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Integration of Evaporative Greenhouse, Internet of Things and Root-zone Cooling to Enhance Growth and Development of Strawberry (*Fragaria x ananassa*) in Tropical Climate

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Abstract: The experiment was carried out during October 2022 to January 2023 at Mae Hea Agricultural Research, Demonstration and Training Center, Faculty of Agriculture, Chiang Mai University, Chiang Mai Province, Thailand; latitude: 18° 44′ 36″ North, Longitude: 98° 57′ 50″ East, and an altitude 304 msl. Evaporative greenhouse, 9.6 x 40 square meters, with 8 planting troughs was prepared, Sensors and Internet of Things (IoT) system were installed to monitor continuously vital parameters, collect data, and send timely alerts to facilitate problem resolution. The data were displayed via IoT platform dashboard. An average air temperature, light intensity, media moisture and CO_2 concentration in the greenhouse during 4 months was 21.1 ◦C, 12,948 Lux, 2 kPa and 495 ppm, respectively. The average maximum temperature in the evaporative greenhouse was 29.6 ◦C, which 4.2 ◦C lower than outside; 33.8 ◦C. Root-zone cooling of the strawberry planting was designed as factorial 3x4 in completely randomized design (CRD). Factor A was the short-day strawberry cultivars: 1) "Pharachatan 88" 2) "Pharachatan 80" and 3) "Akihime". Factor B was the root-zone cooling treatments: 1) normal water dripping (NWD) 2) cold water dripping (CWD) 3) cold water dripping + cold water piping (CWD+CWP) and 4) normal water dripping + cold water piping (NWD+CWP). The results revealed that there was an interaction between the two factors on canopy width, leave width, crown diameter, number of flowers, fruit qualities and fruit color, whereas plant height, leaves length, SPAD and number of inflorescences were not affected by the interaction between the two factors. Four months after the experiment, the root-zone cooling treatments had no effect on chlorophyll contents, whereas "Pharachatan 80" had lower chlorophyll content than others. The CWD+CWP treatment could reduce 2 °C of root-zone temperature and leading to promote vegetative and reproductive growth in strawberry plants. Anyhow, without the root-zone cooling treatment, "Akihime"and "Pharachatan 88" still could produce flowers and yield, but "Pharachatan 80" could not. Furthermore, "Akihime" seemed appreciable in flowering, TSS and yield as compared to others.

Keywords: "Pharachatan 88"; "Pharachatan 80"; "Akihime"; cold water; flowering; IoT

1. Introduction

Strawberry (*Fragaria* × *ananassa* Duch.) is one of the most widely grown economic fruits in many countries of temperate, tropical and subtropical regions, which are different in terms of climate condition. Strawberry is a subtropical fruit that can be adapted and perform well with various climatic conditions. Recently, the consumption of fresh strawberry and industrial processing have increased dramatically [1]. The world production of strawberry is 9.2 million tones China is the largest strawberry producer in the world with 3.8 million tonnes. USA comes second with 1.21 million tonnes and Turkey is the third largest producer with 0.67 million tonnes [2]. In northern part of Thailand, which located in sub-tropical region, is a major area for strawberry production. In 2022, there were around 1,116.32 ha production areas and yielding 19,049 tons in Samoeng, Kalayaniwattana, Mae Wang, Mae Chaem, Fang, and Mae Rim districts, Chiang Mai province [3]. Strawberry cultivation system in Thailand is almost in open field. Planting strawberry is performed during September-October. The strawberry plants require low temperature around of 10-15 °C and daylength less than 14 hrs (short day condition) for flower initiation and preferring cool weather for fruit growth and development [4,5]. Flowering, yield and fruit qualities are strongly depended on the temperature. Climate change make rising in temperature that makes heat stress in strawberry plant causing poor flowering, fruit ripen too quickly leading to low fruit qualities, small size, low sugar, less of aroma and poor texture. In addition, affecting the incidence and severity of pests and diseases [6,7]. Therefore, the climate changes have significantly affected on strawberry production. To mitigate the effects of climate change; protected cultivation and controlling weather conditions have been considered. Growing strawberry plants in the greenhouses is very successful in many temperate-zone countries. The plants can be harvested 3-4 weeks faster and getting more yield than open field production and also preventing damages from heavy rain, cold temperature during the autumn and winter [8,9]. In Thailand, evaporative greenhouse can optimize growing conditions, including temperature, humidity, and light. This can result in higher quality and yield of strawberry production. Anyhow, evaporative cooling works by reducing temperature through the evaporation of water. In tropical areas with high ambient temperature, particularly in day time, it can be challenging to achieve adequate cooling. Compared to air conditioning and refrigeration systems, these systems have lower installation and operating costs. It is advantageous that the temperature inside an evaporative greenhouse is independent of the outdoor temperature. Instead, it largely depends on the dew point temperature, and the relative humidity is relatively low. Insects may become entrapped on the pads' wet surface. Intensive programs of pest management must be provided for strawberry production in the evaporative greenhouse system [10].

