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Platform & Workflow by: [Open Journal Systems](https://openjournal.org)<https://doi.org/10.5281/zenodo.18983571>**Growth Performance and Yield Potential of Turkish Cucumber under Greenhouse Conditions in Khyber Pakhtunkhwa, Pakistan****Hammad Khan**

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**Abstract**

*Cucumber (Cucumis sativus L.) is one of the most widely cultivated vegetable crops due to its nutritional value, short growth cycle, and high market demand. In Pakistan, cucumber productivity is often constrained by climatic variability, limited adoption of improved cultivation practices, and dependence on traditional open-field production systems. Controlled greenhouse cultivation offers an effective approach for improving vegetable productivity by providing stable environmental conditions and enabling efficient nutrient and water management. This study investigated the growth performance and yield potential of Turkish cucumber under greenhouse conditions in Swabi, Khyber Pakhtunkhwa, Pakistan, during the 2024–2025 growing season. A greenhouse experiment was conducted using sandy loam soil amended with farmyard manure and balanced fertilization consisting of nitrogen, phosphorus, and potassium. Turkish cucumber seeds were initially germinated in seedling trays and later transplanted into prepared soil beds within the greenhouse. Key growth parameters, including germination rate, plant height, number of leaves, stem diameter, and fruit yield per plant, were recorded weekly over a ten-week period. Data were analyzed using descriptive statistical methods to assess plant growth trends and yield performance. The results indicated a high germination rate of 94%, demonstrating the adaptability of the Turkish cucumber variety to the local soil and climatic conditions. Vegetative growth was vigorous throughout the experimental period, with plants reaching an average height of 130 cm, producing approximately 46 leaves per plant, and achieving a stem diameter of 7.8 mm by the tenth week. Fruit yield averaged approximately 4 kg per plant, resulting in a total yield of 188 kg per Marla and an estimated production of approximately 74.5 tons per hectare. The harvested cucumbers exhibited desirable quality characteristics, including uniform size, green color, firm texture, and good market acceptability. The findings indicate that Turkish cucumber performs effectively under greenhouse cultivation in Khyber Pakhtunkhwa and has significant potential for improving off-season vegetable production. Adoption of greenhouse technology, combined with proper nutrient management and irrigation practices, can substantially enhance cucumber productivity and contribute to sustainable vegetable farming in Pakistan.*

## 1. Introduction

Agriculture remains a fundamental sector for economic development and food security in many developing countries. In Pakistan, the agricultural sector plays a significant role in supporting rural livelihoods, providing employment opportunities, and contributing to national food supply. Among agricultural commodities, vegetable crops occupy an important position due to their high nutritional value, short production cycle, and increasing demand in domestic and international markets. According to available agricultural statistics, vegetables are cultivated on approximately 0.41 million hectares of land in Pakistan out of the total cultivated area of about 23.4 million hectares, contributing significantly to the national agricultural economy (Ali et al., 2017). However, vegetable productivity in the country often remains below its potential due to climatic fluctuations, inefficient irrigation systems, poor nutrient management, and limited adoption of modern production technologies.

Cucumber (*Cucumis sativus* L.) is one of the most widely cultivated vegetable crops worldwide and holds a prominent position among horticultural commodities. The crop is believed to have originated in South Asia and has been cultivated for more than 3,000 years. Today, cucumber is grown extensively in both tropical and temperate regions because of its adaptability, relatively short growth duration, and high market demand (Grubben & Denton, 2004). Cucumber fruits are widely consumed fresh as salad vegetables and are also used in processed products such as pickles. Nutritionally, cucumbers are valued for their high water content, dietary fiber, and essential micronutrients including vitamin C, potassium, calcium, and iron. These attributes make cucumber an important component of a balanced diet and contribute to human health and well-being. Globally, cucumber ranks among the most important vegetable crops in terms of production and consumption. Major producers include China, Turkey, Iran, and Japan, where the crop is cultivated under both open-field and protected environments. The increasing demand for fresh vegetables throughout the year has encouraged the expansion of greenhouse cultivation systems, which allow farmers to overcome seasonal limitations and achieve higher productivity (Kadakoğlu & Gul, 2024).

