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An Assessment on the Heating Mat System (HMS) for Studying the Initial Growth of Papaya (*Carica Papaya* L.) Seedlings

Fadhilnor Abdullah[1,2]*, Nurul Afidah Umoruddin[1], Syarifah Rokiah Syd Kamaruzaman[1], Kamarul Aizat Abdul Khalid[3], Ahmad Lutfi Mohd Razuwan[2], Badrul Hisham Johari[1], Mohd Khairul Rabani Hashim[2], Zainal Abidin Arsat[2], Muhammad Nur Aiman Uda[2] and Muhammad Firdaus Abdul Muttalib[2]

[1]Institute of Sustainable Agrotechnology (INSAT), University Malaysia Perlis (UniMAP), Sg. Chuchuh Campus, 02100 Padang Besar, Perlis, Malaysia.
[2]Department of Agrotechnology, Faculty of Engineering & Mechanical Technology (FKTM), Universiti Malaysia Perlis (UniMAP), 02600 Arau, Perlis, Malaysia.
[3]Department of Manufacturing, Faculty of Engineering & Mechanical Technology (FKTM), Universiti Malaysia Perlis (UniMAP), 02600 Arau, Perlis, Malaysia.

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ABSTRACT

This study assesses the usefulness of a Heating Mat System (HMS) in regulating different temperatures on the initial growth and survival of papaya (Carica papaya L.) seedlings. Conducted at the Institute of Sustainable Agrotechnology (INSAT), Universiti Malaysia Perlis (UniMAP), the research project aims to address challenges in the papaya propagation stage due to temperature sensitivity. Papaya seeds were pre-germinated, and the seedlings were grown under controlled temperature conditions using HMS at varying levels (±30 °C and ±45 °C) and compared to ambient conditions (treated as a control). The findings revealed that papaya seedlings exhibited the highest survival rates under ambient conditions, with significant declines observed at elevated temperatures. The study also assessed the effect of using HMS on the seedling biomass (shoot and root dry weight), noting that moderate temperature (±30 °C) led to a higher root-to-shoot ratio, suggesting an adaptive response of papaya seedlings to certain temperature changes. This research highlights the sensitivity of papaya seedlings to temperature changes during the early stage of plant growth and also contributes to knowledge in crop physiology as well as the agricultural engineering field.

Keywords: Papaya, Heating Mat System, Temperature sensitivity, Seedling growth, Biomass allocation.

1. INTRODUCTION

Papaya (*Carica papaya* L.) is one of the most economically important fruit crops in many Asian countries, valued for its nutritional and health benefits with a wide range of gastronomic uses. The papaya plant belongs to the *Caricaceae* family and is commonly grown in tropical and sub-tropical parts of the world [1-3]. This crop is widely well-known as a tropical fruit crop that contains many nutritious minerals such as vitamins A, C, and E, as well as dietary fibre and beneficial enzymes like papain [3]. Originating in tropical regions of the Americas, namely in southern Mexico and Central America, papaya cultivation has spread throughout the world and is now a common fruit in many tropical and subtropical climates, especially in Malaysia [4]. Many Asian countries rely heavily on papaya cultivation because of its great output potential and very short growth cycle. After planting, the tree usually starts to bear fruit six to twelve months later. Mature papaya fruits are suitable for harvesting nine to eleven months after flowering [5]. For

*Corresponding author: fadhilnor@unimap.edu.my

growers looking for immediate returns on their investment, papaya is an attractive crop because of its quick growth and early fruit yield.

Despite its many advantages, papaya cultivation faces several challenges, mainly due to the planted trees being sensitive to environmental conditions, especially climate change in terms of temperature variations [6]. In fruit trees, optimum growth requires a proper climate, consistent moisture levels, and well-drained soil or growing media, especially during the initial stage of seedling growth. Papaya is generally propagated through seedlings because of its high germination rate and effective method for establishing new papaya plants. A lot of factors can influence the early growth of papaya seedlings during germination processes [7]. Factors such as temperature can influence the germination processes and early growth of fruit tree seedlings, including papaya plants [8]. Understanding these factors is crucial for optimizing germination conditions to ensure healthy and vigorous plant development. The sensitivity of papaya seedlings during initial growth stages requires steady and ideal thermal conditions, which are often not provided by traditional seedling propagation methods. Variations in growing media temperature can cause poor root formation, unequal germination, and heightened disease susceptibility that may have a negative impact on the survival rates of seedlings [9]. To evaluate the effect of temperature on papaya seedlings' growth, this study utilizes a Heating Mat System (HMS) to test the applicability of this system in regulating the initial growth of papaya seedlings (Figure 1).

