Engineering Journal issn: 0125-8281

Article

Automatic Ecological Control and Mathematical Growth Prediction Models for Lettuce Seedling Nursery System

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Abstract. The research introduces an automatic nursery machine designed to enhance lettuce (green oak salad) seedling cultivation by regulating environmental conditions. The goal is to produce higher-quality lettuce in unfavourable settings. The study outlines two key components of this automatic ecological system: the environmental device design for lettuce control and a mathematical growth prediction model to support the machine's operation. The first component employs an Arduino microcontroller equipped with sensors to manage and accelerate the growth of nursery lettuce. The second aspect concentrates on growth prediction modelling, which informs and regulates the lettuce seedling nursery system. The automatic ecological system is implemented and tested against the community enterprise (CE) method, demonstrating superior results. The lettuce seedlings cultivated with the automatic nursery machine exhibit thicker, stronger stems, larger leaves, and a higher germination rate of 9.18% compared to the CE method. For the mathematical growth prediction models, multiple regression models are developed to correlate lettuce height (H) and stem width (W) with temperature, relative humidity, and light intensity within the automatic nursery machine. The goodness-of-fit analyses indicate reasonable model fits with R^2, MSE, and RMSE values of (W = 0.521, 0.093, 0.305, H = 0.604, 28.025, 5.294), respectively. Therefore, the automatic nursery machine offers an effective means to accelerate lettuce growth, potentially opening opportunities for large-scale industrial applications.

Keywords: Growth prediction, lettuce, light intensity, relative humidity, temperature.

ENGINEERING JOURNAL Volume 28 Issue 5
Received 18 December 2023
Accepted 14 May 2024
Published 31 May 2024
Online at https://engj.org/
DOI:10.4186/ej.2024.28.5.73

DOI:10.4186/ej.2024.28.5.73

1. Introduction

Lettuce (Lactuca sativa) is one of the healthiest vegetables for the human to be consumed and it contains high nutritional values such as vitamin A, vitamins B, vitamin C, vitamin E, calcium, potassium, phosphorus, iron, beta-carotene, carbohydrates, magnesium, and manganese [1, 2]. These obtained nutrition from lettuce have been reported to facilitate the process of blood production and, help nourish eyesight, hair, nerves and muscles. Additionally, chlorophyll contained in lettuce helps detoxification of the body [2-4]. Lettuce has gained widespread popularity in Thailand due to the benefit from its nutrition resulting in high demand and incremental change in its domestic price of 40 to 160 baht per kilogram [5]. Cultivation of lettuce can be generally done in two methods, which are soil cultivation and soilless cultivation (hydroponics). The first method is soil cultivation, this method often involves natural materials that the plants can be cultivated organically. Thus, the cost of cultivation is considerably affordable and the soil contains crucial nutrients to facilitate the growth of plants [6-8]. Alternatively, soilless cultivation has been developed to enable controlled water circulation and mineral management. This cultivation method allows for water conservation and precise nutrient control, promoting optimal plant growth [9-12]. However, this system showed some disadvantages, including the need for large planting areas and generally high development costs. In addition, since this system primarily relies on water for lettuce growth, it can easily lead to diseases through the roots of plants. Consequently, frequent monitoring is necessary to address these issues [13-15]. Both cultivation methods require approximately 40 to 50 days for lettuce to reach full growth and be ready for distribution in the market [16]. Both methods involve planting seedlings in trays about 15 days before transplanting. This is done by sowing the seeds in the trays, watering them daily, and waiting until the seedlings have developed 2 to 3 leaves before moving them to the field. If nurturing seedlings in a specific area is not feasible, change in various environmental factors such as temperature (T) and relative humidity (RH), amount of light, water, and nutrient levels in the soil can impact their growth [12, 16, 17].

