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Research Article

THE DEVELOPMENT OF THE CLOSED-CONTROLLED GREENHOUSE FOR SUNFLOWER SEEDLINGS

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ABSTRACT:
Because of global warming, an average increase in temperatures during the twenty-first century has been expected to reach between 1.5 and 6.0ºC, and it maybe even higher. Small changes in temperatures can cause consequences of great amplitude upon rains, forests, and agriculture. This research studied and developed the closed-controlled greenhouse. The control system based on Arduino technology was utilized in the greenhouse to control the evaporative cooling system and the greenhouse ventilation system. This project aimed to adjust the greenhouse temperature and relative humidity for sunflower seedling. A total of 6 experiments, each experiment took 7 days. Experiments numbered 1 to 3, there was no seedling set inside the greenhouse while the seedling sets were located in the greenhouse for the last three experiments. Nine seedling sets contained 3 different types of nutrient solutions (chemical nutrient, vermicompost and bio-fertilizer solutions), and 3 different types of seedling materials, (coconut fluff, cotton balls and cultivation soil. Three replications were performed in each experiment, thus, 27 seedling sets were placed in the greenhouse. From the first and last three investigated results, the temperatures inside the greenhouse differed from the ambient temperatures in ranges of 3.83 to 4.93 and 3.64 to 4.20 Celsius, respectively. The different relative humidity values between the air inside and outside the greenhouse were in ranges of 19.29 to 33.19%RH and 17.94 and 30.86%RH, respectively. Sunflower sprout production inside the greenhouse was indicated in germination percentages and germination indexes. The germination percentages were above 80% and the germination indexes were above 12. If farmers are interested in sunflower sprout farming to earn income by using the closed-controlled greenhouse, they could take a total of 4 months as a payback period by selling the sunflower sprouts. Therefore, the development of the closed-controlled greenhouse was proved to show its ability in the sunflower sprout seedling.

Keywords: *Sunflower seedlings, Greenhouse, Arduino, Heat Transfer, Fluid Flow*

1. INTRODUCTION

Since Agriculture in Thailand faced with many problems such as pests, inappropriate temperatures and relative humidity values, Thai agricultural products have been unperfected and reduced. Farmer incomes have also been decreased, some farmers changed their ways of agriculture methods from organic farming into inorganic farming.

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More chemical pesticides have been applied in agricultural fields, these substances cause soil problems and high investment in many agricultural businesses. One application which can help the farmers to protect their products from pests is a greenhouse. The greenhouse can be designed and installed equipment to help adjusting its inside conditions; temperatures and relative humidity. The adjustable greenhouse can also be used to enhance number of products. Namhomchan and Seripattananont [1] presented their design and construction of Programmable Logic Control (PLC)-based automatic control system to control temperature and relative humidity in a soilless culture greenhouse. An evaporative cooling system and fogging system was used in this work. Their control part contained of the PLC controller and an analog input device as the analog signal receiver from temperature and relative humidity sensors. Their test results showed that the control system could automatically start and stop operations as scheduled. The evaporative cooling system and fogging system were set to work to maintain the temperature inside the greenhouse to be less than 30°C. This certain temperature was recommended for soilless culture in the greenhouses. The average temperature in the greenhouse was at 30.45°C and the average relative humidity in the greenhouse was at 80.54%RH. Chaloemthoi et al. [2] introduced their machine to control plant watering. They designed the semi-automatic micro-irrigation controller to be applied in small areas, town houses and apartments as in urban communities. They investigated amount of water sprayed by the micro-irrigation systems with two types of nozzles and their electrical power consumptions. Their experimental results showed that the spraying rates of the micro-irrigation systems were 9.069 and 39.867 L/min, respectively. Moreover, the power consumptions were 1.674 and 0.168 W/(L/min), respectively.