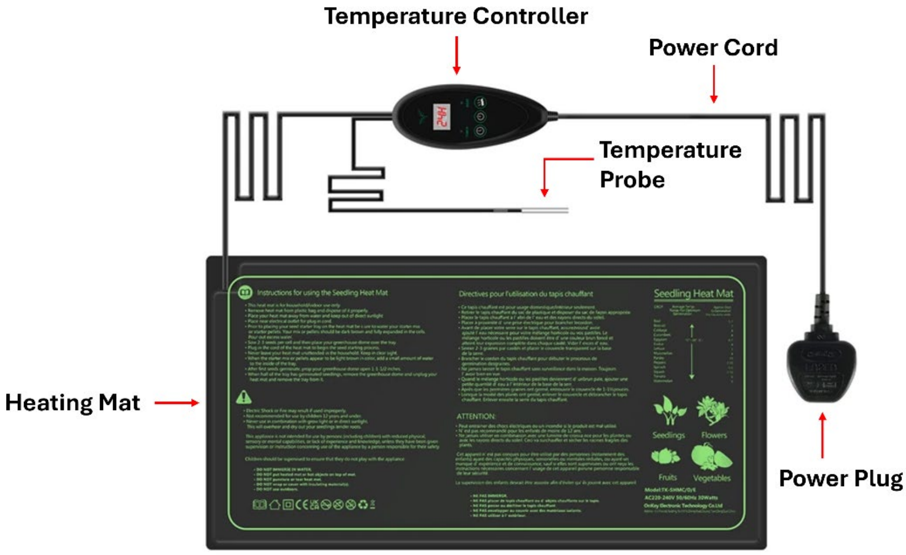

Figure 1: The general overview of the heating mat for studying the initial growth of papaya (*Carica papaya* L.) seedlings.

The HMS provides a controlled and consistent supply of bottom heat, creating an ideal micro-environment for seed germination or seedling growth. By maintaining the growth media temperature within the desired range, HMS can be used to evaluate the responses of papaya seedlings during the initial growth stages. This experiment was also designed to test the applicability of HMS in papaya seedling propagation, exploring its potential benefits in overcoming the challenges associated with traditional methods and improving the efficiency and success rate of papaya cultivation as found in temperate fruit cultivation [10]. This study investigates the use of HMS on the initial survival of papaya (*Carica papaya* L.) seedlings. Additionally, other growth parameters, such as biomass allocation (i.e., fresh and dry matter partitioning) of papaya seedlings, were also evaluated to determine the effectiveness of HMS in promoting growth and proper management for papaya seedlings. This study may hold potential implications for improving papaya management practices, thereby contributing to more sustainable and productive agricultural systems of this commercial fruit crop in Malaysia.

2. MATERIAL AND METHODS

2.1 Preparation of planting materials of papaya seedlings

This study was performed at the Institute of Sustainable Agrotechnology (INSAT), Universiti Malaysia Perlis (UniMAP), located at Sungai Chucuh Campus, Padang Besar, Malaysia. The seeds of papaya (*Carica papaya* L. cv. Sekaki) were subjected to a pre-germination process within propagation pots measuring 5 cm × 5 cm, utilizing burnt rice husk as the germination medium. Following a two-month period after germination, uniform and robust papaya seedlings exhibiting comparable size and uniform in height were carefully selected for the experimental procedure. At this stage, the papaya seedlings possessed 5 to 6 leaves on the primary stem. All the experimental plants were irrigated manually, with an application of 200 ml to 300 ml of tap water daily. The seedlings were positioned within a growing nursery that featured a 50% shade cover provided by netting, facilitating the hardening process until the plants were adequately prepared for HMS testing.

2.2 Overview of The Heating Mat System (HMS)

Figure 1 shows the HMS that has been used for this study (Model name: Heat Mat, Model No. TK-SHMD). The mat has dimensions of 20 inches (50.8 cm) length × 10 inches (24.5 cm) width and is connected to a temperature control device. The mat is connected to a power source through a standard electrical plug (power cord). The power cord to the mat measures 80 cm long, and the cord from the mat to the temperature controller measures 90 cm.