Beyond conventional greenhouses, the implementation of smart farming could boost crop production. Automation may ease the management of growth parameters including temperature, humidity, light, soil moisture, and others [11]. Combining wireless sensors, Internet of Things devices, and artificial intelligence algorithms for real-time data transmission can aid in crop yield forecasting. Urban farming has become essential for guaranteeing food security in areas with high population density [12]. Components of the Internet of Things consist of sensors, wired/wireless communication systems, embedded circuits or microcontrollers, and cloud servers with applicable applications. These components must be chosen to satisfy both the needs of the cultivator and the vegetable growth process. Before selecting the appropriate hardware, it is necessary to collect preliminary survey data, such as geographic location, greenhouse capacity, and soil conditions, among others. Literature suggests that a cost-effective IoT system can effectively automate greenhouse setup [11,13,14]. Arduino Uno is a cost-effective and farmer-friendly microprocessor that is extremely precise and efficient setup [24]. The data monitored, acquired, and gathered by these microcontrollers can result in more efficient plant growth and resource utilization. [15] suggested controlling the greenhouse's ventilation and temperature.

Studying in root-zone temperature is also hence the growth and development, floral cluster development and chemical compositions in many plants [16,17]. [16] showed that cooling root-zone treatment enhanced inflorescences and fruits of strawberry. [18] discovered that nutrient uptake was greatest when the temperature of the root zone was 18°C. The cool treatment enhances water and nutrient absorption by promoting better root function, preventing water stress, and maintaining optimal hydration levels in the plant. This is particularly important for strawberry plants, as they have shallow root systems that are susceptible to drying out in warm conditions. Cooling the root zone can help alleviate heat stress in strawberry plants. Higher root temperature can trigger early flowering and accelerate fruit ripening, resulting in low fruit qualities and a shorter harvesting period. By cooling the root zone, the strawberry plants are better prepared to withstand heat stress, leading to healthier plants and improved yields [19,20]. Cooling root zone techniques such as drip irrigation, mulching, and shading can be employed. These methods help regulate soil temperature, maintain moisture levels, and provide shade to the root system [21,22]. [6] found that fruit contained more fructose, glucose, and total carbohydrates when root zone temperatures were lower (18/12°C). Plastics mulching, air conditioning devices and underground source cooling with heat pumps as a cooler are the techniques used to reduce growth medium temperature. It is important to monitor soil temperature and adjust cooling strategies accordingly to ensure optimal growing conditions for strawberry plants [23]. In this study aimed to investigate growth and development of strawberry grown under evaporative system together with root zone cooling technique and IoT sensors to increase flowering and yield of strawberry in tropical area.

2. Materials and Methods

The experiment was carried out at Mae Hea Agricultural Research, Demonstration and Training Center, Faculty of Agriculture, Chiang Mai University, Chiang Mai Province, Thailand; Latitude: 18° 44′ 36″ North, Longitude: 98° 57′ 50″ East, and an altitude 304 msl.

2.1. Plant materials and experimental design

The three short-day cultivars of strawberry (*Fragaria* × *ananassa*); "Pharachatan 88" ("P88"), "Pharachatan 80" ("P80") and "Akihime" were used in the experiment. Disease-free plantlets from tissue culture were acclimatized in the greenhouse for 1 day and transplanted in the 3 inches pot which contained perlite mixed with coconut coir. After 45 days, the strawberries plants produced stolons and daughter plants. Then, the three-week-old daughter plants in each cultivar were collected, transplanted, and nursed in the greenhouse for the experiment.

Factorial 3x4 in completely randomized design (CRD) was used in this experiment. Factor A were 3 strawberry short-day cultivars; 1) "P88" 2) "P80" and 3) "Akihime". Factor B were 4 root-zone cooling treatments: 1) normal water dripping (NWD) 2) cold water (10-15 C°) dripping (CWD) 3) cold water dripping + cold water piping (CWD+CWP) and 4) normal water dripping + cold water piping (NWD+CWP). Watering 5 times with 1 minute each time during 13:00-17:00 o'clock were done, which strawberry plant received 100 ml of water/ plant/ day.

2.2. Greenhouse conditions, root-zone cooling system and strawberry planting

The evaporative greenhouse, 9.6 x 40 square meters, has a circular cover wrapped in 1.5-millimeter-thick transparent plastic protection with pad-and-fans covered on two sides by a 300 micron-thick, single-layer plastic material (Figure 1).

The strawberry root-zone cooling system consists of several components, including a cooling water tank (a one-cubic-meter insulated plastic container) (Figure 2), an electric pump, pipelines embedded in growing media, and a control unit. The tank was filled with nutrient-rich water in proportion to the anticipated daily water consumption. A cooling coil from a 12000 BTU modified air conditioning unit is submerged in the tank. The unit utilizes a type-K thermocouple thermostat to maintain the tank water temperature between 10-15 °C. The system consists of a 220V, 0.5 horsepower centrifugal water pump.

In September, 2022, 256 strawberry daughter plants were grown 25 cm distancing each in planting trough contained perlite mixed with peatmoss at a ratio 30:70 by volume with 4 different cooling root zone treatments (Figure 3). Sensor specifications for temperatures, relative humidity, carbon dioxide and light intensity measurement were explained in Table 1. The IoT system controlled a daily water drip of 100 milliliters in each plant. This is achieved by administering 20 milliliters of water per drip, five times a day, with each drip lasting for one minute.

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Table 1. Sensors and connections.