Paka et al. [3] improved quantity and quality of mushrooms by using a suitable system to control temperature and humidity for mushroom cultivation in a community. They sent signal from temperature and humidity sensors to a microcontroller board to control operations of a water pump. From their results, the satisfactory level of the mushroom quantity and quality obtained from farmer surveys was at 4.26, the standard deviation of the satisfactory level was at 0.7. They claimed that their system could help increasing the quantity of mushroom to reach an average of 10.1 kgs per batch. Singjaroen and Sakaew [4] designed and constructed a mushroom greenhouse which could be controlled its temperature and humidity by a microcontroller. There were two parts in this research; testing the control system and measuring mushroom quantity. They compared yields of oyster and phoenix mushroom products between two greenhouses; with and without the temperature and humidity controller. From their results, they found that the greenhouse with the controller performed better products than those of the bare greenhouse. The average weight and standard deviation of the controlled greenhouse and bare greenhouse were 1.865 kg, 0.198 and 1.455 kg, 0.225, respectively. They confirmed that temperature and humidity play important roles in the growth of the mushrooms.

Chimreung and Chantho [5] developed a temperature and relative humidity control system for vegetable plantation in a greenhouse. They brought two air properties; dry bulb temperature and relative humidity, to calculate other properties; dew point temperature, enthalpy, humidity ratio, specific volume and wet bulb temperature. Their system used the Arduino board commanded by LabVIEW (trademark) program. They claimed that their calculated properties were accurate. However, they did not show the controlled parameter results of their system when it worked with any actual greenhouses. Dos Santos and De Castilho [6] experimentally investigated the germination of the ornamental sunflower seedlings in different substrates compositions. They performed their experiments inside a greenhouse. They measured average germination time, chlorophyll content, length, fresh and dry mass of shoot and root. They also evaluated germination percentages and indexes. They concluded that the composition, which was prepared from coconut fiber, carbonized rice hull, peat, expanded vermiculite (1:1:1:1) and slow release fertilizer, provided the best production (fresh and dry mass).

Healthy food in global markets has expanded. People choose to buy vegetables and fruits from how they seed and plant. Sunflower sprouts are among them because they can be eaten as fresh sprouts and cook food. Yookate et al. [7] published their investigations; effects of seedling media and soaking treatments of seeds on production of sunflower sprouts. They informed that the sprouts could be produced by seedling of the sunflower seeds in the suitable seedling media for 7 days. Seeding media and soaking treatments play important factors for the sunflower sprout production. They compared results from 2 experiments; different seedling media and different processes of seed soaking before seedling. They claimed that the significant interaction; among water temperatures, durations of soaking, percentages of seed germination, seedling height and hypocotyl width, was found. They concluded that soaking of the seeds in warm water at 50°C for 16 hours was the best treatment because it delivered the highest sunflower sprout production. There was a study in manufacturing of germinated Bambara groundnut by hot air fluidized bed drying (HA) technique [8]. Their results showed that the germination from unshelled Bambara groundnut (UBG) got the maximum value of germination rate and GABA (gamma-aminobutyric acid) content.

The main objective of this work is to develop the closed-controlled greenhouse by designing, fabricating and experimentally investigating the control system. The greenhouse was utilized in sunflower seedling. The control system was based on Arduino technology. The design was based on an affordable investment cost, simple circuit and commands. Sunflower sprout production was used to confirm the performance of the closed-controlled greenhouse (the combination of the control system, the evaporative cooling and the greenhouse). A simple payback calculation was performed to show feasibility of the combination. The sunflower sprout production was indicated by germination percentages and germination indexes.

2. Experimental Setup

The control system was designed to control temperatures and relative humidity of air inside the greenhouse by turning on and off an evaporative cooling system and air circulating fans of the greenhouse. The fabrication was performed domestically at our laboratory. In this work, the temperatures and relative humidity values of air inside and outside the greenhouse were measured in 6 experiments. There was no sunflower seedling sets placed in the greenhouse in the first three experiments while the sunflower sprout production was evaluated in the last three experiments.

