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Monitoring Environmental Factors Associated with Indoor Growth Chambers and Greenhouses for Cannabis Cultivation

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Abstract

Greenhouse cultivation has no seasonal limitations and research is being conducted globally to assess control of environmental factors within greenhouses to optimize growing conditions. Attempts to improve the environmental factors in greenhouse cultivation include control of temperature, relative humidity, light intensity, carbon dioxide level, and air flow rate. Furthermore, indoor cultivation systems (growth chambers) have been developed and researched for comparison with greenhouse cultivation. In our study, comparative environmental data were collected in association with cannabis cultivation for a greenhouse and growth chamber, since commercial cannabis cultivation can include such methods. Accordingly, the data in this research were collected by choosing the same cannabis cultivars for both cultivation methods and by controlling the internal growing environments that affected cultivation. Data also were collected on the plant biochemical properties over the same time period and the collected data were analyzed using psychrometric charts.

The findings of this research show that if the internal environment of the indoor cultivation method is well-regulated, better results in cannabidiol (CBD) extraction from blossoms can be achieved as compared to greenhouse cultivation, in which environmental regulation is less precise. Therefore, we conclude that if we can control the internal environment of greenhouse cultivation to be similar to the indoor cultivation method, the productivity of the two methods should be similar. The findings of this research can be used to develop greenhouse cultivation methods for other plants in order to improve future productivity and efficiency.

Keywords

Greenhouse; Environmental factors; Humidity control; Temperature control; Cannabis cultivation; Growth chambers

1. Background and Literature Review

Studying the environmental factors of plant cultivation involves examining various elements that affect plant growth and development within a controlled environment. The environmental factors associated with each cultivation method will contribute to the productivity of each growing cycle. Hence, this study conducted

a trial cultivation of cannabis cultivation in both indoor growth chamber and greenhouse settings with emphasis on the cannabis extraction as the end marker. Control of temperature, relative humidity (RH), light intensity, carbon dioxide, and etc. required by cannabis was used for cultivation and results compared between the two systems to determine the optimal conditions of the environmental factors for growth with the highest level of efficiency. (Pérez-Bermúdez & Rognoni Martínez, 2023)

The research approach for this study including conducting a literature review and collecting primary data from both growth chamber and greenhouse cannabis cultivations. The environmental factors from the growth chamber/indoor cultivation were comprehensively controlled and compared with the greenhouse cultivation that was subjected to less control. We intended to use the findings of this research to expand upon the development of cultivation methods for other types of plants in the greenhouse setting, thereby providing guidance for the general population in cultivating various plants in the future

Hemp and cannabis are classified as an annual plant from the cannabis family (Figure 1). The differences between hemp and cannabis can be identified based on morphology and phytochemistry. The hemp stem is greater than 2 meters in length, with long internodes. The hemp leaf is green-yellow and bigger than the cannabis leaf. Each leaf is divided into 7-9 leaflets attached with a clear spacing and produces no sticky resin. The seeds are large and have a rough surface with lines. The row spacing in planting is relatively narrow, as only the hemp fiber will be used. Tetrahydrocannabinol (THC), a psychoactive addictive substance in the hemp, is less than 0.3% while Cannabidiol (CBD) is more than 2%. Hence, the hemp is not considered as a narcotic plant. Conversely, the cannabis stem is not more than two meters in length. The cannabis leaf is dark green and smaller than the hemp leaf. Each leaf is divided into 5-7 leaflets. The leaf blades attach closely to each other or spread in a circle close to the inflorescence bracts. The seeds are small and have a glossy surface. The row spacing in planting is relatively wide, as only the cannabis leaves will be used. The cannabis extract contains 1-15% Tetrahydrocannabinol (THC) and up to 20% Cannabidiol (CBD). The burnt leaf smells like dry grass and produces a psychoactive substance (Samphanpanich & Sukcharoen, 2019).

Figure1. Differences between hemp leaf (left) and cannabis leaf (right) (Samphanpanich,2019)

From the above-mentioned information, the basic differences are: The cannabis contains approximate 5-15% THC and THC content is greater than CBD. The hemp contains 0-1% THC and CBD is greater than THC by a 2:1 ratio. If the plant material contains no more than 0.3% THC on a dry-weight basis, then it is treated as hemp. If the THC quantity is greater than the legal limit (0.2% THC by dry weight), it shall be treated as cannabis. (Symons, 2024)

Hemp and cannabis are classified as narcotics, category V. The production, disposal, import, export or possession require a license from the Minister of Public Health with the approval of the Narcotics Control Committee for each case, in accordance with Section 26 of Narcotics Act, B.E.2522 (Criminal Drug Offences, 2022). The Thai government legalized cannabis cultivation as of the 29th January 2021 to enable public cultivation for commercial and medical purposes (Narcotics Control Division Cannabis, 2023). However, the law contains a transitional provision requiring private entities intending to undertake cannabis cultivation to apply for a cultivation license through the local agricultural agency. This licensing process facilitates official inspection of the source of cultivated cannabis and to ensure that the cultivated cannabis would not be misused. The licensee is required to present a production plan, sales plan, and use plan in accordance with the approval process. In addition, the cultivated seeds must be approved by the Food and Drug Administration (FDA) Thailand. As such, cannabis cultivation still requires a license and shall comply with the purposes specified by the application for the license. In 2024, the cannabis-Hemp Act is a proposed law that aims to regulate the cultivation, extraction, processing and use of cannabis and hemp in Thailand. The Public Health Ministry of Thailand has already completed the first draft of the act, which will not reclassify cannabis as a narcotic, but will still restrict and control any misuse of cannabis. The act in 2024 still requires prior permission for personal cannabis cultivation and prohibit cannabis smoking in shops.

