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Growth and yield of purple pakchoi *(Brassica rapa* var. *Chinensis)* under different cultivation systems and plant population densities

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Abstract. Rapid urbanization in Indonesia has converted productive agricultural land, thereby threatening national food security. Urban farming has emerged as a sustainable solution to address limited land availability. The increasing land constraints further limit the available cultivation area. Urban farming is a sustainable solution to land limitations for food needs of urban communities. Purple pakchoi *(Brassica rapa* var. *Chinensis)* is a leafy vegetable with high economic value, rich in anthocyanins, and has a short growing season; suitable for urban cultivation systems. This study aimed to evaluate the effects of different cultuvation system; conventional and floating, with different population densities on the growth and yield of purple pakchoi. The experiment was arranged using a split-plot design. Growth variables included leaf and stem parameters, while yield variables included fresh and sry weight, also water conten of plant organ. The results showed that cultivation system significantly affected the number of leaves, leaf length and width, canopy diameter, and stem thickness. Plant population density siginificantly influenced all yield parameters. Higher population density reduced individual plant weight but increased total fresh weight per pot, indicating more efficient land use. However, plant morphology including leaf characteristics was not significantly affected by either factor. The highest yield per pot was obtained under conventional system with high population density (3 plant pot^{-1}); 88.15 g pot^{-1}. Overall, the floating cultivation system supported comparable growth to the conventional system. These findings suggest that optimizing cultivation system and plant population density can improve productivity of purple pakchoi in urban farming system.

Key words: cultivation system, food security, plant density, purple pakchoi, urban farming.

INTRODUCTION

Indonesia faces challenges in food supply due to rapid urbanization. According to national statistics and World Bank projections, approximately 70% of Indonesia's population will reside in urban areas by 2045 (Central Bureau of Statistics, 2024). This rapid urban expansion has led to conversion of many productive agricultural land into residential and industrial areas (Gandharum et al., 2022), thereby reducing arable land while food demand continues to increase. The decrease in agricultural land is inversely proportional to increasing demand for food due to population growth (Wang, 2022). If not properly managed, this conditions poses a serious threat to national food security. Along with increasing market demand and increasingly limited agricultural land, urban farming has become an alternative solution to increase food security, especially vegetable productivity.

Urban farming has emerged as a starategic solution land limitations while enhancing food production in urban areas. It enables the cultivation of crops in limited spaces through both horizontal and vertical approaches (Akintuyi, 2024), including conventional yard-based system (Fadilah et al., 2022) and controlled-environment such as mini greenhouses, hydroponics, and vertical cultivation system (Hussen & Ahmed, 2025). Vegetable crops are perticularly suitable for urban farming system due to their short growth cycle, high nutritional value, and economic potential. One promosing crop is pakchoi *(Brassica rapa* var. *Chinensis),* wich is widely consumed and has high market demand globally and in Indonesia (Rubatzky & Yamaguchi, 1998; Zhang et al., 2014; Priadi & Nuro, 2017), and considered to supplementing selenium for humans (Li et al., 2018). Purple pakchoi, in particular contains anthocyanins that function as natural antioxidant (Song et al., 2020), making it a valuable horticultural commodity for urban agriculture. Purple pakchoi is a horticultural commodity well-suited for urban farming systems. This plant belongs to the Brassicaceae family which is highly adaptable to different environmental conditions and has a short planting cycle (Kim et al., 2021). In addition, pakchoi adapts well to itensive cultivation system and can be grown in containers, making it suitable for urban farming condition. However, previous studies have primarily evaluated cultivation system or plant population density separatly under urban lowland conditions. Although previous studies have evaluated the effects of cultivation system and plant population density on purple pakchoi is still limited. Therefore, this study provides a novel contribution by simultaneously evaluating cultivation system x plant population density interactions to optimize purple pakchoi production in urban ecosystem.

The growth and yield of purple pakchoi are influenced by several factor, including cultivation system and plant population density. Cultivation system determine the efficiency of recource use such as light, water, nutrient, and growing space (Arina et al., 2021). Conventional system rely on soil based media, while floating cultivation system utilize water based media where plant roots absorb nutrients through continous water contact. Floating cultivation provides more continuous water availabillity through capillary movement from the water layer beneath the growing medium. This floating system has advantages in maintaining consistent water availability and is particulary suitable for areas prone to waterlogging or limited irrigation control (Chowdhury & Moore, 2017; Kartika et al., 2021). Although is generally carried out to maintain agricultural cultivation practices in wetland on flood or rainy conditions (Jaya et al., 2021; Kartika et al., 2021; Siaga & Lakitan, 2021), they are recommended for ecologically sustainable urban agriculture (Zhang, et al., 2014; Orsini et al., 2014). In addition, plant population density affect the level of competition among plant for light, nutrients, and space, wich ultimately influences plant growth and yield (Pant & Sah, 2020). Pervious studies have reported that lower plant density tends to inclease individual plant grwoth, whereas higher densuty can maximize yield per unit area, especially under limitde land condition (Ria et al., 2023).

