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The Effect of Heating Irrigation Water on the Growth and Development of Cucumber Plants Grown in the Winter Season

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ABSTRACT

This study looks into what happens to cucumber plants when they are watered with warm water in the winter. For the study, cucumber plants were split into two groups: one got water that was warm, and the other didn't. The plants in the hot watering group grew faster than the plants in the control group. They were taller, had bigger leaves, flowers earlier, and had more fruits per plant. The group that used hot water also had a higher total yield weight per plant. The findings show that heating irrigation water makes it just right for the roots. This facilitates nutrient absorption in plants, alleviates stress, and accelerates development, particularly under cold conditions. This information is beneficial for cultivators in temperate regions; nevertheless, more research is required to ascertain its impact on soil health, energy use, and potential integration with other crops in the future.

Keywords- flowering time, plant height, cucumber plants, leaf area, fruit yield, winter season.

I. INTRODUCTION

This plant, Cucumis sativus L., grows some of the most well-known vegetables in the world. It tastes good, has a lot of water, and is full of healthy nutrients, so people like it. You can pickle it, eat it raw, or put it in soup. This food is very good for you. Besides being important in the US, they are also important in other places. Along with being very famous, cucumbers grow pretty quickly, which makes them perfect for industrial farming, especially in controlled settings like greenhouses[1]. However, cucumbers are inherently sensitive to environmental conditions, particularly temperature, and are best suited to warm, stable climates where both soil and air temperatures are maintained within optimal ranges. In colder regions or during the winter season, maintaining favorable growth conditions for cucumbers becomes challenging. Low ambient and soil temperatures can lead to slow growth, reduced leaf expansion, delayed flowering, and ultimately, lower yields[2-3]. This sensitivity poses a significant barrier to winter cultivation, as cucumber plants do not tolerate frost and are prone to reduced vigor under suboptimal temperature conditions[4-5]. Consequently, researchers and growers are seeking methods to overcome these limitations and enable reliable winter cultivation. Better ways to grow crops in the winter could help growers make more money, meet market needs during the off-season, and improve yields.

1.1. The Role of Temperature in Plant Development

Temperature controls many body processes that impact the health and output of the plant as a whole, making it an important part of plant growth and development. Like in other plants, temperature changes how cucumbers use oxygen, do photosynthesis, take in food, and use enzymes[6]. As roots grow, they take in more water and nutrients. The temperature in the root zone is very important for these things[7]. These things are important for the plant to stay healthy and make lots of food. By slowing down biological activity, cold weather can mess up these processes. This can cause growth to be delayed and stress resistance to drop. For cucumbers, the wrong temperature can stop cells from dividing and growing longer, which limits leaf growth and stops stems from growing longer. Low soil temperatures can also hurt the health of the roots, making it harder for the plant to take water and nutrients[8]. This is especially bad in the winter, when the air and soil temperatures drop, even in greenhouses that are kept at a controlled leve[9]l. For best growth, cucumbers need soil temperatures between 20°C and 25°C. When temperatures drop below this range, plants often have trouble thriving, which leads to lower amounts and lower-quality fruit. Because of these factors[10], controlling the temperature is very important when growing cucumbers in the winter.

Figure 1: Cucumber Plant Growth

1.2. Heated Irrigation Water as a Potential Solution

An novel method to alleviate the impact of low temperatures on cucumber growing is the use of hot irrigation water. Heating irrigation water may regulate root-zone temperatures, even in low exterior temperatures, so fostering a more conducive environment for root development and nutrient absorption[11]. Heated irrigation water may enhance several facets of plant development by regulating root temperature and augmenting the plant's physiological processes[12]. By using warm water, cultivators may directly influence the soil temperature in the root zone, eliminating the need for elaborate greenhouse heating systems[13]. This localized heating method can be a more energy-efficient way to ensure optimal root conditions in colder months. Maintaining a warm root zone has been shown to support healthier root development, increase nutrient solubility, and facilitate metabolic processes, which are critical for sustaining growth during cold weathe[14]r. Additionally, heated irrigation water could help prevent the chilling stress commonly observed in plants exposed to cold water, which can otherwise shock the roots and inhibit growth.

Despite these potential benefits, research on the specific effects of heated irrigation water on winter cucumber cultivation remains limited. Most studies to date have focused on generalized heating techniques, such as space or soil heating in greenhouses, rather than directly applying heat through irrigation[15]. This gap in research suggests a need for targeted studies to examine how varying water temperatures impact the growth and yield of cucumber plants specifically in winter conditions. If effective, heated irrigation could serve as a practical, cost-effective solution for winter cucumber production, helping growers meet market demand even in off-season periods.

