Effect of root zone cooling and evaporative cooling in greenhouse on the growth and yield of potato seed by aeroponics in tropical lowlands

Eni Sumarni[1*], Afik Hardanto[1], Poppy Arsil[2]

(1. Lab. of Bio-Environment and Control Engineering. Agricultural Technology Department, Faculty of Agriculture, Jenderal Soedirman University, Purwokerto, Jl. Dr. Suparno, Karangwangkal, Postal Code. 53123
2. Lab of Information Management and Agroindustrial System. Agricultural Technology Department, Faculty of Agriculture, Jenderal Soedirman University, Purwokerto, Jl. Dr. Suparno, Karangwangkal, Postal Code 53123)

Abstract: The purpose of this research was to determine the effects of evaporative cooling and air conditioner (AC) on the growth and yield of aeroponic potato plants in the lowlands planted with the application of root zone cooling. Nutrients were used at an electrical conductivity (EC) of 1-2 mS cm^{-1} and pH of nutritional solutions was 6. Two types of cooling measures were applied: evaporative cooling and air conditioning (AC) with a target temperature of 25°C. Two potato varieties (genotype 007 and granola) were used. The design used was a completely randomized with separate plot design. The main plot is the type of cooling (evaporative cooling and AC) and potato variety as the subplot. Growth data were analyzed by the F test followed by the DMRT test at the 5% level of significance. From the results of this research, we concluded that the evaporative cooling system could provide a decrease in air temperature in lowland greenhouses. However, the optimal humidity and temperature for the growth and development of aeroponic potato plants in the lowlands were not achieved when the air temperature in the greenhouse was high. The cooling by AC creates a more even temperature and humidity compared with the evaporative cooling. The humidity level inside a greenhouse that is not exposed to evaporative cooling (far from the plant area) reaches 42%. The difference in air humidity achieved with two different cooling type methods reached 2% at 13.00 hour and 6% at 16.00 hour. The application of cooling above the plant with AC resulted in a higher number of tubers and higher tuber weight compared with evaporative cooling. The average number of tubers produced from the application of AC was 19.3 crop bulbs, and the average tuber weight was 10.4 grams per tuber, while the application of evaporative cooling resulted in an average of 9.4 crop bulbs and an average tuber weight of 6.3 grams per tuber.
Keywords: aeroponics, potato seed, lowland, evaporative cooling, greenhouse, root zone cooling.

Citation: Sumarni, E., A. Hardanto, and P. Arsil. 2021. Effect of root zone cooling and evaporative cooling in greenhouse on the growth and yield of potato seed by aeroponics in tropical lowlands. Agricultural Engineering International: CIGR Journal, 23 (1):28-35.

1 Introduction

Potato seed production technology can produce a large number of healthy seed tubers through aeroponic technology. Potato seeds in the form of tubers can also facilitate planting. Research on an aeroponic system for potato seeds in humid tropical lowlands was carried out by modifying the restricted climate in the root zone by cooling (root zone cooling), so that the optimal temperature of the root section for the formation and

Received date: 2019-10-29 **Accepted date:** 2020-03-03
***Corresponding author: Eni Sumarni,** Associate Professor, Departement of Agricultural Technology, Jenderal Soedirman University. Purwokerto. Jl. dr. Suparno. Karangwangkal. Postal Code. 53123. Email: arny0565@gmail.com. Tel:+6281391396079, Fax: (+62281) 638791.

growth of potato seeds could be maintained (Sumarni et al., 2013a, 2013b, 2019). The temperature in the lowland greenhouse can reach 40 °C at the point of maximum solar radiation during the day. Air temperature control in the root zone (root zone cooling) can improve the growth of broccoli (Perez, 2009), increase photosynthesis and lettuce productivity (Jie, 1998), and increase the rate of root growth and nutrient uptake in tomato plants (Kawasaki et al., 2013) and potato plants in the lowlands (Sumarni et al., 2019). Therefore, climate zone cooling was carried out to maintain the temperature at the root of the plant (Sumarni et al., 2019).

Some results of previous research showed that evaporative cooling could reduce heat stress in the greenhouse and area around the canopy (Fuchs, 1993; Fuchs et al., 2006; Helmy et al., 2013). The adoption of evaporative cooling in a greenhouse can reduce temperatures by 4°C-5°C. Hence, research on the development of potato seed production in lowlands with the application of an aeroponic system of root zone cooling and evaporative cooling is important for improving the condition of the top of the plant.

