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Full Length Article

Garlic Production in Indonesian Tropical Lowland using Root Zone Cooling and Aeroponic System

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Abstract

Garlic (*Allium sativum* L.) is widely used in Indonesian cuisine for its medicinal benefits due to its antibiotic properties. Despite this, Indonesia continues to rely on imports to meet its garlic demand. Efforts are required to increase garlic production, including implementing an aeroponic system to cool the root zone in the Lowland region. This research aimed to assess the growth and yield of garlic using Root Zone Cooling and aeroponic systems in lowland areas. The experimental design used was the Completely Randomized Design with two factors, namely Root Zone Temperature (RZT), consisting of temperature modifications at 13°C, 15°C, 23°C and 28°C, and Garlic varieties consist of Lumbu Kuning and Lumbu Hijau with four replications. Data were analyzed using ANOVA, followed by the Duncan Multiple Range Test (DMRT) at a 5% significance level. The research results indicate that there is an interaction between the variety used and the temperature in Root Zone Cooling. The best plant height and leaf number for Lumbu Hijau were achieved at 13°C, while Lumbu Kuning had the best plant height at 15°C and the highest leaf number at 23°C. Both varieties had a 94% bulb formation rate at 13–23°C. A temperature of 13°C was optimal for bulb diameter, particularly for Lumbu Hijau, while Lumbu Kuning showed no significant difference between 13°C and 15°C. These findings suggest that temperature strategies tailored to the plant's needs can optimize garlic production in lowland areas.

Keywords: Aeroponic; Agronomic; Garlic; Lowland; Spice

Introduction

Garlic (*Allium sativum* L.) is a widely used cooking spice among the majority of the Indonesian population and also has the potential to be used for medicinal purposes due to its antibiotic properties. Traditional medicine in Indonesia has incorporated garlic for over 4000 years (Morales-Gonzales 2019; Agustina 2020). Previous research reported that the plant has anti-inflammatory, anti-obesity, anticancer, antidiabetic, antifungal, kidney protection, heart protection, nerve protection and antibacterial properties (Bayan *et al*. 2014; Ibrahim *et al*. 2018; Shang *et al*. 2019).

Garlic has also become an essential contributor to economic growth, serving as a strategic food commodity (FAO 2019; Septiana *et al*. 2020). The low productivity of garlic is attributed to the limited cultivation areas, primarily concentrated in highland areas. The plants require a growth temperature of 15–25°C (Department Pertanian 2009), resulting in frequent cultivation in highland areas. During the cold period, plants undergo biochemical changes that promote bulb formation and differentiation. However, these areas in Indonesia are endemic to bacteria and viruses that can harm plants. These areas are also often situated on sloped terrain with gradients greater than 30%, increasing the susceptibility to erosion (Basuki 2014). Extreme conditions such as frost can be detrimental to plants grown in open fields.

Given these conditions, there is a need for cultivation technologies feasible not only in highland but also in lowland areas to support increased garlic production in Indonesia. The previous research of Rafiuddin *et al.* (2023) using conventional farming system results showed that the average number of cloves per bulb for Lumbu Hijau in lowland areas was only 2.6, while its potential is 12 to 20 cloves when grown in highland areas. Similarly, the bulb diameter of Lumbu Hijau in the lowlands reached only 1.89 cm, whereas its potential diameter is 3.9 to 4.0 cm when grown in highland areas. This in because garlic thrives in cooler temperatures, usually between 13°C and 18°C, which are more common in highland areas. In lowland areas, high

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temperatures disrupt the vernalization process, the cooling period necessary for proper bulb development. Without adequate exposure to cold temperatures, garlic fails to form and develop bulbs. In addition, lowland areas tend to have longer days and higher daytime temperatures. Garlic is sensitive to the length of day and the heat it experiences, affecting its ability to form quality bulbs. Longer, hotter days in lowland areas can result in poor bulb formation and lower yields (Chotimatul *et al.* 2022).

