

Effects of Nitrogen Concentration in Nutrient Solution on Growth, Yield and Phytochemical and Aromatic Compounds of *Persicaria Minor* Cultivated using Using Hydroponics System

ABSTRACT

Persicaria minor, locally known as kesum and belonging to the family Polygonaceae, is a widely used aromatic herb in Malaysia. Cultivating kesum hydroponically using a deep-water culture (DWC) system presents an alternative method for growers to enhance crop yields. ~~In this system, a liquid fertilizer solution is delivered directly to the plant roots without any growth medium or water flow.~~ This system delivers a liquid fertilizer solution directly to the plant roots, eliminating the need for a growth medium or water flow. Kesum contains phytochemical compounds such as quercetin-3-glucuronide and quercitrin, which have medicinal properties. The primary objective of this study was to assess the effects of nitrogen concentration on the growth, yield, phytochemical (quercetin-3-glucuronide and quercitrin) and aromatic (aldehyde and caryophyllene) content of kesum cultivated in a hydroponic system. Plants were grown under four nitrogen concentration regimes: 200 mg/L, 100 mg/L, 50 mg/L, and 0 mg/L. The experiment was conducted under a side-netted rain shelter and arranged in a Randomized Complete Block Design (RCBD) with four replications. The plants were harvested eight weeks after planting. ~~The result indicted These those~~ supplemented with 100 mg/L of nitrogen exhibited the best growth performance and biomass yield, along with the highest levels of aromatic compounds (aldehyde C-10: 5.80% and aldehyde C-12: 12.23%). Plants treated with 50 mg/L of nitrogen produced the highest amounts of quercetin-3-glucuronide (98.261 µg/mL) and quercitrin (61.367 µg/mL) compared to other treatments. Additionally, plants receiving 200 mg/L of nitrogen had the highest caryophyllene content (12.53%). In conclusion, the deep-water culture system in hydroponics can effectively cultivate kesum, allowing for adjustments in nitrogen concentration to achieve optimal yields, phytochemical levels, or aromatic compound production based on specific objectives.

Keywords: Hydroponics, nitrogen, *Persicaria minor*, Quercetin-3-glucuronide, Quercitrin, aldehyde C-10 and aldehyde C-12

INTRODUCTION

Persicaria minus, commonly known as kesum, is a herbal plant native to Southeast Asia that thrives in moist, watery environments. Its aromatic leaves are often used in cooking

[1]. Kesum is rich in micronutrients, total phenolic content (TPC), and natural antioxidants, offering numerous medicinal benefits, including antioxidant, anti-inflammatory, and anti-aging properties. It also supports memory enhancement and boosts the immune system [2, 3]. This shrub grows to a height of 45-60 cm and features small, narrow leaves (5-7 cm) with pointed tips. The leaves are green, while the plant has reddish, cylindrical stems with short nodes that root easily. Kesum also bears purple flowers.

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Kesum is classified as an aromatic herbal plant with notable nutraceutical, pharmaceutical, and therapeutic properties [4, 5]. Two key aromatic compounds, aldehyde and caryophyllene, are being actively researched in the essential oil of *Persicaria* species [6]. Aromatic aldehydes contribute to the fragrance and flavor of plants and include compounds such as aliphatic aldehydes, analogous alcohols, sulfanyl derivatives, sesquiterpenoids (like caryophyllene and its derivatives), and monoterpenoids [6]. Research on the essential oil of *Persicaria* spp has demonstrated its antibacterial properties [6, 7], hydrogen peroxide radical scavenging activities, antifungal properties [1], and inhibitory effects against pathogenic bacteria [8]. This study will focus on aldehydes and their derivatives, particularly in relation to their antimicrobial, ~~antioxidant~~antioxidative, anti-inflammatory, and immunomodulatory effects.