Specific environmental conditions are required for the optimal growth of good-quality potatoes. Extreme environmental conditions, for example, temperature or humidity that is too high/too low, can cause a decrease in plant growth and tuber yield. A high air temperature above the plant canopy (leaves) encourages vegetative growth and stimulates stem extension (Tadesse et al., 2001). High temperatures greater than 25°C -30°C tend to increase stem length and branching but reduce leaf size and leaf area. Decreasing the size of potato leaves by reducing the temperature can also change the permeability of cell membranes or reduce the conductance of stomata and have a negative impact on the supply of CO_2 for photosynthetic assimilation. An increase in air temperature to greater than 20°C can negatively affect crop production in greenhouses located in tropical and subtropical countries (Damasceno et al., 2017).

Efforts to cool the air temperature above the plants can be done by providing cold air or cold water flow and also evaporative cooling. Evaporative cooling (EC) is a process used to reduce the air temperature through evaporation of water into an airflow. Air humidity is important because it has an influence on the rate of water loss from plants. Evaporative cooling can be carried out directly or indirectly (Jain, 2007; Al-Juwayhel et al., 2004). The process of air cooling by spraying or spouting water into the air directly is a type of direct evaporative cooling (Yunianto, 2018). Evaporative cooling can reduce the air temperature over plants by 4°C -5°C (Helmy et al., 2013). Air cooling using an air conditioner (AC) is an attempt to cool the air until it reaches the desired temperature and humidity of a specific location (Arismunandar and Heizo, 1991). However, energy consumption for temperature reduction up to 26°C reaches 902 kJ, whereas with evaporative cooling is only 389 kJ (Yunianto, 2018).

Thus, studies on the effects of the combination of root zone cooling and evaporative cooling on the growth and development of aeroponic potato plants in wet tropical lowlands are needed to improve the condition of the leaves and stems of potato plants and increase the production of aeroponic potato seeds in the lowlands. The purpose of this research is to determine the effect of evaporative cooling and cold air (AC) on the growth and yield of aeroponic potato plants in lowlands planted with the application of root zone cooling.

2 Materials and methods

This aeroponic potato seed production study combined the application of root zone cooling was used in previous studies (Sumarni et al., 2019) with evaporative cooling and air conditioner (AC) to the top of the plant. The temperature of the root cooling zone used was 10°C-15°C (Sumarni et al., 2013a, 2019).

Table 1 Nutritional formula for aeroponic potato seed production (Otazu, 2010)

Nutrient	Concentration
KNO_3	5.40 me L^{-1}
NH_4NO_3	4.4 me L^{-1}
Ca superphosphate	2.60 me L^{-1}
$MgSO_4$	1.00 me L^{-1}
Fe (EDTA-Fe 6%)	8 mgL^{-1}
B (boric acid)	1 mgL^{-1}
Micro (Fertilon*)	12 mgL^{-1}

The evaporative cooling temperature obtained by the spraying cold water and AC was 25°C. The electrical conductivity (EC) of the fertilizer solution used was 1-2 mS cm^{-1}, and pH of nutritional solutions was set at 6.0. The nutritional formula used was following Otazu (2010) (Table 1).

The following treatments were applied:

1. Cooling to the top of plant (C) type: 1. Evap (evaporative cooling by cold water spray), 2. AC (cold air conditioner)

2. Potato variety (V): V_1 (genotype 007), V_2 (granola).

Evaporative cooling was applied to the top of the plant by administering bursts of cold water (Evap) and cold air using an AC. The evaporative cooling and AC were placed 80 cm above the styrofoam surface (Figures 1 and 2). The greenhouse used in each application of cooling was 5 m wide and 4 m long. The cooling with cold air from the AC was 840 W. Aeroponic planting of potato seeds with evaporative cooling and AC were carried out in the same greenhouse separated by a wall that is made impermeable (closed from the intake air).