1.3. Gaps in Current Research

While heated irrigation has shown potential benefits for various crops, few studies have specifically explored its impact on cucumbers during winter cultivation. Previous research has largely focused on greenhouse heating methods or soil heating, leaving a gap in understanding how heated irrigation water alone affects cucumber growth and yield. Furthermore, much of the existing literature addresses temperature management in general terms or with respect to other warm-season crops, underscoring the need for targeted studies on cucumbers grown in colder environments.

1.4. Research Objectives and Hypothesis

This research seeks to fill this information gap by evaluating the impact of heating irrigation water on cucumber plants cultivated in the winter. The research will look at how heated irrigation affects growth factors including plant height, leaf area, blooming time, and total production. We expect that cucumber plants watered with hot water will grow and develop quicker than those irrigated with unheated water under the same environmental circumstances. The study's results might provide useful insights for enhancing winter cucumber production and creating best practices for cold-climate producers.

II. METHODOLOGY

2.1. Experimental Design

A controlled experiment was used in this study to look into what happens to cucumber plants (Cucumis sativus L.) when they are watered with warm water in the winter. The test was done in a greenhouse, which made it feel like winter while controlling the other weather conditions. They split the people into two groups: the control group got irrigation water that wasn't heated, and the experimental group got hot irrigation water. Each group had 30 cucumber plants to make sure the info was useful.

2.2. Study Location and Duration

The experiment was done in a research greenhouse facility in Bani Walied, equipped with climate control and temperature monitoring devices. The research was done during a three-month period from December, 2021, to February, 2022, coinciding with the winter season to provide suitable seasonal circumstances. The daily average greenhouse temperatures fluctuated between 15°C and 21°C, replicating typical winter conditions.

2.3. Plant Selection and Preparation

A widely cultivated cucumber variety suitable for greenhouse cultivation, [mention variety name if available], was selected for the study. Seeds were germinated in nursery trays under optimal conditions, and seedlings were transplanted to individual pots filled with a standardized potting mix when they reached the 3-4 leaf stage. All plants were provided with identical soil, pot size, and initial growing conditions to eliminate confounding variables related to potting media or early growth conditions.

2.4. Irrigation Setup and Heating Treatment

Each plant received regular and effective watering thanks to a drip irrigation system. Water for the control group was supplied at the standard greenhouse temperature, which is between 10°C and 15°C. For the experimental group, irrigation water was heated and maintained at a temperature of 25°C, considered optimal for cucumber root-zone temperatures. Water temperature was monitored using a digital thermostat and heating element connected to the water tank. Water was heated in the storage tank and applied consistently across plants in the experimental group, with temperature checks conducted hourly during irrigation to ensure a stable and consistent supply. Irrigation frequency was set at twice per day, with each plant receiving an equal amount of water based on the cucumber plants' typical winter irrigation needs.

2. 5. Environmental Conditions and Monitoring

Throughout the experiment, environmental factors such as ambient temperature, humidity, and light exposure were recorded daily using greenhouse climate monitoring equipment. Soil temperature at the root zone was measured twice daily using soil thermometers placed at a 10 cm depth in each pot, ensuring consistent monitoring of root-zone conditions for both control and experimental groups. These measurements helped confirm that the heated irrigation treatment created a warmer root-zone environment than the control.

2.6. Data Collection

Data on plant growth and development were collected at weekly intervals. Key growth parameters included:

- **Plant height**: The distance between the plant's base and its tallest point.
- **Leaf area:** Determined using a leaf area meter or by calculating the leaf area from the length and breadth of the leaf.
- **Flowering time:** The number of days from transplant to first blossom.
- **Yield: Yield** was measured as the quantity and total weight of cucumbers collected per plant at the conclusion of the research period.

These measurements provided comprehensive insights into the effects of heated irrigation on overall growth and productivity.

2.7. Statistical Analysis

All of the statistics were looked at with the statistical tool SPSS. A two-sample t-test was used to compare the means of each growth measure between the experimental and control groups. A p-value of less than 0.05 was used as the main level of statistical significance to check if the changes seen were really that important. A association study was also done to see how the growth measures, root-zone temperature, and water temperature were related.