In many countries, greenhouse technology has become a critical component of modern horticulture, providing controlled environmental conditions that enhance plant growth and protect crops from adverse weather conditions. In Pakistan, cucumber cultivation has gradually expanded over the past two decades due to its profitability and relatively short harvesting period. Despite this progress, productivity levels remain comparatively low when compared with global standards. Traditional open-field production methods often expose the crop to unfavorable environmental conditions, including temperature fluctuations, water stress, pest infestations, and nutrient deficiencies. These factors collectively limit plant growth and reduce yield potential. Furthermore, many farmers lack access to improved seed varieties, modern irrigation systems, and advanced cultivation practices that could significantly improve production efficiency (Khattak et al., 2021).

Greenhouse cultivation provides an effective solution to many of these challenges by enabling controlled environmental conditions that support optimal plant growth. In greenhouse systems, factors such as temperature, humidity, light intensity, and soil moisture can be regulated to create favorable conditions for crop development. These systems also allow for more efficient use of water and fertilizers, reduce pest pressure, and facilitate year-round production. Several studies have demonstrated that greenhouse cultivation can significantly increase cucumber yields compared with traditional open-field farming. For example, Kumar et al. (2017) reported that greenhouse-grown cucumber cultivars exhibit improved vegetative growth, higher fruit yield, and better fruit quality due to stable environmental conditions and optimized nutrient management.

In addition to environmental control, proper nutrient management plays a crucial role in enhancing cucumber productivity. Nitrogen, phosphorus, and potassium are essential macronutrients required for plant growth, photosynthesis, and fruit development. Jilani et al. (2009) demonstrated that balanced application of NPK fertilizers significantly improves cucumber growth parameters, including plant height, leaf development, and fruit yield. Similarly, Rahman et al. (2016) found that split application of nitrogen fertilizers enhances off-season cucumber production by improving nutrient availability during critical growth stages. Organic amendments such as farmyard manure and compost also contribute to improved soil fertility, microbial activity, and water retention capacity, thereby supporting sustainable crop production (El-Hamdi et al., 2017). Another important factor influencing cucumber productivity is the selection of suitable cultivars. Different cucumber varieties exhibit

considerable variation in growth characteristics, disease resistance, fruit quality, and yield potential. Modern breeding programs have developed improved cultivars that are better adapted to greenhouse environments and capable of producing higher yields under controlled conditions. Turkish cucumber varieties, in particular, have attracted attention due to their desirable fruit characteristics, including uniform shape, crisp texture, and attractive green color. These qualities make them highly preferred in local vegetable markets as well as in commercial supply chains.

Economic considerations also play a significant role in the adoption of improved vegetable production technologies. Off-season cucumber cultivation under protected environments has been shown to generate higher profits compared with conventional farming practices. Ishaq et al. (2003) estimated that farmers engaged in off-season cucumber production in Pakistan achieved higher net returns due to increased market prices during periods of limited supply. Similarly, recent studies have highlighted the economic viability of controlled cultivation systems, emphasizing that improved management practices and modern technologies can substantially enhance farm income (Bilal et al., 2024). Despite the potential advantages of greenhouse cultivation, limited research has been conducted to evaluate the performance of Turkish cucumber varieties under local conditions in Khyber Pakhtunkhwa. Climatic variability, soil characteristics, and local management practices may influence plant growth and productivity. Therefore, it is necessary to conduct experimental studies that assess the adaptability, growth performance, and yield potential of these varieties under controlled greenhouse conditions. Such research can provide valuable insights for farmers, agricultural extension workers, and policymakers seeking to promote sustainable vegetable production systems.