Since kesum's growth is highly dependent on soil moisture, it is often grown using traditional techniques on mineral or peat soils with effective irrigation systems [9]. Kesum is traditionally cultivated using conventional methods in mineral or peat soils with efficient irrigation systems, as its growth heavily depends on soil moisture [9]. However, this method requires large areas and significant labor, particularly during planting and harvesting. Moreover, excessive fertilizer use in conventional farming can lead to environmental pollution, particularly through leaching into soil and groundwater. An alternative approach is to use the deep water culture (DWC), also known as the raft technique, which is one of the simplest and most cost-effective hydroponic methods. In DWC, liquid fertilizer is delivered directly to the plant roots without any growth medium or water flow [10]. This technique is practical for growing leafy vegetables like mustard, kale, pakchoy, and herbs such as pegaga, selom, kaduk, basil, mint, and even kesum. The use of hydroponic systems has shown potential to increase the growth and yield of kesum, as demonstrated by the significant yield improvements seen in other leafy and fruiting vegetables grown hydroponically.

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Several studies have demonstrated the crucial role of nitrogen nutrition in fruit growth, development, and production processes [11, 12, 13]. Nitrogen concentration in fertilizers may also affect plant secondary metabolite synthesis and metabolism [14]. Previous research has indicated that nitrogen fertilizers significantly influence the production of active compounds in plants [13]. For instance, nitrogen application has been shown to enhance the essential oil yield in patchouli compared to plants grown without nitrogen [15]. Therefore, this study aims to assess the effects of nutrient solutions on the growth,

yield, and aromatic compounds of *Persicaria minor* cultivated using a Deep-water hydroponic system.

MATERIALS AND METHODS

Study Area

The research was conducted in a rain shelter at the MARDI Station in Serdang, Selangor, Malaysia. This structure measured 30 meters in length, 10 meters in width, and 4.5 meters in height. The shelter's framework consisted of galvanized steel, with a transparent polyethylene film (180 mm thickness) ~~serv~~ing as the roof. The sides were enclosed with insect-repellent netting featuring 0.1 x 0.1 mm² mesh openings. To minimize insect intrusion, a double-door entry system controlled access to the shelter. ~~access to the shelter was controlled through a double-door entry system.~~

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Experiment unit

The experiment utilized the deep-water culture (DWC) hydroponic technique, also known as the floating raft method. Fiberglass containers measuring 90 cm wide x 300 cm long x 25 cm high served as the hydroponic tanks. Kesum plant cuttings were placed in 1.6 cm diameter holes spaced 17 cm apart on 2.5 cm thick polystyrene sheets. These sheets floated on the nutrient solution surface, covering the entire container. Each tank was equipped with a 60-watt submersible water pump connected to a PVC pipe, ensuring uniform fertilizer distribution. The setup also included two 100 L fertilizer stock barrels, an EC meter for monitoring fertilizer concentration, and sponges as a germination medium for the cuttings.

Planting ~~material~~ technique

Kesum plants were propagated using stem cuttings measuring 30 cm in length, each containing 7-9 nodes. The cuttings were prepared by removing leaves and side shoots, leaving only the leaves on the main shoots. For planting, each cutting was clamped with a wet sponge to serve as a germination medium and inserted into a planting hole on the polystyrene. Half of the cutting (15 cm) was submerged in the fertilizer solution, while the other half remained above the polystyrene surface. To minimize stress on the plant material, the planting was carried out in the evening. The Kesum cuttings began to develop roots after ~~a period~~ of three days.

Treatments and Experimental Design

The experiment employed a Randomised Complete Block Design (RCBD) with four treatments, each replicated four times and containing 80 plants per treatment. The treatments consisted of varying nitrogen concentrations: T1 at 0 mg/L, T2 at 50 mg/L, T3 at 100 mg/L, and T4 at 200 mg/L. To maintain plant health, routine horticultural

practices were followed, including regular pest and disease management. This involved biweekly applications of Malathion as an insecticide and Benlate as a fungicide.