Several researchers have attempted to develop ecological controls for lettuce cultivation, such as controlling the T and RH within the range of 25-30 °C and 60-80%, respectively, by using water spray to reduce the T in the cultivation house [7]. Regarding the regulation of light intensity (LI), light emitting diode (LED) lamps are deployed to substitute the solar light source in case of inadequate light intensity [18-21]. The optimal control of light wavelength is categorized into three distinct ranges. The first wavelength range, for seed germination to seedling growth, a combination of blue and red wavelengths, specifically 450 nm and 660 nm, respectively is recommended, with a ratio of blue 75% blue light to 25% red light [22, 23]. The second wavelength range is used to accelerate the growth of leaves and stems by providing light that is suitable for photosynthesis. In this range, the wavelength of blue light (450 nm) and red light (660 nm) is incorporated with far-red light 790 nm at a ratio of 50:50 [19, 23-26]. The final wavelength range is designed for the flowering and propagation stage. It involves a combination of blue light (450 nm) and red light (660 nm) with far-red light (790 nm) at a ratio of 25:75. Additionally, each lettuce crop is exposed to approximately 1% of white light [27]. In addition, the potential of hydrogen ion (pH) level of water was also controlled at pH 6.0. Typically, the water used for cultivation have a pH level in the range of 5.0 to 9.0 [12]. The process of cultivating seedlings through transplantation into larger plots has demonstrated an advantage over direct seeding, primarily attributable to the decreased quantity of seeds required [28]. This cultivation method is important to strengthen the seedlings before transplanting them into the field, enabling them to endure harsh environmental conditions. However, it's essential to maintain precise environmental control during the early stages, from germination to the vulnerable seedling phase [29]. The use of mathematical growth prediction models in modern agriculture has been showed in numerous studies [30-33]. These studies involved utilizing advanced data analysis techniques and machine learning algorithms by taking various measured data and factors obtaining from sensors or analog methods to generate growth prediction models with remarkable accuracy. The predictive models serve as powerful tools for sustainable agriculture, ensuring efficient resource utilization and contributing to global food production [34].

The research, therefore, develops the automatic nursery machine for lettuce seedlings with automatic ecological control such as T and RH, a lighting system utilizing LED lamps and natural light, as well as water pH control for watering lettuce seedlings. The study has also examined the parameters influencing lettuce seedling cultivation, and mathematical growth prediction models have been employed to establish correlations between cultivation conditions and plant growth facilitated by the developed nursery machine.

2. Materials and Methods

This section is divided into two parts such that the automatic nursery system for automatic ecosystems control lettuce seedling and the mathematical growth prediction models for the automatic nursery system. The overview process of methodology in this work shown in Fig.1. The automatic nursery system and the CE system were developed to compare the plant growth performance which mentions in the first subsection while the last subsection involves the data acquisition from the automatic nursery machine designed from an Arduino Mega 2560 microcontroller equipped with various sensors to build the predictive models.

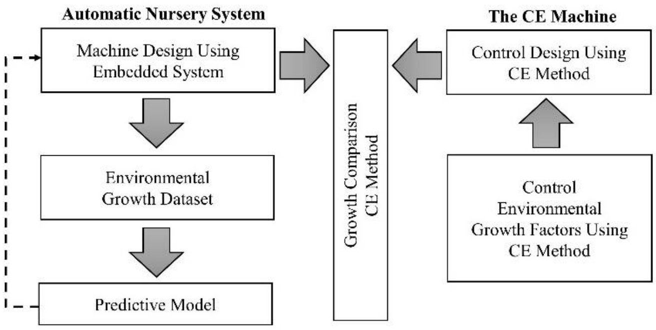


Fig. 1. The overview process of methodology in the study.

2.1. The Automatic Nursery System for Lettuce Seedlings with Automatic Ecological Control

The research developed an automatic ecosystem control system for a lettuce seedling size of 65x68x120 cm^3. This system maintains T and RH in the nursery room. The wall of the nursery chamber was installed with an insulation sheet. There were two nursery layers in this nursery system, each tier can accommodate two seedling trays. Below each level of the nursery, there was a drain tray size 56x58x2 cm^3 to collect wastewater after watering and transfer the wastewater to the outside of the nursery system, as shown in Fig. 2.

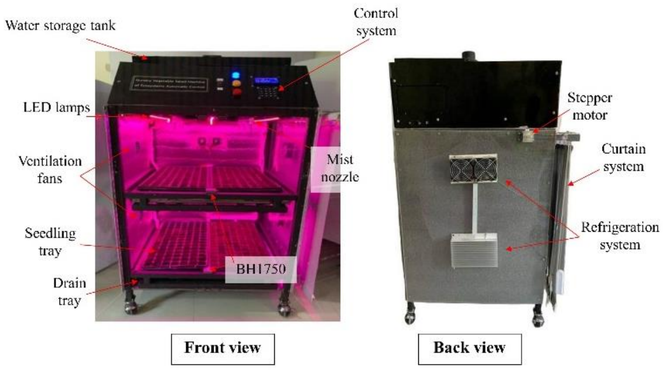


Fig. 2. The automatic nursery system for lettuce seedlings with automatic ecological control.