Indonesia has not yet developed the technology for controlling greenhouse microenvironments in wet tropical areas on a large scale. This is due to the difficulty of reducing the air temperature in the greenhouse at high solar radiation. The concept of limited cooling (zone cooling) is to cool a restricted zone of plant growth areas (plant roots); this cooling method is not intended to cool the entire volume of air in the plant house (Nurwahyuningsih 2017). Climate modification technology at the root zone through the aeroponic method has been applied for potato seed production in lowland areas (≤ 250 m above sea level). This technology was successfully used for producing potato seeds in lowland areas, with yields ranging from 10–20 bulbs (Sumarni *et al*. 2013, 2016, 2019, 2020). Moreover, Root Zone Temperature (RZT) technology combined with evaporative cooling (upper plant management) produced 30–40 bulbs/plant, with some even yielding 80 bulbs in lowland areas (Sumarni *et al*. 2021). It has also been successfully used to increase the yield and quality of tomatoes (He *et al*. 2019), cucumbers (Muthir *et al*. 2019), chili peppers (Amaliyah *et al*. 2018), paprika (Yurina *et al*. 2014) and shallots (Margiwiyatno and Sumarni 2011). Based on the achieved results, this technology can be applied to garlic production in lowland areas. Therefore, this research aimed to assess the growth and yield of garlic using RZT modification in Indonesian tropical lowland.

Aeroponics also can increase crop yields by enhancing the roots' oxygenation, which promotes faster growth and more efficient nutrient uptake, resulting in healthier plants and higher yields. Additionally, aeroponic systems reduce the risk of soil-borne pests and diseases and use water more efficiently, making them ideal for regions with water scarcity (Juan *et al.* 2023). When combined with root zone cooling, which maintains an ideal temperature range for garlic growth, these systems ensure optimal bulb formation, particularly in regions with high ambient temperatures that otherwise hinder bulb development. Root zone cooling prevents heat stress, improving bulb size, quality, and uniformity. These technologies create a controlled environment that maximizes garlic production in the limited arable land.

Materials and Methods

Experimental location and time

This research was carried out from May 2023 to September 2023, in a semi-cylindrical type of greenhouse features a sturdy iron frame for structural support. A semi-cylindrical greenhouse is a specific type of greenhouse design that typically features a curved, semi-circular or arched roof, which distinguishes it from more traditional rectangular or gabled greenhouse shapes. This design is often chosen for its ability to optimize light distribution, reduce wind resistance, and improve temperature regulation. Walls shielded with insect netting to prevent pests, and a roof constructed from UV-resistant plastic to optimize sunlight penetration while protecting plants Sethi *et al.* (2009). Experiment located in lowland with an altitude of ± 115 m above sea level.

Materials

The equipment needed for this research includes an aeroponic machine consisting of a nutrient solution reservoir tank, electric water pump, timer, water hose, PVC pipe, nozzle, and tool frame. It also uses an EC meter, PH meter, styrofoam, hybrid recorder, thermocouple, oven, desiccator and weather station.

The materials used in this research include Lumbu Hijau and Lumbu Kuning varieties of garlic seeds and AB mix nutrient solution to provide the plant nutrients.

Preparing an aeroponic system includes making an aeroponic chamber. The experimental aeroponics chamber measures 1.5 m (L) x 1 m (W) x 1 m (H) with a planting distance of 15 cm x 15 cm. So, in one chamber there are 45 plants (there are 5 x 9 plants).

Experimental design

The experimental design used was the Completely Randomized Design with two factors. The first factor was the variety treatment, namely V1 (Lumbu Kuning) and V2 (Lumbu Hijau). Lumbu Kuning variety is a local variety originating from Batu, Malang, Indonesia and has a harvest age of 105–116 HST with a productivity of 18–24 tons/ha wet or 6-8 tons of dry bulbs (high potential productivity). The Lumbu Hijau variety has a harvest age of 112–120 days, has a strong aroma, and produces 8–10 tons of dry bulbs/ha (high potential productivity). These varieties are good for planting in areas with an altitude of 600–900 m above sea level. The second factor was the temperature of Root Zone Temperature (RZT), namely RZT1 (13°C), RZT2 (15°C), RZT3 (23°C) and RZT4 (28°C control). So, the total treatment combination is 8 combinations.