There are six (6) temperature levels that can be adjusted, which are L01 (temperature range approximately 20 °C [68 °F]), L02 (temperature range approximately 25 °C [77 °F]), L03 (temperature range approximately 30 °C [86 °F]), L04 (temperature range approximately 35 °C [95 °F]), L05 (temperature range approximately 40 °C [104 °F]) and L06 (temperature range approximately 45 °C [113 °F]). This heating mat is also equipped with a temperature probe, which helps monitor the soil temperature to ensure it remains at the desired level (Figure 1). Additionally, the timer can be adjusted to six (6) levels: 4, 8, 12, 16, 20, and 24 hours. The controller displays the desired temperature and is used to regulate the heat provided by the mat to ensure ideal growing conditions for seedlings.

The heating mat consists of a heating element (silicone heating wire) covered with an insulation barrier and wrapped inside a foldable, water-resistant plastic layer (PVC material). This mat is typically used in horticulture and gardening to provide a controlled warm environment for seeds to germinate and grow, especially in colder climates or during off-seasons.

2.3 An experimental setup using HMS

The HMS experiment was conducted in the specially designed growth chamber that was equipped with growth light, as shown in Figure 2. This diagram illustrates the HMS setup in a growth chamber for our study involving different temperature treatments for papaya seedlings. The papaya seedlings were placed on the top of a heating mat that is enclosed in a growth chamber with a grow light source on the top. There were two polystyrene barriers dividing the treatment into sections and preventing overflow heat between the treatment. The electrical supply provides power to the entire system, including the heating mat and timer. The temperature controller was connected to the heating mat to maintain the specified temperature. There was also a temperature probe that was positioned in the growth pots to monitor the temperature. The timer was set to turn on the temperature and grow light for 12 hours (7.00 am to 7.00 pm) and to turn off for another 12 hours (7.00 pm to 7.00 am).

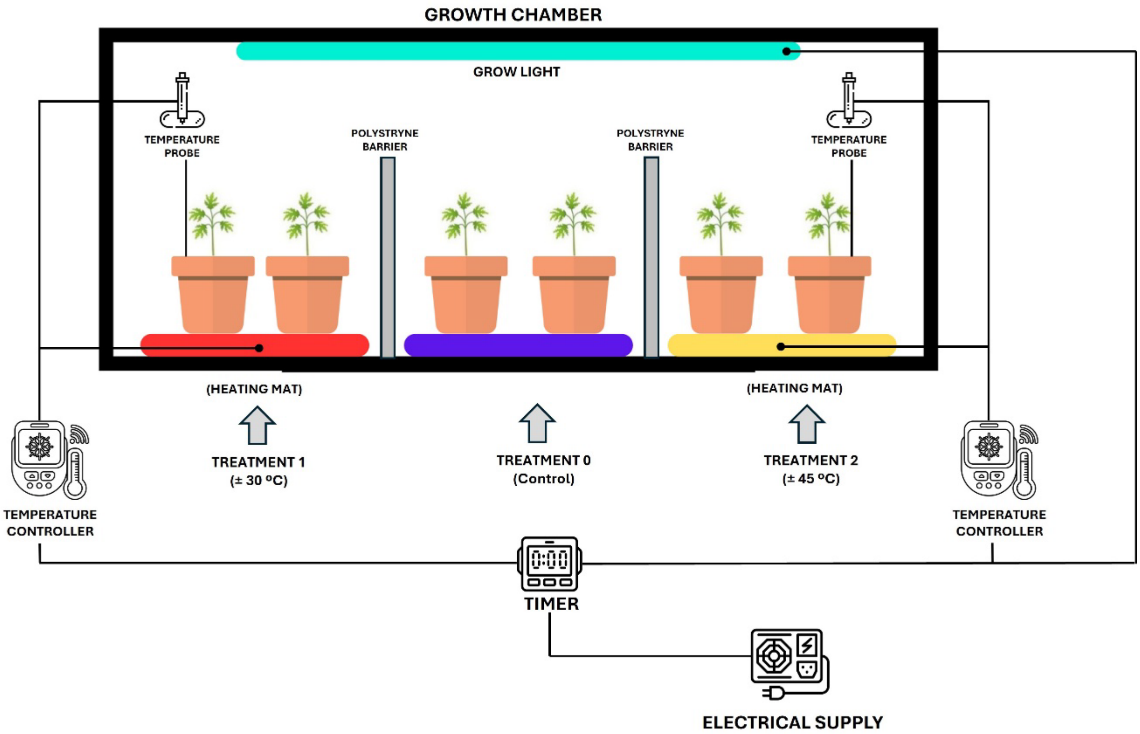

Figure 2: The schematic diagram of the arrangement of papaya (*Carica papaya* L.) seedlings on the Heating Mat System (HMS) in the growth chamber.