The greenhouse was 1.8 m in width, 2.1 m in length and 3.1 m in height, its frame was covered with UV protection plastic sheets. The control system or called the controller consisted of an Arduino board, temperature and humidity sensors (DHT11 model), a relay, an LCD monitor, status lamps and a circuit breaker. All components were connected as shown in Fig. 1 and controlled by Arduino commands. Reasons of choosing Arduino technology in this work were its common commands and its low-cost components. Then, the controller was connected to switch on and off a water pump of the evaporative cooling system and two fans (Fig. 2); one was opposite the cooling system and another one was on the top part of the greenhouse. The controller was intended to be simple because we wanted farmers as main users to adjust, to maintenance, to fix and to modify it by themselves. The evaporative cooling system consisted of cooling pad (1.02 m x 0.72 m x 0.07 m), a water pump and water tubes.

We designed to use 3 seedling materials; coconut fluff, cotton balls and cultivation soil, and 3 nutrient solutions; commercial (chemical) nutrient solution, vermicompost solution and bio-fertilizer solution, in the experimental investigation (Fig. 3). The bio-fertilizer was locally prepared by mixing manure, molasses and microorganism. We also aimed to show that organic solutions; vermicompost and bio-fertilizer solutions could produce high amount of the sunflower sprouts. Total of 27 seedling sets; 3 seedling materials and 3 nutrient solutions with 3 replications, were placed inside the greenhouse during the last three experiments.

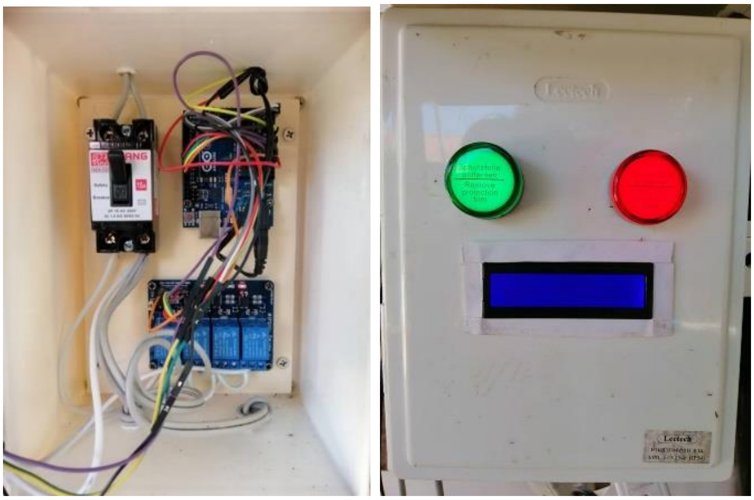

Fig. 1. The control system based on Arduino technology.

Fig. 2. The evaporative cooling system and fans.

Fig. 3. Sunflower seeds, coconut fluff, cultivation soil and cotton balls, and 3 nutrient solutions; (a) commercial (chemical) nutrient, (b) vermicompost and (c) bio-fertilizer solutions.

3. NUMERICAL INVESTIGATION

The sunflower sprout production can be evaluated by using two indicators. The first one is a germination percentage [9] which can be calculated by the following equation;

$$\text{Germination percentage} = \frac{S}{N} \times 100 \qquad (1)$$

where number of sprouts (S) can be counted after the seeds were planted. The numbers of sunflower seeds (N) in this work were fixed at 50 seeds per one seedling set.
Another one is a germination index [10] which can be calculated by the following equation;

$$\text{Germination index} = \frac{\sum G}{T} \qquad (2)$$

where G is a germination percentage per day and T is a germination period. We emphasized that these two indicators could show that the controller and the greenhouse set were one of the best ways in the sunflower seedling.