No.	Sensors	Connection/Signal	Number
1	Light intensity, air temperature/humidity, and Carbon Dioxide content	RS485	2 sets
2	Water meter	RS485	1 piece
3	Soil temperature probe	Type-k thermocouple /WiFi	16 sets
4	Cold-water temperature probe	Type-k thermocouple /WiFi	3 sets
5	1-phase power meter	RS485	1 set
6	3-phase power meter	RS485	1 set
7	Air-condition control with thermostat	Thermocouple type-k	1 set
8	Water dripping with scheduling timer and water-pumping control with 220V solenoid	Thermocouple type-k	1 set
9	Internet router gateway and internet sim	3G/4G/WiFi	2 sets
10	Sensor interface board using ESP8266 with RS485, I2C, SPI, and serial interface	-	1 set

Figure 1. The evaporative greenhouse equipped with a pad-and-fan system. The exhaust blowers draw in outdoor air through water-cooling pad to lower the room's temperature.

Figure 2. Cooling water tank system to generate 10-15 ◦C cold water.

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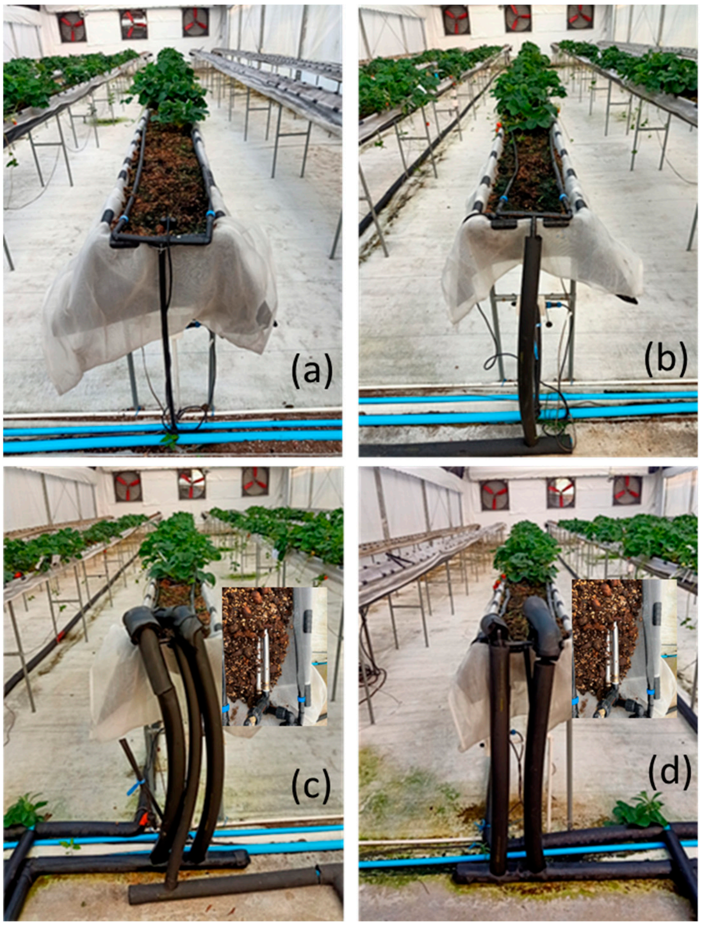

Figure 3. Four cooling root zone treatments; (a) normal water dripping (NWD), (b) cold water dripping (CWD), (c) cold water dripping + cold water piping (CWD+CWP) and (d) normal water dripping + cold water piping (NWD+CWP).

2.3. Greenhouse monitoring system

Climate conditions in the evaporative greenhouse such as temperature, relative humidity, light intensity, CO_2 content, as well as media temperature and media moisture were monitored by installed sensors and IoT system (Table 1). Figure 4 depicts the schematic diagram of the components including a pad-and-fans evaporative cooling, u-shape grown-media channels, cold-water storage and pipelines, sensors and IoT system.

A temperature monitor embedded in the growing media controls the operation of the pump. Using insulated PVC pipelines, cold water is circulated through double steel pipes inserted into the growing media (Figure 5) and then returned to the storage tank. Utilizing double pipelines maximizes the surface area for heat transmission between the cold water inside the pipe and the growing media. The calculation for this is straightforward, using the convective heat loss equals capacity heat in fluid, or $q=mc_p\Delta T$, formula. Lastly, the control box serves multiple functions: it regulates the operation of the pump based on the soil temperature probe, manages refrigeration systems based on the water temperature probe in the tank, and accumulates data from all sensors in the growth channel to relay to the IoT junction box.