Nutrient supplementation

The fertilizer used in this study was formulated by MARDI specifically for vegetable plants, based on research by Yaseer Suhaimi et al. (2009, 2011). All components were water-soluble and prepared as two separate stock solutions at 100 times the final concentration. Stock A contained calcium nitrate and iron, while Stock B included all other nutrients. Each component was dissolved individually in tap water (pH 5.5 - 6.5) to ensure complete dissolution before being combined in 100-liter vessels. To attain the appropriate electrical conductivity (EC) in the hydroponic containers, Stocks A and B were mixed in a 1:1 ratio. A submersible pump was utilized for five minutes to guarantee complete mixing. The fertilizer concentration was checked at least biweekly, or whenever solution levels dropped owing to evaporation and plant uptake. The EC of kesum plants was kept between 2000 and 2400 mS/cm during the cultivation period. ~~For the hydroponic containers, Stocks A and B were mixed at a 1:1 ratio to achieve the desired electrical conductivity (EC). A submersible pump was used for five minutes to ensure thorough mixing. The fertilizer concentration was monitored at least biweekly, or when solution levels decreased due to evaporation and plant uptake. For kesum plants, the EC was maintained between 2000 – 2400 mS/cm throughout the cultivation period.~~

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Parameter measurement

The growth of kesum plants was assessed eight weeks after planting by recording plant height, stem diameter, canopy size, fresh and dry weights of leaves and shoots, and SPAD value. Randomly selected plants were harvested at the eight-week mark to evaluate their growth and yield. The weights were taken immediately after harvest to prevent desiccation and water loss from the leaves.

Preparation of extracts

The aerial parts of *P. minor* were collected, rinsed under running tap water to remove surface contaminants, and cut into small pieces. The samples were then dried in a hot air oven at 50°C for 72 hours. Once dried, they were ground into a fine powder and extracted with 70% methanol (1:10) using sonication for 1 hour. The mixture was centrifuged at 10,000 rpm for 15 minutes, and the extraction process was repeated three times under the same conditions. The combined filtrates were concentrated to dryness using a rotary evaporator to obtain the crude extracts.

Phytochemicals compound analysis

The methanolic crude extracts were filtered through a 0.22 µm nylon membrane filter before analysis. Quercetin-3-glucuronide and quercitrin were identified using high-performance liquid chromatography (HPLC), equipped with an auto-sampler, diode array detector (DAD), and column oven. Chromatographic separation was achieved

using a Waters XBRIDGE-C18 column (150 mm x 4.6 mm x 3.5 μ m) at 40°C. The mobile phase consisted of water with 0.1% formic acid (phase A) and acetonitrile with 0.1% formic acid (phase B), with a gradient elution. The flow rate was set to 1.3 mL/min, and the injection volume was 5 μ L. UV-vis detection was performed at 375 nm using the DAD detector. The quantities of quercetin-3-glucuronide and quercitrin in the extracts were calculated by comparing the peak areas to those of standard compounds using calibration curves.

Aromatic content analysis

After harvesting, the kesum plants were initially sun-dried and then air-dried for 48 hours to reduce moisture content by approximately 40%. The dried samples were ground into a powder and extracted with hexane for 24 hours. The extract was filtered and analyzed using a UV-spectrophotometer at a wavelength of 248 nm to assess aldehyde and caryophyllene content.

Statistical Analysis

The data obtained were analyzed statistically using analysis of variance (ANOVA) to determine the significant effects of the variables under investigation, with SAS version 9.1 software. The Duncan Multiple Range Test (DMRT) was used to assess mean differences, with a significance level of $p \leq 0.05$. Mean differences were evaluated using the Duncan Multiple Range Test (DMRT) at a significance level of $p \leq 0.05$.

RESULTS AND DISCUSSION

Effects on pPlant growth and biomass

Table 1 summarizes the plant growth parameters, including plant height, stem diameter, plant canopy, SPAD value, and both fresh and dry biomass per plant. The results show that nitrogen concentration treatments had a significant effect ($p < 0.05$) on these parameters. T3 (100 mg/L nitrogen) led to the tallest plants at 75 cm, although there was no statistically significant difference in plant height among the treatments. The largest stem diameter was seen in T2 (50 mg/L nitrogen), followed by T4 and T3. Similarly, there were no significant differences in plant canopy between the treatments.

The highest SPAD values were observed in plants treated with 200 mg/L of nitrogen, followed by those receiving 100 mg/L and 50 mg/L, respectively. Research has demonstrated that increasing nitrogen concentrations tends to elevate SPAD values, leading to darker green leaves in kesum plants. Previous studies have found a significant correlation between SPAD values and the chlorophyll and nitrogen content in plant leaves [18]. Also, Sakamoto and Suzuki (2022) also reported that nitrogen deficiency leads to reduced chlorophyll levels in leaves, resulting in premature plant death. Plants exposed to 0 mg/L of nitrogen exhibited severe deficiency symptoms and died within three weeks of planting. These findings indicate that kesum plants require a minimum of 50 mg/L of nitrogen for proper growth. Suitable nitrogen concentrations not only promote growth but also serve as effective fertilizers [20].