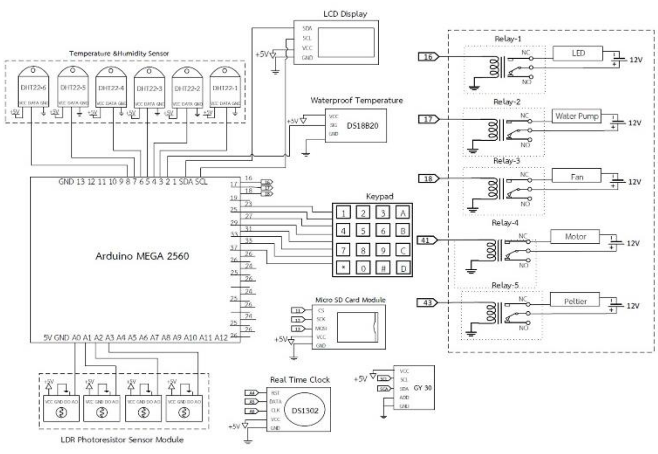


Fig. 3. The control circuit of the automatic nursery system for lettuce seedlings.

Figure 3 describes the control circuit design of a nursery system for lettuce seedlings with an automated ecological control system such as T and RH, LI, and pH of water for watering lettuce seedlings. The lettuce nursery ecological control is processed with an Arduino Mega 2560 microcontroller and the data that is read from various sensors is recorded into a secure digital (SD) card. This system has the following key components: 1) A water storage tank with a size of 26x37x26 cm^3 was installed above the nursery system and the pH of the water used to water the lettuce seedlings were automatically controlled. 2) The watering system for lettuce seedlings was controlled by spraying water from a 0.5 mm mist nozzle spread over the nursery chamber. Six misting nozzles were installed per layer; each nozzle was 27 cm apart from the column and 16 cm from each row. Watering the lettuce seedlings was carried out through a 12 V_{dc} pump and the water was pumped from the water storage tank at two intervals, 7:00 a.m. and 5:00 p.m., for 25 seconds each interval. 3) The drain tray with a size of 56x58x2 cm^3 was to collect water from the nursery tray and drain it after watering. 4) Lettuce seedling tray with 105-wells seedling tray, size 28x54x4 cm^3, serves as a tray to support lettuce seeds. 5) The T and RH control system in the nursery chamber was equipped with a DHT22 T and RH sensor (accuracy ± 0.5) of 3 units per layer. 6) The refrigeration system was installed behind the machine through the control of the Peltier. 7) The LED lamp set was equipped with 3 sets per layer: left, middle, and right. The LED lamps were controlled through the LI measurement in the nursery room with the BH1750 LI sensors and the sensors were installed with two sensors per layer. The LED lamp system will compensate for red and blue light wavelengths at 660 nm and 460 nm, respectively, when seedlings receive insufficient light for daily growth. 8) The curtain system was equipped with a BH1750 LI sensor to control the angular movement (rotation) of the stepper motor for opening/closing the curtain system. The controller will open the light curtain and switch on the LED lamp set when the LI is less than 250 lx. If the LI is less than 20,000 lx, the light curtain will be closed. As shown in Fig. 4.

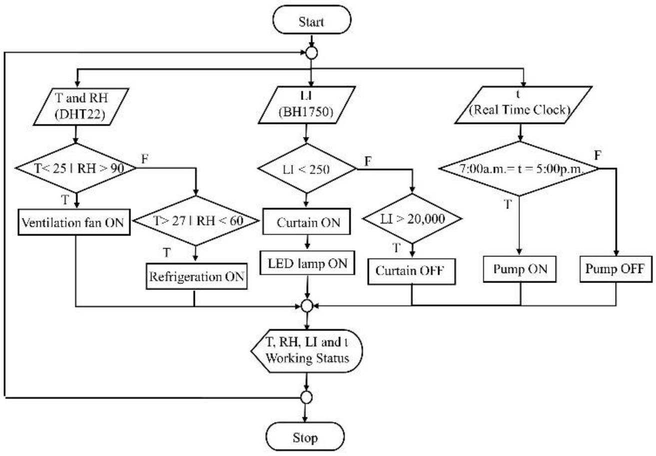


Fig. 4. System flowchart.