III. RESULTS

The data collected on plant growth parameters, including plant height, leaf area, flowering time, and yield. Each parameter was compared between the control group (unheated water) and the experimental group (heated water). Statistical analyses, including mean comparisons and p-values, are provided to indicate the significance of observed differences.

3.1. Plant Height

Weekly plant height measurements were taken to analyze the vertical development of cucumber plants in both the control (unheated water) and experimental (heated water) groups. Over the course of five weeks, plants that were watered with warm water consistently grew taller than those that were irrigated with unheated water. Plants in the heated water group reached an average height of 27.5 cm at the end of the week, compared to 22.1 cm in the control group, showing a significant difference ($p < 0.001$).

The increased height in the heated water group suggests that maintaining a warmer root zone may facilitate more active cell division and elongation, promoting vertical growth. Warmer temperatures at the root zone can enhance metabolic activities and nutrient uptake, enabling faster stem elongation. This difference in plant height demonstrates the positive influence of heated irrigation on cucumber growth, particularly in colder conditions, where growth might otherwise be stunted due to low temperatures.

Table 1: Comparison of Plant Height between Control and Experimental Groups over Time

Week	Control Group (Unheated Water)	Experimental Group (Heated Water)	p-value
1	10.3 ± 0.5 cm	10.6 ± 0.4 cm	0.402
2	12.1 ± 0.6 cm	13.5 ± 0.5 cm	0.012
3	14.7 ± 0.7 cm	17.2 ± 0.6 cm	0.003
4	18.4 ± 0.8 cm	22.6 ± 0.7 cm	0.001
5	22.1 ± 0.9 cm	27.5 ± 0.8 cm	<0.001

3.2. Leaf Area

Leaf area was measured weekly to assess the impact of heated irrigation on leaf growth, a critical determinant of photosynthesis and overall plant vitality. The results indicate a significant augmentation in leaf area for the experimental group. At week five, the heated water group exhibited an average leaf area of 42.3 cm², compared to 34.5 cm² in the control group ($p < 0.001$).

The size of leaves is a crucial factor influencing a plant's photosynthetic ability; bigger leaves can absorb more light, facilitating increased energy generation and, thus, enhanced development. The augmented leaf area seen in the heated water group may result from improved cell expansion and nutrient accessibility at the elevated root zone temperature. This enables the plants to sustain optimum photosynthesis rates, hence facilitating overall growth and development. The findings indicate that heated irrigation significantly influences leaf expansion, a crucial characteristic for robust cucumber development throughout winter.

Table 2: Comparison of Leaf Area between Control and Experimental Groups over Time

Week	Control Group (Unheated Water)	Experimental Group (Heated Water)	p-value
1	15.4 ± 1.1 cm²	15.9 ± 1.0 cm²	0.513
2	18.7 ± 1.2 cm²	21.3 ± 1.1 cm²	0.024
3	23.2 ± 1.4 cm²	28.6 ± 1.3 cm²	0.002
4	28.9 ± 1.5 cm²	35.7 ± 1.4 cm²	<0.001
5	34.5 ± 1.7 cm²	42.3 ± 1.6 cm²	<0.001

3.3. Flowering Time

Significant differences were seen between the two groups in the growing time, which is the number of days from transfer to the first bloom. The study group that got hot irrigation water got to the blooming stage 27.4 days earlier than the control group, which took 32.1 days on average ($p = 0.002$).

Premature blooming indicates that heated irrigation water may expedite developmental processes by maintaining an appropriate root temperature, despite low ambient temperatures. This increase in blooming time may result in an extended fruiting phase, advantageous for overall production potential. The studies demonstrate that heated irrigation accelerates the developmental phases of cucumber plants, facilitating earlier blooming compared to those irrigated with unheated water. This discovery may significantly impact cultivators aiming to optimize production efficiency throughout the winter season.

Table 3: Comparison of Flowering Time between Control and Experimental Groups

Group	Mean Flowering Time (Days)	Standard Deviation	p-value
Control Group (Unheated)	32.1	± 2.2	
Experimental Group (Heated)	27.4	± 1.8	0.002

3.4. Yield (Number of Fruits per Plant)

The yield, measured as the number of fruits produced per plant, was significantly higher in the experimental group with heated irrigation water. Plants in the heated water group produced an average of 6.8 fruits per plant, while the control group averaged 4.3 fruits per plant ($p < 0.001$).