Regarding the benefits of hemp, CBD, mainly found in the inflorescence, can be used as a medical pain reliever or tranquilizer or as additives in foods, cosmetics, or herbal products. Other parts of the hemp, such as the seeds, can produce oil used in food supplements. The hemp fiber can be used for weaving. The stem core can be used as a component of cellular lightweight concrete or fiberglass insulation in cars, etc. Based on the benefits of hemp, it has potential to become a new cash crop.

A cannabis strain named Alternative Cannabinoid Dietary Cannabis or ACDC strain was used in this research, whose extract according to previous research, contains 20% CBD and up to 0.42% THC. Based on information from the consumers, cannabis of ACDC strain tends to generate a cheerful, delighted, and relaxed sensation. With the high CBD, ACDC strain is suitable to be an alternative medicine, used for the relief of anxiety, inflammation, migraines, nausea, nervous system conditions, joint effusion, and bipolar disorder. In addition, it is widely used for the treatment of chronic pain or relief of chemotherapy side effects (Way of leaf, 2023).

1.1 Cannabis Cultivation

At present, cannabis cultivation can be divided into 3 types (Nonthnathorn et al., 2021), as follows:

1.1.1 Cannabis cultivation in the open field This is the cultivation method that involves the lowest investment cost but which is associated with insect problems and general plant diseases, in addition to a lack of control for lighting, temperature, and humidity (Figure 2). Because cannabis are short-day plants, the plants blossom only when their sunlight exposure over a 24-hour period (1 day) is below the critical day length. This means that cannabis will blossom only when they receive less than 12 hours of sunlight per day and if they receive more than 12 hours of sunlight per day, the cannabis will not blossom but their leaves and stems will grow instead, which is one additional reason why production cannot be controlled as desired.

Figure 2. Open field cultivation (Credit: Researcher)

1.1.2 Cannabis cultivation in the greenhouse: This is a semi-open, semi-closed method of cultivation by which the cultivator can control some of the environmental factors (Figure 3). In greenhouse cultivation, the system has to be designed by the grower, including evaporative pads and misting systems to reduce temperature and increase internal humidity, a system for watering plants to promote appropriate nutrient absorption, a liquid fertilizer system to enhance fertilizer effectiveness, a carbon dioxide refilling system to promote photosynthesis, a lighting system to reduce light intensity, a pesticide/herbicide system to prevent and control pests/weeds, and an automatic control system to enhance climate control in the greenhouse (Namhormchan & Muangchan, 2020). These features have to be added to the greenhouse system to promote internal environmental control and since the environment inside the greenhouse is closed, cultivation within requires the aforementioned systems to promote natural growth. However, we note that growers might not use all of the aforementioned systems if designs can rely on the internal environment of the greenhouse such as the switching on or off of an internal lighting system by turning it off when there is sufficient natural lighting and turning it on when there is insufficient external lighting in the greenhouse, or non-use of a pesticide/herbicide control system to reduce cost but assuming there access control to prevent harmful organisms from entering the greenhouse, etc. The advantage of greenhouse cultivation is that the cost involved in the construction of a greenhouse is much lower than growth chamber/indoor cultivation. In addition, since cannabis normally has a life cycle in the range of 90-120 days, open field cultivation allows for only 1-2 cultivation cycles but greenhouse cultivation allows for up to 3-4 cultivation cycles per year.

Figure 3. Greenhouse cultivation (Credit: researcher)

1.1.3 Cannabis cultivation with an indoor system: Similar to greenhouse cultivation, indoor system cultivation requires the grower to choose a system to control the internal environment. However, it differs with respect to the control system, which must be chosen in its entirety in order to ensure the development of the plants grown in the indoor system. One advantage of this cultivation method is that the grower can control all of the internal environmental factors in their entirety, such as temperature, relative humidity, lighting, airflow, and insects (Figure 4). Hence, the outcome of this method is high productivity per plant, high quality, and good safety. Nevertheless, this system also has some challenges. For example, indoor cultivation involves major investment and a larger area per plant (Nonthnathorn et al., 2021).

Figure 4. Indoor/Growth chamber cultivation (Credit: researcher)

From the above, the different cultivation methods have their own strengths and weaknesses, depending on the decisions of the growers, whether in terms of environment, budget, cannabis strains, and maintenance of each type of plant, which requires grower expertise. Growing also requires licensing as previously discussed. However, it is generally accepted that growing hemp/cannabis in growth chambers/indoors is the best and most effective cultivation method that generates the highest prices because it allows growers to control various internal factors within their systems to maximize productivity.

1.2 Classification of Cannabis Growth Rooms of the Indoor System

The growth chamber/indoor system consists of 3 rooms (Mehboob et al., 2020) as follows;

1.2.1 Propagation growth room: This room is for breeding and nursery during the first 3-5 weeks. This room does not need the intense light and air-conditioning. However, the light for the plant growth should be 18-24 hours/day.

1.2.2 Vegetative growth room: This process will take 2-8 weeks after the first stage. Aside from controlling the variables affecting the cannabis growth, such as temperature and humidity, the main feature of the vegetative growth room is the high intensity of light. The light is turned on for 18 hours and turned off for 6 hours to accelerate the stem and leaf growth and prevent premature flowering.

1.2.3 Reproductive growth room: The cannabis plants are kept in this room for 6-8 weeks. The room requires a high intensity of light, while the humidity control system also is very important. In the reproductive growth room, the light is turned on for 12 hours and turned off for 12 hours to stimulate the flowering. The nutrition is conveyed to nourish the flowers and the leaf/stem growth is accordingly suspended.

