draie. (2026). Analysis of the Physiological Performance and Productive Yield of Cucumber (*Cucumis sativus* L.) in Smart Greenhouses. *International Research Journal of Innovations in Engineering and Technology - IRJIET*, 10(9), 100-109. Article DOI https://doi.org/10.47001/IRJIET/2026.109011

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