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Controlled Environment with Artificial Lighting for Hydroponics Production Systems

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Abstract This study was aimed to observe hydroponics plants and food production in a controlled environment that was developed using a controlled room equipped with an air conditioner, chiller, humidifier and artificial lighting. Air temperature, water temperature, relative humidity, pH of nutrient solution, electrical conductivity and light intensity inside the controlled environment were monitored daily using several sensors with and without plants grown in hydroponics system. Melon (*Cucumis melo*, cv Sakata) was cultivated and grown hydroponically. The effect of environment on plant growth was evaluated. Based on the results, air temperature inside controlled environment was between 23-26 ^{o}C and relative humidity was 60-80%. These values of air temperature and relative humidity inside controlled environment were suitable for growing plant material. Furthermore, environmental conditions (air temperature, relative humidity, water nutrition temperature, pH and dissolved oxygen in liquid nutrition of hydroponics) inside controlled environment could be maintain at optimum conditions for growing melon plant from seedling until 45 days after sowing. The hydroponic system inside controlled environment can be used for plant food production with optimal environmental conditions.

Key words: Artificial lighting, Controlled environment, Hydroponics, Melon fruit, Plant and food production.

Introduction

Controlled Environment Agriculture is a combination of horticultural and engineering techniques that optimize crop production, crop quality, and production efficiency. Plants are maintained in controlled environment where environmental conditions, like lighting, nutrient supply, temperature and humidity can be strictly controlled by computer. It is unlikely that crops will be

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grown using sunlight. To simplify and obtain a precise conditions in plant-environment system, a controlled environment was commonly utilized for conducting this research. Controlled environments such as a greenhouse, a phytotron and a growth chamber have provided a precise environmental condition for plants growth. In the growth chamber, a standard or defined environment in which plants are grown can be set up and the effect of one or more controllable environmental parameters on growth of plants can be evaluated (Hammer and Hopper, 1997). Environmental parameters that determine plant growth are important to improve and increase plant-food production system.

Soilless culture, such as hydroponic system, is often used to simulate plant growth under controlled conditions as if plants were grown in the field. By applying soilless culture system, it is possible to provide a very nearly homogenous root environment. Satisfactory control of root growth medium's temperature can be obtained in soilless culture system (Graves, 1983). Hydroponics is a technology for growing plants without soil in a nutrient solution consisting of water and fertilizer (Asher and Edwards, 1983; Jensen and Collins, 1985; Resh, 2004). In some plants from tropical region, the production in controlled environment such as in a greenhouse is possible to be established and was proven advantageous. Production can take place throughout the year, whereas plant production in the open field is normally affected by heavy rainfall and wind (Zabeltitz, 1998). Tropical controlled environment is important not only for research but also for plant and food production especially in anticipating the effects of climate change to plant and food production. For common and simple controlled environment, usually, radiation, temperature and humidity can be controlled. In this study a system for hydroponics plant and food production in a controlled environment using a controlled room equipped with an air conditioner, chiller, humidifier and artificial lighting was developed.

Materials and methods

System for Controlled Environment Room with Hydroponics

In this study, a room in which its environment has been modified and controlled was developed to suit the requirements of plants for cultivation and food production. The room was devided into two. The first room served as the main room for hydroponic plant cultivation and the second room functioned as a preparation room to make and store liquid growth medium. The main room was 420 cm in length, 160 cm in width and 380cm in height. This room was equipped with a portable air conditioner (MPN-1-09CR, Midea, China) to control air temperature, a chiller (A-0.5, Adamchiller, Indonesia) to control water temperature of nutient, a humidifier (SW-1, Krisbow, China) to maintain humidity level, and up-down artificial lighting to provide light intensity for plants.

Within this hydroponic system, a water bath was used to control water temperature inside a pot with 123 cm in length, 86 cm in width and 45 cm in height. The pot for plant growth measured 78 cm in length, 24 cm in width and 30 cm in height. The temperature of liquid nutrient was controlled at 24 ± 2 ^{o}C using water bath which was connected to the chiller. For up-down artificial lighting, the height of lamp was concomittantly depending on the growth behaviour of the plant. During seedling stage, the height of lamp was set up to 10-15 cm above the plant. Then for the weeks that followed, the lamp was scrolled up using a pulley to adjust the height of lamp. The daily light intensity and light duration per day was set up and controlled by using a timer. The daily light intensity (diurnal) was based on the different light intensities from 6:00 to 7:00 in the morning with intensity of 1500 lux, from 7:00 to 9:00 am with intensity of 10000 lux and from 9:00 am to 14:00 pm with intensity of 20000 lux, and then the light intensity was decreased from 15:00 to 16:00 pm with 10000 lux and the last time set from 16:00 to 18:00 pm with 1500 lux. From 18:00 pm to 6:00 am, it was set as dark period in the main room. In addition, air temperature inside the main room was set up only in the daytime with temperature condition between 23 $\pm$ 2 ^{o}C and the humidity was maintained by using a humidifier. The schematic diagram of the controlled environment room with hydroponic system is shown in Fig.1. The main room with pulley and plant material is shown in Fig. 2.