1.3 Environmental Factors Affecting Cannabis Cultivation

According to the literature review and additional data collection, there are many environmental factors that affect cannabis cultivation (Pérez-Bermúdez & Rognoni Martínez, 2023). The growth chamber/indoor cultivation should have total control of these variables to optimize productivity. These variables are as follows;

1.3.1 Light

Artificial light is a main variable influencing the success of cannabis cultivation. The light duration affects the stem and flower growth. The stem and leaf development require a light cycle of light 18 hours/day, while the flowering requires only 12 hours/day to support their growth. There are 3 light characteristics to consider:

1.3.1.1 Light intensity is the measure of the photosynthetic photon flux density (PPFD). It is the measure of the radiant energy in the waveband that promotes plant photosynthesis and has the units of micromole/square meter/second (µmol/m2/s). Each growth phase of cannabis needs different light intensity. The stem growth phase requires a light intensity at 400-650 PPFD (µmol/m2/s), while the flower growth phase should get a light intensity at 800-1200 PPFD (µmol/m2/s) (Moher et al., 2022).

1.3.1.2 Light spectrum: At present, the Light Emitting Diode (LED) technology is very popular. LED lamps emit white light, which includes a combination of all colors in the color spectrum, but mostly consists of the blue, green and red wavelengths. In the vegetative growth room (leaf generating room), red light is less important, but in the reproductive growth room (flower generating room), red light is highly important for growth. Hence, we need to increase the red light availability (Danziger & Bernstein, 2021).

1.3.1.3 Light duration: The cannabis is classified as a short day plant. To stimulate the stem and leaf growth, the light must be turned on for 18 hours and turned off for 6 hours. To stimulate the flower growth, the plants should be later moved to the room where the light is turned on for 12 hours and turned off for 12 hours (Sriwongchai et al., 2021).

1.3.2 Temperature

Temperature control in growth chamber/indoor cultivation is achieved via a comprehensive air conditioning system. At least 2 air conditioners should be turned on using an alternating schedule to control daytime temperatures within the range of 24-26 degrees Celsius and for nighttime temperatures within the range of 18-20 degrees Celsius (Sriwongchai et al., 2021). In this research, two split type air conditioners were used by turning them on alternatingly from 8:00 am to 8:00 pm and from 8:00 pm to 8:00 am, respectively. The temperature setting for both time periods was 25 degrees Celsius throughout the entire duration of each period.

1.3.3 Relative Humidity

Normally, the relative humidity should be maintained at 60%. The relative humidity generally affects the plant's transpiration. Too high humidity could promote fungal growth on the plant. Likewise, humidity control for the indoor growth chamber is necessary for cannabis cultivation. The dehumidifier must be installed in each room. In particular, the relative humidity in the reproductive growth room must be maintained under 55%. In the reproductive growth room, the temperature and relative humidity affect the cannabis's transpiration which consequently affects the photosynthesis rate. Hence, the temperature and relative humidity management is highly important to the plant's transpiration (Sriwongchai et al., 2021).

Both temperature and relative humidity must be consistent to maintain the Vapor Pressure Deficit, VPD, which is the difference between the water vapor pressure in saturated air and the actual water vapor pressure in the air. The relative humidity suitable for plant growth is in the range of 60-90%. A relative humidity less than 60% may alleviate the water stress. A relative humidity higher than 95% for long periods of time, especially during the night, accelerates fungal growth on the plant (Wollaeger & Runkle, 2015) in the growth room at 0.8-1.1kPa during the initial phase of flowering and at 1.0-1.5 kPa during the late phase of flowering or around the 18^{th}-21^{st} week. If VPD in the growth room is too low, the water produced from the transpiration process could not evaporate. The leaves would be too wet. On the contrary, if VPD in the growth room is too high, the leaves would be too dry and the plant growth would be affected.

1.3.4 Carbon Dioxide, (CO_2)

Similar to other kinds of plants, cannabis needs carbon dioxide (CO_2) in the photosynthesis process to produce their own foods. The carbon dioxide (CO_2) concentration in the atmosphere of the indoor cultivation system must be maintained at 1000 ppm, which is an advantage of the indoor cultivation system. Unlike the open field or greenhouse cultivation systems, the farmer can add carbon dioxide into the indoor cultivation system, if needed.

1.3.5 Air Flow

All kinds of plants rely on the natural wind to evaporate the water produced from the leaves through transpiration. This process of accelerated air circulation can stimulate photosynthesis. To increase air flow for the cannabis indoor cultivation system, electric fans are installed on the wall, simulating the natural wind in the open air. Carbon dioxide (CO_2) is heavier than other types of gas. The electric fans blow CO_2 through the growth room atmosphere and help to enhance stomatal opening and gas exchange in the leaf. In general, the desired range of air speed is 0.3-0.5 m/s (Dr.Greenhouse, 2023)

1.4 Cultivation in the Greenhouse

Cultivation in the greenhouse is suitable for farmers who have adequate space and capital. This cultivation method is cheaper than the indoor cultivation system, but the farmer needs to manage the variables affecting the plant growth. The greenhouse-environment controlling techniques can be divided into 3 groups (Namhormchan & Muangchan, 2020) as follows:

i. Cooling Techniques, such as natural or mechanized ventilation, shading material, evaporative cooling system, and fogging system.
ii. Heating Techniques, such as solar collector and ground collector.
iii. Passive Techniques, such as earth tube system, geothermal heat pump, rock bed and north wall, etc.

Figure 5. Map of the distribution of the reviewed greenhouse-environment controlling technologies worldwide (Ghoulem et al., 2019).