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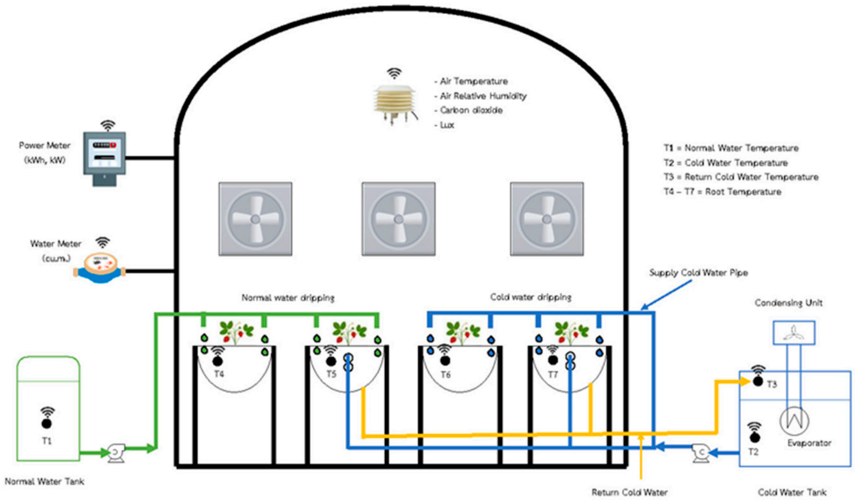

Figure 4. Single line diagram of the evaporative greenhouse and root zone cooling system.

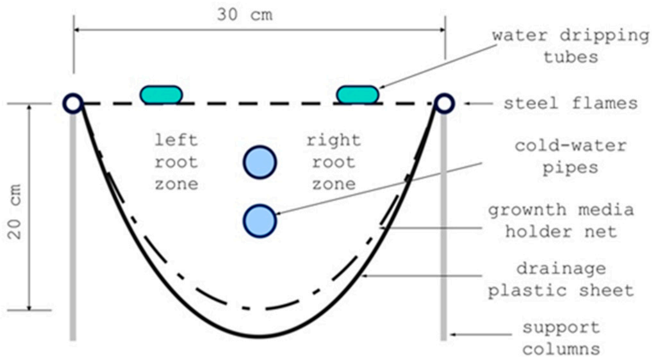

Figure 5. Double steel pipes of cold water inserted into the growing media.

2.4. Physiology Measurement

Strawberries were planted under evaporative greenhouse from late of September 2022. Plant height, canopy width, leaf width, leaf length, crown diameter, number of inflorescences and number of flowers were measured, as well as chlorophyll content (by using SPAD-502; Minolta Corp., Spectrum Technologies, Osaka, Japan), fruit weight, fruit size and fruit firmness.

2.5. Total soluble solid

The total soluble solid was measured by using digital refractometer. It has a wide measurement range of 0.0 - 53.0% Brix (ATAGO Pal-1, ATAGO Co., Tokyo, Japan)

*2.6. Colorimetric evaluation (CIEL*a*b*)*

The Colorimetric evaluation was measured by Konica Minolta CR-400, Japan which the lightness value, L* defines black at 0 and white at 100. The a* axis is relative to the green–magenta opponent colors, with negative values toward green and positive values toward magenta. The b* axis represents the blue–yellow opponents, with negative numbers toward blue and positive toward yellow [19].

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2.7. Statistical Analysis

Statistically comparative data were analyzed by analysis of variance and mean difference was compared using LSD at a 95% confidence level by using Statistica 9 software (analytical software SX, version 9, Tallahassee, FL, USA).

3. Results

The data from IoT sensor system showed that during October, 2022 until January, 2023, average air temperatures in the evaporative greenhouse were 23.2, 21.6, 21.1 and 18.6 °C, respectively. The maximum and minimum of temperatures and RH were 29.6 °C, 15.9 °C, 90% and 56%, respectively (Table 2). Average CO_2 concentration was 495 ppm and light intensity was 43,923 lux (Table 3). On the other hand, in outdoor condition the air temperature during 4 months was 25.6, 24.9, 23.0 and 20.8, respectively. The maximum and minimum temperatures and RH were 33.8 °C, 14.3 °C, 98% and 34%, respectively (Table 4). The maximum temperature in evaporative greenhouse was lower than maximum outdoor temperature about 4 °C, anyhow the minimum temperature was higher about 2 °C than outdoor.

In the first month after cooling treatments (October), the root-zone temperatures (RZT) of strawberry plants were not significantly different among treatments. The average RZT was 23.8, 24.3, 22.9 and 24.4 °C in NWD, CWD, CWD+CWP and NWD+CWP treatment, respectively. Anyhow three months after that (January), the RZT was 19.2, 19.7, 17.7 and 19.5 °C, respectively. The CWD+CWP treatment could reduce RZT about 2 °C as compared to others. It seemed that NWD, CWD and NWD+CWP treatments gave no different temperatures in the root zone (Figure 6). The dashboard features graphs of growing media, air, and water temperatures, ambient and indoor relative humidity, light intensity and carbon dioxide concentration. Figure 7 depicts the example plot display root-zone temperatures in different cooling treatments.

Table 2. Temperature and relative humidity in the evaporative greenhouse.

Months	T (Max) (°C)	T (Min) (°C)	T (Aeverage) (°C)	RH (Max) (%)	RH (Min) (%)	RH (Aeverage) (%)
October	31.4	17.6	23.2	90	62	83.9
November	34	18.1	21.6	91	42	83.8
December	29.3	14.9	21.1	89	53	84.2
January	23.7	13.1	18.6	90	68	83.5
Average	29.6	15.9	21.1	90	56	83.9

Table 3. CO_2 concentration and light intensity in the evaporative greenhouse (07.00-16.00 o'clock).

