Application of root zone cooling in various hydroponic methods for potato seed production in lowland wet tropics of Indonesia

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Abstract: The application of root zone cooling in aeroponic systems is an alternative method to enhance potato seed production in lowland tropical areas. This method requires further investigation of various hydroponic systems in lowland areas to improve seed production. Therefore, this research aimed to obtain growth and yield for potato seed using root zone cooling in aeroponic and Nutrient Film Technique (NFT) in lowland areas of Indonesia. The factors tested included hydroponic type (H): H1 (Aeroponics) and H2 (NFT), as well as origin of tubers: U1 (shoot cuttings), U2 (root cuttings), and U3 (tubers). A factorial randomized block design was used with four replicates and the data obtained were analyzed using ANOVA. In cases of treatment effects, further comparisons were made using the DMRT test at a 5% significance level. The results showed that aeroponic with root zone cooling application yielded higher average plant height, leaf count, tuber count, and weight compared to NFT system. The average number of seed produced in aeroponic ranged from 9.6 to 12.2 tubers plant^{-1}, while 1.0 to 1.2 tubers plant^{-1} was obtained in NFT system. Furthermore, the highest average seed weight was obtained from aeroponic, ranging from 3.3 to 3.5 g, and 0.8 to 1 g in NFT.

Keywords: aeroponic, seed, lowland, potato, Nutrient Film Technique (NFT), wet tropics, root zone cooling

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1 Introduction

Potato is essential food commodities in Indonesia, alongside rice, required by a significant portion of the population annually. This commodity plays a significant role in the global processed food industry, with the demand predicted to increase by 3.5% in 2027 (Tiwari et al., 2022). Currently, the productivity of potato in Indonesia is 19 tons ha^{-1} (Kementerian Pertanian, 2021), which is insufficient to meet domestic needs. Potato household consumption in 2021 reached 771.46 thousand tons, an increase of 11.75% (81.09 thousand tons) from 2020 consumption. Potato consumption from the household sector is about 28.42% of total consumption (Badan Pusat Statistik, 2022).

The low productivity of potato is attributed to several factors, including a reduction in the planting area, unpredictable climatic conditions such as high

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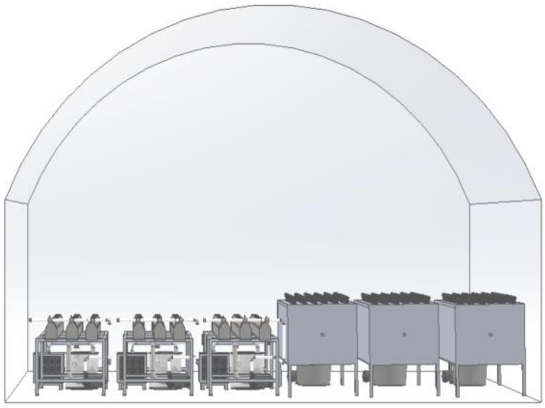
rainfall variability (Las et al., 2021), and a lack of access to healthy and high-quality seed. In Indonesia, the demand for potato seed is 143,740 tons, but only about 7 tons (4.9%) are available. This scarcity is particularly prevalent in highland and medium-altitude areas, which are key production centers due to frost damage during extreme weather events, the presence of cyst nematodes, and declining seed quality (Sumarni et al., 2013; Sumarni et al., 2021; Sumarni et al., 2022). Consequently, there is a need for improved cultivation method capable of producing healthy seed, delivering high yields, and ensuring seed availability.