4. RESULTS AND DISCUSSION

4.1 Testing of the controller function in the closed-controlled greenhouse

After the greenhouse set was placed, the controller was installed inside the greenhouse set. Temperatures and relative humidity were measured three times a day; at 8.30am, 12.30pm and 6.30pm, for 7 days. The 7-day period was chosen according to the literature [7] and information provided by practical sunflower sprout farming. Results; average different temperatures and relative humidity values of air inside the greenhouse obtained from the first three experiments, were displayed in Table 1. Positive relative humidity differences can be defined as the differences of relative humidity values; for the plantation, the inside relative humidity should be higher than the ambient relative humidity. Temperature differences can be defined as the differences of temperatures between inside and ambient air; the ambient temperature is higher than the inside temperature. The average values were calculated by using data obtained from 7-day periods in all three experiments. Table 1 also showed that the ambient temperatures were different among the first three experiments; there was no seedling set in these experiments. Figures 4 and 5 represented the differences of average air temperatures and relative humidity values between inside and outside the greenhouse obtained from the experiments numbered 1, 2 and 3. The results implied that the controller could provide the average temperature differences at 8.30am, 12.30pm and 6.30pm in ranges of 3.83 – 4.27°C, 4.00 – 4.93°C and 4.06 – 4.29°C or average values of 4.04°C, 4.48°C and 4.19°C, respectively. While the relative humidity differences at 8.30am, 12.30pm and 6.30pm were in ranges of 25.06 – 33.19%RH, 19.21 – 20.73%RH and 24.64 – 30.57%RH or average values of 30.01%RH, 19.76%RH and 28.47%RH, respectively. These differences represented that the closed-controlled greenhouse helped to adjust temperatures inside the greenhouse to be lower than ambient temperatures about 4°C. The highest average temperature difference at 4.93°C was taken from the second experiment, the average ambient temperature of this experiment was also the highest temperature at 34.64°C. The suitable temperatures for general seedling are 15 – 35°C [11], the controller could adjust the greenhouse condition to be a suitable condition for the sunflower seedling. The seed germination relates to biochemical-physiological processes activated in the seeds treatments carried out to break seed dormancy, moisture or humidity plays an important role in the germination [12]. These three experiments were used to test the controller functions in the greenhouse since we aimed to provide highest humidity inside the greenhouse. We took photos of temperature distributions inside the greenhouse by using the infrared thermometer camera trademarked FLIR E40, Fig. 6 revealed one temperature distribution taken from the third experiment at 12.30pm.

Table 1: Ambient temperatures (Amb. Temp.), average different temperatures (Avg. Temp. Diff.) and relative humidity (%RH) values of air inside the greenhouse from the first three experiments.

Experiment No.	Avg. Temp. Diff. (Amb. Temp.) at 8.30am in °C	Avg. Temp. Diff. (Amb. Temp.) at 12.30pm in °C	Avg. Temp. Diff. (Amb. Temp.) at 6.30pm in °C	Avg. %RH Diff. (Amb. %RH) at 8.30am	Avg. %RH Diff. (Amb. %RH) at 12.30pm	Avg. %RH Diff. (Amb. %RH) at 6.30pm
1	4.27 (29.34)	4.00 (33.86)	4.29 (30.33)	31.77 (67.41)	19.34 (54.97)	30.21 (66.53)
2	3.83 (27.99)	4.93 (34.64)	4.06 (29.49)	33.19 (65.14)	20.73 (53.14)	30.57 (66.71)
3	4.01 (28.93)	4.50 (33.59)	4.23 (29.99)	25.06 (71.71)	19.21 (52.71)	24.64 (73.14)