Months	Co_2 (Max) (ppm)	Co_2 (Min) (ppm)	Co_2 (Aeverage) (ppm)	Light intensity (Max) (Lux)	Light intensity (Min) (Lux)	Light intensity (Average) (Lux)
October	659	408	509	51,498	538	12,040
November	745	407	519	53,087	382	15,287
December	740	407	489	46,769	48	12,565
January	549	409	461	24,338	65	11,899
Average	673	408	495	43,923	258	12,948

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Table 4. Outdoor air temperature and relative humidity.

Months	T (Max) (°C)	T (Min) (°C)	T (Aeverage) (°C)	RH (Max) (%)	RH (Min) (%)	RH (Aeverage) (%)
October	34.6	16.3	25.6	98	40	84.3
November	35.2	17.1	24.9	98	41	82.1
December	33.5	12.9	23.0	99	43	82
January	31.9	10.7	20.8	98	35	75.8
Average	33.8	14.3	23.6	98	34	81

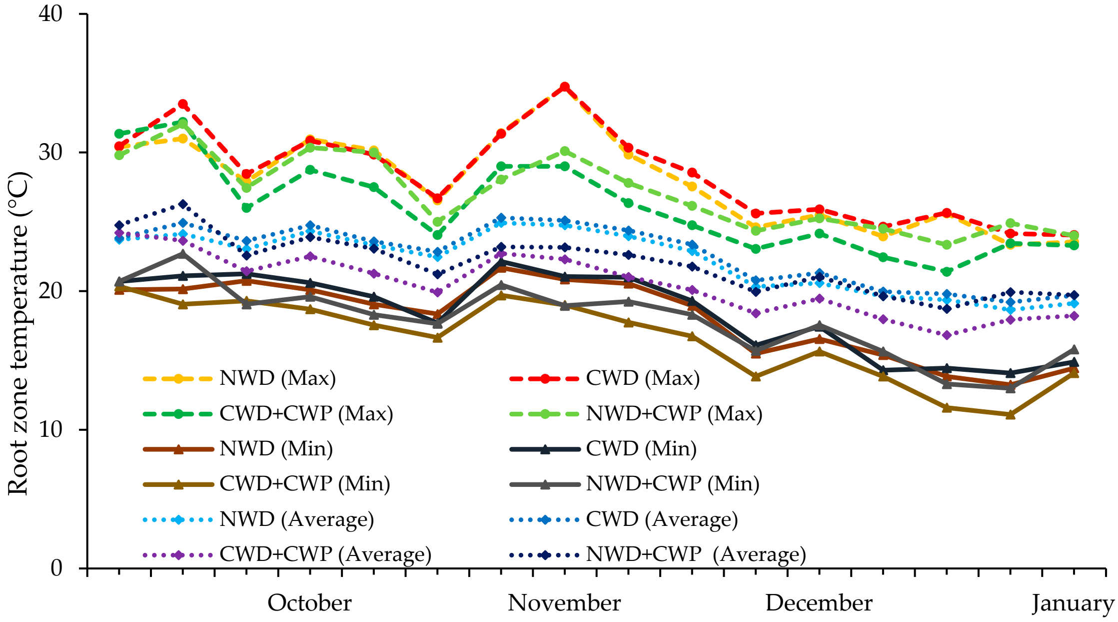

Figure 6. Root-zone temperature of strawberry plants after treatments.

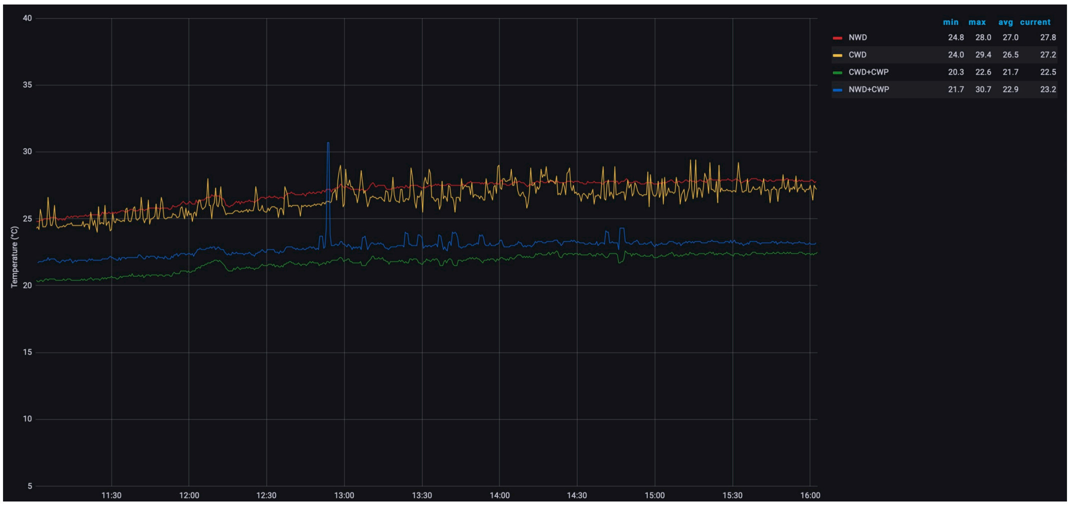

Figure 7. The dashboard displays root-zone temperatures in different cooling treatments.