The greenhouse-environment controlling techniques applied in different countries are determined by the plant type and geography. Figure 5 summarizes the distribution of greenhouse-environment controlling technologies employed globally and we can see that the specific controlling techniques tend to be influenced by the differences of weather and temperature in each continent. The key cooling techniques in Asia are natural ventilation, mechanical system, roof cooling, solar-hybrid system, fan-pad combined with shading mechanisms, ground system, indirect-direct evaporative cooling, desiccant system, solar system, and fogging system, which are necessary to control the greenhouse environment, making it suitable for cultivated plants (Ghoulem et al., 2019). In this research, Thailand is located in tropical South East Asia. Hence, the greenhouse temperatures and humidity are very high. We should choose a cooling system that can achieve the lowest temperatures but also consider the effects of relative humidity on plant growth in the greenhouse.

According to the general working principle of the evaporative cooling system (Franco et al., 2014), which will be applied in this research, the construction budget is not very high, maintenance is easy, and it has a long usage life. The evaporative cooling system functions in such a manner that the exhaust fans draw the outside air inwards through the cooling pad to reduce the air's temperature (Figure 6). Inside the cooling pad, the pumps push the water throughout the pad. When the hot air outside the greenhouse moves through the cooling pad, the heat is transferred into the water. This heat is used to accelerate the evaporation on the cooling pad. The vapor combines with the air from the cooling pad, making it cooler and more humid. In general, the temperature is reduced by 3-14 degrees Celsius (Boonyanant, 2011) depending on the water temperature and outside air temperature.

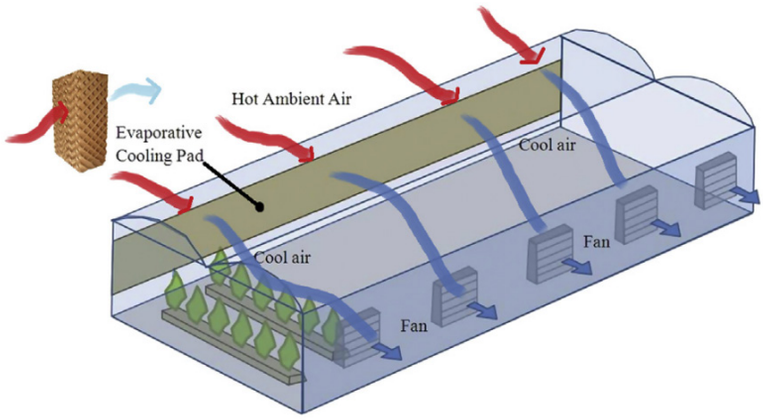

Figure 6. Schematic of a fan-pad cooling system for greenhouse (Ghoulem et al., 2019).

2. Methodology

The research was conducted at the Trio Farm, Dan Makham Tia District, Kanchanaburi Province. The Trio Farm operated a business to cultivate medicinal cannabis using the three aforementioned systems, namely, open field cultivation with a field 25 meters wide and 50 meters long, 2 greenhouses, namely, Greenhouse A and Greenhouse B, each sized 200 square meters, and indoor growth chamber system, which consisted of five growth chambers in two buildings as shown in Figure 7.

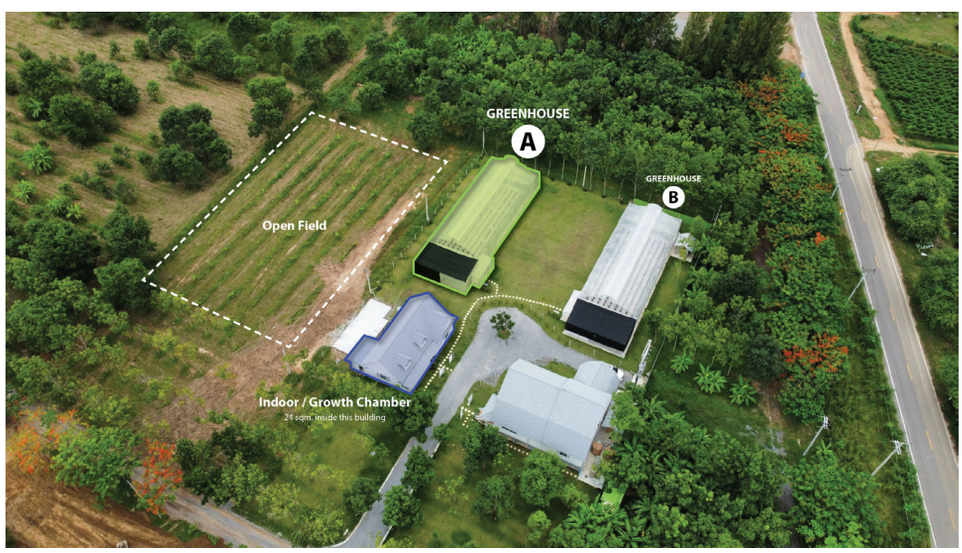

Figure 7. Aerial view of Trio farm, Dan Makham Tia District, Kanchanaburi, location for all data collection (Credit: researcher)

Before conducting the research, we chose cannabis belonging to the ACDC strain as mentioned previously for the experiment. This strain was chosen for cultivation in the growth chamber/indoor system and consisted of 16 plants total, while 162 plants were chosen for greenhouse cultivation with the cultivation period lasting from 1 June to 30 August 2022 or a total of 13 weeks. The experiment was divided into the following time periods:

I. **Propagation growth period:** June1-28, 2022. The period was 4 weeks.

II. **Vegetative growth period:** June 29-August 2, 2022. The period was 5 weeks.

III. **Reproductive growth period:** August 3-30, 2022. The period was 4 weeks.

In the propagation growth period, all ACDC cannabis seeds used in the experiment were sown in a controlled growth chamber for 4 weeks. Then during the vegetative growth period, we divided the 162 seedlings to plant in Greenhouse A, while the remaining 16 plants were then grown in the same experimental chamber. Data for the environmental factors were collected from both systems during the vegetative growth period by selecting data from July 1-131, 2022 for analysis. The energy values from this research were recorded hourly throughout the entire 9-week experiment, with the details about the data collection in both systems summarized as follows:

2.1 Indoor/Growth Chamber Cultivation

Data collection was achieved by the Daikin brand controller model BRC1E63 for an automatic data collection system that ensured convenient, 24-hour monitoring and recording of the environmental factors. The time period chosen for analysis was the time period for conducting the experiment in the vegetative growth room. The experimental chamber was 25 square meters in size and 16 plants were arranged in experimental trays (1 plant/square meter) with space provided for the surrounding walkway (Figure 8). In this experimental chamber, we controlled the previously mentioned environmental factors as follows:

2.1.1 Light Intensity: Light intensity was set to 600 PPFD throughout the entire lab experiment period by turning the lights on for 18 hours and off for 6 hours.

2.1.2 Indoor temperature: We used 2 air conditioners. Both were split type air conditioner systems with temperatures set to remain constant at 25 degrees Celsius.

2.1.3 Relative humidity: A measurement instrument by the Daikin brand controller model BRC1E63 was used to control humidity to remain in the range of 60-70% throughout the entire experiment.

2.1.4 Carbon dioxide: We chose a carbon dioxide measurement instrument by the JEDTO brand CO_2 meter air quality monitor to help ensure the atmospheric level remained constant at 1000 PPM. In cases where the level dropped below the setting, we had prepared a carbon dioxide gas tank for refilling to meet requirements, since carbon dioxide affected the photosynthesis of the cannabis plants.

2.1.5 Air flow system: Because carbon dioxide is a heavier gas than other gases in the experimental chamber, fans were prepared for mixing the air to enhance the photosynthesis process.

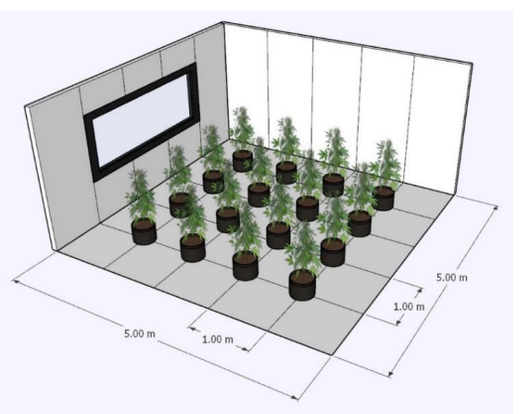

Figure 8. Growth Chamber/Indoor dimensions

Figure 9. Temperature and relative humidity controller

Figure 10. Light intensity is set for 600PPFD throughout the indoor cultivation room (Right) Setting the light intensity monitor (Left)

2.2 Greenhouse Cultivation

The size of the greenhouse in this experiment was 10 meters wide and 23 meters long. The greenhouse was divided into a maintenance area sized 30 square meters (3 meter x 10 meters) and a growing area sized 200 square meters (10 meter x 20 meters). In the growing area, we planted ACDC cannabis plants with a spacing of 1 meter to allow the planting of up to 162 plants (1 plant/square meter)(Figures 11(a),11(b),11(c),11(d)). In this greenhouse, the environmental factors were not very controllable. The environmental factors in the greenhouse can be summarized as follows:

2.2.1 Light intensity: Only natural lighting was used, by which light intensity varied from day to day.

2.2.2 Indoor temperature: We installed an automatic evaporative system. Normally, when an air conditioner was not working and the temperature inside the greenhouse rose to 30 degrees Celsius, the evaporative system would function.

2.2.3 Relative humidity: An instrument was used to control humidity to remain in the range of 60-70% throughout the entire experiment

2.2.4 Carbon dioxide: We installed a carbon dioxide measurement device with a setting at 1000 PPM. If the level fell below the setting, we had a prepared carbon dioxide tank for refilling to meet the requirement.

2.2.5 Air flow system: Because carbon dioxide is a heavier gas than other gases in the experimental chamber, fans were prepared to mix the air and enhance the photosynthesis process.

Data collection for both systems involved the use of an automatic data collection system or a smart farming system in which the growing management system used Internet of Things or IoT equipment to provide 24-hour monitoring and access to controlled factors.

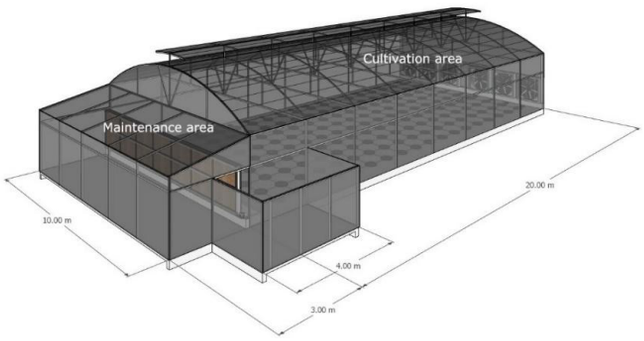

Figure11(a)

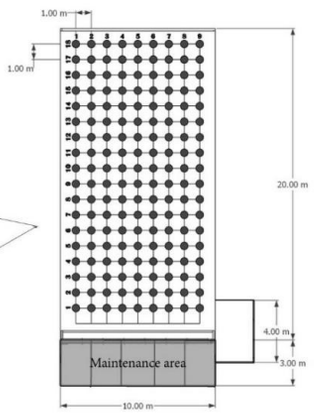

Figure11(b)