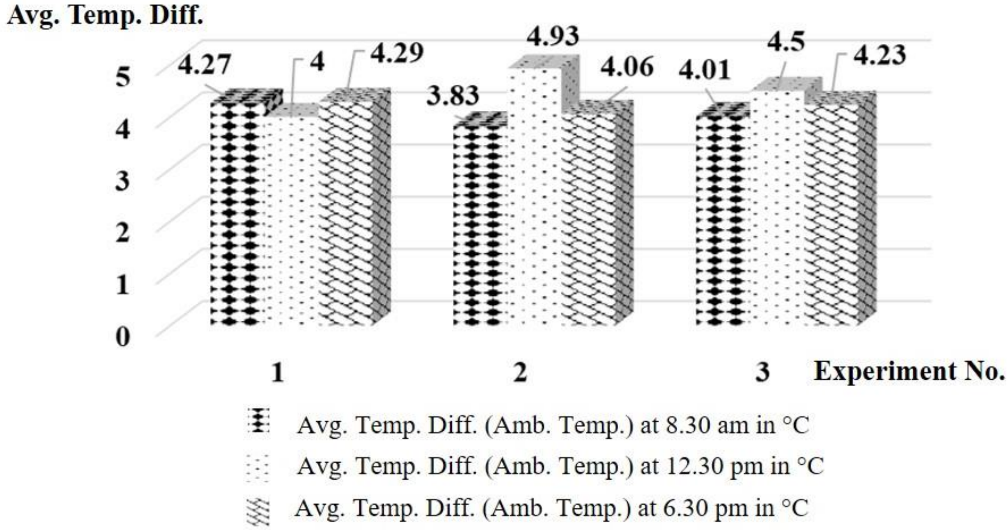

Fig. 4. Average different temperatures in the first three experiments.

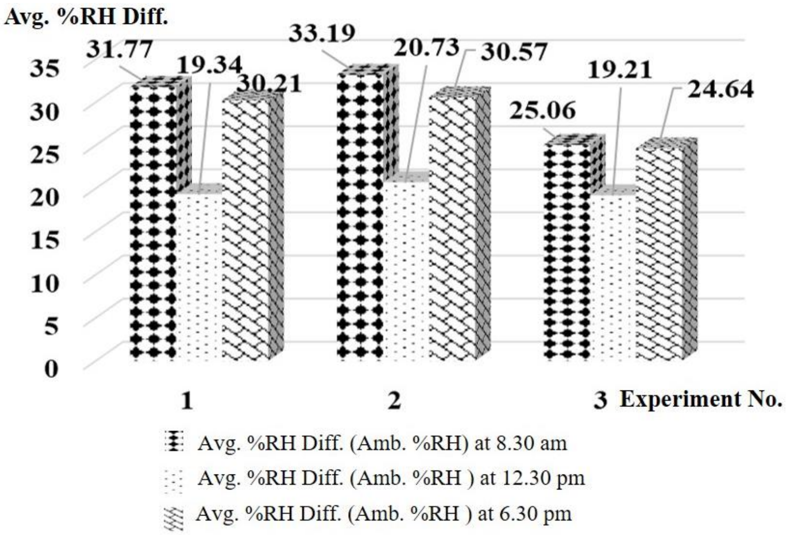

Fig. 5. Average different relative humidity values in the first three experiments.

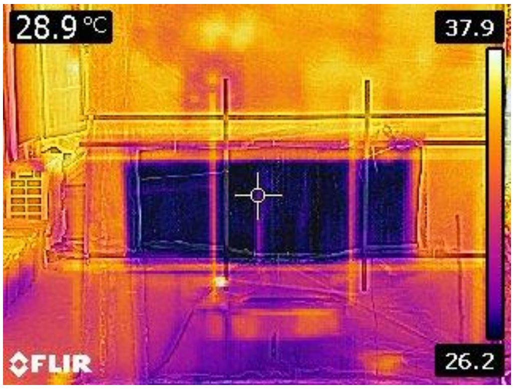

Fig. 6. The temperature distribution of the third experiment at 12.30pm.

4.2 Temperatures and relative humidity values in Sunflower seedling

After the closed-controlled greenhouse was proved its ability to adjust temperatures for the seedling. Seedling sets were prepared by using 3 different seedling materials; coconut fluff, cultivation soil and cotton balls. Three different nutrient solutions; chemical nutrient, vermicompost and bio-fertilizer solutions, were also prepared for the last three experiments. Therefore, 9 seedling sets contained different seedling materials and different nutrient solutions. Three replications of 9 seedling sets were placed in each experiment. Every experiment took 7 days in the seedling. Table 2 reported ambient temperatures, average different temperatures and relative humidity values of air between inside and outside the greenhouse obtained from the last three experiments. Figures 7 and 8 compared the differences of average air temperatures and relative humidity values from the experiments numbered 4, 5 and 6. The results showed the same trends as in the previous section, at 8.30am, 12.30pm and 6.30pm in average ranges were 4.07 – 4.20, 4.04 – 4.19 and 3.64 – 4.01°C and their average values were 4.14, 4.11 and 3.86°C, respectively. The average ranges of the relative humidity differences at 8.30am, 12.30pm and 6.30pm were 22.00 – 28.36, 23.30 – 26.31 and 17.94 – 30.86 %RH and their average values were 24.31, 24.32 and 22.70 %RH, respectively. The differences were almost the same values as the first three experiments while there were 27 seedling sets in these three experiments. The average air temperatures inside the greenhouse were also lower than the ambient temperatures. Even, we noticed the higher ambient temperatures in the last three experiments, the temperature differences were lower than the previous results. These lower difference may be caused by natural heat transfer inside the greenhouse, seedling materials and sunflower sprouts naturally absorbed heat from air inside the greenhouse. The closed-controlled greenhouse was proved its potential to control air temperatures inside the greenhouse in the range of the suitable germination temperatures. Figure 9 was one photo of the temperature distribution taken from the fifth experiment at 8.30am.