DOI:10.4186/ej.2024.28.5.73

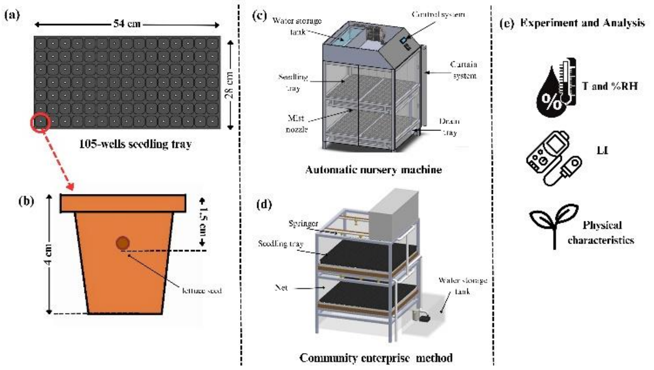


Fig. 5. The experimental diagram of the automatic nursery machine and CE method.

To facilitate a comparison with the CE method, a design will be created and installed as shown in Fig. 5(d). However, this design requires manual control of various factors in contrast to the automatic nursery system. The study of essential parameters for the growth of lettuce seedlings was performed through an experiment with an automatic ecological control nursery machine. The conceptual framework summarizes the cultivation process of lettuce seedlings into three parts, as shown in Fig. 5. The first part involved soil and the lettuce seed preparation. Peat moss was used as the soil and soil was fully filled in a 105-wells seedling tray as shown in Fig. 5(a). This type of soil is considered a high-quality potting soil that can hold water and maintain moisture levels for lettuce seedlings [35-37]. Additionally, pores allow plants to get air thoroughly, suitable pH, and there are enough nutrients for plants to be used for a long period. The lettuce seed preparation was carried out as follows: fully coated seeds were coated with starch or clay and nutrients to maintain the seed conditions and moisture [38-40]. The lettuce seeds were planted at a depth of 1.5 cm in 105-wells seedling trays, as shown in Fig. 5(b), where the seeds will have the highest chance of germination [41]. The second part was the experimental process of cultivating lettuce seedlings for a period of 15 days. The automatic nursery machine, as shown in Fig. 5(c), and the community enterprise (CE) method, as shown in Fig. 5(d), were both used to cultivate lettuce seedlings. In both experiments, lettuce seedlings were planted in 4 nursery trays at a time (3 repetitions). The first method (Fig. 5(c)) of cultivation is to insert the experimental sample inside the machine that has been developed. This automatic nursery machine can maintain a chamber T of 25-27 °C and an RH of 60-90%. The light curtain and the LED lamps installed in the nursery room were used to adjust the LI for the lettuce seedlings. The functioning condition was that if there is too much LI, greater than 20,000 lx, the curtain will be closed. To compensate for the intensity of light on the lettuce seedlings if the LI is too low, lower than 250 lx, the curtains will be opened and the LED lamp set are turned on. The watering system was automatically sprayed with water between the hours of 7:00 a.m. and 5:00 p.m. To fit the growth of lettuce seedlings, the water for the seedlings was adjusted to a pH of around 6±0.5 using diluted potassium hydroxide solution and diluted nitric solution. Furthermore, this machine recorded the ecological data, T, %RH and LI, in the nursery chamber every 15 minutes. The second method, the CE method, (Fig. 5(d)) was cultivated lettuce seedlings in an environment where the ecological conditions and pH of the water for the lettuce seedlings were uncontrolled. The final part of both methods was to collect the results and analysed the lettuce cultivation parameters, height (H) and stem width (W), and germination rate, every day during a period of 15 days, as shown in Fig. 5(e).