The present study was conducted to evaluate the growth performance and yield potential of Turkish cucumber (*Cucumis sativus* L.) under greenhouse conditions in Swabi, Khyber Pakhtunkhwa, Pakistan. The specific objectives of the study were to examine the germination rate, monitor vegetative growth parameters such as plant height, leaf number, and stem diameter, and assess fruit yield under controlled cultivation conditions. By analyzing these parameters, the study aims to determine the suitability of Turkish cucumber for greenhouse production in the region and to contribute to the development of improved vegetable farming practices that enhance productivity and sustainability.

## 2 Literature Review

### 2.1 Importance and Global Production of Cucumber

Cucumber (*Cucumis sativus* L.) is one of the most widely cultivated vegetable crops across the world and holds significant importance in both subsistence and commercial agriculture. The crop is believed to have originated in South Asia and has been cultivated for more than three thousand years due to its adaptability and economic value. According to Plant Resources of Tropical Africa 2: Vegetables by Gerrit J. H. Grubben and O. A. Denton, cucumber has spread to various tropical and temperate regions and has become an important horticultural commodity in global vegetable production. The fruit is widely consumed fresh as a salad vegetable and is also used in processed forms such as pickles. Nutritionally, cucumber contains essential vitamins and minerals including vitamin C, potassium, calcium, and dietary fiber, which contribute to maintaining human health.

Global cucumber production has increased significantly over the past few decades due to rising consumer demand and improvements in agricultural technologies. Major cucumber-producing countries include China, Turkey, Iran, and Japan. According to Bülent Kadakoğlu and Mustafa Gul (2024), market demand for cucumber continues to increase due to its widespread consumption and commercial value. Seasonal fluctuations in cucumber prices also indicate the importance of controlled cultivation systems that allow farmers to supply the crop throughout the year. In Pakistan, cucumber cultivation has gradually expanded in response to increasing domestic demand and favorable market conditions. However, productivity levels remain relatively low compared with international standards due to limited adoption of modern cultivation techniques and improved seed varieties.

### 2.2 Greenhouse Cultivation and Modern Production Technologies

Greenhouse cultivation has emerged as an effective strategy to improve vegetable productivity by providing controlled environmental conditions that support plant growth. Protected cultivation allows farmers to regulate factors such as temperature, humidity, light intensity, and irrigation, thereby minimizing the effects of

adverse climatic conditions. Research conducted by Q. Ali, M. T. I. Khan, and M. Ashfaq (2017) demonstrated that improving energy efficiency in greenhouse systems can reduce greenhouse gas emissions while maintaining high levels of cucumber productivity. Their findings highlight the potential of greenhouse cultivation to support environmentally sustainable vegetable production. Recent studies have also explored the economic benefits of modern cucumber production systems. A. Bilal and colleagues (2024) compared hydroponic cucumber farming with traditional soil-based cultivation methods. Their research showed that hydroponic systems can produce significantly higher yields and economic returns, emphasizing the advantages of controlled cultivation environments. Similarly, S. Kumar and co-authors (2017) reported that greenhouse cucumber cultivars exhibit improved vegetative growth and fruit quality when compared with crops grown under open-field conditions. These studies suggest that greenhouse cultivation, combined with modern management practices, can significantly enhance cucumber productivity and profitability.

### **2.3 Nutrient Management and Organic Fertilization**

Efficient nutrient management is essential for achieving optimal cucumber growth and yield. Nitrogen, phosphorus, and potassium are the primary macronutrients required for plant development, influencing processes such as root formation, photosynthesis, and fruit production. Research conducted by M. Jilani and colleagues (2009) demonstrated that balanced application of NPK fertilizers significantly improves cucumber growth parameters including plant height, leaf development, and fruit yield. Similarly, K. Rahman, S. Jailani, and J. Khan (2016) reported that split application of nitrogen fertilizer enhances off-season cucumber production in plastic tunnel systems by ensuring continuous nutrient availability during critical growth stages. In addition to chemical fertilizers, organic amendments play an important role in sustainable cucumber production. K. El-Hamdi and colleagues (2017) investigated the effects of organic and biofertilization treatments on cucumber growth and found that organic fertilizers improve soil fertility, enhance microbial activity, and increase fruit yield. Similarly, Y. Tavakoli and S. Khoshkam (2013) demonstrated that organic fertilizers significantly improve the productivity of greenhouse-grown cucumbers by enhancing soil structure and nutrient availability. Studies by Y. Tuzel and co-authors (2013) further showed that winter green manuring contributes to improved soil organic matter and better crop performance in greenhouse cultivation systems.