Hydroponic is a controlled cultivation system capable of delivering high yields and quality with high schedule ability. This system provides balanced and essential nutrients for plant growth and development (Corrêa et al., 2008; Pereira and Nova, 2008) and reduces the potential for tuber contamination by soil pathogens. Furthermore, it decreases the use of pesticides, ensuring that the produce is safe for human consumption, environmentally friendly, and extending the shelf-life of post-harvest products (Pereira and Nova, 2008; Benton Jones Jr, 2014). Previous investigations expanded potato cultivation area to lowland areas using aeroponic system, limited root zone cooling technology, and evaporative cooling to improve plant performance due to high-temperature stress. This method aimed to create a microclimate that supports the initiation, growth, and development of potato tubers in lowland areas. Conventional seed production using soil, rice husk charcoal, and cocopeat as the medium yields 5-8 tubers/plant in highland areas, but it is not produced in lowland areas. The integration of aeroponic system with root zone cooling in lowland areas has successfully increased the number of seed, and the appearance of leaves, yielding more than 15 tubers/plant (Sumarni et al., 2013; Sumarni et al., 2021). The evaluation results of evaporative cooling placement have increased the number of tubers to more than 30 tubers/plant (Sumarni et al., 2023). However, there is no investigation on the application of root zone cooling to other hydroponic systems for seed growth and yield, contributing to the availability of seed quality in lowland tropical areas such as Indonesia.

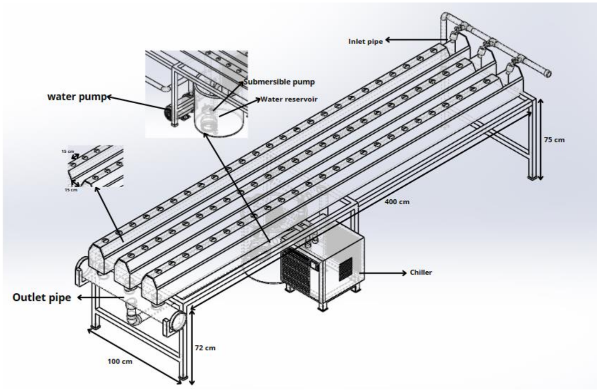
Nutrient Film Technique (NFT) hydroponic system is a potential candidate for certified commercial-scale seed production (Wheeler et al., 1990) and has been widely used for vegetable cultivation. This system consists of channels with a slope ranging from 0.3% to 2%, where the roots are submerged in a thin, film-like layer of nutrient solution. Subsequently, the nutrient solution is continuously circulated through the system, flowing down through a reservoir (Corrêa et al., 2008). This research aimed to obtain the growth and yield of seed through the application of root zone cooling in both aeroponic and NFT systems, using different potato varieties in lowland wet tropics of Indonesia.

2 Materials and methods

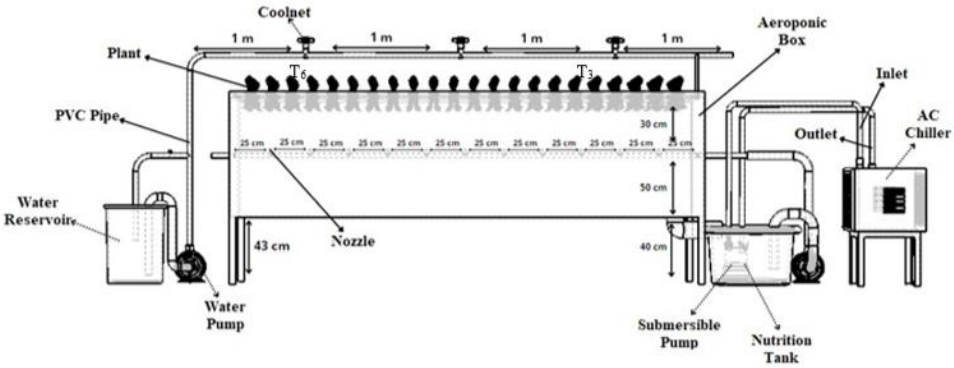
This research was conducted from August to November 2023 inside a semi-cylindrical greenhouse at an elevation of approximately ±115 meters above sea level at the Faculty of Agriculture, Universitas Jenderal Soedirman. The research layout is presented in Figure 1. In this research, the root zone cooling was applied at a temperature of 10°C (Sumarni et al., 2013; Sumarni et al., 2021; Sumarni et al., 2022). Several factors were examined to obtain growth and yield data for potato seed from the application of root zone cooling in aeroponic and NFT systems. The factors tested included hydroponic type (H): H1 (aeroponics) and H2 (NFT), as well as origin of tubers: U1 (shoot cuttings), U2 (root cuttings), and U3 (tubers). Microclimate parameters observed included air temperature, relative humidity (RH) inside and outside the greenhouse, as well as sunlight intensity inside the greenhouse. Growth parameters observed were plant height, leaf count, and tuber weight per tuber. Subsequently, a factorial randomized block design with 4 replications was used for the experiment, and data obtained were analyzed using ANOVA. When there were treatment effects, further comparisons were made using the DMRT test at a 5% significance level.