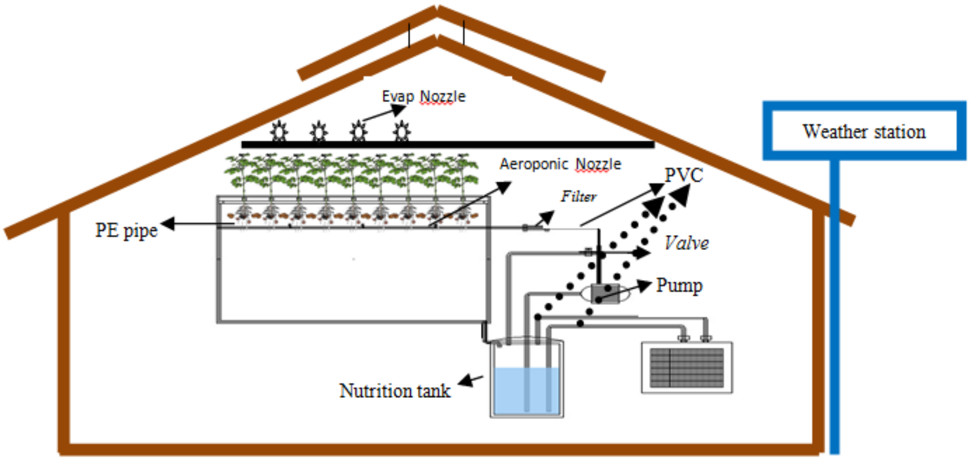

Figure 1 Layout of the apparatus for evaporative cooling with cold-water bursts (Figure aeroponics system (Sumarni et al., 2019))

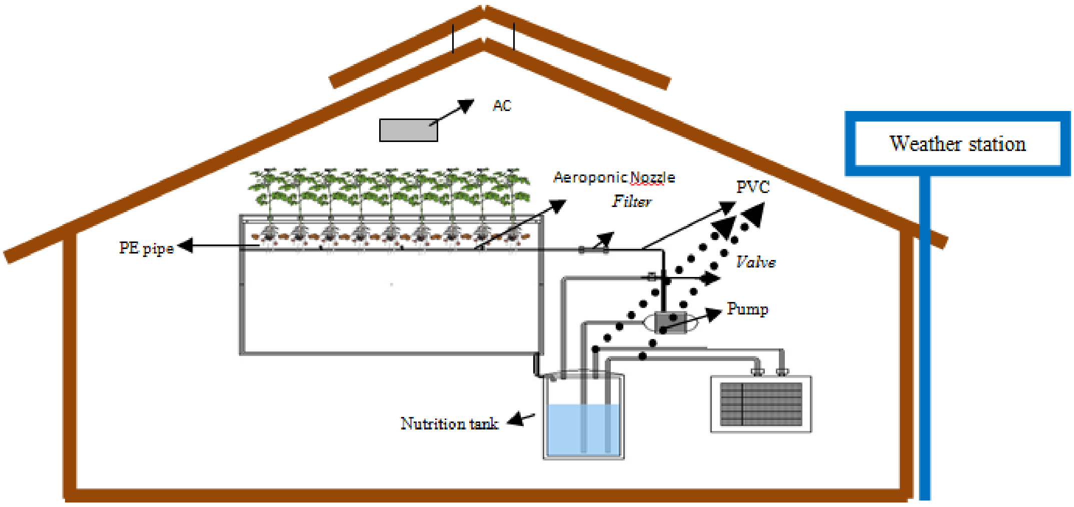

Figure 2 Layout of the apparatus cooling above a plant by AC (Figure aeroponics system (Sumarni et al., 2019))

The plant growth parameters observed included plant height, number of leaves, number of tubers, and tuber weights. The design used was a split-plot, randomized complete design with cooling top the plant as the main plot and potato variety (G) as the subplot. The experiment was replicated five times. Growth data were analyzed by the F test followed by the DMRT test at the 5% level of significance. The microclimate in the root and leaf area, including temperature, humidity, and light, was measured and observed to obtain climate information on the research area.

3 Results and discussion

3.1 Air temperature and relative humidity in the greenhouse

Air temperature and relative humidity (RH) are environmental factors that influence the growth and initiation of potato tubers. The average temperature and RH in a lowland greenhouse reach their peaks during the day around 13:00. In the present study, the average temperature inside the greenhouse at that time reached 41.8°C and the RH reached 42% (Figure 3). The average temperature and relative humidity (RH) of each replication is presented in Figure 5 and 7. These conditions are considered extreme for the growth of aeroponic potato plant in the lowlands, because potato plants require a temperature of 15-20°C for optimal growth.