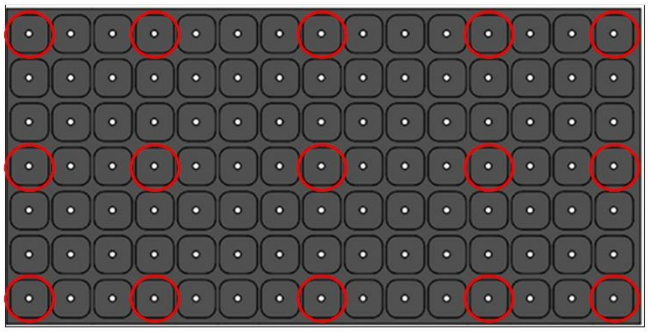


Fig. 6. The 15 points sampling position of lettuce seedlings in 105-wells seedling trays.

Fig. 7. The 15 points sampling position of lettuce seedlings in 105-wells seedling trays.

The measurements were recorded with 15 points in the 105-wells seedling trays, as illustrated as circles in Fig. 6, where the sampling points were evenly distributed throughout the samples. The germination of lettuce seedlings was observed daily between the automatic nursery machine method and the CE method. The H of lettuce seedlings was measured from the soil surface to the top of the leaves with a ruler and the W of lettuce seedlings was measured with a digital vernier calliper Mitutoyo, accuracy 0.01 mm, where each measurement was repeated 3 times, as shown in Fig. 7. The collected data were used for statistical analysis to find mathematical models for growth prediction of lettuce seedlings.

2.2. The Mathematical Growth Prediction Models for the Automatic Nursery System.

In the study, mathematical growth prediction models were utilized to monitor and analyse parameters that affect lettuce growth. These models integrated data from various sensors through a microcontroller and employed data analytics techniques. The collected data from the microcontroller was then utilized to generate and model growth predictions. These predictions were applied to provide suggestions and control for the lettuce seedling nursery system, which involves the following steps:

(1) Data Collection: The microcontroller, equipped with sensors, was deployed in the automatic nursery machine to record real-time data on environmental conditions such as T, RH, and LI. Additionally, H and W data were periodically measured and collected using measurement equipment.

(2) Data Preprocessing: The data collected from the SD card underwent preprocessing to remove noise, handle missing values, and, if necessary, normalize the data. Data preprocessing techniques ensure that the data is in an appropriate format for analysis.

(3) Feature Extraction: Relevant features related to lettuce germination were extracted from the preprocessed data. These features may include T, RH, and LI for environmental conditions, as well as H and W for lettuce growth.

(4) Model Development: Mathematical growth prediction models were constructed using statistical techniques. Common approaches encompass regression models, decision trees, random forests, support vector machines (SVM), and artificial neural networks (ANN). In the study, multiple regression models were developed to establish relationships between the H and W of lettuce and the T, RH, and LI.

(5) Model Training and Evaluation: The predictive models were trained using historical data, enabling them to learn the relationships between the collected features and lettuce growth parameters. The performance of the models was evaluated using appropriate metrics, such as coefficient of determination (R-squared), mean squared error (MSE) and root mean squared error (RMSE).

(6) Real-time Prediction and Monitoring: Once the model is trained and validated, it can be employed to make real-time predictions on lettuce growth based on the current sensor readings. This capability allows farmers or stakeholders to continuously monitor lettuce growth and take timely actions, such as adjusting environmental conditions or optimizing harvesting schedules.

(7) Integration and Decision Support: The predicted lettuce growth information can be integrated into decision support systems that provide recommendation action insight to farmers, supply chain managers, or retailers. These insights assist in optimizing storage, transportation, and distribution processes to ensure the maintenance of lettuce quality throughout the supply chain.

3. Results and Discussion

3.1. The Ecological Control inside the Lettuce Nursery System

A T and RH in the automatic nursery machine affect the cultivation of lettuce seedlings. DHT22 sensors were used to measure T and %RH and the microcontroller will process and control the T with the cooling system, and a mist spray and a ventilation fan were used to control the %RH. The ecological data in the nursery are recorded every 15 minutes for a period of 15 days on an SD card. The BH1750 sensor was used to measure the LI and the microcontroller will adjust the LI in the lettuce seedling nursery chamber using the curtain and the LED lamp, and the data of LI was recorded in an SD card. The LI in the automatic nursery machine was recorded every 30 minutes for 15 days in order to collect the LI and analyse the appropriateness of the lettuce seedlings.