Figure11(c)

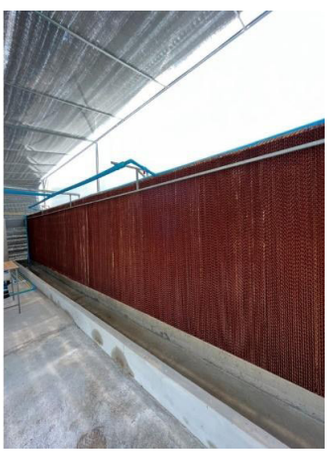

Figure11(d)

Figure 11(a) Dimensions of the Greenhouse, **Figure11(b)** Cannabis cultivation in the greenhouse, which was configured as 1 plant/sqm (Total of ACDC Cannabis cultivation in Greenhouse is 162 plants), **Figure11(c)** Cannabis placement in the greenhouse, **Figure11(d)** Cooling pad of the evaporative system in the greenhouse

A comparison of environmental conditions for both experimental configurations (indoor growth chamber and greenhouse) is provided in Table 1. Temperature and light intensity were the two environmental conditions for which we had lesser control.

Table 1. The comparison table of the environmental factors between Growth Chamber/Indoor and Greenhouse Cultivation.

	Growth Chamber/Indoor Cultivation	Greenhouse Cultivation
Light Intensity	Light intensity was set to 600 PPFD throughout the entire lab experiment period.	Only natural lighting was used in the greenhouse.
Indoor Temperature	The temperature was set constantly at 25 degrees celsius.	Used the evaporative system. When the temperature inside was over 30 degrees Celsius. The system would function.
Relative Humidity	The Relative Humidity was set in the range of 60-70%.	The Relative Humidity was set in the range of 60-70%.
Carbon Dioxide	The Carbon Dioxide must be maintained at 1000 PPM.	same as indoor.
Air flow system	Electric fans are installed to accelerate the air circulation.	same as indoor.

After monitoring the environmental factors in both growing systems for a period of time, we attempted to maintain the temperature and relative humidity in both cultivation systems at levels summarized in Figures 12 and 13.

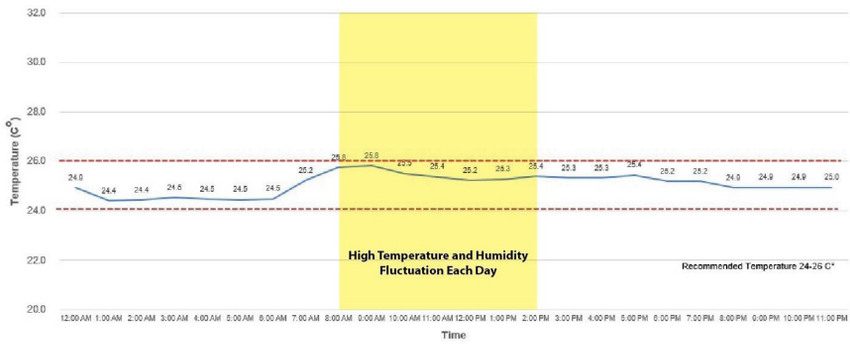

Figure12. The graph of average daily temperature in the indoor growth chamber during July1-31, 2022.

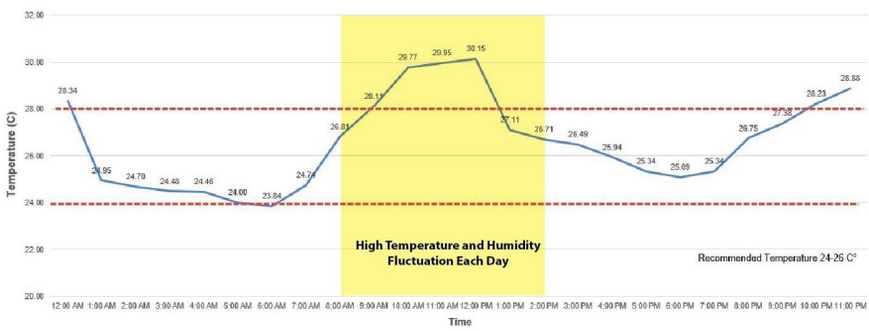

Figure13. The graph of average daily temperature in the greenhouse during July1-31, 2022.

After collecting data throughout the entire vegetative growth period of the saplings, where the environmental conditions were as summarized in Table 1, and after sorting them for cultivation in the prepared area for the growth chamber/indoor cultivation system the saplings were planted to compare with greenhouse cultivation where the air conditioning used an evaporative system. Accordingly, it was found that temperatures in the growth chamber/indoor system did not significantly vary throughout the data collection period, since settings were applied to the air conditioner system in the growth chamber. However, for greenhouse cultivation, the evaporative air conditioner system functioned when indoor temperatures exceeded 30 degrees Celsius, so temperatures varied to a greater extent during the data collection period of the experiment..

Data for relative humidity in both experimental systems is summarized in Figures 14 and 15. The relative humidity for both systems was higher than we had anticipated, whereby the average relative humidity of the indoor system was 76% and the average relative humidity of the greenhouse system was 85%. Thus, it was possible to conclude that the greenhouse which utilized the evaporative air conditioning system likely would experience higher humidity than the indoor cultivation system due to the fact that the air ventilation system functioned by bringing water vapor into the greenhouse, leading to lower temperature but also automatically higher internal humidity (Xu et al., 2015).