(a) Aeroponic and NFT installation



(b) NFT system



(c) Aeroponic system

Figure 1 Research layout (Sumarni et al., 2013; Sumarni et al., 2021; Sumarni et al., 2022)

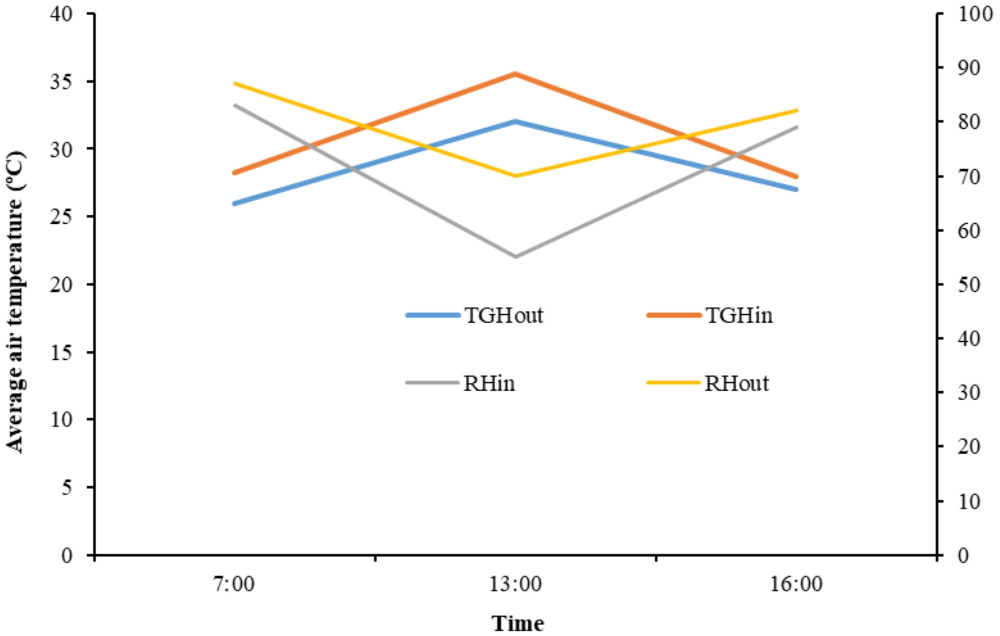
3 Results and discussion

3.1 Air temperature and humidity around the greenhouse

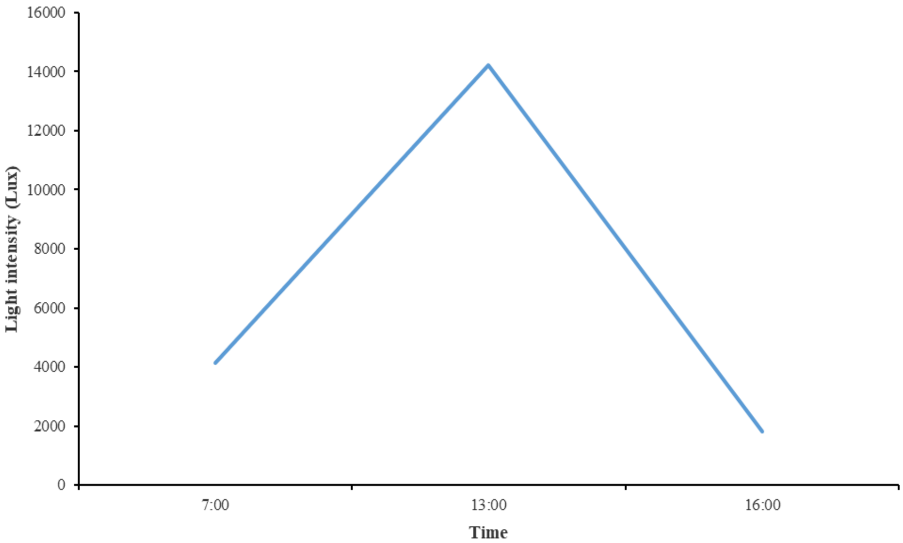
A greenhouse is a building for cultivating plants in order to get quality results at any time and can be done outside the season. Greenhouses are generally designed to be closed with a glass or plastic roof, so that air circulation is reduced and the temperature inside the greenhouse increases when the intensity of solar radiation entering the greenhouse is high (Kawasaki and Yoneda, 2019). The phenomenon of air temperature inside the greenhouse being hotter than the temperature outside the greenhouse was also shown in this research (Figure 2a and Figure 2b). Natural ventilation becomes ineffective if the surrounding environment is high enough. This requires mechanical control that can