Table 2: Ambient temperatures (Amb. Temp.), average different temperatures (Avg. Temp. Diff.) and relative humidity (%RH) values of air inside the greenhouse from the last three experiments.

Experiment No.	Avg. Temp. Diff. (Amb. Temp.) at 8.30am in °C	Avg. Temp. Diff. (Amb. Temp.) at 12.30pm in °C	Avg. Temp. Diff. (Amb. Temp.) at 6.30pm in °C	Avg. %RH Diff. (%RH) at 8.30am	Avg. %RH Diff. (%RH) at 12.30pm	Avg. %RH Diff. (%RH) at 6.30pm
4	4.07 (29.27)	4.09 (34.20)	3.64 (30.07)	22.00 (77.00)	26.31 (57.29)	17.94 (79.00)
5	4.20 (28.81)	4.19 (33.96)	3.94 (28.71)	28.36 (63.86)	23.30 (50.57)	30.86 (63.57)
6	4.16 (29.44)	4.04 (34.14)	4.01 (29.07)	22.57 (65.39)	23.34 (54.76)	19.29 (79.00)

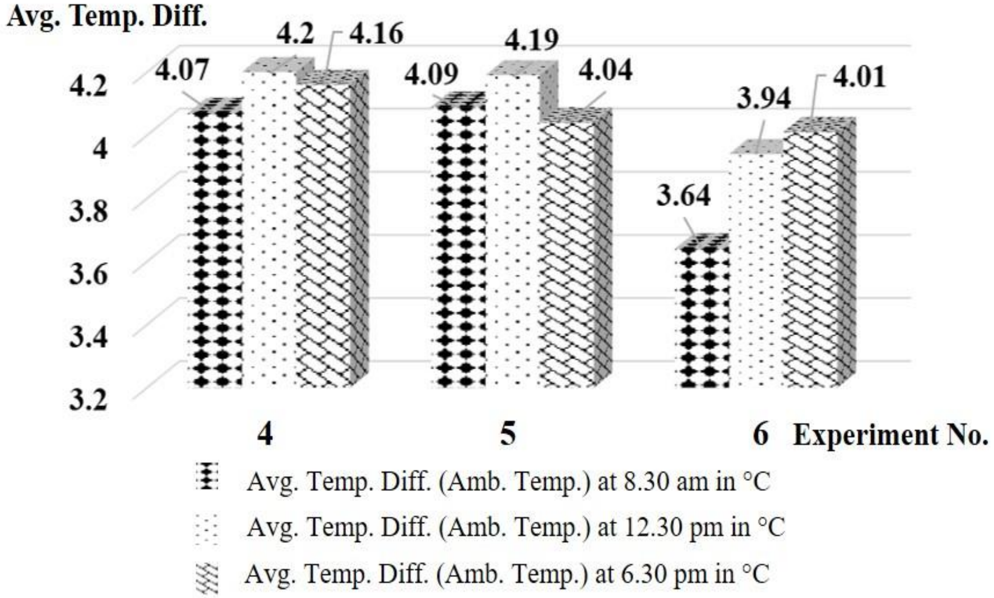

Fig. 7. Average different temperatures in the last three experiments.