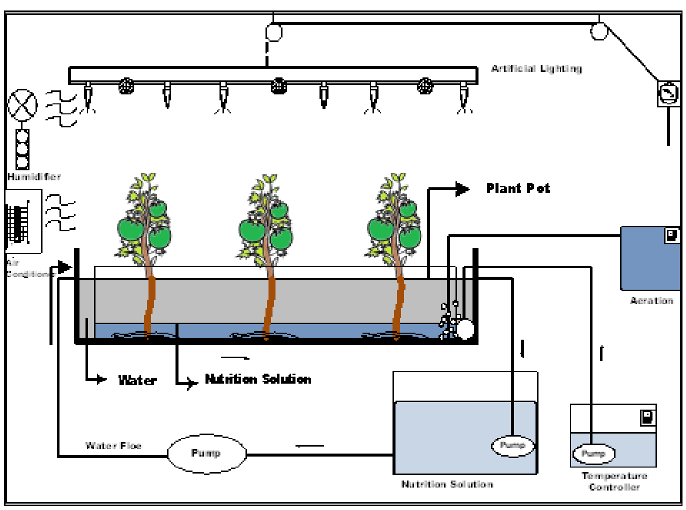

Fig. 1. Schematic diagram of the controlled environment with hydroponics using up-down artificial lighting.

Fig. 2. Pulley for up-down artificial lighting (left). Hydroponics plant-food production with an artificial lighting in the controlled environment (right).

The supporting room, located in one side of the main room measured 345 cm in length, 160 cm in width and 380 cm in height. In this room, the water to make liquid nutrient was obtained from the well that was connected with the pump and the water was filtered before being used to make liquid nutrient. The nutrient solution was then stored in this room and connected with the hydroponic pot using a pipe. The main room and support room was separated using a curtain.

Methods for Hydroponic System Evaluation

For developing a controlled environment within hydroponic system, the air temperature in the main room without plant materials, without and with air conditioner and light were observed. The system's performance was evaluated using some parameters of environmental conditions during growth of plants until 30 days; these parameters were light intensity, air temperature, relative humidity, water temperature, electrical conductivity, pH and oxygen concentration. These parameters were observed using several sensors: for light intensity (LX-103, Lutron, Taiwan), air temperature (TR-7iu, T and D, Japan) relative humidity (TN-12, Tanita, Japan), environmental conditions on hydroponics such as water temperature of nutrient solution in hydroponics ((TR-7iu, T and D, Japan), electrical conductivity of nutrient solution (DEC-1, Atago, Japan), oxygen concentration in water of nutrient solution (DO-5510, Lutron, Taiwan) and pH (PH-208, Lutron, Taiwan).

Plant Materials

Melon (*Cucumis melo*, cv Sakata) was cultivated and grown hydroponically using a commercial fertilizer for nutrient solution with an electrical conductivity of 2-3 mSm^{-1} and pH 5-6 with an ion concentrations in the standard nutrients solution (in mg L^{-1}). It contained 45.2 $N\text{-}NO_3^-$, 68.5 $P\text{-}PO_4^{3-}$, 210.7 K^+, 105.3 Ca^{2+}, 38.1 SO_4^{2-}, 18.3 Mg^{2+}, 0.4 Fe^{2+}, 0.2 Mn^{2+}, 0.1 Cu^{2+}, 0.03 Zn^{2+} and 0.02 MoO_4^{2-}. Interaction between melon plant and environment in the controlled room was also identified.

Results and discussion

System Evaluation without Plant Materials

To have base information on the regular temperature of the environment without air conditioner and artificial lighting, a sensor was placed 150 cm above the floor (temp-1) and another sensor was placed 50 cm above the floor (temp-2). The measurements were taken every 10 minutes for 3days . It was observed that during the daytime (between 8:00 am in the morning until 16:00 pm in the afternoon), the air temperature in the first place was higher compared to that on the lower (second) place. This is probably due to half of the wall of the main room was made from wood, another part of the wall was made with cement. In the afternoon until early next morning, air temperature was similar between these two places. The maximum air temperature during this time is 31^{o}C. This may affect the growth of the plant and fruit production in the controlled environment room, and so it must be decreased using air conditioner in the main room. When an air conditioner was used, it was observed that the maximum air temperature decreased to 27^{o}C from 31^{o}C.