reduce the temperature according to the plant's needs. Therefore, in this study control was carried out through controlled cooling in a limited area of the root area (Figure 2c).

Lowland areas are characterized by hot air temperatures, as indicated in the measurement results during the seed production in this research. The average air temperature inside the greenhouse at 7:00 AM reached 28.2°C, 35.5°C at 1:00 PM, and 28°C at 4:00 PM. Meanwhile, the outdoor air temperature was 26°C in the morning (7:00 AM), 32°C at 1:00 PM, and 27°C at 4:00 PM (Figure 2a).

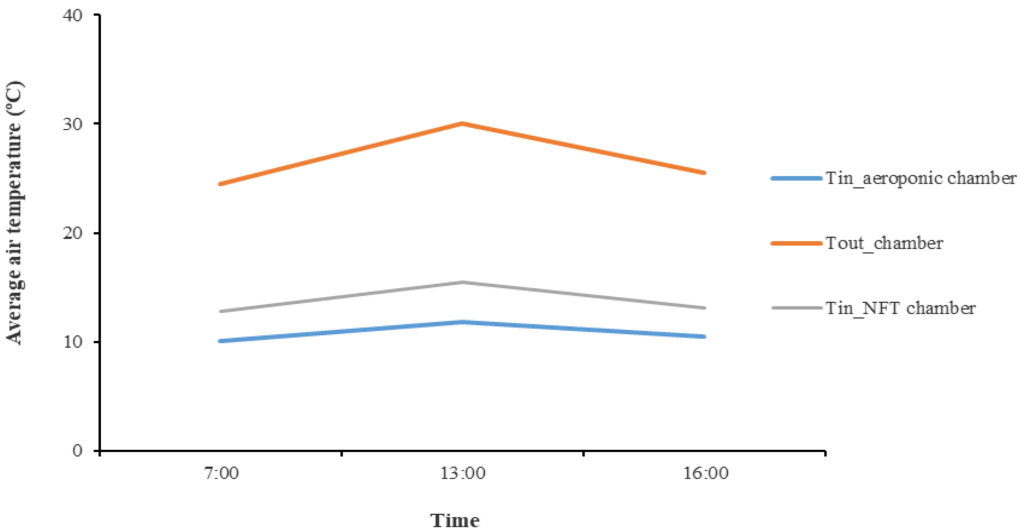
Air humidity (RH) inside the greenhouse at 7:00 AM, 1:00 PM, and 4.00 PM was 83%, 55%, and 79%. These values were lower compared to the average RH outside the greenhouse at 7:00 AM, 1:00 PM, and 4:00 PM, which were 87%, 70%, and 82%, respectively. The average sunlight intensity entering the greenhouse was 6716.78 Lux, with 4145.7 Lux at 7:00, 14205.7 Lux at 1:00 PM, and 1799 Lux at 4:00 PM, as presented in Figure 2b.