Three months after treatment, there was an interaction between 2 factors as in Table 6. Each strawberry cultivar responded to the root-zone cooling treatments differently. "P80" and "Akihime" strawberry in all root-zone cooling treatments showed higher performance in canopy width and leave width significantly than "P88". On the other hand, "P88" and "Akihime" strawberry together with CWD+CWP treatment gave bigger crown than "P80" which had no difference in crown diameter

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(Table 6). In terms of reproductive growth, CWD+CWP and NWD+CWP treatments seemed to promote flowering in "P80" and "Akihime" strawberry. Anyhow, "P80" strawberry had few numbers of flower as compared to "P88" and "Akihime" (Table 7). The interaction was not found in plant height, leave length, chlorophyll content and number of inflorescences. "Akihime" gave the highest plant height and leave width as compared to "P80" and "P88". Whereas, "P80" had the lowest chlorophyll content and the number of inflorescences. The root-zone cooling treatments had no effect on the chlorophyll content. Furthermore, CWD+CWP treatment could promote number of inflorescences significantly as compared to normal water treatment (Table 8). There was an interaction between 2 factors in term of fruit qualities. The root-zone cooling treatments trended to have better fruit qualities, particularly in "Akihime", in term of fruit weight, fruit length, TSS, yield and fruit color. Anyhow, "P88" gave higher fruit firmness than other cultivars (Tables 9 and 10) (Figures 7 and 8).

Table 6. Canopy width, leaves width, crown diameter and number of flowers in different treatments.

Treatments		Canopy width (cm)	Leaves width (cm)	Crown diameter (mm)	No. of flowers
P88	NWD	28.55 d	7.31 c	15.26 cde	8.62 ab
	CWD	29.71 d	6.71 c	18.24 bcd	11.59 ab
	CWD+CWP	29.80 d	7.12 c	19.65 ab	10.11 ab
	NWD+CWP	28.81 d	7.17 c	16.35 bcde	5.46 bc
P80	NWD	38.86 abc	7.68 bc	18.61 bcd	0.00 c
	CWD	40.40 a	9.23 ab	19.22 abc	0.00 c
	CWD+CWP	38.25 abc	9.32 a	18.92 bcd	6.18 bc
	NWD+CWP	34.19 bcd	7.63 bc	18.51 bcd	9.18 ab
Akihime	NWD	38.15 abc	6.81 c	14.57 de	11.20 ab
	CWD	33.20 cd	6.52 c	13.86 e	10.28 ab
	CWD+CWP	43.03 a	8.00 abc	23.51 a	15.37 a
	NWD+CWP	39.51 ab	7.96 abc	18.55 bcd	15.30 a
	A	**	**	ns	**
	B	ns	Ns	**	*
	A x B	*	*	*	**

Note: means followed by different lowercase letters within the same column are significantly different at p < 0.05, (ns = non-significant; * = significant).

Table 7. Plant height, leaves length, SPAD and number of inflorescences of three cultivars of strawberry.

Cultivars	Plant Height (cm)	Leaves length (cm)	SPAD	No. of inflorescences
P88	21.08 b	6.92 c	41.46 a	1.17 a
P80	22.99 b	8.44 b	33.51 b	0.31 b
Akihime	24.94 a	9.67 a	40.03 a	1.43 a
F-test	**	**	**	**

Note: means followed by different lowercase letters within the same column are significantly different at p < 0.05, (ns = non-significant; * = significant).

Table 8. Plant height, leaves length, chlorophyll content and number of inflorescences in different root-zone cooling treatments.

Treatments	Plant Height (cm)	leaves length (cm)	Chlorophyll content (SPAD unit)	No. of inflorescences
NWD	22.35	8.21 ab	39.37	0.68 b
CWD	22.56	8.70 a	39.09	0.85 ab
CWD+CWP	23.70	8.67 a	37.70	1.25 a
NWD+CWP	23.41	7.79 b	37.16	1.10 ab
F-test	ns	*	ns	**

Note: means followed by different lowercase letters within the same column are significantly different at $p < 0.05$, (ns = non-significant; * = significant).

Table 9. Strawberry fruit quality and yield in different treatments.

Treatments		Fruit weight (gram)	Fruit width (mm)	Fruit length (mm)	Fruit firmness (kg)	TSS(%Brix)	Yield (gram/plant)
P88	NWD	7.60 b	22.84 ab	27.44 d	0.27 de	9.08 c	65.5
	CWD	11.66 a	26.27 a	32.38 bcd	0.30 cd	10.28 abc	131.1
	CWD+CWP	7.24 b	22.95 ab	27.59 d	0.37 abc	9.97 abc	73.2
	NWD+CWP	9.33 ab	24.34 ab	31.01 cd	0.24 def	10.28 abc	50.9
P80	NWD	-	-	-	-	-	-
	CWD	-	-	-	-	-	-
	CWD+CWP	9.63 ab	24.46 ab	30.06 cd	0.41 ab	10.85 ab	59.5
	NWD+CWP	12.04 a	25.32 ab	27.43 d	0.41 a	10.74 ab	110.5
Akihime	NWD	7.50 b	22.11 b	34.01 bc	0.15 f	10.62 abc	84.0
	CWD	9.32 ab	23.71 ab	31.89 bcd	0.19 ef	9.39 bc	95.8
	CWD+CWP	10.04 ab	23.56 ab	40.41 a	0.19 ef	11.48 a	154.3
	NWD+CWP	9.51 ab	22.77 b	36.39 ab	0.33 bcd	10.37 abc	145.5
	A	*	*	*	*	*	-
	B	*	*	*	*	*	-
	A x B	*	*	*	*	*	-

Note: means followed by different lowercase letters within the same column are significantly different at $p < 0.05$, (ns = non-significant; * = significant).