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The Significant significant effects of nitrogen concentration were observed on the fresh and dry weight of leaves and shoots across the treatments ($P<0.05$). The highest fresh weight of leaves and shoots per plant was recorded in T3 (174 g), followed by T2 (159 g) and T4 (152 g). The study showed that a nitrogen concentration of 100 mg/L produced the optimal vegetative biomass. Additionally, the dry weight of leaves and shoots per plant increased in proportion to the fresh weight. The findings also indicated that plant height contributed to the overall vegetative biomass, as taller plants yielded more biomass.

Nitrogen is a known nutrient that can influence plant growth and development by affecting photosynthesis and the uptake of minerals [21, 22]. Application of nitrogen at the rate of 80 – 100 kg/ha had increased kesum yield compared to 180 – 200 kg/ha in conventional soil planting [9]. Nitrogen fertilizer significantly increased the plant biomass, height, canopy and SPAD value as shown in the study [14]. Previous reports showed that hydroponically grown plants have different growth characteristics compared with soil grown plants [23]. The responsiveness level of hydroponically grown plants to nitrogen concentration might be different from soil grown plants [24]. Nitrogen promotes the number of meristematic cells and their growth leading to the formation of biomass. Furthermore, nitrogen application is known to increase the levels of cytokinin, which affects cell wall extensibility [25, 26].

Table 1. Effects of nitrogen concentration in nutrient solution on plant growth after two months of cultivation

Treatment	Plant height (cm)	Stem diameter (mm)	Plant canopy (cm)	SPAD value	Fresh weight of leaves and shoots per plant (g)	Dry weight of leaves and shoots per plant (g)
T1: 0 mg/L	nil	nil	nil	nil	nil	nil
T2: 50 mg/L	75 ^a	7.2 ^a	51 ^a	44 ^b	159 ^b	35.9 ^b
T3: 100 mg/L	78 ^a	6.3 ^b	52 ^a	48 ^a	174 ^a	40.5 ^a
T4: 200 mg/L	74 ^a	6.5 ^b	56 ^a	52 ^a	152 ^c	31.3 ^b

Mean values in the same column followed by the same letter are not significantly different at $p < 0.05$

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Effects on pPhytochemical content

Significant nitrogen concentration effects were on quercetin-3-glucuronide and quercitrin content between treatments (Figure 1). Plants treated with ~~T2~~ or 50 mg/L of nitrogen concentration showed the highest quercetin-3-glucuronide (98.261 $\mu\text{g/mL}$) and quercitrin (58.467 $\mu\text{g/mL}$) content. Meanwhile, plants supplemented with 100 mg/L of nitrogen concentration gave the lowest value of quercetin-3-glucuronide (56.291 $\mu\text{g/mL}$)

and plants cultivated with 200 mg/L of nitrogen produced the lowest quercitrin content (55.315 $\mu\text{g/mL}$). Data revealed that plants supplemented with 100 mg/L of nitrogen concentration raised the highest vegetative biomass but low in both quercetin-3-glucuronide and quercitrin content. Contrast to the plants supplemented with 50 mg/L of nitrogen concentration which gave the lowest biomass but high in both both quercetin-3-glucuronide and quercitrin content.

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There is a trend between biomass and phytochemical content, where lowered biomass increases the plant's bioactive compound. Optimal nitrogen concentration application rate can increase the yield and active ingredients of *A. mongolica* [14]. Previous studies revealed that increased nutrient concentration can enhance strawberry, cucumber, lettuce, tomato, melon productivity and quality parameters in soilless conditions [27, 28,29, 30, 31]. The positive effects of nutrient concentration in plants have been widely studied, on the morphological and physiological characteristics. Nitrogen concentration affected the growth, yield, fruit quality, and chemical composition of plants [32]. Extract derived from the leaves of *P. minor* has been reported to contain quercetin-3-glucuronide and quercitrin which give the plant its antioxidant properties [33].