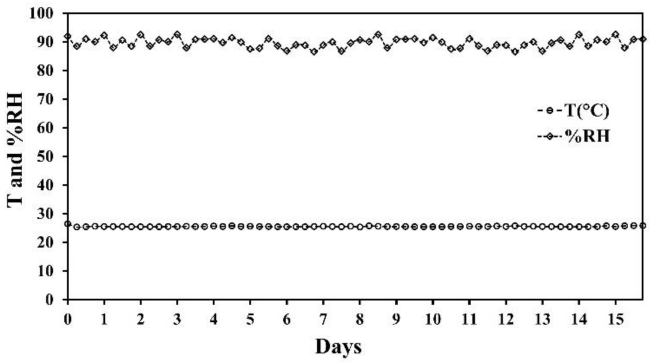


Fig. 8. The T and RH inside the automatic nursery machine throughout a 15-day period.

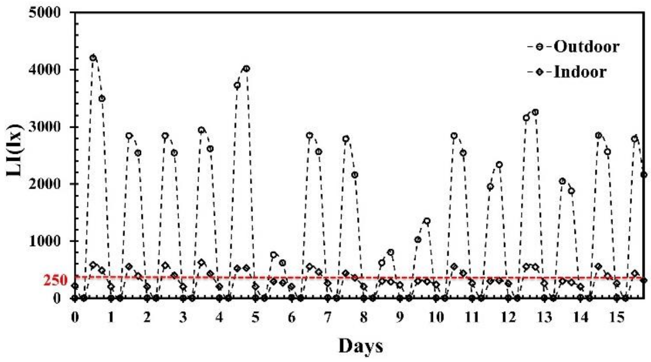


Fig. 9. The LI of the automatic nursery machine over a 15-day period.

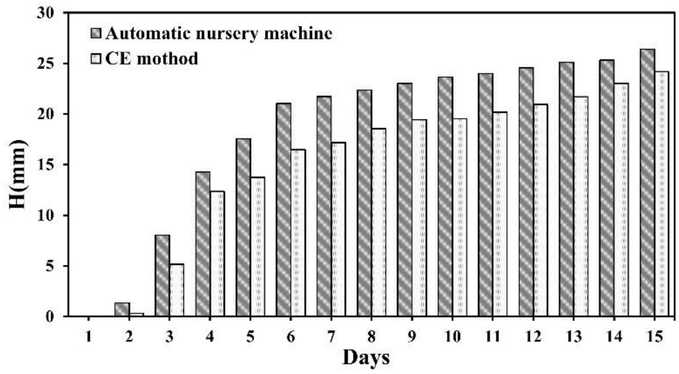
Figure 8 shows the T and RH in the nursery chamber as measured by the DHT22 sensor and recorded in an SD card every 15 minutes for a period of 15 days using the Arduino mega 2560, each point shown in the graph is an average of 19 points of 15 minutes. The DHT22 T and RH sensors at 6 positions obtained average readings of T and RH for 15 days that were equal

DOI:10.4186/ej.2024.28.5.73

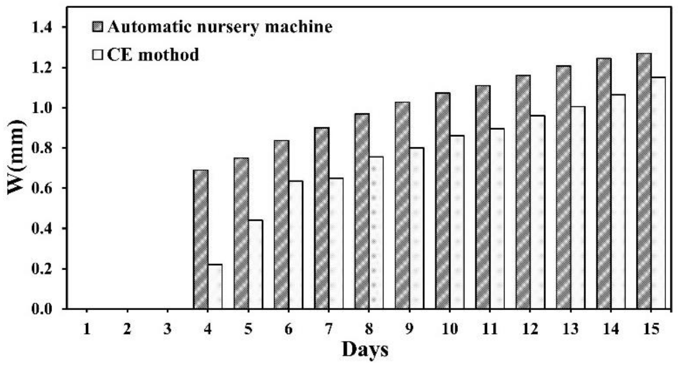
to 25.60±0.59 °C and 89.00±2.55 %RH, respectively. The average T was in the range of high growth rate, T between 25 to 30 °C as reported in the literature [42], during the cultivation of lettuce seedlings in the nursery chamber, however, when the T in the nursery chamber rises over 30°C, lettuce seedlings underwent dormant and develop slowly [43]. Therefore, it can be concluded that the automatic nursery machine can control the T and RH of the nursery chamber according to the target values throughout the cultivation period with accuracy and low tolerance. Figure 9 showed the LI monitoring graph over 15 days period inside the automatic nursery machine, the result showed the LI were in the range of 0 lx to 600 lx. At noon, a high LI value was measured from the outside of the automatic nursery machine. It was found that the stepper motor works to adjust the angle of the curtain in relation to the BH1750 sensor data. In the event that the LI inside the automatic nursery machine is less than 250 lx, the LED lamps illuminate to compensate for the insufficient light of the lettuce. The first wavelength range that facilitate seed germination and seedlings was provided with a combination of blue and red wavelengths of 450 nm and 660 nm, respectively (the ratio of blue light to red light is approximately 75:25) [22, 23]. In addition, from 11:00 p.m. to 6:00 a.m., it was found that measured LI values were low to allow the lettuce to stop photosynthesis during night-time. However, the T and RH still remain automatically controlled during this time.