Plant cultivation procedures

The nutrients used for plant fertilizer were AB Mix. A pH of 6 and an EC of 1 mS/cm are maintained from day 1 to day 30 after sowing (DAS). From day 31 to day 50 DAS, the EC is increased to 1.5 mS/cm. After day 50 DAS until harvest, the EC is adjusted to 1.8 mS/cm. The nutrient watering duration was 10 min, with the timer off for 2 min.

Data recording

The data recording procedure for plant growth was the measurement of the following:

- Plant height measuring from the base of the plant to the tip of the tallest leaf.
- Leaf number: The number of leaves per plant is counted periodically to assess vegetative growth.
- Bulb formation: The number of bulbs formed per plant is recorded, including any instances of multiple bulbs or lack of bulbing.
- Bulb diameter: The diameter of the garlic bulbs is measured at harvest or when the bulbs are fully developed.
- Environmental Conditions: Temperature (air and root zone) and humidity levels are monitored at 07:00, 13:00, and 16:00 to ensure they remain within the optimal range for garlic growth.

Statistical analysis

The growth parameters observed included plant height, number of leaves, percentage of bulbs, and diameter. Data were analyzed with ANOVA, followed by Duncan's Multiple Range Test (DMRT) at a 5% level. The root zone cooling technology applied was in accordance with previous research (Sumarni *et al*. 2013, 2023) (Fig. 1).

Results

Microclimate around the greenhouse

The air temperature inside and outside the greenhouse indicated significant differences by 1–3°C. The maximum air temperature inside the greenhouse reached 36.2°C (at 13:00), while outside was 32°C. Furthermore, air humidity demonstrated a difference of 5% to 13%, with RH in the greenhouse at 7:00, 13:00 and 16:00 reaching 85%, 59%, and 84%. The values obtained outside the greenhouse were 90%, 72% and 89%, respectively (Fig. 2 and 3).

The air temperature in the aeroponic root zone cooling chamber for garlic showed that RZT control was able to maintain the temperature around the root areas according to the desired level. The temperature deviation that occurred was estimated to be in the range of 1–2°C. This control mechanism successfully reduced the temperature in the root areas by 15°C when the air temperature in the greenhouse reached 36°C during the day (13:00).

Growth and yield of garlic in each treatment

The statistical analysis results showed that the root zone cooling and variety treatment significantly affected plant height, the number of leaves and the percentage of bulbous plants in (Table 1).

The analysis results showed that plant height (Table 1) of Lumbu Hijau highest at a temperature of 13°C, which was 49.00 cm. But, in Lumbu Kuning, the plant height did not show any significant difference between those treated with temperatures of 13 and 15°C, which was 44.07–44.43 cm. The best plant height in Lumbu Hijau, treated with a temperature of 13°C, was 49.00 cm, compared to other temperature treatments and varieties.

The analysis results showed the largest number of leaves (Table 1) in Lumbu Hijau compared to Lumbu Kuning. Lumbu Hijau had the largest number of leaves at a temperature of 13°C, namely 5.10 leaves, while in Lumbu Kuning, the largest number of leaves was at an RZT temperature of 28°C, namely 4.40 leaves.

The analysis results showed that the percentage of bulb plants (Table 2) at temperature treatments of 13, 15, and 23°C ranged from 94–95%. At a temperature treatment of 25°C in Lumbu Hijau, only 81.67% were bulbs, and in Lumbu Kuning, only 76.33% were bulbs.

The results analysis of bulb diameter (Table 2) showed that the Lumbu Hijau bulb was larger than the Lumbu Kuning bulb. The largest diameter of the Lumbu Hijau bulb at an RZT temperature of 13°C is 6.26 cm, while in Lumbu Kuning, the best bulb diameter at temperatures of 13 and 15°C is around 4.83 to 5.26 cm. In tropical highland, Lumbu Hijau and Lumbu Kuning can achieve a diameter of 3.0–3.8 cm and 3.3–3.9 cm (Handiana 2018). This indicates that the research results produced a tuber diameter larger than the average.