### **2.4 Pest Management, Varietal Performance, and Economic Aspects**

Effective pest management and cultivar selection are crucial factors influencing cucumber productivity. Sucking pests such as aphids, jassids, and whiteflies can significantly reduce crop yield if not properly controlled. Research conducted by S. Sarade and colleagues (2019) demonstrated that integrated pest management (IPM) strategies effectively control pest populations while reducing reliance on chemical pesticides. Adoption of IPM practices therefore contributes to sustainable vegetable production and environmental protection. Varietal performance also plays an important role in determining cucumber productivity. H. Khattak and co-authors (2021) investigated the effects of different gardening patterns on the field performance of several cucumber genotypes and found that planting arrangement and cultivar selection significantly influence plant growth and yield. Additionally, I. Siddique and colleagues (2020) evaluated cucumber cultivars for resistance against the root-knot nematode *Meloidogyne incognita*, identifying varieties that demonstrated moderate resistance and improved growth performance. Foliar nutrient application has also been shown to enhance productivity; for example, S. Siddique (2017) reported that calcium and magnesium sprays significantly improved cucumber growth and fruit yield.

Economic factors further influence farmers' adoption of improved cultivation techniques. M. Ishaq, G. Sadiq, and S. H. Saddozai (2003) analyzed the cost and profit functions of off-season cucumber production in Pakistan and concluded that protected cultivation generates higher returns compared with traditional farming systems. Environmental considerations are also becoming increasingly important in agricultural planning. Research conducted by I. Shah and colleagues (2022) revealed that farmers in District Swabi perceive climate change as a significant challenge affecting crop productivity. These findings highlight the importance of adopting climate-resilient practices such as greenhouse cultivation to ensure sustainable vegetable production in the region.

Overall, existing literature demonstrates that greenhouse technology, improved nutrient management, pest control strategies, and appropriate cultivar selection play critical roles in enhancing cucumber productivity. However, limited research has specifically examined the growth performance and yield potential of Turkish cucumber varieties under greenhouse conditions in Khyber Pakhtunkhwa. Therefore, the present study aims to evaluate the adaptability and productivity of Turkish cucumber under controlled cultivation conditions in Swabi, providing insights that may support the development of improved vegetable production practices in the region.

### **3 Methodology**

#### **3.1 Study Area and Experimental Site**

The present study was conducted during the 2024–2025 growing season at the greenhouse facility of the University of Swabi, located in District Swabi, Khyber Pakhtunkhwa, Pakistan. The district lies between approximately 33°55' to 34°23' north latitude and 72°13' to 72°49' east longitude. The region experiences a subtropical climate characterized by hot summers and relatively mild winters. Average summer temperatures reach around 27°C, while winter temperatures may fall below 20°C. June and July are generally the hottest months, whereas August often experiences high humidity levels that can influence plant growth and crop productivity. The greenhouse facility was selected for the experiment because it provides a controlled environment that minimizes external climatic variability and allows precise management of crop growth conditions.

#### **3.2 Experimental Design and Greenhouse Structure**

The experiment was conducted using a controlled greenhouse cultivation system to evaluate the growth performance and yield potential of Turkish cucumber (*Cucumis sativus* L.). The greenhouse structure consisted of a walk-in tunnel covered with transparent polyethylene sheets that allow adequate sunlight penetration while protecting plants from extreme weather conditions. The structure measured approximately 10.7 meters in length and 3.8 meters in width, providing a total experimental area equivalent to one Marla (approximately 25.29 square meters).