3.2. The Ecological Control inside the Lettuce Nursery System

Lettuce seeds were planted at a depth of 1.5 cm from the soil surface in 4 of 105-wells seedling trays and underwent seedling cultivation in the automatic nursery machines and the CE method for cultivation comparison. The experiment was repeated 3 times for determining the growth of lettuce seedlings by randomly measuring the H and W of lettuce seedlings in mm scale over a period of 15 days. Figure 10 shows the comparative results of the cultivation of lettuce seedlings through the automatic nursery machine and the CE method over a period of 15 days. The results showed that the H of lettuce seedlings could not be measured for both methods of cultivation of lettuce seedlings due to the seeds have not yet germinated beyond the surface of the soil for day 1. During days 2 to 4, the seedlings appeared to grow rapidly and the H increased dramatically. Regarding the W of the lettuce seedlings from both methods, from days 1 to 3, it was found that the W of lettuce seedlings was very small which caused implication for a digital vernier calliper to undergo the W measurement. On day 4, lettuce seedlings with the automatic nursery machine showed a larger W when compared to the CE method. It has been observed that the stem showed good strength, was not easily bent and contained 3 leaves. Moreover, the leaves are larger and stronger than the CE method.



(a)



(b)

Fig. 10. Comparison of (a) H and (b) W of lettuce seedlings through the automatic nursery machine and the CE method over 15 days.

When considering the growth of lettuce seedlings on day 15 through the automatic nursery machine, the average H and W of the lettuce seedling were 26.39±0.31 mm and 1.27±0.01 mm, respectively, while the CE Method showed the average H and W of the lettuce seedling were 24.17±0.21 mm and 1.13±0.02 mm, respectively. The results illustrate that the value of the H of the lettuce seedlings through the automatic nursery machine on day 6 was comparable to the value of the lettuce seedlings from the CE method on day 13 indicating that the nursery machine can reduce the time of seedling by 7 days or about 116%. when compared to the CE method.

3.3. Multiple Regression Models for Growth Prediction Models

A multiple regression model was developed to relate the H and W of lettuce seedlings to the T, RH and LI of the automatic nursery machine.

The LI was related to the W of lettuce (LI: $r = 0.537$, Fig. 11(a), Multiple Regression Model: LI, Table 1). T and RH had a negative effect on the W of lettuce (T: $r = -0.451$, RH: $r = -0.324$, Fig. 11(a), Multiple Regression Model: T, RH, Table 1).

The LI was related to the H of lettuce (LI: $r = 0.511$, Fig. 11(b), Multiple Regression Model: LI, Table 2). T and RH had a negative effect on the H of lettuce (T: $r = -0.551$, RH: $r = -0.358$, Fig. 11(b), Multiple Regression Model: T, RH, Table 2).

The goodness-of-fit analyses revealed that the model fit the data reasonably well (W of lettuce: Eq. (1), $R^2 = 0.521$, H of lettuce: Eq. (2), $R^2 = 0.604$).

$$Y_1 = 21.540 + 0.009X_1 - 0.759X_2 - 0.036X_3 \quad (1)$$

$$Y_2 = 507.950 + 0.156X_1 - 17.714X_2 - 0.792X_3 \quad (2)$$

Where, X_1, X_2, X_3, Y_1, Y_2 stand for LI, T, RH, W of lettuce and H of lettuce, respectively.