Discussion

The internal temperature of the greenhouse is higher than the external temperature of the greenhouse (Fig. 2), which is due to the greenhouse effect. Greenhouses allow sunlight to enter through their walls and roofs, which heat up the air inside. However, the heat produced does not easily escape because the greenhouse roof is made of transparent materials, such as glass or plastic, blocking most heat radiation from escaping. As a result, the temperature inside the greenhouse increases higher than outside the greenhouse (Li *et al*. 2019).

The temperature and humidity levels (Fig. 2) show sub-optimal conditions for the growth and development of garlic in lowland. Temperatures in the lowlands inhibit bulb formation due to the translocation of photosynthate, which does not lead to bulb formation and development, and the inhibition of the production of phytohormones, which play a role in bulb development.

The study results indicated that, overall, garlic growth and yield (Table 1 and 2) were optimal at a root zone temperature of 13°C. Low temperatures, typically between 5°C to 15°C, are crucial for vernalization and the initiation of bulb formation, particularly for hardneck garlic varieties. These conditions promote hormonal changes that enable the plant to transition from vegetative growth to bulb development. The cold conditions signal to the plant that it is time to prepare for reproduction, leading to the formation

Table 1: Effect of root zone cooling and variety on plant height (cm) and leaf number

Treatment	Plant height (cm)		Leaf number	
	Lumbu Hijau	Lumbu Kuning	Lumbu Hijau	Lumbu Kuning
RZT 13°C	49.00 A a	44.07 A b	5.10 A a	3.77 C b
RZT 15°C	44.26 B a	44.43 A a	4.60 C a	4.00 B b
RZT 23°C	37.20 D a	34.27 C b	4.10 B a	4.10 B a
RZT 28°C	40.10 C a	37.50 B b	4.76 D a	4.40 A b

Note: Numbers followed by the same capital letter in the same column and variable indicate no significant difference based on the DMRT test at the 5% level
Numbers followed by the same lower cases letter in the same row and variable indicate no significant difference based on the DMRT test at the 5% level

Table 2: Effect of root zone cooling and variety on percentage of bulbous plants (%) and bulb diameter (cm)

Treatment	Percentage of bulbous plants (%)		Bulb diameter (cm)	
	Lumbu Hijau	Lumbu Kuning	Lumbu Hijau	Lumbu Kuning
RZT 13°C	95.00 A a	95.00 A a	6.26 A a	5.26 A b
RZT 15°C	95.00 A a	94.83 A a	5.60 B a	4.83 A b
RZT 23°C	94.00 A a	94.00 A a	4.33 C a	4.03 B a
RZT 28°C	81.67 B a	76.33 B b	4.50 C a	3.56 B b

Note: Numbers followed by the same capital letter in the same column and variable indicate no significant difference based on the DMRT test at the 5% level
Numbers followed by the same lower cases letter in the same row and variable indicate no significant difference based on the DMRT test at the 5% level

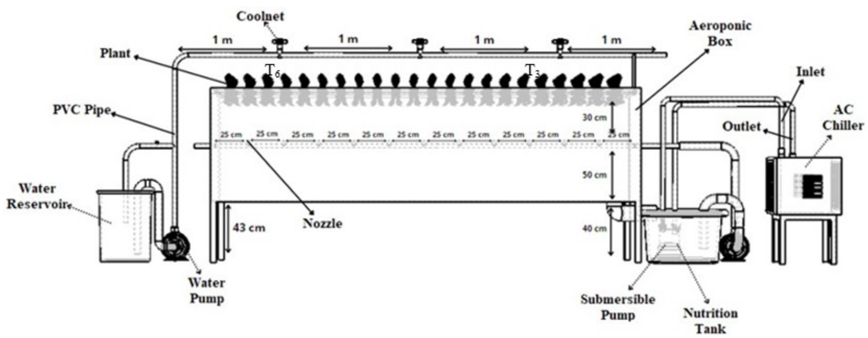

Fig. 1: Aeroponic system and root zone cooling applied to garlic (Sumarni *et al*. 2013, 2023)

of bulbs (Atif *et al*. 2020).