2.4 Measurement of survival, growth and biomass of seedlings

In this study, the survival rate of papaya seedlings was observed every day for each treatment to observe the sensitivity of papaya seedlings to the changes in temperature. The survival rate was calculated using a standard formula, which is the number of surviving seedlings for each day divided by the total number of seedlings for each treatment. The survival rate was expressed in percentage (%) by multiplying the total number of survived seedlings for each treatment by 100. The destructive sampling was also conducted at day 12 following temperature treatment to evaluate whether there were significant differences in the biomass of papaya seedlings between the temperature treatments. The data on shoot and root dry weight (g) were collected for each treatment, including the control (no temperature treatment). The dry weight of each component (shoot and root) was determined after drying the sample at 80 °C until the weight of the samples was constant and measured using digital balancing. Additionally, the root-to-shoot ratio was also calculated by dividing the root dry weight (g) by the shoot dry weight (g) in order to reveal the effect of different temperatures induced by HMS on biomass allocation of papaya seedlings.

2.5 Experimental design and statistical analysis

The HMS setup (Figure 2) allows for the controlled study of the effects of different temperature treatments (T1: ±30 °C and T2: ±45 °C) on papaya seedling plants, with a control group at ambient conditions for comparison (T0: room temperature, approximately 23 to 24 °C [75 °F]). The experiment was arranged at a Completed Randomised Design (CRD) with 24 single-replicated plants per treatment. All the data were manually entered in an Excel spreadsheet and summarised using the Pivot Table in Microsoft Excel. Data were analyzed using the SAS programme (version 9.0, SAS Institute Inc., NC, USA) and the differences between means were compared by the T-Test at the $P \leq 0.05$ level and presented in the bar graph. However, data comparison for destructive sampling (i.e., shoot and root dry weight, including the root-to-shoot ratio) could only be conducted for T0 and T1, as the seedlings in T2 died due to the temperature effect.

3. RESULTS AND DISCUSSION

3.1 Effect of HMS on the survival of papaya seedlings

Figure 3 shows the survival rate of papaya seedlings (%) over a period of 16 days following different temperature treatments. For T0, the survival rate of papaya seedlings had remained relatively high and stable throughout the entire 16-day observation period, even though a slight decline was observed after day 12 (Figure 3). The survival rate of papaya seedlings exposed to ±30 °C temperature (T1) for the first five days was initially stable but started to decline gradually from day 6 and continued to decrease steadily until it dropped to 0% by day 16. Surprisingly, in those papaya seedlings that have been exposed to ±45 °C temperature (T2), the survival rate dropped sharply within the first four days (Figure 3) and reached 0% survival by day 5. These results exhibited that the papaya seedlings show the highest survival rate under 0 °C (T0) conditions. The survival rate of papaya seedlings was decreased significantly with higher temperature treatments, with the most drastic reduction being seen under the ±45 °C (T2) condition (Figure 3).