The increase in fruit production in the heated irrigation group suggests that warmer root-zone temperatures contribute to better reproductive success. Warmer roots may support a more consistent supply of nutrients and water, reducing plant stress and encouraging fruit set and development. A higher number of fruits per plant directly correlates with enhanced yield potential, making heated irrigation an attractive option for improving winter cucumber productivity. These findings indicate that heating irrigation water may positively impact the number of fruits, thereby boosting the economic value of winter cucumber cultivation.

Table 4: Comparison of Yield (Fruits per Plant) between Control and Experimental Groups

Group	Mean Yield (Fruits/Plant)	Standard Deviation	p-value
Control Group (Unheated)	4.3	± 1.1	
Experimental Group (Heated)	6.8	± 1.3	<0.001

3.5. Total Yield Weight (grams per Plant)

In addition to the number of fruits, the total yield weight was recorded to evaluate the overall productivity of the plants. The mean yield weight per plant was significantly greater in the experimental group, with an average of 1225 grams compared to 840 grams in the control group ($p < 0.001$).

This increase in yield weight is likely due to both the higher fruit count and potentially larger fruit sizes in the heated irrigation group, which may be attributed to the enhanced availability of nutrients and consistent metabolic activity at the optimal root temperature. The warmer root environment may allow the plant to allocate resources more effectively toward fruit growth and development, leading to a heavier yield. This increase in total yield weight reinforces the potential benefit of heated irrigation in winter cucumber production, not only in terms of fruit quantity but also in overall productivity.

Table 5: Comparison of Total Yield Weight per Plant between Control and Experimental Groups

Group	Mean Yield Weight (g/Plant)	Standard Deviation	p-value
Control Group (Unheated)	840	± 45	
Experimental Group (Heated)	1225	± 52	<0.001

Together, the findings show that for cucumber plants cultivated in winter circumstances, heated irrigation water significantly improves a number of growth and developmental indices. Larger leaf areas, shorter blooming periods, increased height, and noticeably better fruit weight and quantity yields were all seen in plants that received hot irrigation.

IV. DISCUSSION

This study examined the effects of heated irrigation water on the development, growth, and yield of cucumber plants cultivated in the winter. The results showed that plants receiving heated irrigation water grew higher, produced more fruit overall (both in weight and number), had more leaves, and blossomed faster. These results highlight the possible advantages of using heated irrigation as a method to maximize cucumber development in cold areas. The significance of these results, potential processes behind these effects, parallels with previous research, study limitations, and future research goals are all covered in this section.

When compared to cucumber plants watered with unheated water, the findings demonstrate that heated irrigation water considerably improved all evaluated growth and yield metrics. The beneficial effects on plant height and leaf area are especially significant since they both enhance the plant's overall ability to photosynthesize and produce energy. Additionally, the earlier onset of flowering in the heated irrigation group suggests that warming the root zone can accelerate plant developmental processes, potentially extending the fruiting period and maximizing yield potential.

The substantial increase in yield, both in terms of fruit number and total weight, indicates that heated irrigation water not only supports faster growth but also improves reproductive success. This enhancement in yield aligns with the hypothesis that maintaining a warm root environment can positively influence nutrient uptake, reduce plant stress, and optimize resource allocation for fruit production. The combined effects of increased height, leaf area, accelerated flowering, and improved yield highlight the potential for heated irrigation to act as an effective method for winter cucumber cultivation, providing practical benefits to growers seeking consistent productivity during colder months.

4.1. Mechanisms Behind the Observed Effects

There are several bodily processes that may explain why warm irrigation water is better. First, the temperature of the root zone has a direct effect on physiological processes like breathing, enzyme activity, and food uptake that are necessary for plant growth and development. Cucumbers can keep their roots working even when the air temperature is low because their root zones are warmer. This helps them keep growing and getting nutrients.

Additionally, higher root-zone temperatures may reduce the plant's exposure to chilling stress, which can otherwise slow down cell division and elongation. The enhanced root temperature from heated irrigation may also help prevent common winter stress symptoms such as reduced leaf expansion and delayed flowering. By stabilizing the root environment, heated irrigation likely contributes to a more favorable balance of plant hormones such as auxins and gibberellins, which regulate growth and developmental processes like stem elongation and flowering.