Low temperatures may act as a signal for garlic plants, resulting in increased production of MeJA. MeJA may also affect the growth of storage organs (bulbs), as jasmonates are known to regulate the development of storage tissues (Ben-Michael *et al.* 2018). Under cold temperatures, MeJA may help facilitate the transition from vegetative growth to reproductive growth and bulb formation. By promoting starch synthesis, cell expansion, and cell division, MeJA may help garlic focus its energy on bulb development rather than vegetative growth (Lloyd *el al.* 2016).

Bulbing process is also controlled by the interplay between bulbing hormones and gibberellins (GA). Given that bulbing is associated with the disruption of microtubules, jasmonic acid (JA) and methyl jasmonate (MeJA) are considered potential bulbing hormones due to their ability to disrupt microtubules and their extensive presence in higher plants (Mathew *et al.* 2011). Salicylic acid (SA) is crucial for garlic bulb formation, and MeJA probably increased the endogenous levels of SA in garlic plants, thereby enhancing the bulbing process (Wu *et al.* 2016).

Low temperatures garlic encourages to allocate more carbon to the bulb rather than to vegetative growth. As temperatures decrease, ABA may help facilitate this carbon redistribution by modulating the transport of sugars and nutrients to the developing bulbs. This process is essential for the bulb enlargement phase, where the plant stores energy for future growth or reproduction.

IAA plays a critical role in cell elongation and tissue differentiation. In garlic, auxins like IAA contribute to the enlargement of bulb tissues, improving bulb size by promoting the development of the storage tissues within the bulb. IAA also influences root growth, which supports better nutrient uptake and contributes to bulb growth and quality.

The results of the root zone cooling application in aeroponic system were in accordance with previous research (Sumarni *et al.* 2013, 2019). This suggests that technology is stable for controlling roots temperature. In previous research, the application of root zone cooling by providing cold air maintained the temperature at 10–20°C (Kuncoro *et al.* 2021; Wang and Izozaki 2022). Therefore, it was concluded that aeroponic system can create conditions for maintaining lower and more consistent roots temperature. These conditions, in turn, contribute to improved growth and development of garlic bulbs.

Using root zone cooling aeroponic systems in tropical lowland areas offers significant potential to address critical agricultural challenges such as high temperatures, water scarcity, and land degradation. In these areas, where traditional agriculture is often hampered by limited climatic

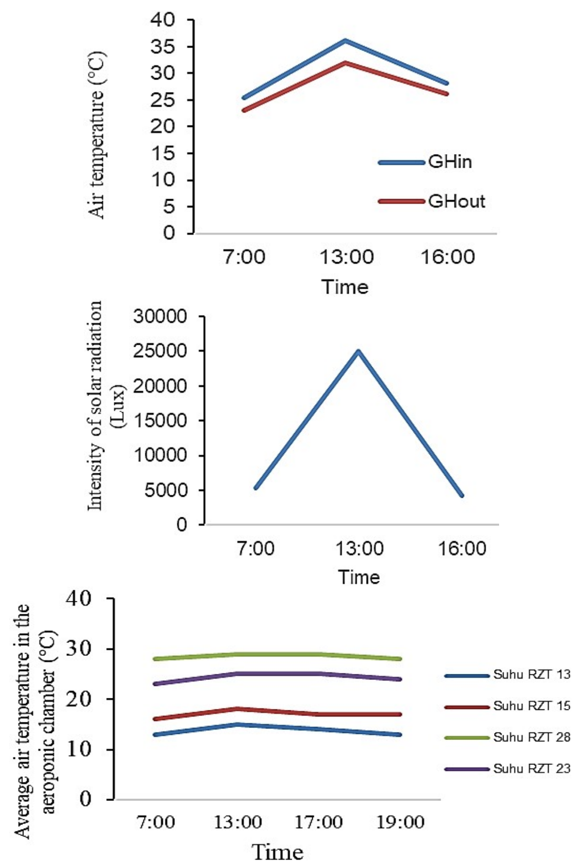

Fig. 2: The air temperature, the intensity of solar radiation and average air temperature in the aeroponic chamber