4.3 Sunflower sprout enhancement by the closed-controlled greenhouse

We defined the enhanced production of sunflower sprout production by using two indicators; germination percentages and germination indexes. Table 3 indicated all indicators provided by the last three experiments. The germination percentages and germination indexes in Table 3 were average values calculated from 3 experiments; 3 replication of 9 different nutrient solutions and seedling materials in each experiment. The literature [13] mentioned that the sunflower germination percentages were in the range of 70 to 80%. All sunflower germination percentages in our work obtained from all nutrient solutions and seedling materials were above 80%. The closed-controlled greenhouse enhanced the production to be closer to 90%. From Table 3, we also found that coconut fluff provided the highest germination percentage with the minimum standard deviation value and germination index. The bio-fertilizer solution as an organic-nutrient solution imparted the best germination percentage with the minimum standard deviation value while the vermicompost solution as another organic-nutrient solution provided the best germination index. The natural organic solutions were proved their performances in enhancing the sunflower sprout production. Sunflower seedling farmers can make these organic solutions by themselves, their farming investment cost do not have to rely on chemical solution prices. Figure 10 was taken during our harvesting in the fifth experiment.

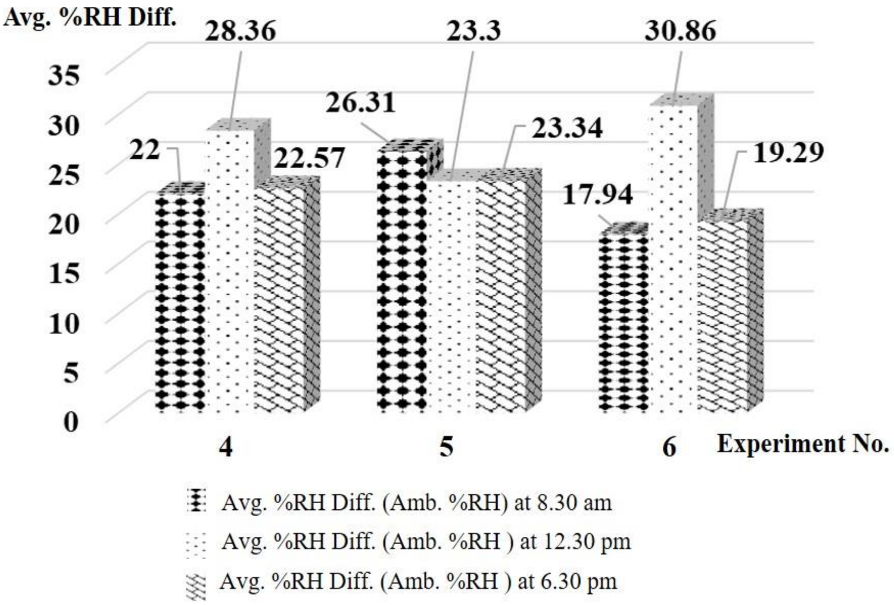

Fig. 8. Average different relative humidity values in the last three experiments.

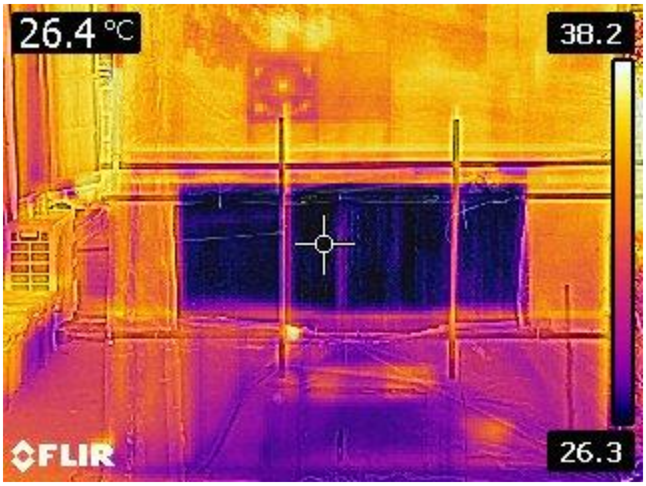

Fig. 9. The temperature distribution of the fifth experiment at 8.30am.