Plants were arranged in rows with a spacing of 50 cm between plants and 50 cm between rows to ensure adequate light distribution, airflow, and nutrient availability. The greenhouse remained open at both ends to facilitate natural ventilation and to maintain suitable temperature and humidity levels inside the structure. This layout ensured optimal plant growth while minimizing the risk of fungal diseases that may occur in poorly ventilated environments.

#### **3.3 Plant Material and Seedling Preparation**

The plant material used in this study consisted of certified Turkish cucumber seeds (*Cucumis sativus* L.), selected due to their known high yield potential, desirable fruit quality, and adaptability to protected cultivation systems. Prior to transplanting into the greenhouse soil, the seeds were first sown in plastic seedling trays filled with a mixture of sandy loam soil and compost. Seedlings were maintained in the trays for approximately three to four weeks until they developed sufficient root systems and reached a height of approximately 10–12 cm. During the seedling stage, proper irrigation and care were provided to ensure uniform germination and healthy plant development. Once the seedlings reached the appropriate growth stage, they were carefully transplanted into the prepared soil beds inside the greenhouse.

#### **3.4 Soil Preparation and Fertilization**

Soil preparation was carried out before transplanting to ensure optimal growing conditions for the cucumber plants. The soil used in the greenhouse was sandy loam with a pH range between 5.5 and 6.8, which is considered suitable for cucumber cultivation. The soil was thoroughly ploughed and leveled to improve aeration and drainage. Farmyard manure (FYM) was incorporated into the soil as an organic amendment at a ratio of approximately one-third FYM to two-thirds soil. The addition of organic manure improves soil fertility, increases water retention capacity, and enhances microbial activity in the soil. In addition to organic manure, chemical fertilizers were applied to supply essential plant nutrients.

Nitrogen was provided in the form of urea (46% N), while phosphorus was supplied through di-ammonium phosphate (DAP), which contains 18% nitrogen and 46% phosphorus. Potassium fertilizers were also applied according to recommended agronomic practices. Half of the nitrogen fertilizer and the full dose of phosphorus

and potassium were applied during transplanting, while the remaining half of nitrogen was applied approximately 30 days after transplanting to support vegetative growth and fruit development.

### 3.5 Irrigation and Crop Management Practices

Proper irrigation management is essential for cucumber production because the crop requires consistent soil moisture throughout its growth cycle. In the present study, irrigation was applied daily to maintain soil moisture at optimal levels without causing waterlogging. The watering process was conducted manually using watering cans to ensure uniform distribution of water across the experimental area. Crop management practices included regular monitoring of plant growth and health. Lateral shoots were pruned periodically to maintain a single main stem per plant, which improves light penetration and air circulation within the canopy. Plants were also trained vertically using strings attached to overhead supports in the greenhouse. This vertical training method helps reduce plant crowding, facilitates harvesting, and allows the plants to utilize available space efficiently.

### 3.6 Pest and Disease Management

Pest and disease management were conducted throughout the experimental period to maintain plant health and prevent yield losses. The greenhouse environment reduces pest infestation compared with open-field cultivation; however, regular monitoring was still necessary. Plants were inspected weekly for common cucumber pests such as aphids, jassids, and whiteflies. Integrated pest management practices were followed to control pest populations. Chemical pesticides were applied only when pest populations reached levels that could potentially damage the crop. This approach minimized unnecessary pesticide use while ensuring effective pest control and maintaining crop productivity.

### 3.7 Data Collection and Observations

Data collection was conducted systematically over a period of ten weeks after transplanting. Observations focused on both vegetative growth parameters and yield-related characteristics. Key parameters measured during the study included germination rate, plant height, number of leaves per plant, stem diameter, and fruit yield. Germination rate was calculated by dividing the number of successfully germinated seeds by the total number of seeds sown and multiplying the result by 100 to obtain the percentage value. Plant height was measured weekly using a measuring tape from the base of the plant to the tip of the main stem. The number of leaves per plant was recorded by counting fully developed leaves on each plant during weekly observations.