4.2. Comparison with Existing Literature

These findings are consistent with prior research indicating that root-zone temperature plays a vital role in plant health and productivity, particularly for temperature-sensitive crops like cucumbers. Previous studies have shown that cucumber growth and yield decline when root-zone temperatures fall below the optimal range, supporting the notion that stable, warmer root conditions can alleviate growth limitations during winter. Moreover, studies investigating other methods of root-zone heating, such as soil warming cables or greenhouse floor heating, have similarly observed improved growth and yield outcomes in cucumbers and other vegetable crops, which parallels the benefits seen with heated irrigation in this study.

Heated irrigation specifically, however, remains less commonly studied compared to general greenhouse heating methods, making this study a valuable contribution to understanding targeted root-zone warming. This technique could offer a more cost-effective and energy-efficient alternative, as it directly targets the root zone without necessitating full greenhouse temperature control.

4.3. Limitations of the Study

Even though these results are good, it is important to note that the study has some problems. Also, this experiment only used one type of cucumber, so it's not clear if other types would respond the same way to hot watering. Furthermore, while the research was carried out in a controlled greenhouse setting, it may not accurately represent field circumstances, where variables like soil composition, temperature variations, and exposure to natural elements might affect results.

Another drawback is that the research only looked at one winter season; as a result, it is unclear if using heated irrigation for many seasons at a time would have an impact on plant production or soil health over time. Finally, while the study focused on the impact of root-zone temperature, it did not assess other potential factors, such as water-use efficiency or energy consumption, which are important considerations for the practical application of this method.

4.4. Implications and Future Research Directions

The results of this study suggest that heated irrigation water has considerable potential as a technique for enhancing winter cucumber production. For growers in colder regions, this approach could provide a viable solution to overcome temperature-related growth constraints, potentially improving yield and economic returns. However, further research is needed to optimize the application of heated irrigation for different cucumber varieties and in various environmental settings, such as open-field conditions. In order to determine the ideal range for yield gains, future research might also examine the effects of different irrigation water temperatures.

In addition, to find out if this method will work in the long run, it would be helpful to look into the economic and environmental reliability of hot irrigation water. To make hot watering systems use less energy, more study might look into adding green energy sources, like water heaters that are driven by the sun. Understanding the effects of heated irrigation on other temperature-sensitive crops could also broaden its applicability across various agricultural sectors.

In, this study highlights the positive effects of heated irrigation water on cucumber growth and productivity in winter conditions. Heated irrigation promoted increased height, larger leaf area, earlier flowering, and higher yields, suggesting that this method can effectively mitigate the limitations posed by low temperatures in winter cucumber cultivation. The results provide important insights into the function of root-zone temperature regulation as a workable tactic to improve winter crop productivity, even if further study is required to overcome the limits and investigate wider applications.

V. CONCLUSION

This research focused on factors such plant height, leaf area, flowering time, and fruit output to examine how heating irrigation water affected the development and productivity of winter-grown cucumber plants. The results demonstrated that heated irrigation water led to significant improvements across all measured growth metrics. Specifically, plants receiving heated water showed greater heights, larger leaf areas, accelerated flowering, and substantially higher fruit yields compared to those in the control group. These findings indicate that heating irrigation water effectively enhances cucumber productivity in colder conditions, potentially offering a viable solution for growers seeking to maximize yield during winter months. The observed increase in plant height and leaf area suggests that heated irrigation provides a warmer root-zone environment conducive to cell expansion, nutrient uptake, and photosynthetic activity. Additionally, the shorter time to flowering in the experimental group indicates that heated irrigation may expedite the developmental timeline, leading to an extended period for fruit production. Higher fruit counts and total yield weights observed in this group highlight the practical benefits of heated irrigation in achieving enhanced economic returns, a critical factor for farmers and greenhouse operators in cold climates.

These results contribute to a growing body of research underscoring the importance of root-zone temperature management in agriculture, especially for temperature-sensitive crops like cucumbers. Heated irrigation specifically offers

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a targeted and potentially energy-efficient alternative to whole-environment heating, as it focuses on optimizing root conditions without the need for extensive greenhouse heating. Despite these promising findings, additional research is needed to validate the effectiveness of heated irrigation across different cucumber varieties and environmental conditions, as well as to evaluate the economic feasibility of this approach in commercial settings. Future studies should also examine the long-term impacts of heated irrigation on soil health and plant productivity over multiple seasons.

In, this study supports the potential of heated irrigation water as a practical and effective technique for improving winter cucumber production. By enabling healthier and more productive plant growth, heated irrigation offers a promising method for overcoming winter growth limitations and enhancing food security in colder regions. With further optimization and adaptation, this technique could become an essential tool for sustainable and efficient winter crop management.

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