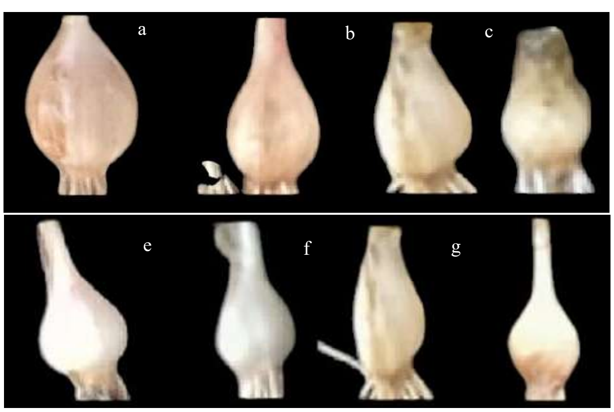

Fig. 3: Performance of Lumbu hijau at RZT **a**. 13°C, **b**. 15°C, **c**. 23°C, **d**. 25°C, Lumbu Kuning at RZT **e**. 13°C, **f**. 15°C, **g**. 23°C, **h**. 25°C

conditions, root zone cooling further enhances these systems by optimizing root health, preventing heat stress and increasing nutrient uptake, which is critical for temperature-sensitive crops as illustrated by Sakamoto *et al.* (2016). This combination increases yields, improves quality, and promotes water efficiency, using up to 90% less water than conventional soil-based farming. While this technology is up-and-coming, its implementation will require overcoming challenges such as high initial investment costs, energy consumption for cooling and technical training. However, the potential for improved food security, economic growth, and environmental sustainability makes it an attractive solution for tropical lowland areas facing the pressures of climate change.

The root zone cooling technique could be adapted and scaled for commercial garlic production in Indonesia by integrating it into controlled environment agriculture (CEA) systems, such as greenhouses or indoor farming facilities. These systems would allow farmers to maintain optimal temperatures for garlic growth, especially since Indonesia's tropical climate often poses challenges with high ambient temperatures that can hinder bulb development. In these controlled settings, aeroponic or hydroponic systems could be combined with cooling technologies to deliver nutrients efficiently while regulating root temperatures. For larger-scale field applications, passive cooling methods—such as water circulation in buried pipes or soil moisture management—could reduce cooling systems' cost and energy consumption. Moreover, solar-powered cooling systems could make the technology more energy-efficient and economically viable, especially for rural farmers with limited access to consistent electricity. Cooperative farming models could be implemented to scale the technique for broader adoption, where smallholder farmers share resources and equipment, lowering individual investment costs. Further research into affordable cooling systems, optimal cooling durations, and cost-benefit analyses would be essential to make this technology accessible to a broader range of producers. By addressing these factors, root zone cooling could significantly enhance garlic yields and quality in Indonesia's tropical climate, helping to overcome temperature-related production challenges.

Conclusion

Root zone cooling for garlic production in tropical lowlands showed that maintaining optimal root temperature (at 13°C in the Lumbu Hijau variety and 13–15°C in the Lumbu Kuning variety) can significantly improve garlic growth, reduce heat stress, and enhance bulb development. These temperatures were ideal for fostering healthy root growth and minimizing the adverse effects of high ambient temperatures, which are common in tropical climates like Indonesia. For garlic producers, the practical takeaway is that achieving and maintaining these specific root zone temperatures through cooling systems could lead to healthier plants, larger bulbs, and higher yields.

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Author Contributions

The corresponding author and each member of the writing team actively contributed to the research, data processing, discussion and preparation of this paper collectively and are responsible for its contents.

Conflict of Interest

All authors declare no conflict of interest.

Data Availability

Data presented in this study will be available on a fair request to the corresponding author.

Ethics Approval

Not applicable to this paper.

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