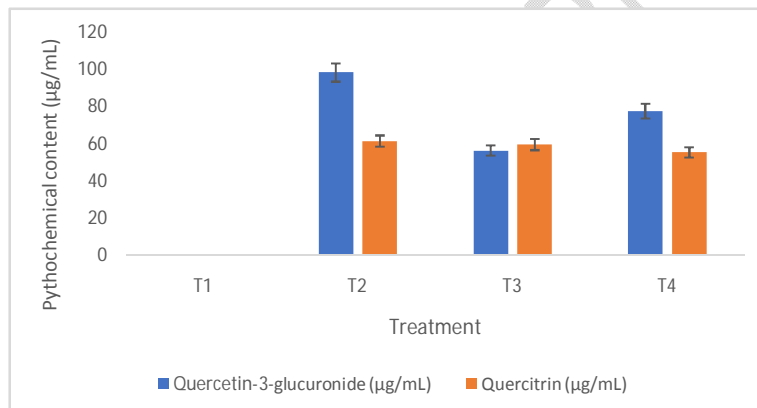


Figure 1: Effects of nitrogen concentration in nutrient solution on quercetin-3-glucuronide and quercitrin content in plants after two months of cultivation

Effects on aromatic content

Significant effects of nutrient concentration were found on the levels of aldehyde-C10, aldehyde C-12, and caryophyllene across treatments (Figure 2). Plants treated with 100 mg/L of nitrogen (T3) had the highest aldehyde-C10 (5.80%) and aldehyde C-12

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(12.23%) content, but the lowest caryophyllene content (9.13%) among all treatments. Conversely, plants treated with 200 mg/L of nitrogen (T4) showed the lowest aldehyde-C10 (0.75%) and aldehyde C-12 (2.11%) content, but the highest caryophyllene content (12.53%). The results indicate that plants given 100 mg/L of nitrogen produced the most vegetative biomass, along with high aldehyde C-10 and C-12 content. However, those treated with 200 mg/L nitrogen produced lower biomass but higher caryophyllene levels.

There is a trend between aldehyde and caryophyllene where a high content of aldehyde in the plant sample lowered caryophyllene content and vice versa. Similar studies on *Kickxiaegyptiaca* essential oil revealed the same pattern linking aldehyde and caryophyllene trends, where high aldehyde with lower caryophyllene content [34]. Generally, nitrogen applications increase oil content and yield in aromatic plants by stimulating biomass, leaf area development and photosynthetic rate level [35]. The results of the present study are also supported by the findings of Daneshian et al. (2009) and Azizi et al. (2009) on plants other than *P. minor*.

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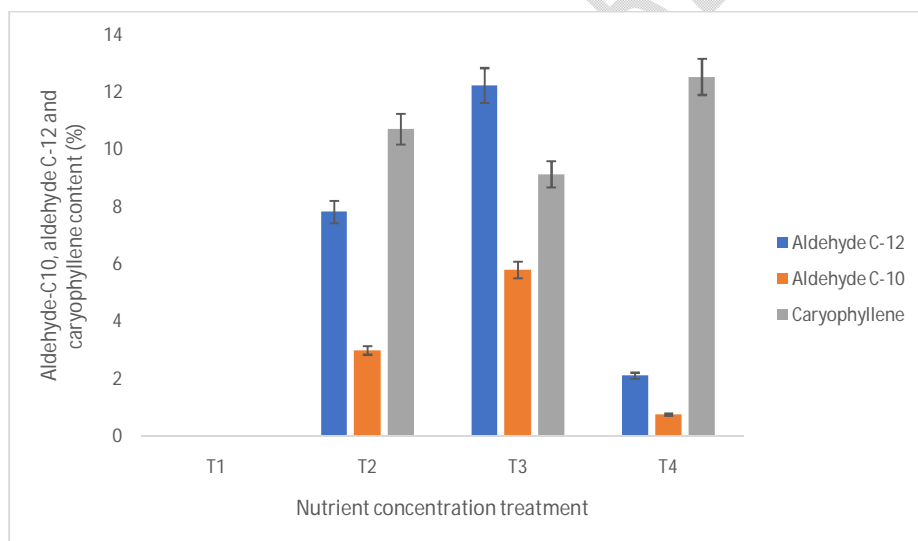