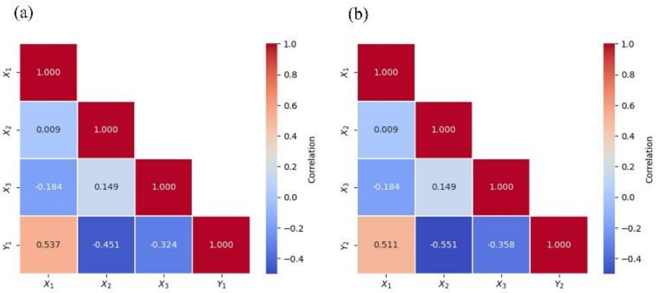


Fig. 11. Comparison of (a) H and (b) W of lettuce seedlings through the automatic nursery machine and the CE method over 15 days.

Table 1. Estimated coefficients in multiple regression model between the LI, T and RH variables and the W of lettuce.

Variables	*β*	*S.E.*	*t-Statistic*
LI	0.009	0.004	2.395*
T	-0.759	0.372	-2.040
RH	-0.036	0.047	-0.774
Constant	21.540	9.875	2.181*

β : coefficients, *S.E.*: standard error.
* Significant at the P levels of < 0.05 (two-tailed)
MSE: 0.093
RMSE: 0.305

Table 2. Estimated coefficients in multiple regression model between the LI, T and RH variables and the H of lettuce.

Variables	*β*	*S.E.*	*t-Statistic*
LI	0.156	0.062	2.489*
T	-17.714	6.459	-2.742
RH	-0.792	0.808	-0.980
Constant	507.950	171.334	2.925*

β : coefficients, *S.E.*: standard error.
* Significant at the P levels of < 0.05 (two-tailed)
MSE: 28.025
RMSE: 5.294

4. Conclusions

The cultivation of lettuce seedlings through our developed automatic nursery machine was significantly better than that of the CE method. The automatic nursery machine effectively controlled crucial ecological conditions for lettuce growth throughout the process. These conditions included: 1) controlling the automatic watering system during 7:00 a.m. and 5:00 p.m. 2) maintaining optimal T and RH in the nursery chamber at 25-27 °C and 70-90% RH, respectively, through the measurements of the DHT22 sensor to activate the cooling and ventilation systems, and 3) regulate LI with light curtains and LED lamps. The LED lamps will be illuminated for lettuce seedlings through the measurement of the BH1750 sensor; if LI is greater than 20,000 lx, the light curtain is closed, if the LI is less than 250 lx, the light curtain is opened and the LED lamps will illuminate so that lettuce seedlings can increase photosynthesis in the event of insufficient sunlight. These factors resulted in the lettuce seedlings in the developed prototype machine being able to produce fertile seedlings, strong, grow quickly and have a high survival rate prior to being planted into large plots when compared with the CE method. The lettuce seedlings cultivated through the automatic nursery machine had average H and W of 26.39±0.31 mm and 1.27±0.01 mm, respectively. In contrast, the CE method had average H and W of 24.17±0.21 mm and 1.13±0.02 mm, respectively. Notably, on day 6, the H of lettuce seedlings from the automatic nursery machine was comparable to the H of lettuce from the CE method on day 13, effectively reducing the seedling time by up to 7 days or about 116%. The literature [7] found that the T and RH for cultivation play a major factor that affects the growth of plants. The literature reported that the value of about 25–30 °C and 65–90 %RH were the optimized values for cultivation. If the T and RH are different from this range, it will cause abnormal plant growth. Furthermore, controlling LI via LED lamps emitting blue light at a wavelength of 450 nm and red at a wavelength of 660 nm (the ratio of blue light to red light is approximately 75:25) can accelerate the growth of seedlings as reported in the literature [22, 23]. By consistently controlling these ecological conditions, the automatic nursery machine enhances the integrity and survival rate of seedlings prior to transplantation in large plots.

Acknowledgement

The authors are deeply grateful to the Faculty of Science and Industrial Technology, Prince of Songkla University, Surat Thani campus, Thailand. The research was financially supported by Prince of Songkla University, Surat Thani Campus Collaborative Research Fund. Grant number SIT6403082S.

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DOI:10.4186/ej.2024.28.5.73

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