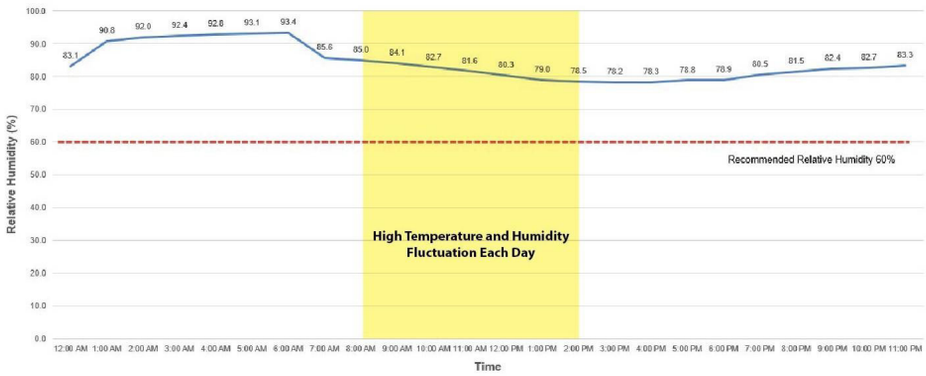

Figure 14. The graph of average relative humidity in the indoor growth chamber during July1-31,2022.

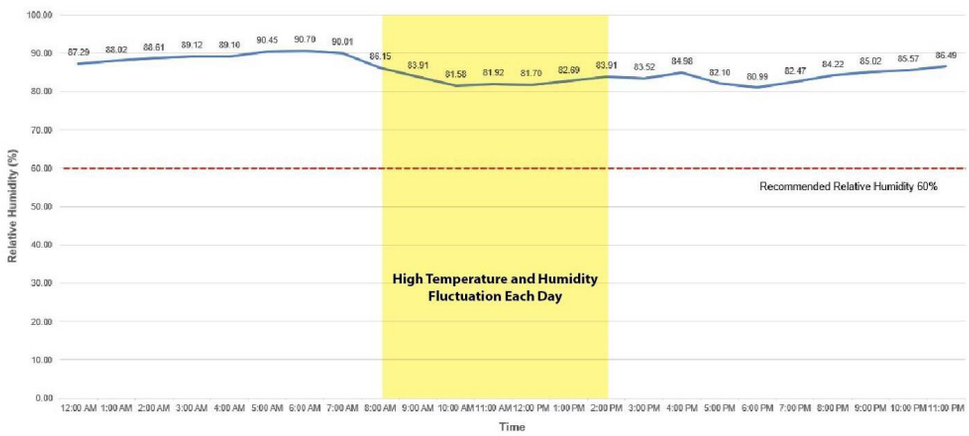

Figure 15. The graph of average relative humidity in the greenhouse during July1-31,2022.

Accordingly, we used the findings from the data collection to analyze results with a psychrometric char (Figure 16), which compared the findings of the temperatures and relative humidity for Thailand throughout the entire year as a baseline for interested people to simultaneously compare external factors.

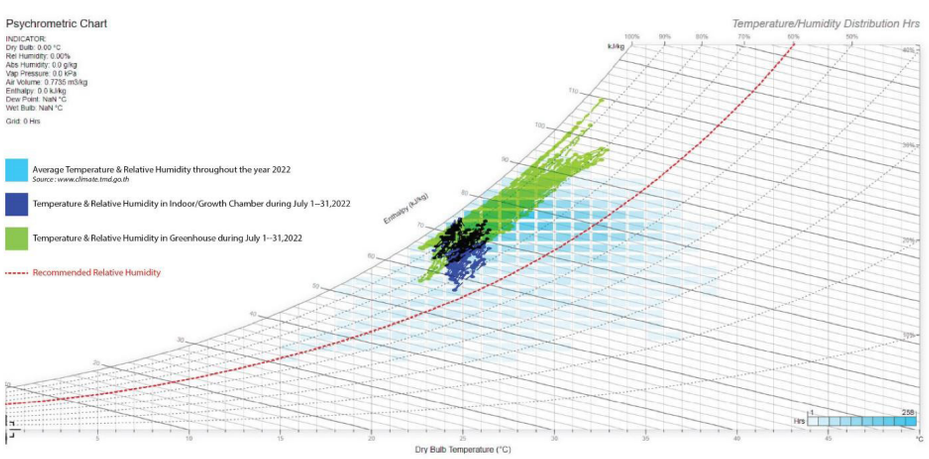

Figure 16. Psychrometric chart of the temperature and relative humidity comparison in the growth chamber/indoor and greenhouse.

Figure 16 shows that the temperature and relative humidity of the growth chamber/indoor system were clustered but remained reasonably above the required relative humidity line (60%). Meanwhile, the temperature and relative humidity values in the greenhouse cultivation were considerably more variable.

We compared information from both cultivation systems on the same graph and found that there was some overlap in the state of the systems. This shows that both cultivation systems contained elements that would facilitate plant growth. Thus, if we could reduce variability or make improvements to create optimal conditions for plant growth in the greenhouse environment, we would be able to use them in place of the indoor growth chambers , which are significantly more expensive.