Stem diameter was measured using a vernier caliper at approximately two to three centimeters above the soil surface to assess the structural strength of the plant. Fruit yield was recorded at each harvest by weighing the cucumbers harvested from each plant. The average yield per plant was then calculated, and total yield per Marla was determined by multiplying the average yield per plant by the total number of plants grown in the greenhouse.

### 3.8 Data Analysis

The collected data were organized and analyzed using basic descriptive statistical methods. Mean values were calculated for each growth parameter to evaluate plant performance over time. Graphical representations were prepared to illustrate growth trends in plant height, leaf development, and stem thickness throughout the experimental period. Yield data were further extrapolated to estimate production per hectare, allowing comparison with national and international cucumber production standards. The results were then interpreted in relation to findings from previous studies to determine the adaptability and productivity of Turkish cucumber under greenhouse conditions in Khyber Pakhtunkhwa.

## 4 Results and Discussion

### 4.1 Germination Performance and Early Plant Establishment

Seed germination is a critical stage in vegetable crop production because it determines plant establishment and ultimately influences yield potential. In the present study, the Turkish cucumber (*Cucumis sativus* L.) exhibited a high germination rate of approximately 94 percent under greenhouse conditions. This high percentage indicates that the selected variety possesses strong adaptability to the soil and climatic conditions of District Swabi, Khyber Pakhtunkhwa. The favorable germination performance observed in this experiment may be attributed to the controlled environmental conditions provided by the greenhouse system. Protected cultivation helps maintain optimal temperature and moisture levels, which are essential for uniform seed germination and early seedling growth. Similar observations have been reported in previous studies, where greenhouse

environments were found to enhance germination rates and seedling vigor in cucumber cultivation. For instance, research conducted by Sanjay Kumar and colleagues demonstrated that cucumber cultivars grown under protected cultivation exhibit improved germination and early vegetative growth compared with crops grown under open field conditions.

The high germination percentage observed in the present study indicates that the Turkish cucumber variety is well suited for greenhouse cultivation in the region. Healthy seedling establishment during the early growth stage also contributed to uniform plant development throughout the experimental period.

The early germination and seedling establishment of Turkish cucumber were successfully observed under greenhouse conditions. A representative image of cucumber seedling emergence is shown in **Figure 1**.

Growth Parameters	Unit	1st Week	2nd week	3rd week	4th week	5th week	6th week	7th week	8th week	9th week	10th week
Rate of Germination	%	94									
Height of Plants	Cm	3.7	10	16	26	50	74.7	99	116	130	145
No. of Leaves	Count	2	4	7	10	14	19	24	30	37	46
Stem length	mm	1.5	2	2.8	4.6	5.6	5.9	6.4	7	7.2	7.8
Fruit Yield	kg/plant								3	3.5	4

**Figure 1. Germination and early seedling development of Turkish cucumber under greenhouse conditions.**

#### 4.2 Vegetative Growth Performance

Vegetative growth parameters such as plant height, leaf development, and stem thickness provide important indicators of plant health and overall crop performance. Weekly observations revealed a consistent increase in plant height during the ten-week growth period. At the early stage of development, plants exhibited moderate growth; however, rapid vertical expansion was observed after the fourth week, which corresponds to the vegetative growth phase typical of cucumber plants. By the tenth week, the average plant height reached approximately 145 cm.

The number of leaves per plant also increased steadily throughout the observation period. By the end of the tenth week, the plants had developed an average of 46 leaves per plant. Leaf development plays a crucial role in crop productivity because leaves are responsible for photosynthesis and energy production. A higher leaf count therefore contributes to increased carbohydrate production and ultimately enhances fruit development.

Stem diameter measurements further indicated healthy plant growth, with an average diameter of approximately 7.8 mm recorded by the tenth week. Stem thickness is an important indicator of plant vigor and structural strength, as thicker stems allow plants to support heavier fruit loads.

The observed growth trends suggest that the greenhouse environment provided favorable conditions for cucumber development. Adequate temperature regulation, proper irrigation, and balanced fertilization contributed to improved vegetative growth. Similar findings have been reported by Muhammad Jilani and colleagues, who demonstrated that balanced nutrient application significantly enhances cucumber growth parameters including plant height and leaf development. Likewise, studies conducted by Shahid Rahman and co-authors reported that optimized nutrient management in plastic tunnel systems promotes vigorous vegetative growth and improved crop performance.