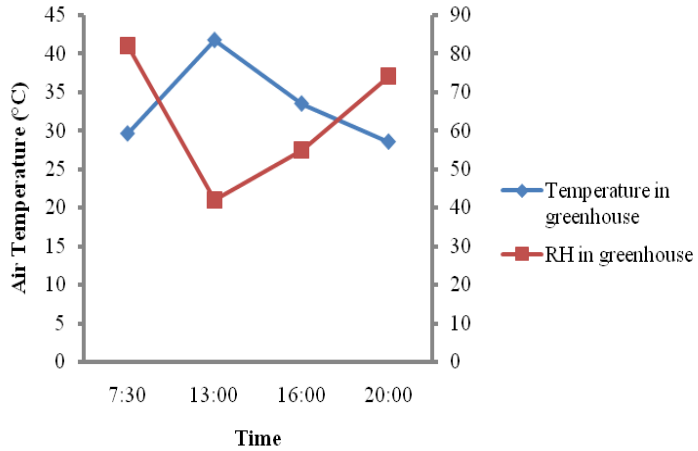

Figure 3 Average air temperature and relative humidity in the greenhouse

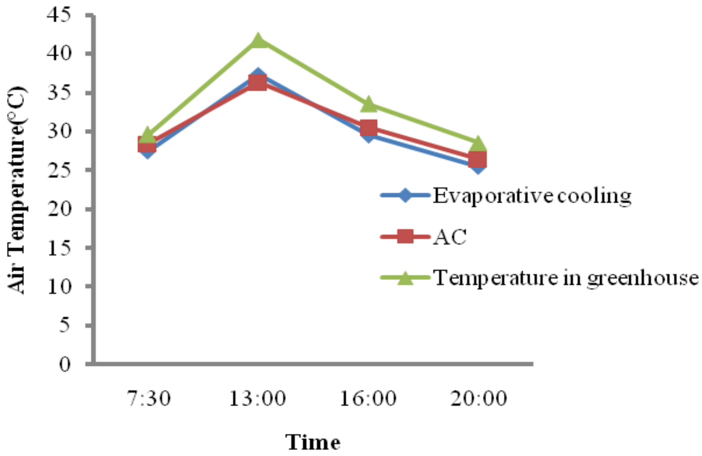

Figure 4 Effect of evaporative cooling and AC on the air temperature around potato plants

Therefore, research on an effective and efficient evaporative cooling system is needed in order to assist the aeroponic potato plant in optimizing its growth. The high temperature of the air inside the greenhouse, in addition to its position in the lowlands, can also be triggered by poor ventilation in the greenhouse. In this study, we also attempted to control the temperature and RH of the air over the plant by evaporative cooling in the form of cold-water and AC, in order to maintain optimal conditions for potato plants. The effect of providing evaporative cooling on the temperature around the plant is presented in Figures 4 and 5. The evaporative cooling nozzle is placed at a height of 80 cm above the styrofoam surface, thereby reducing the unfavorable impact on plant height growth. But it can be considered laying nozzle higher (100 cm) or can be raised and lowered according to plant conditions.

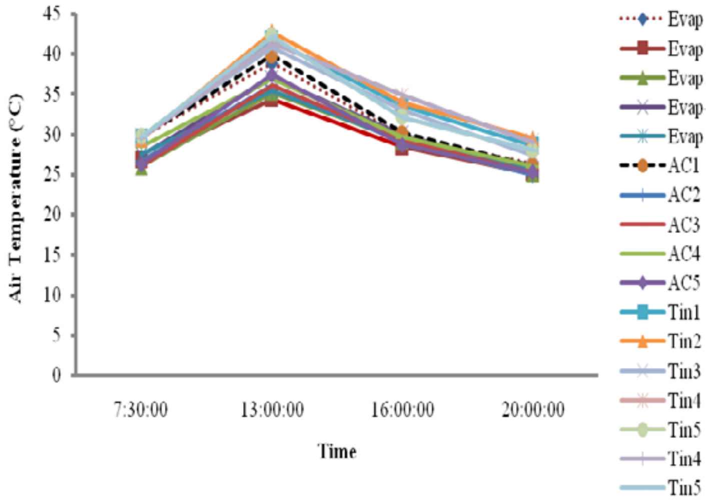

Figure 5 Effect of evaporative cooling and AC on the air temperature each replication