(a) Average air temperature inside and outside greenhouse



(b) Average solar radiation intensity inside and outside the greenhouse



(c) Average air temperature inside and outside root zone cooling system

Figure 2 Average air temperature, humidity and solar radiation intensity inside and outside the greenhouse

3.2 Air temperature inside aeroponic and NFT systems

The average air temperature outside aeroponic system at 7:00 AM, 1:00 PM, and 4:00 PM was 23.5°C, 30°C, and 24°C. In the aeroponic system with root zone cooling application, the results showed temperatures ranging from 10.1°C to 11.8°C between 7:00 AM and 4:00 PM, and 12.8°C to 15.5°C in NFT system, as presented in Figure 2c. The greenhouse air temperature in lowland areas reached 35.5°C, which was higher than the outside air temperature at 32°C, with a difference of 3°C, as presented in Figure 3. The air humidity inside the greenhouse during the daytime (at 1:00 PM) was around 55%, with an average of 68%. This condition was not optimal for the growth and development of potato tubers because the plant thrived in a cool environment with temperatures of 15°C-20°C and humidity of 80%-90% (Ritter et al., 2001). The hot air temperature in lowland areas exceeding the optimal requirements resulted in plant damage, such as wilting and scorching, and did not support tuber development. Furthermore, temperatures >30°C accelerated aging and potato death (Sumarni et al., 2013; Sumarni et al., 2021; Sumarni et al., 2023; Kar and Kumar, 2007; Wang et al., 2009; Midmore, 1992; Rykaczewska, 2015).

In this research, the control of root zone cooling in aeroponic and NFT systems was effective in maintaining a lower root temperature compared to the external environment. Aeroponic system showed a higher response to root zone cooling application and reduced the air temperature by more than 15.9°C. Meanwhile, NFT system reduced by 12.9°C compared to the temperature outside the chamber. Similarly, indicated that aeroponic system was stable for root temperature control (Sumarni et al., 2013; Sumarni et al., 2022; Sumarni et al., 2019). In other reports, root zone cooling with cold air also maintained temperatures of 10°C-20°C (Kuncoro et al., 2021; Wang et al., 2022), depending on chilled nutrient water, spraying (aeroponic system), or flowing (NFT system) to the plant roots. This method was selected because water has a higher heat capacity than air, allowing cooled water to maintain its temperature longer (Matsuoka and Suhardiyanto, 1992).

3.3 Potato seed growth and yield

The statistical analysis results indicated significant interactions and differences in plant height, leaf count, and potato tuber seed yield from the treatments applied. These included hydroponic type and origin of potato tubers used as initial seed for lowland hydroponic planting with root zone cooling application.

3.3.1 Plant height and leaf count

The type of hydroponics and the origin of potato seedlings in the application of root zone cooling in lowland areas produced varying results regarding average plant height and leaf count. For all three types of seed origin, hydroponic type 1, which was aeroponics, yielded higher average plant heights compared to NFT type at 42 days after planting (DAP), ranging from 54.8 cm to 56.7 cm. NFT system with shoot-cutting seedlings produced an average plant height of 44.3 cm, higher than with root-cutting and tuber seedlings, ranging from 37.7 cm to 38.0 cm, as shown in Table 1. Meanwhile, plant appearances in aeroponic and NFT systems are presented in Figures 3 and 4.

Table 1 Interaction of hydroponic type and seed origin on average plant height growth

Treatment	Plant height (cm)	Leaf count (sheet)
	42 DAP	42 DAP
H1U1	56,7 [a]	83,6 [a]
H1U2	57,8 [a]	82,7 [a]
H1U3	54,8 [a]	81,7 [a]
H2U1	44,3 [b]	73,0 [b]
H2U2	37,7 [c]	44,2 [c]
H2U3	38,0 [c]	48,5 [c]

Note: Numbers followed by the same letter in the same column are not significantly different based on the DMRT at the level α = 5%; DAP = days after transplanting

Figure 3 Development of aeroponic potato plants in the lowlands with the application of root zone cooling

Figure 4 Development of NFT system potato plants in the lowlands with the application of root zone cooling

Aeroponic produced the highest average leaf count for all three seed origins, ranging from 81.7 to 83.6 leaves. As shown in Table 1, the average leaf count of 73.0 leaves was obtained from NFT with shoot-cutting seedlings, and the lowest was obtained from the root-cuttings and tubers, which were 44.2 and 48.5 leaves, respectively.