#### 4.3 Fruit Development and Yield Performance

Fruit yield is the most important indicator of the economic viability of any crop production system. In this study, the Turkish cucumber plants produced fruits of uniform size, smooth texture, and bright green color,

indicating good market quality. On average, each plant produced approximately 4 kilograms of cucumber fruits during the harvesting period. Based on the total number of plants grown within the greenhouse structure, the total yield was calculated to be approximately 188 kilograms per Marla. When extrapolated to a hectare scale, the estimated yield reached approximately 74.5 tons per hectare. This yield level is considerably higher than the average yield reported for open-field cucumber cultivation in many parts of Pakistan.

The higher productivity observed in this experiment can be attributed to several factors associated with greenhouse cultivation. Controlled environmental conditions allow for optimal temperature and humidity levels, which are essential for cucumber flowering and fruit development. In addition, the vertical training system used in the greenhouse improved light penetration and air circulation within the plant canopy, thereby enhancing photosynthetic efficiency and reducing disease incidence. Comparable results have been reported in previous studies examining cucumber production under protected cultivation systems. Research conducted by Khalid El-Hamdi and colleagues found that improved nutrient management in controlled environments significantly enhances cucumber fruit yield. Similarly, Yusuf Tavakoli demonstrated that organic fertilization combined with greenhouse cultivation can substantially increase cucumber productivity and fruit quality.

Mature plants produced healthy fruits with uniform size and color. The growth habit and fruit development of Turkish cucumber plants cultivated in the greenhouse are illustrated in **Figure 2**.



**Figure 2. Vegetative growth and fruit development of Turkish cucumber plants under greenhouse conditions.**

#### **4.4 Environmental and Economic Implications of Greenhouse Cucumber Production**

Beyond agronomic performance, greenhouse cultivation also offers important environmental and economic benefits. Controlled cultivation systems enable farmers to produce vegetables throughout the year, including during off-season periods when market prices are typically higher. This creates opportunities for increased farmer income and improved food supply stability. Previous research conducted by Qaiser Ali and colleagues highlighted that energy-efficient greenhouse management practices can reduce greenhouse gas emissions while maintaining high productivity levels. These findings emphasize the potential role of protected agriculture in promoting environmentally sustainable crop production.

Economic analyses also indicate that greenhouse vegetable cultivation can generate higher profits compared with traditional open-field farming. For example, studies by Muhammad Ishaq and co-authors reported that off-season cucumber production in protected environments yields higher economic returns due to increased market demand and limited supply during certain periods of the year. In the context of climate change and increasing environmental variability, greenhouse cultivation represents a promising approach for improving agricultural resilience. Farmers in Khyber Pakhtunkhwa are increasingly recognizing the benefits of protected agriculture systems as a strategy to maintain crop productivity under changing climatic conditions.

#### **4.5 Comparison with Previous Studies**

The findings of the present study are consistent with earlier research demonstrating the positive impact of greenhouse cultivation on cucumber productivity. Studies conducted in various regions have shown that

protected cultivation systems significantly enhance plant growth, fruit quality, and overall yield compared with conventional field production methods. For instance, investigations on cucumber genotypes by Hidayat Khattak and colleagues indicated that improved cultivation practices and appropriate varietal selection can significantly increase cucumber yield. Similarly, research focusing on pest management strategies by Sachin Sarade demonstrated that integrated pest management approaches contribute to maintaining plant health and ensuring sustainable crop production.

The results obtained in the present study confirm that Turkish cucumber varieties possess strong growth potential and adaptability under greenhouse conditions in Khyber Pakhtunkhwa. The high germination rate, vigorous vegetative growth, and substantial fruit yield observed in the experiment indicate that the variety is suitable for protected cultivation systems in the region.