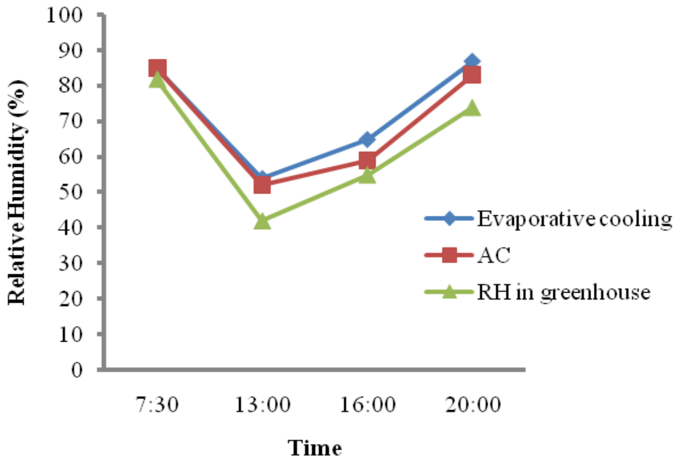

Figure 6 Air humidity in the distribution of cooling the top of the plant

The distribution of evaporative cooling and AC in this research provided a decrease in temperature ranging from 1°C to 4°C. Cooling the top of plant with an AC machine, through direct contact between air and water vapor, affects heat and mass transfer between air and water vapor. The distribution of evaporative cooling creates an air RH level around the plant of 54% during the daytime, whereas AC create 52% RH. A burst of cold air with AC creates even more heat and RH than the evaporative spray of cold water. The RH inside a greenhouse that is not exposed to evaporative cooling (far from the plant area) reaches 42%. The difference in RH between the two methods of evaporative cooling reached 2% at 13.00 and 6% at 16.00. At the time of evaporative cooling generate higher RH around the plant than AC (Figure 6) anda each of replications in Figure 7.

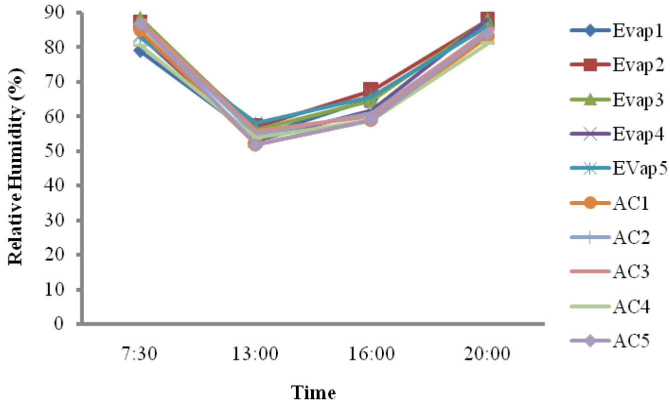

Figure 7 Air humidity in the distribution of cooling the top of the plant each replication

In other studies, evaporative cooling system was able to reduce the temperature, and this condition depends on the type of air flow towards the flow of water bursts (Kachwaha, 1998). Evaporative cooling system can reduce the energy used by 25% to 60% compared with an AC, because the cooling system only moves the water from the fan. Other studies also reported that the use of evaporative cooling in direct contact systems for cooling the room could reduce the ambient temperature to 6^{o}C, from 32^{o}C to 26^{o}C.

However, the comfort standard of the space cannot be achieved due to an increase in RH from 65% to 89% (Yunianto, 2018). From the results of evaporative cooling research for the production of aeroponic potato plants in the lowlands, it can be said that the evaporative cooling system with direct cold water bursts and AC can provide a decrease in air temperature in the lowland greenhouse. Optimum RH and temperature for the growth and development of aeroponic potato plants in the lowlands were not achieved when the air temperature in the greenhouse was high. The distribution of evaporative cooling creates a RH of 87% (20:00) when the air temperature in the greenhouse is not yet high.

3.2 Plant growth

The result of statistical analysis of the variables plant height growth, number of leaves, number of tubers, and tuber weights demonstrated that cooling the top of plant gave different results for these variables. The variety of conditions tested gave different results for plant height, number of leaves and tuber weight; while for tuber weight the conditions tested did not affect the outcome.