Table 10. Strawberry fruit color in different treatments.

Treatments		L	a	B
P88	NWD	34.23 d	31.60 b	15.84 bcd
	CWD	35.89 cd	25.30 d	15.12 cd
	CWD+CWP	36.38 bcd	26.28 d	16.71 bc
	NWD+CWP	38.53 abc	26.17 d	14.22 cd
P80	NWD	0.00 e	0.00 e	0.00 e
	CWD	0.00 e	0.00 e	0.00 e
	CWD+CWP	34.26 d	26.19 d	11.63 d
	NWD+CWP	36.01 bcd	26.49 d	13.27 cd
Akihime	NWD	38.65 abc	35.13 a	21.32 a
	CWD	37.11 bcd	27.20 cd	14.66 cd
	CWD+CWP	38.88 ab	31.86 ab	16.20 bc
	NWD+CWP	40.34 a	30.54 bc	19.73 ab
	A	**	**	**
	B	**	**	**
	A x B	**	**	**

Note: means followed by different lowercase letters within the same column are significantly different at $p < 0.05$, (ns = non-significant; * = significant).

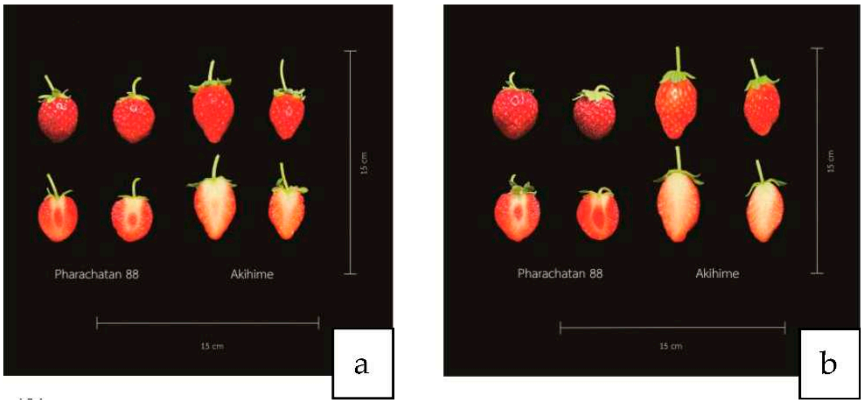

Figure 7. The "P88" and "Akihime" strawberry fruits after (a) NWD and (b) CWD treatments.

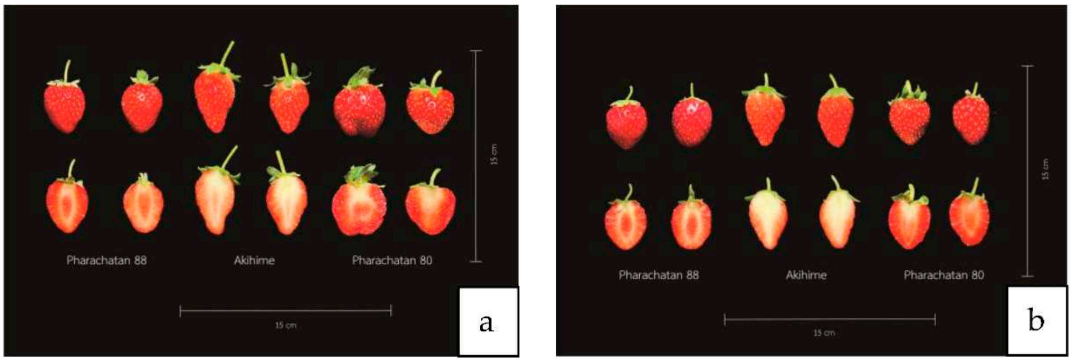

Figure 8. The "P88", "Akihime" and "P80" strawberry fruits after (**a**) NWD+CWP and. (**b**) CWD+CWP treatments.

4. Discussion

Strawberry is classified in a group of sub-tropical fruit. Almost commercial strawberry cultivars are June-bearing or short-day strawberry that need cool temperature (vernalization) to induce flower bud. Strawberry plants vernalized at 2 °C for 2 weeks had the highest percentage of flowering, number of inflorescences, number of flowers per inflorescence and number of flowers per plant as compared to vernalized at 4 °C [24]. [25] also indicated that cooling of the crown to 10–20°C induced flower bud differentiation of June-bearing strawberries. Extreme high or low temperature effected on flower development pollination and fruit malformation in strawberry [26,27] Nowadays, climate change and global warming raise ambient and soil temperatures causing strawberry productivity to decline. Protected strawberry cultivation or strawberry production in greenhouse is alternative way to avoid the effects of climate conditions [28].