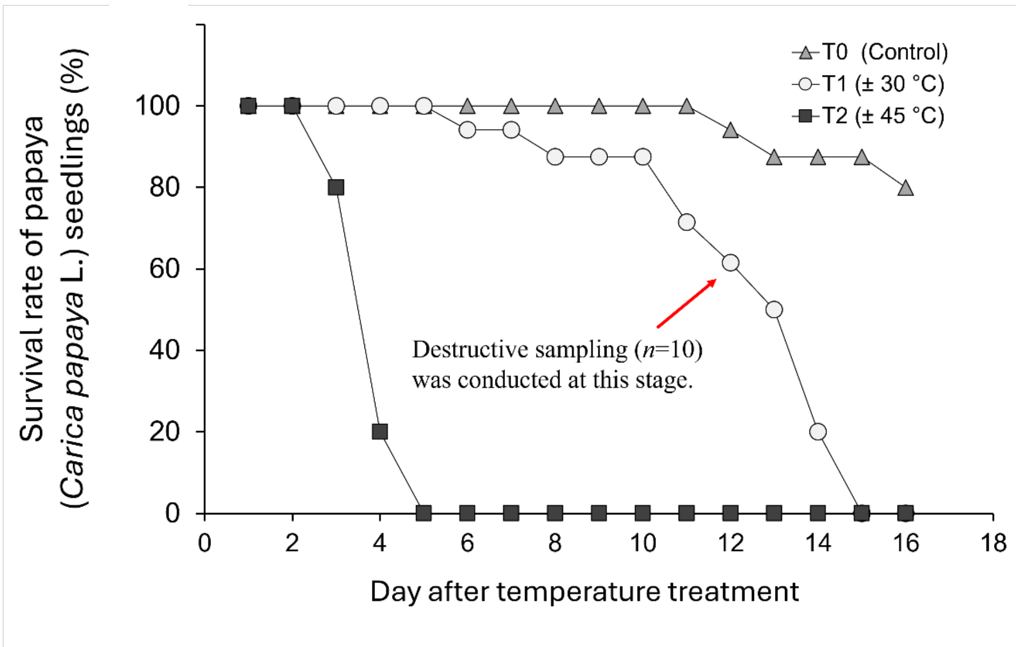

Figure 3: Daily survival rate (%) of papaya seedlings (*Carica papaya* L.) after temperature treatments.

The results also indicate that the roots of papaya seedlings are sensitive to changes in temperature. Similar to the study on tomato (*Solanum lycopersicum*) plants, Erwin and Guenthner [11] tested different temperatures exposed to the growing media, and they found that tomato root health was decreased as the temperature increased from 35 to 50 °C. According to Michael and Burke [12], the temperature either above or below a suitable range of plants generally may inhibit growth, especially on the root architecture by creating temperature stress [13, 14]. The result in Figure 3 also implies that excessively high temperatures could severely decrease cell division in the root meristem of papaya seedlings, leading to complete root death [9, 11]. It was notable that the suitable temperature range for the growth of papaya seedlings in field conditions is between 21 °C and 33 °C [15]. In this study, the survival rate of seedlings in control and temperature treatments of ±30 °C (T1) was relatively high compared with the seedlings in ±45 ºC temperature (T3) (Figure 3), indicating papaya seedlings can survive well in lower temperatures, possibly due to mechanisms that protect cellular integrity and function at lower temperatures [14]. However, the seedlings exposed to ±45 ºC temperature (T3) were completely death, indicating that the papaya seedlings did not sufficiently adapt to the extreme temperature changes during the initial stage of growth.

3.2 Effect of HMS on biomass of papaya seedlings

Figure 4 shows the effects of different temperature treatments induced by HMS on the shoot dry weight (Figure 4A), root dry weight (Figure 4B), and root to shoot ratio (Figure 4C) of papaya seedlings. The average of shoot dry weight of T0 (control) and T1 (±30 °C) was almost similar, with 0.17 g and 0.18 g, respectively (Figure 4A). The *P*-value of 0.21 indicates that there was no statistically significant difference in the shoot dry weight between the control group (T0) and the ±30°C treatment group (T1). In addition, the average root dry weight of papaya seedlings without temperature treatment (T0) and the ±30 °C treatment group (T1) were about 0.042 g and 0.050 g, respectively. It was noted that the root dry weight of papaya seedlings exposed to ±30 °C temperature (T1) was slightly higher than that of the control (T0) (Figure 4B). However, the *P*-value of 0.39 suggests that there was no statistically significant difference in the root dry weight of papaya seedlings between these two treatment groups. Although no statistically significant differences were observed in shoot and root dry weights between the control (T0) and the ±30 °C treatment (T1) (Figure 4), these results are valuable as they indicate that papaya seedlings can tolerate moderate increases in root-zone temperature without severe growth reduction.