Evaporative cooling with bursts of cold water resulted in greater plant height at 21 and 56 days after planting (DAP) (30.5 cm and 68.9 cm, respectively). Cooling the top of plant with AC resulted in a plant height of 28.9 cm at 21 days after planting and 50.9 cm at 56 days after planting. The number of leaves at 56 days after planting was greater with AC versus evaporative cooling. Evaporative cooling with bursts of cold water treatment showed 41.1 leaves while with AC 20.8 leaves were observed (Table 2).

3.3 Plant height and number of leaves

Table 2 Effect of the type of evaporative cooling on aeroponic potato seed production on average plant height and number of leaves

Treatment	Plant Height (cm)		Number of Leaves (sheet)	
	21 DAP	56 DAP	21 DAP	56 DAP
Evaporative cooling	30.5 a	68.9a	11.1 a	20.8 b
AC	28.9 b	50.9b	8.7 b	41.1 a

Note: Numbers followed by the same letter in the same column show no significant difference based on DMRT at the level of $\alpha = 5\%$.

Results suggest that evaporative cooling with bursts of cold air is more effective than AC under various temperature and RH conditions in the greenhouse. The use of an air conditioner at a height of 80 cm above the plant provides a continuous source of evaporative cooling. Cooling by AC at the top of the plant combined with root zone cooling provides slower plant growth but a greater number of leaves than evaporative cooling with bursts of cold water. However, it should be kept in mind that heat from solar radiation entering the greenhouse raises the air temperature to an extreme level, necessitating a well-designed greenhouse ventilation system and proper placement of the hot air exhaust, in order to support the performance of AC. This is in accordance with previous studies finding that cooling air can reach 85% efficiency, considering the difference between the initial temperature before cooling and the coldest temperature that can be achieved for a variety of outdoor temperature and humidity conditions (Walker and Duncan, 1914).

Evaporative cooling with bursts of cold water results in a greater plant height but a smaller number of leaves compared with AC. Evaporative cooling with cold-water bursts uses a nozzle to spray water in the form of mist over the surface of the plant. Drops of water that fall onto the surface of the plant will contribute to the cooling effect of evaporation. The nozzle used has a capacity of 2.2 L h^{-1}. The problem is that falling water droplets are not in the form of fine grains, and the performance of evaporative cooling with bursts of water depends on the pressure of the working pump. In this study, evaporative cooling was carried out in 10-min bursts of cold water sprayed every 15 min. The timing of this administration still causes some plants to change leaf and stem colors and requires an increase in fungal disease control (Figure 6). Thus, further studies are needed to determine the optimal timing of evaporative cooling with bursts of cold water in the production of aeroponic potato seeds in wet tropical lowlands in order to reduce the onset of disease due to the drop in air temperature and rising air humidity (RH). RH that is suitable for potato plant growth is 80-90% (Sunarjono, 2007).

Figure 6 Condition of the top of the plant in evaporative cooling with bursts of cold water

The potato plant variety used in aeroponic potato seed production in lowlands affected the outcome. The granola variety yielded higher plants and more leaves up to 56 days after planting. The plant height and leaf number in the granola variety at 56 days after planting were 50.5 cm and 32.5 sheets, respectively, while genotype 007 gave a plant height of 38.9 cm and 29.4 sheets at 56 days after planting (Table 3). From these results, it can be seen that granola is more adapted to being planted in the lowlands with the application of evaporative cooling. Granola is the most important potato variety grown in Indonesia. Granola is a variety that is widely cultivated by farmers in Indonesia and is used for fresh and processed consumption, such as chips. Granola has advantages high resistance to drought (De Putter et al., 2014). Genotype 007 is a new genotype produced by potato breeders in the Batur plateau, Banjarnegara, Indonesia, so its adaptability has not been good in the lowlands.

Table 3 Effect of potato seed variety on the production of aeroponic potato seeds on the average height of plants and number of leaves

Treatment	Height of Plant (cm)		Number of Leaves (sheet)	
	21 DAP	56 DAP	21 DAP	56 DAP
Genotype 007	8.7 b	38.9 b	15.4 b	29.4 b
Granola	10.9 a	50.5 a	10.8 a	32.5 a

Note: Numbers followed by the same letter in the same column show no significant difference based on DMRT at the level α = 5%

3.4 Number and weight of bulbs

Application of evaporative cooling with bursts of cold air gives the highest number of tubers and tuber weights compared with evaporative cooling with bursts of cold water. The average number of tubers produced by the application of evaporative cooling was 19.3 crop bulbs, and the tuber weight was 10.4 g $tuber^{-1}$, while the application of evaporative cooling with cold-water bursts gave an average tuber number of 9.4 plants and tuber weights of 6.3 g $tuber^{-1}$ (Table 4).