Figure 2: Effects of nutrient solution strength on aldehyde C-10, aldehyde C-12 and caryophyllene contents in plants after two months of cultivation

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CONCLUSION

Studies revealed that *Persicaria Minor* plants respond very well to 50–200 mg/L of nitrogen concentration. When supplemented with nitrogen concentrations ranging

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between 50 – 200 mg/L, the plant was able to grow and produce vegetative biomass. Plants supplemented with 100 mg/L of nitrogen concentration gave the best plant growth performance and the highest aldehyde-C10 and aldehyde C-12 content. Meanwhile, the best nitrogen concentration to obtain the highest quercetin-3-glucuronide and quercitrin contents was 50 mg/L of nitrogen concentration. Plants treated with 200 mg/L nitrogen produced lower biomass but higher caryophyllene levels. Thus, it can be concluded that for plant growth, biomass yield, aldehyde-C10 and aldehyde C-12 content, the nutrient concentration at 100 mg/L is the efficiency rate of application for *Persicaria Minor* grown using a hydroponic system. However, 50 mg/L of nitrogen concentration can be considered to obtain high quercetin-3-glucuronide and quercitrin content. Conversely, 200 mg/L of nitrogen concentration could be an option for high caryophyllene content.

REFERENCES

- [1] Chan, Y. S., Cheah, Y. H., Chong, P. Z., Khor, H. L., Teh, W. S., Khoo, K. S., Ong, H. C., & Sit, N. W. (2018). Antifungal and cytotoxic activities of selected medicinal plants from Malaysia. *Pakistan Journal of Pharmaceutical Sciences*, 31(1), 119–127.
- [2] Musa Ahmed, A., Razauden, M. Z., Atiqah, W. N., W. H., Husni, A. MS, Nik Ahmad Nizam, N. M., Zarita, Z., & Farediah, A. (2015). Antibacterial properties of *Persicaria minor* (Huds.) ethanolic and aqueous-ethanolic leaf extracts. *Journal of Applied Pharmaceutical Sciences*, 5(2), 050–056.
- [3] Vimala, S., Rohana, S., Rashih, A. A., & Juliza, M. (2011). Antioxidant evaluation in Malaysian medicinal plant: *Persicaria minor* (Huds.) leaf. *Sci J Med and Clin trials*, 7487, 2276.
- [4] Arasu, M. V., Arokiyaraj, S., Viayaraghavan, P., Kumar, T. S. J., Duraipandiyar, V., Al-Dhabi, N. A., & Kaviyarasu, K. (2019). One step green synthesis of larvicidal, and azo dye degrading antibacterial nanoparticles by response surface methodology. *Journal of Photochemistry and Photobiology. B, Biology*, 190, 154–162.
- [5] Jongrungraungchok, S., Madaka, F., Wunnakup, T., Sudsai, T., Pongphaew, C., Songsak, T., & Pradubyat, N. (2023). In vitro antioxidant, antiinflammatory, and anticancer activities of mixture Thai medicinal plants. *BMC complement. Médecine Therapeutique*, 23, 43.
- [6] Fujita, K., Chavasiri, W., & Kubo, I. (2015). Anti-salmonella activity of volatile compounds of Vietnam coriander. *Phytotherapy Research*, 29(7), 1081–1087.
- [7] Wannissorn, B., Jarikasem, S., Siriwangchai, T., & Thubthimthed, S. (2005). Antibacterial properties of essential oils from Thai medicinal plants. *Fitoterapia*, 76(2), 233–236..
- [8] Nanasombat, S., & Teckchuen, N. (2009). Antimicrobial, antioxidant and anticancer activities of Thai local vegetables. *Journal of Medicinal Plants Research*, 3(5), 443–449.