Temperature as an environmental factor can affect plant production through physical and physiological processes. In the physical process, one principle is that the temperature of the organ exposed to solar radiation can estimate from complete heat balance but there is considerable uncertainty about the choice of an appropriate heat transfer coefficient. In the physiological processes, temperature can affect the growth of plants, rate of photosynthesis, stomata opening, respiration rate, and also temperature can be an inhibitor of physiological plant production system, when temperatures are lower or higher than optimum range of temperature occurred (Monteith, 1977).

For simple and common plant and food production in a controlled environment room the radiation from artificial lighting, temperature, humidity, carbon dioxide, and air movement must be maintained. Minimum requirement for environmental conditions of radiation, temperature and humidity can be controlled (Langhans and Tibbits, 1997).

Radiation in the controlled environment room is the source of energy for plant growth and development. The effect of radiation on plants has been a subject for studies in photosynthesis, photomorphogenesis and bioenergetics. The type of lamp that commonly used in the growth chamber such as:

incandescent lamps and fluorescent lamps (cool white phosphor lamps, daylight phosphor lamps, warm white phosphor, deluxe cool white phosphor, gro-lux phosphor and vita-lite phosphor) (Sager and McFarlane, 1997). In this study, cool daylight lamp was used as part of fluorescent lamp, wherein this lamp have several advantages such as good for producing violet –blue light and orange-red that are required by plants. The lamp is locally available and not so expensive (Kenyon, 1992).

System Evaluation with Plant Materials

The daily measurements light intensity (Fig. 3) and air and water temperature (Fig. 4) during growth of melon production in a controlled environment using hydroponics system was recorded. The data was observed at 09:00 every morning. Light intensity at this time was relatively stable at 8800 lux. The intensity reached 20000 lux at maximum at 11:00 am to 14.00 pm. The air and water temperatures were also stable between 24-26 ^{o}C, where water temperature was relatively lower compared with air temperature. For relative humidity, it was observed that relative humidity varied depends on the air temperature and light intensity, where minimum relative humidity can be observed about 55%. These results indicated that effects of environmental conditions on plant and fruit production in the controlled environment room can be maintained and unfavourable conditions can be minimized

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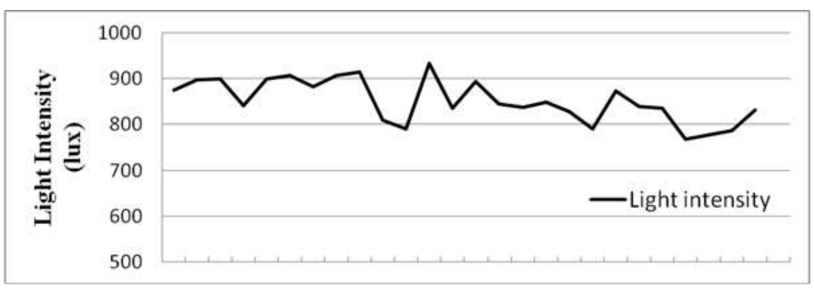

Fig. 3. Time course pattern of air temperature inside controlled environment room without an air conditioner and artificial lighting for 3 days, measurement was taken every 10 minutes.

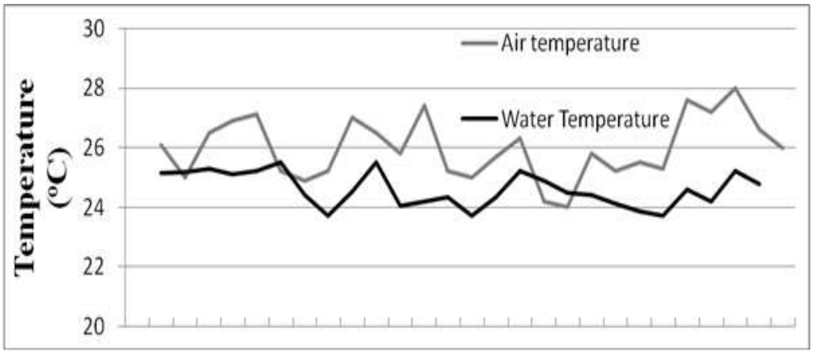

Fig. 4. Time course pattern of air temperature inside controlled environment room with an air conditioner and light intensity using an artificial lighting for 3 days, measurements were taken every 10 minutes.