Table 4 Effect of evaporative cooling treatment type on aeroponic potato seed production on the average number of tubers and tuber weights

Treatment	Number of Tubers (bulbs)	Tuber Weight (g)
Evaporative cooling	9.4 b	6.3 b
AC	19.3 a	10.4 a

Note: Numbers followed by the same letter in the same column show no significant difference based on DMRT at the level α = 5%

Cooling with AC combined with root zone cooling at the root area gave a higher number and weight of tubers compared with evaporative cooling combined with root zone cooling. This is presumably because evaporative cooling can reduce air temperatures in the greenhouse, but increases its relative humidity. This is for some plants undesirable because it can cause fungal and fungal infections and decreased transpiration (Mutwiwa et al., 2007). These results are in accordance with those of previous studies, in which cooling of cucumber growth chambers with a fan combined with irrigation was able to prevent excess heat and minimize nutrient loss (Nikolaou et al., 2019).

In this research, the sprayer nozzles were placed 1 m apart and installed at a height of 80 cm above the surface of the aeroponic potato plant box. The main obstacle to the application of evaporative cooling with a cold-water spray system through the nozzle is that the distribution of water droplets needed to cool the upper surface of the plant was not achieved. The next obstacle is that particles in the water carried during the spraying process can accumulate on the surface of the plant and cause mold or discoloration on the leaves. This is in accordance with previous studies that reported on the disadvantages of direct spraying of cold water as a method of cooling.

Regarding the difficulty of achieving high efficiency, the pump pressure required to create a fine mist is also a concern in this application. A burst of cold water released through nozzles in the form of a fine mist can achieve a temperature reduction sufficient to increase the growth and quality of the plant (Walker and Duncan, 1914; Both, 2008).

The potato variety used in this research had an effect on the number of tubers, but not the tuber weights. The granola variety produced more tubers per plant than genotype 007, an average of 17.5 vs. 11.2, respectively. The tuber weights of the granola variety and genotype 007 ranged from 5.9 grams to 6.8 grams tuber^{-1} (Table 5).

Table 5 Effect of potato seed variety on aeroponic potato seed production on average tuber number and weight

Treatment	Number of Tubers (bulbs)	Tuber Weight (g)
Genotype 007	11.2 b	5.9
Granola	17.5 a	6.8

Note: Numbers followed by the same letter in the same column show no significant difference based on DMRT at the level α = 5%

4 Conclusion

From the results of evaporative cooling research for the production of aeroponic potato plants in the lowlands, it can be said that an evaporative cooling and cooling the top of plant by AC can provide a decrease in air temperature in the lowland greenhouse. However, the optimal relative humidity and temperature for the growth and development of aeroponic potato plants in the lowlands were not achieved when the air temperature in the greenhouse was high. Cooling by AC creates a even more temperature and humidity than the evaporative cooling. The relative humidity level inside the greenhouse that was not exposed to cold-water bursts (far from the plant area) reached 42%. The difference in air relative humidity in the application of two different cooling methods reached 2% at 13:00 and 6% at 16:00. At the time of evaporative cooling, bursts of cold water generate higher relative humidity around the plant than AC. This result suggests that the distribution of AC is more effective than that of evaporative cooling with bursts of cold water under various temperature and relative humidity conditions outside the greenhouse. The application of AC yields higher tuber numbers and weights compared with evaporative cooling. The average number of tubers produced with the application of cooling by AC was 19.3 crop bulbs, and the average tuber weight was 104 grams tuber^{-1}, while the application of evaporative cooling with cold-water bursts gave an average tuber number of 9.4 plants and an average tuber weight 6.3 grams tuber^{-1}.Thus, from this study, the use of air conditioners to reduce air temperatures distributed to plants combined with root zone cooling are better than evaporative cooling. Thus, further research on the application of evaporative cooling by varying the distance between nozzles, the height of evaporative cooling above the plant, and the resulting mist grain, in order to increase its efficiency, is needed.

Acknowledgments

The authors thank Kemenristekdikti for an Applied Research Grant with Contract Number: P / 1817 / UN23 / 14 / PN / 2019, which funded this research.

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