## **5 Conclusion and Recommendations**

### **5.1 Conclusion**

The present study evaluated the growth performance and yield potential of Turkish cucumber (*Cucumis sativus* L.) under greenhouse conditions in District Swabi, Khyber Pakhtunkhwa, Pakistan. The findings demonstrate that the selected cucumber variety exhibited strong adaptability to the controlled greenhouse environment and produced promising agronomic results. The germination rate recorded during the experiment reached approximately 94 percent, indicating that the Turkish cucumber seeds possess high viability and adaptability to local soil conditions. Early plant establishment was uniform and vigorous, which contributed to consistent vegetative growth throughout the experimental period. Observations of vegetative parameters revealed a steady increase in plant height, leaf number, and stem diameter over the ten-week growth cycle. By the final observation stage, plants attained an average height of approximately 130 cm, with about 46 leaves per plant and an average stem diameter of 7.8 mm. These results indicate strong plant vigor and favorable growth conditions within the greenhouse environment.

Fruit development and yield performance further confirmed the productivity potential of the crop under protected cultivation. Each plant produced an average fruit yield of approximately 4 kg. The overall production from the greenhouse structure reached about 188 kg per Marla, which corresponds to an estimated yield of approximately 74.5 tons per hectare. This yield level is considerably higher than typical open-field cucumber production reported in many regions of Pakistan. The fruits produced during the study were uniform in size, smooth in texture, and bright green in color, indicating good market quality and consumer acceptability.

The high productivity observed in this study can largely be attributed to the advantages of greenhouse cultivation. The controlled environment helped maintain optimal temperature, humidity, and soil moisture conditions, which are essential for cucumber growth and fruit development. Additionally, the application of balanced fertilization, incorporation of farmyard manure, and adoption of vertical plant training methods contributed to improved plant performance and yield.

Overall, the results indicate that Turkish cucumber varieties can successfully adapt to greenhouse cultivation systems in Khyber Pakhtunkhwa. The study confirms that protected agriculture has the potential to enhance vegetable production, improve crop quality, and increase farmers' income in the region.

### **5.2 Recommendations**

Based on the findings of this study, several recommendations can be proposed for improving cucumber production under greenhouse conditions in Pakistan.

First, farmers should be encouraged to adopt greenhouse cultivation systems for cucumber production, particularly for off-season vegetable farming. Protected cultivation allows growers to maintain favorable environmental conditions throughout the growing season and helps reduce the negative impacts of climate variability. Increased adoption of greenhouse technologies can therefore contribute to more stable and efficient vegetable production systems.

Second, the Turkish cucumber variety evaluated in this study demonstrated strong growth performance and high yield potential under greenhouse conditions. Farmers in Khyber Pakhtunkhwa and similar agro-climatic regions may consider cultivating this variety as a viable option for commercial production. However, further

research involving additional cucumber cultivars could provide broader insights into varietal adaptability and yield potential under protected cultivation systems.

Third, proper nutrient management practices should be implemented to maximize crop productivity. The combined use of organic manure and balanced chemical fertilizers proved beneficial in improving soil fertility and supporting plant growth. Farmers should follow recommended fertilization schedules to ensure adequate nutrient availability throughout the crop growth cycle.

Fourth, effective crop management practices such as vertical plant training, regular pruning, and timely irrigation should be adopted to maintain healthy plant growth and maximize yield. These practices improve light penetration, enhance air circulation, and reduce the risk of pest and disease infestation within the greenhouse environment.

Finally, further research should focus on optimizing greenhouse production techniques, including irrigation scheduling, integrated pest management strategies, and the use of advanced cultivation systems such as hydroponics. Comparative studies between different cucumber varieties and cultivation methods could also provide valuable information for improving productivity and sustainability in vegetable farming.

In conclusion, greenhouse cultivation of cucumber presents a promising opportunity for enhancing vegetable production in Khyber Pakhtunkhwa. The adoption of improved varieties, efficient management practices, and modern agricultural technologies can significantly contribute to sustainable agricultural development and increased food security in the region.

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