Meanwhile, it was found that root to shoot ratio of papaya seedlings exposed to ±30 °C temperature (T1) was significantly higher (*P*=0.05) than the control group (T0) (Figure 4C). Based on the results above, it was found that although the shoot dry weight and root dry weight of papaya seedlings show an increase under the ±30 °C treatment, these changes are not statistically significant (Figures 4A and 4B). However, the result in Figure 4C may suggest that the ±30 °C temperature treatment (T1) may lead to a higher allocation of biomass to the roots relative to the shoots compared to the control. Furthermore, the significant increase in the root to shoot ratio under the ±30 °C treatment (T1) suggests a possible adaptive response of the papaya seedlings to moderate temperature stress, where more resources are allocated to root development.

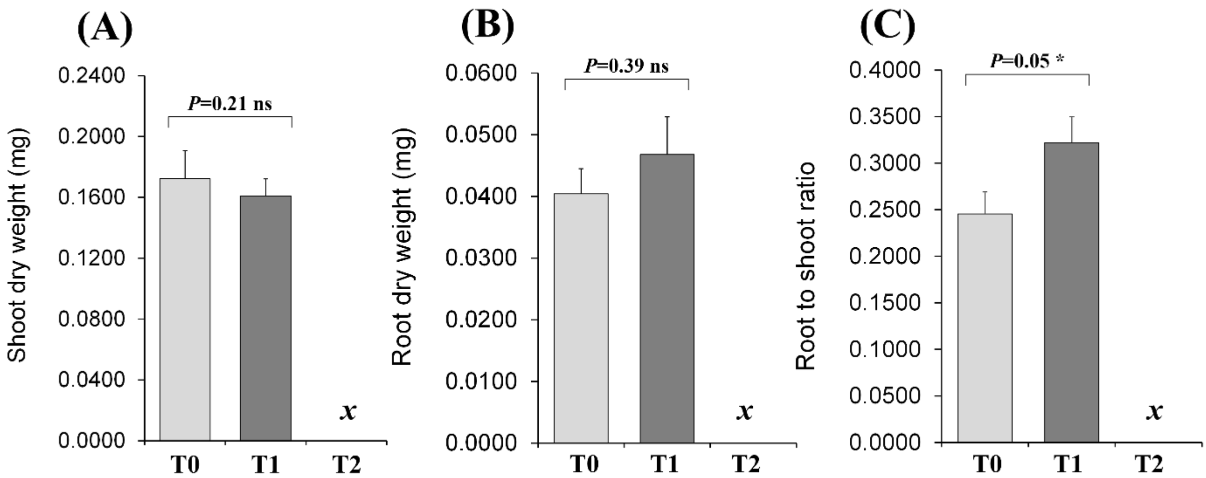

Figure 4: Effect of temperature induced by HMS on biomass parameters of papaya seedlings. (A) shoot dry weight (g), (B) root dry weight (g), and root to shoot ratio. Bars indicate the standard error of means. [x]Data for T3 (±45 °C) could not be obtained due to plant death.
* or ns - significant or not significant, respectively, according to the T-Test at $P \leq 0.05$.

4. CONCLUSION

In this study, the Heating Mat System (HMS) was found to be effective in maintaining targeted temperatures and tested on the plant seedlings, such as papaya (*Carica papaya* L.). However, its effects on seedling growth responses were limited and required further investigation. Overall, this research highlights that papaya seedlings can tolerate and slightly adapt to ±30 °C without significant detrimental effects on shoot and root dry weights, but they exhibit an altered growth pattern favoring root development (Figures 3 and 4). However, extreme temperatures around ±45 °C are beyond their tolerance threshold. Nevertheless, only two (2) temperature ranges were tested (i.e., ±30 °C and ±45 °C) in this study. Therefore, further study with HMS will be conducted with different temperature gradients (e.g., 20-35 °C), as well as tested at different types of crop species (e.g., vegetables and small fruit crops).

It was evident in this study that papaya seedlings at two-month-old growth stage are highly sensitive to temperature changes induced by HMS. Therefore, future experiments are planning to use older planting materials (more than two-month-old) with modifications and improvements on HMS. In addition, future designs for laboratory experiments using HMS need to be aligned with similar growth conditions of temperature and light intensity to obtain comparable results and prevent bias. Understanding how plants respond to temperature changes and integrate this information into their growth and development is crucial to determine how plants adapt to climate change and to apply this knowledge to agricultural engineering viewpoints. Therefore, utilization of the electrical Heating Mat System (HMS) in regulating root-zone-temperature in the context of seedlings growth and development will contribute to the improvement of plant physiological aspects and the agricultural engineering field.

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