It was found out that melon plants can grow normally because temperature and relative humidity are suitable for plant growth but after seedling stage and during plant growth, there was an elongation of internodes and smaller leaves of melon plant which could be due to low irradiance. The low irradiance from artificial lighting was not enough to promote a better plant growth and there is a need to increase intensity of the artificial lighting. Fluorescent lamps when used as source of artificial lighting have advantages for plant growth such as it continuous uniform distribution of light, have high photosynthetically active radiation and the spectrum generally matches the requirements of plants. However, they also have many disadvantages such as lamp output and the intensity decreases rapidly during first 100 hours which significantly affects air temperature in their environment (Sager and McFarlane, 1997).

The oxygen concentration (Fig. 5), electrical conductivity (Fig. 6) and pH (Fig. 7) of water nutrient solution during growth of melon in the controlled environment using hydroponic system were also observed. The data was observed at 09:00 every morning. Oxygen concentration, electrical conductivity and pH of water on nutrient solution were relatively stable and controlled. These results indicated that hydroponics system can be adopted for plant and fruit production in the controlled environment room.

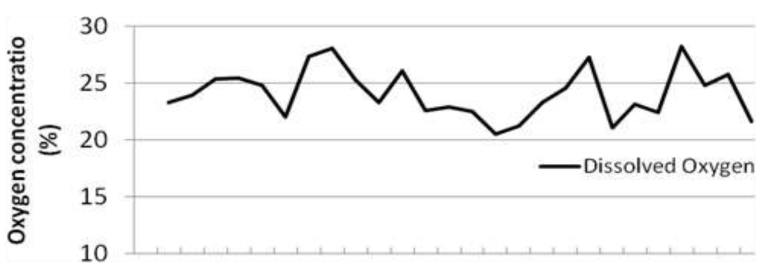

Fig. 5. Time course pattern of dissolved oxygen in the nutrient solution.

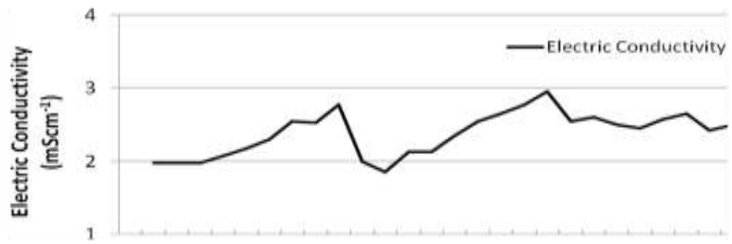

Fig. 6. Time course pattern of electric conductiity in the nutrient solution.

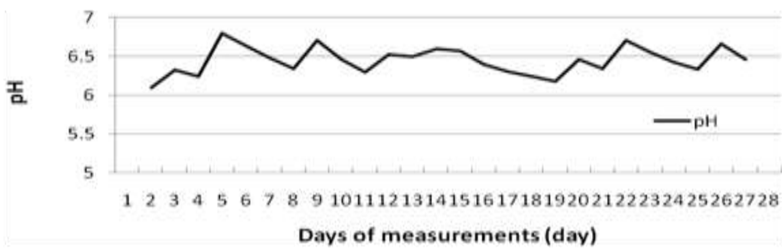

Fig. 7. Time course pattern of pH in the nutrient solution.

The effect of water in the root environment or water stress may conceivably arise either from an insufficient supply or from an excessive water activity in the plants' environment system. The common effect of the plant response to excess water stress (flooding) is oxygen deficit in the root environment. The other case of water stress that may occur, in the case of terrestrial plants in nature, when there is water deficit called drought stress (Levitt, 1980). Water stress during plant growth in this hydroponics system was not observed. Electrical conductivity is also important to be controled because plants take up water and also ions in the nutrient solution. When water was removed from the nutrient solution, the volume of the solution naturally decreases and this will affect the total concentration of the solution (Resh, 2004). This indicates that variation in concentration and composition of the nutrient solution can be maintained for plant growth. In this study the electrical conductivity is which is between 2-3 $mScm^{-1}$ was maintained.

Water quality and hardness are important for plants to grow and their concentration in water of nutrient solution must be maintained because increasing hardness of water can make several ions such as iron making it unavailable but lower concentration in hardness of water can affect the concentrations of calcium and magnesium that are needed by plants (Sager and McFarlane, 1997).

Conclusion

Controlled environment with hydroponic systems using up-down artificial lighting can be used for plant growth and fruit production.

Acknowledgements

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