3.3.2 Number of seed per tuber and tuber weight

The application of root zone cooling in these two types of hydroponic systems in lowland area provided information about the interaction. The highest average number of seed was obtained from aeroponic system and all three seed origins, ranging from 9.6 tubers to 12.2 tubers/plant. The average number of seed in NFT with shoot-cutting seedlings was 1.2 tubers/plant. Meanwhile, the lowest was obtained from NFT system with seedlings from root cuttings and tubers, which were 1.0 and 1.2 tubers/plant, as presented in Table 2.

Table 2 Interaction of hydroponic type and seed origin on number of tubers and tuber weight

Treatment	Number of tubers (tuber)	Tuber weight/tuber (gr)
H1U1	12,2 ^{a}	3,5 ^{a}
H1U2	9,9 ^{a}	3,3 a
H1U3	9,6 ^{a}	3,4 ^{a}
H2U1	1,2 ^{b}	0,8 ^{b}
H2U2	1,0 ^{c}	1,0 ^{b}
H2U3	1,2 ^{c}	0,8 ^{b}

Note: Numbers followed by the same letter in the same column are not significantly different based on the DMRT at the level α = 5%; DAP = days after transplanting

The highest average weight of seed per plant was obtained from aeroponic system, with seedlings originating from shoot-cuttings, root-cuttings, and tubers, ranging from 3.3 grams to 3.5 grams. As illustrated in Table 2, NFT system with seedlings from shoot-cuttings, root-cuttings, and tubers produced the lowest results, ranging from 0.8 g to 1 g. The appearance of seed in aeroponic and NFT systems is presented in Figure 5.

(a) Potato seeds in NFT

(b) Potato seeds in aeroponic

Figure 5 Potato seeds in aeroponic systems and NFT with root zone cooling in the lowlands

The growth and development of potato, including the height, leaf count, tuber count, and weight, in lowland areas showed the highest results with aeroponic system with root zone cooling application, as shown in Tables 1 and 2. This was supported by the ability to optimize aeration in root zone through fine nutrient mist and maintain moisture balance. The optimization catered for water and oxygen needs in root zone as well as the environment to provide complete access to root area until harvest (Lakhiar et al., 2009; Gruda, 2019; Calori, 2017). For higher yields of tubers (Kaguongo et al., 2008). The nutrient spray formation also provided a more even cooling effect (Sumarni et al., 2013; Sumarni et al., 2019) in aeroponic compared to NFT, with a thin nutrient flow of approximately ± 4 mm in root zone.

Previous research compared aeroponic and NFT systems in highland areas with suitable climates for potato seed production from the Monalisa and Ágata varieties per unit of installation area (Factor et al., 2007). The results showed that aeroponic produced 875 tubers m^{-2} (91% more efficient) compared to NFT, which produced 246 tubers m^{-2}. In potato cultivation research at lowland areas with extreme temperatures, aeroponic could create lower and more uniform root zone temperatures than NFT. This condition led to superior growth and development of potato seedlings in aeroponic system, resulting in a higher yield. Furthermore, the seed yields were higher than conventional systems in highland areas, which typically only achieved 1-8 tubers/plant.

4 Conclusion

In conclusion, this research indicated that the hydroponic system showed promising potential as an alternative method for obtaining high-yield potato seed. The production of seed in lowland areas was achieved through hydroponic cultivation and root zone cooling application. Aeroponic system with root zone cooling yielded higher average plant height, leaf count, tuber count, and weight compared to NFT. Based on the results, aeroponic system with root zone cooling was considered a cultivation technology for expanding potato seed production in lowland areas, with the need for further research to enhance system management.

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