- [9] Azmil, A. R., I., Omar, T., & Ahmad, A. W. (2001). Effect of agronomic practices on the yield and oil quality of kesum (*Polygonum minus*). *Journal of Tropical Agriculture and Food Science*, 29(1), 1–6.
- [10] Yaseer Suhaimi, M., Izyani, R., Effendi, M., Nor, M., SitiNurzahidah, Z. A., Zakry Al-Asyraf, A. L., & Muhammad Faidhi, T. (2022). Penanamankesumsecarahidroponik. *Buletin Teknologi MARDI*, 31, 9–15.
- [11] Savvas, D., & Passam, H. (2002). *Hydroponic production of vegetables and ornamentals*. Embryo Publication.
- [12] Guérouneau, C., Bigey, J., Longuesserre, J., Navatel, J.-C., Pommier, J.-J., & Raynal-Lacroix, C. (2003). *La culture du fraisiers substrat; centre technique interprofessionnel des fruits et légume*. Paris, France.
- [13] Zhou, J., Kulkarni, M. G., Huang, L. Q., Guo, L. P., & Van Staden, J. (2012). Effects of temperature, light, nutrients and smoke-water on seed germination and seedling growth of *Astragalus mongolicus*, *Panax notoginseng* and *Magnolia officinalis*—Highly traded Chinese medicinal plants. *Biology*, 79, 62–70.
- [14] Wang, L., Yang, L., Xiong, F., Nie, X., Li, C., Xiao, Y., & Zhou, G. (2020). Nitrogen Fertilizer Levels Affect the Growth and Quality Parameters of *Astragalus mongolicus*. *Molecules*, 25(2), 381.
- [15] Singh, M., Sharma, S., & Ramesh, S. (2002). Herbage, oil yield, and oil quality of patchouli (*Pogostemon cablin* (Blanco) Benth.) influenced by irrigation, organic mulch, and nitrogen application in semi-arid tropical climate. *Industrial Crops and Products*, 16(2), 101–107.
- [16] Yaseer Suhaimi, M., Mohamad, A. M., & Mahamud, S. (2009). Planting containerized ginger (*Zingiber officinale* Roscoe) using fertigation. In Proceeding of 20th Malaysian Society of Plant Physiology conference (pp. 10–11).
- [17] Yaseer Suhaimi, M., Mohamad, A. M., Mahamud, S., Rezuwan, K., Fadlilah Annaim Huda, H., & Azman, J. (2011). Effects of temperature gradient generated by fan-pad cooling system on yield of cabbage grown using fertigation technique under side netted rain shelter. *Journal of Tropical Agriculture and Food Science*, 39(1), 93–101.
- [18] Huang, J., He, F., Cui, K., Buresh, R. J., Xu, B., Gong, W., & Peng, S. (2008). Determination of optimal nitrogen rate for rice varieties using a chlorophyll meter. *Field Crops Research*, 105(1–2), 70–80.
- [19] Sakamoto, M., & Suzuki, T. (2022). Effect of nutrient solution concentration on the growth of hydroponic sweet potato. *Agronomy*, 10, 1708.