After the data collection, we brought the cannabis blossoms obtained from both cultivation systems in equal quantities of 0.155 grams to test for CBD (Cannabidiol) level at the Cannabis Extraction and Analysis Laboratory of Kasetsart University, Thailand. This process of extracting CBD is known as decaboxylation, i.e., the process of subjecting the test blossoms to high heat, after which the extraction process yields 2 types of CBD, namely, CBDA (Cannabidiolic Acid) and CBD (Geskovski et al., 2021). Decarboxylation is a process in the realm of cannabis chemistry. In particular, the activation of the psychoactive attributes inherent in its cannabinoid constituents, such as THC and CBD. In its natural state, unprocessed cannabis harbors THCA (tetrahydrocannabinolic acid) and CBDA (cannabidiolic acid), which serve as the inert precursors to THC and CBD, respectively. Upon subjecting cannabis to thermal energy through methods like combustion, vaporization, or culinary preparation, the decarboxylation process ensues, wherein a carboxyl group is dissociated from THCA and CBDA, culminating in the conversion to their pharmacologically active derivatives, THC and CBD. Analogously, this decarboxylation phenomenon applies to other cannabinoid acids present within the cannabis matrix. In order to calculate the percentage of CBDtotal, the following equation was used:

$$\% \text{ of CBDtotal} = \% \text{ of CBD} + (\%\text{of CBDA} \times 0.877)$$

Equation 1. The formula to calculate the CBD total (Fundacion Canna, 2023).

After calculating CBDtotal with equation 1, we show the results in Tables 2 and 3. It can be seen that the CBDtotal from the indoor growth chamber cultivation had a value of 8.46% and that the CBDtotal from the greenhouse cultivation had a value of 5.63%.

Table 2 CBD extract from cannabis blossom from the growth chamber/indoor cultivation system was at 8.46%.

Quantitative Results

Detector A

ID#	Name	Ret. Time	Area	Height	Conc.	Units
1	CBDV	4.050	5065	481	0.004	%W/W
2	CBDA	5.390	8874211	1020074	8.683	%W/W
3	CBGA	0.000	0	0	0.000	%W/W
4	CBG	0.000	0	0	0.000	%W/W
5	CBD	6.043	678429	62969	0.845	%W/W
6	THCV	6.615	26200	3771	0.040	%W/W
7	CBN	7.932	57536	9083	0.050	%W/W
8	THC	8.889	70539	8579	0.110	%W/W
9	CBC	9.722	10802	1903	0.017	%W/W
10	THCA-A	10.142	11012	1564	0.016	%W/W

Total THC = (0.016x0.877)+0.11= 0.12%

Total CBD = (8.683x0.877)+0.845= 8.46%

Table 3 CBD from cannabis blossom from the greenhouse cultivation system was at 5.63%.

Quantitative Results

Detector A

ID#	Name	Ret. Time	Area	Height	Conc.	Units
1	CBDV	0.000	0	0	0.000	%W/W
2	CBDA	5.370	8390618	978661	6.154	%W/W
3	CBGA	0.000	0	0	0.000	%W/W
4	CBG	0.000	0	0	0.000	%W/W
5	CBD	6.026	252447	22603	0.236	%W/W
6	THCV	6.581	8742	1153	0.010	%W/W
7	CBN	7.140	7146	819	0.005	%W/W
8	THC	8.195	18109	3031	0.021	%W/W
9	CBC	8.854	67592	7487	0.080	%W/W
10	THCA-A	9.085	331860	55941	0.369	%W/W

Total THC = (0.369 x 0.877) + 0.021 = 0.345 %

Total CBD = (6.154 x 0.877) + 0.236 = 5.63 %

3. Conclusions

Knowing the environmental factors that affect cannabis cultivation in both indoor growth chamber and greenhouse cultivation is important to design agronomic strategies to enhance plant growth and CBD levels. In this research, we have assessed the effects of the main environmental factors on cannabis cultivation and explored the effect of the different cultivation systems on the tested cannabis strain.

In this study, we attempted to control the environmental factors present in both systems, such as light intensity, which was set to 600 PPFD for indoor cultivation but relied on natural lighting for greenhouse cultivation, the temperatures of both systems, relative humidity, carbon dioxide levels and air ventilation. These factors all influenced CBD levels of cultivated cannabis. In this research, we only varied the two important factors of temperature and relative humidity between the two experimental systems. Thus, analysis results were achieved up to a certain level and from the analysis of the temperature and relative humidity values in comparison between the indoor growth chamber cultivation and greenhouse cultivation systems. We found that the temperature of the indoor system was better controlled due to the temperature settings of the internal air conditioning system, which differed from the temperature of the greenhouse cultivation system, in which temperatures had greater uncertainty and had a higher and non-constant average due to use of an evaporative air conditioning system in which sensors were installed for cases where air temperatures exceeded 30 degrees Celsius. When temperatures exceeded 30 degrees Celsius, the evaporative air conditioning system was triggered, which led to variations in the temperatures for the greenhouse cultivation system. Meanwhile, relative humidity in the indoor system and greenhouse system were greater than desired, with an average of 76% for indoor cultivation and 85% for greenhouse cultivation. The higher humidity for the greenhouse, in particular, was caused by the evaporative system. Past research has shown that cannabis would achieve good development if humidity was controlled to approximately 60% (Sriwongchai et al., 2021). Hence, the our conclusion is that the aforementioned likely caused the CBD values of the cannabis from both cultivation systems to be lower than may be desired. Furthermore, we believe that if the relative humidity of both systems can be more effectively controlled to an average of about 60%, the CBD levels from dry blossom extracts should rise up to a satisfactory level or nearly 20% of CBD as mention above. (Way of leaf, 2023)

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Author Contributions

Conceptualization, P.C. and S.P.; methodology, P.C., S.P., and A.S.; software, S.P.; validation, P.C., S.P., and A.S.; formal analysis, P.C. and A.S.; investigation, P.C., S.P., and A.S.; resources, P.C. and A.S.; data curation, S.P.; writing-original draft preparation, P.C., S.P., and A.S.; writing-review and editing, P.C., S.P., and A.S.; visualization, S.P.; supervision, A.S.; Project administration, P.C.; funding acquisition, P.C. All authors have read and agreed to the published version of the manuscript.

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