Table 3: Average germination percentages (including standard deviations of the percentages) and average germination indexes obtained from 3 replications in the last three experiments.

Nutrient solutions	Germination percentage (%)			Average (S.D.)	Germination index			Average
	coconut fluff	cotton balls	cultivation soil		coconut fluff	cotton balls	cultivation soil	
Chemical	91.11	86.00	89.78	88.96 (4.50)	13.44	12.69	12.70	12.94
Vermicompost	90.67	83.56	89.78	88.00 (3.95)	13.98	13.21	13.84	13.67
Bio-fertilizer	90.67	88.00	90.15	89.85 (2.71)	13.45	13.52	12.84	13.27
Average (S.D.)	90.81 (0.47)	85.85 (4.41)	90.15 (1.78)		13.62	13.14	13.13	

4.4 Sunflower sprout investment cost by applying the closed-controlled greenhouse

As we demonstrated the performance of the closed-controlled-temperature greenhouse in the sunflower seedling. We would also like to show its financial feasibility in in the sunflower seedling. The total cost of the controller was 2,000 Baht (66.67 USD). The total cost of the greenhouse, the cooling system and the fans were 3,500 Baht (116.67 USD), 800 Baht (26.67 USD) and 1,200 Baht (40 USD), respectively. The monthly expense of the sunflower sprout farming was 1,080 Baht taken from monthly cost of seeds, public utility, coconut fluff and bio-fertilizer solution. An average sunflower sprout price was 80 Baht (2.67 USD) per one kilogram. The average sunflower sprouts harvested from this greenhouse were 40 kilograms per one month, a farmer can get a monthly profit of 2,120 Baht (70.67 USD); 2,120 = (80x40) – 1,080 Baht. We defined a common payback rate in months (no compound interest) as the total investment expense divided by a monthly profit. With the monthly profit of 2,120 Baht (70.67 USD), the payback rate was 3.54 months; 3.54 = (2,000 + 3,500 + 800 + 1,200) / 2,120 month.

Fig. 10. Some sunflower sprouts harvested from the fifth experiment.

5. Conclusion

This work aimed to deliver another tool in the plantation; the sunflower sprout farming. We developed the closed-controlled greenhouse for the sunflower sprout farming. In this work, the control system was designed, fabricated and evaluated its performance in the greenhouse. A possibility and potential of the closed-controlled greenhouse were shown in terms of germination percentages and germination indexes. These two terms were taken to represent the sunflower sprout productions from the greenhouse. The first three investigations were used to validate the control system performance, no seedling set was applied. Without any seedling sets, the minimum temperature difference between ambient and inside temperatures was 3.83°C while the maximum difference was 4.93°C. The minimum and maximum differences of the relative humidity values; the relative humidity values of air inside the greenhouse were higher than those of ambient air, were 19.29%RH and 33.19%RH, respectively. After the control system was proved its functions, the seedling sets were put inside the greenhouse for the last three experiments. A total of 27 seedling sets was placed in the greenhouse, 3 replications of 9 different combinations of seedling materials and nutrient solutions. The minimum and maximum differences of the temperatures; ambient temperatures were higher than inside temperatures, were 3.64°C and 4.20°C, respectively. The minimum and maximum relative humidity differences were 17.94%RH and 30.86%RH, respectively. The accuracy of data in this work was shown in a term of standard deviation. All standard deviation values were lower than 5. We noted that all germination percentages were above 80%, the maximum germination percentage with the minimum standard deviation value was obtained from the sunflower sprouts grown in the coconut fluff and sprayed by the bio-fertilizer solution. Therefore, the developed-closed-controlled greenhouse presented its performance and possibility in the sunflower sprout farming by its sunflower sprout production and its payback period at 4 months.

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NOMENCLATURE

G	germination per day
T	germination period, day
S	The total of sprouts
N	The total of seeds, 50 seeds per one seedling set

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