- [20] MousaviKouhi, S. M. M., Lahouti, M., Ganjeali, A., & Entezari, M. H. (2014). Comparative phytotoxicity of ZnO nanoparticles, ZnOmicroparticles and Zn₂t on rapeseed (*Brassica napus* L.): Investigating a wide range of concentration. *Toxicological and Environmental Chemistry*, 96(6), 861–868.
- [21] Santachiara, G., Borrás, L., Salvagiotti, F., Gerde, J. A., & Rotundo, J. L. (2017). Relative importance of biological nitrogen fixation and mineral uptake in high yielding soybean cultivars. *Plant and Soil*, 418(1–2), 191–203.
- [22] Wu, Y. W., Li, Q., Jin, R., Chen, W., Liu, X. L., Kong, F. L., Ke, Y. P., Shi, H. C., & Yuan, J. C. (2019). Effect of low-nitrogen stress on photosynthesis and chlorophyll fluorescence characteristics of maize cultivars with different low-nitrogen tolerances. *Journal of Integrative Agriculture*, 18(6), 1246–1256.
- [23] Manzocco, L., Foschia, M., Tomasi, N., Maifreni, M., Dalla Costa, L., Marino, M., Cortella, G., & Cesco, S. (2011). Influence of hydroponic and soil cultivation on quality and shelf life of ready-to-eat lamb's lettuce (*Valerianellalocusta* L. Laterr). *Journal of the Science of Food and Agriculture*, 91(8), 1373–1380.
- [24] Miller, M. H., Walker, G. K., Tollenaar, M., & Alexander, K. G. (1989). Growth and yield of maize (*Zea mays* L.) grown outdoors hydroponically and in soil. *Canadian Journal of Soil Science*, 69(2), 295–302.
- [25] Lawlor, D. W. (2002). Carbon and nitrogen assimilation in relation to yield: Mechanisms are the key to understanding production systems. *Journal of Experimental Botany*, 53(370), 773–787.
- [26] Bloom, A. J., Frensch, J., & Taylor, A. R. Influence of inorganic nitrogen and pH on the elongation of maize seminal roots. (2006). *Annals of Botany*, 97(5), 867–873.
- [27] Asao, T., Asaduzzaman, M., Mondal, M. F., Tokura, M., Adachi, F., Ueno, M., Kawaguchi, M., Yano, S., & Ban, T. (2013). Impact of reduced potassium nitrate concentrations in nutrient solution on the growth, yield and fruit quality of melon in hydroponics. *Scientia Horticulturae*, 164, 221–231.
- [28] Sapkota, S., Sapkota, S., & Liu, Z. (2019). Effects of nutrient composition and lettuce cultivar on crop production in hydroponic culture. *Horticulturae*, 5(4), 72.
- [29] Conesa, E., Niñirola, D., Vicente, M. J., Ochoa, J., Bañón, S., & Fernández, J. A. (2009). The influence of nitrate/ammonium ratio on yield quality and nitrate, oxalate and vitamin C content of baby leaf spinach and bladder campion plants grown in a floating system. *Acta Horticulturae*. Papers presented at The International Symposium on Soilless Culture and Hydroponics, International Society for Horticultural Science, held at Leuven, Belgium, 2008(843), (269–274).

- [30] Fallovo, C., Roupael, Y., Cardarelli, M., Rea, E., Battistelli, A., & Colla, G. (2009). Yield and quality of leafy lettuce in response to nutrient solution composition and growing season. *Journal of Food, Agriculture and Environment*, 7, 456–462.
- [31] Nakro, A., Bamouh, A., Bouzlama, H., San Bautista, A., & Ghaouti, L. (2023). The effect of potassium–nitrogen balance on the yield and quality of strawberries grown under soilless conditions. *Horticultrae*, 9(3), 304.
- [32] Tabatabaei, S. J., Fatemi, L. S., & Fallahi, E. (2006). Effect of ammonium: Nitrate ratio on yield, calcium concentration, and photosynthesis rate in strawberry. *Journal of Plant Nutrition*, 29(7), 1273–1285.
- [33] Baharum, S. N., Bunawan, H., Ghani, M. A., Mustapha, W. A., & Noor, N. M. (2010). Analysis of the chemical composition of the essential oil of *Polygonum minus* Huds. using two-dimensional gas chromatography-time-of-flight mass spectrometry (GC-TOF MS). *Molecules*, 15(10), 7006–7015.
- [34] Abd-ElGawad, A. M., El-Amier, Y. A., Bonanomi, G., Gendy, A. E.-N. G. E., Elgorban, A. M., Alamery, S. F., & Elshamy, A. I. (2022). Chemical composition of *Kickxiaegyptiaca* essential oil and its potential antioxidant and antimicrobial activities. *Plants*, 11(5), 594.
- [35] Sangwan, N. S., Farooqi, A. H. A., Shabih, F., & Sangwan, R. S. (2001). Regulation of essential oil production in plants. *Plant Growth Regulation*, 34(1), 3–21.
- [36] Daneshian, A., Gurbuz, B., Cosge, B., & Ipek, A. (2009). Chemical components of essential oils from basil (*Ocimum basilicum* L.) grown at different nitrogen levels. *International Journal of Natural and Engineering Sciences*, 3, 9–13.
- [37] Azizi, A., Yan, F., & Honermeier, B. (2009). Herbage yield, essential oil content and composition of three oregano (*Origanum vulgare* L.) populations as affected by soil moisture regimes and nitrogen supply. *Industrial Crops and Products*, 29(2–3), 554–561.