Nowadays, IoT applications have been used widely to make smart farming. [29] used the IoT system to analyze environmental and crop information in strawberry plantation. The IoT system consists of three major components which are sensor device, IoT cloud, and platform. [30] also reported that the IoT system can provide in the greenhouse strawberry production in Malaysia. It helps to increase efficiency in terms of monitoring and data acquisition for research purposes. Furthermore, it will allow for precision application of nutrients, pesticide and water to the strawberry. Thailand located in tropical region, strawberry production in the greenhouse faced on high temperature during summer leading to poor flowering and short harvesting period. In this study, installed sensors and IoT system were effective to monitor parameters that affecting growth and development of strawberry. In this experiment cold water was automatically dripped to manipulate root zone temperature (RZT) of three short-day strawberry cultivars grown in evaporative greenhouse. The results revealed that dripping the cold water (10-15 ◦C) direct onto the

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surface of growing media could not reduce RZT during October, 2022-January, 2023. The growing media was a mixer 70:30 percentage of peatmoss and perlite. The perlite is an insulator to keep temperature consistently, dripping 10-15 ◦C cold-water for 1 minute 5 times in the afternoon (20 ml/time) might be not sufficient to reduce temperature in the growing media. Interestingly, the cold-water dripping combined with embedding cold-water pipe in the growing media could reduce about 2 ◦C RZT. The maximum RZT was 23.4 ◦C and the minimum was 11.1 ◦C, while average air temperature and RH was 21.5 ◦C and 84%, respectively. Average CO_2 concentration and light intensity in the evaporative greenhouse was 495 ppm and 43,923 lux, respectively. These conditions could promote vegetative and reproductive growth of strawberry plants in our experiment. It was also reported that increasing light intensity from 27,000 to 54,000 lux at 15-21 ◦C was increasing in CO_2-uptake and photosynthesis of June-bearing strawberry [31]. Optimum RZT enhances respiration, oxygen consumption and cell viability of the root leading to high nutrient uptake and biomass accumulation. RZT could also alter the vegetative and reproductive growth of hydroponically grown strawberry plants [20]. [32] found that large RZT fluctuations negatively affected strawberry plant growth and leaf area as well as an uptake of some nutrients. Consistently with [33] reported that groundwater cooling was reduced rhizosphere temperature from 26.9 C to 24.9 C and effective in improving the growth and productivity of strawberries under high temperature conditions. Furthermore, cooling RZT at around 20°C with short-day (8-h daylength) treatment for 22 days accelerated and stabilized the flower bud formation of two cultivars, "Nyoho" and "Tochiotome" [19]. On the other hand, it was found that root-zone heating to maintain temperature 20-23 ◦C was effective in increasing the productivity and quality of strawberries during winter-season cultivation in the greenhouse [34]. In our experiment, "Akihime" and "P88" strawberry after the RZC treatments gave better flowering and yield than "P80". The RZC treatments had no effect on chlorophyll contents, whereas "P80" had lower chlorophyll content than others. In addition, RZC treatments seemed to enhance fruit weight, TSS and yield as compared to non-cooling treatment. Different strawberry cultivars responded to environmental conditions differently. Six strawberry cultivars; "Maehyang", "Seolhyang", "Keumhyang" (Korean short-day cultivars), "Akihime", "Red pearl", and "Sachinoka" (Japanese short-day cultivars) were exposed to short-day (10-h photoperiods) conditions at 800 m elevation for 35 days beginning in late June and found that they produced number of flowers and fruits differently [35]. The seven 9 h short days at 21/21 °C (day/night) followed by seven 9 h short days at 21/12 °C (day/night) was the most effective conditioning treatment for off-season 'Sweet Charlie' strawberry production in greenhouse [36]. [37] reported that strawberry fruit harvested at a root zone temperature of 15 °C had greater soluble solid content (SSC) than harvested at 22 °C. Higher RZT affected on less uptake of P, K and Mg bout 35% [30]. It has been known that K plays crucial role on sugar translocation from source to sink. [38] indicated that K nutrient is positively correlated with sugar content (°Brix) in "Fortuna" strawberry fruit. Study in another plant, such as tomato, it was also confirmed that cooling RZT promoted growth and nutrient uptake as well as effected sugar accumulation in tomato fruit [39]. It can be concluded that the integration of evaporative greenhouse, internet of things and root-zone cooling can enhance growth, flowering, fruit quality and yield of strawberry in tropical lowland cultivation.

5. Conclusions

The IoT system monitored, collected and displayed climatic conditions under the evaporative greenhouse during October, 2022 until January, 2023 and indicated that average air temperature was 21.1 °C with 83.9% RH, 495 ppm CO_2 and 12,948 Lux light intensity. Under these conditions the cold-water dripping (10-15 °C) combined with embedding cold-water pipe in the growing media treatment could reduce root zone temperature about 2 °C and leading to promote the vegetative and reproductive growth of "Akihime", "Pharachatan 88" and "Pharachatan 80" strawberry cultivars as well as fruit qualities and yield. Without the root-zone cooling treatment, "Akihime"and "Pharachatan 88" still could produce flowers and yield, but "Pharachatan 80" could not. Therefore, "Pharachatan 80" cultivar might not be preferable for growing in the evaporative greenhouse at altitude 304 msl.

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