Research on the interaction between cultivation systems and plant populations in purple pakchoi is still limited, even though this information is crucial for developing specific technical recommendations. A deep understanding of the growth response and yield of purple pakchoi to different combinations of cultivation systems and plant population will significantly contribute to the development of efficient and sustainable cultivation technologies. Therefore, this study aims to determine the effect of different cultivation systems and plant population densities on the growth and yield of purple pakchoi under urban farming conditions. This research is expected to provide appropriate technical recommendations for the development of purple pakchoi cultivation in urban environments, thereby supporting food security and economic programs for urban communities.

MATERIALS AND METHODS

The experiment was conducted under tropical lowland conditions at the Jakabaring Research Facility (104°46′44″E; 3°01′35″S), Palembang, South Sumatra, Indonesia. During the experimental period, the average air temperature was 35 °C with relative humidity 51%. Purple pakchoi *(Brassica rapa* var. *Chinensis)* seeds were obtained from a commercial supplier. Seeds were soaked in tap water for 15 minutes to ensure uniform germination. The seed sown in seedling trays containing a mixture of soil and chicken manure (1:1 v/v). The chicken manure contained approximately 3–5% N, 1.5–3.5% P, and 1.5–3.0% K. Seedlings at 14 days after sowing (DAS); when they had developed two true leaves, were transplanted into plastic pots. Each pot was filled with a growth medium consisting of soil and chicken manure (3:1 v/v) (Fadilah et al., 2022). The medium was sanitized 14 days before transplanting using a bio-sterilizer containing *Streptomyces* sp., *Geobacillus* sp., and *Trichoderma* sp. at a dose 200 mL per plant.

In the conventional system, plants were irrigated manually twice daily (morning and afternoon) to maintaing field capacity conditions. In the floating system, the pots were placed on floating rafts positioned above a water pond, allowing continuous water supply to the growing media through capillary movement from the bottom of the pots. Weeding was carried out manually whenever weeds appeared in the pots. Fertilization was applied using NPK fertilizer at 14 days after planting (DAP) at a dose of 3 g per pot. Pest and disease control was conducted manually through mechanical removal when necessary.

Experimental design

The experiment was arranged using a split-plot design with three replications. The main plot factor consisted of two cultivation systems: 1) conventional cultivation; where plants were grown in pots placed on land (C1), and 2) floating cultivation, where pots were placed on floating rafts positioned on a water pond. The subplot factor was plant population density consisting of three levels (Fig. 1); 1 plant pot^{-1} (D1); 2 plant pot^{-1} (D2); and 3 plants/pot (D3). Each pot had a surface area of 452 cm² and adjusted proportionally to simulate different spatial competition levels under limited urban growing conditions. Therefore, the effective growing area per plant was 452 cm² in D1, 226 cm² in D2, and 151 cm² in D3. Each treatment combination was randomly assigned within each replication. Main plot consisted of 3 replications; each replication consisted of 18 pots, so there were 54 pots in each main plot and a total of 108 pots.

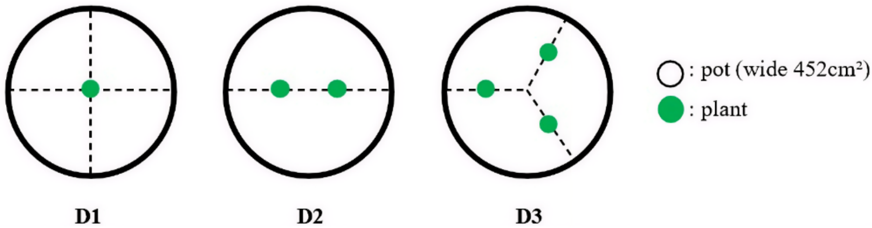

Figure 1. Location of purple pakchoi per pot in plant population density treatment.

Data measurement

Collected data on plant growth included number of leaves, leaf length, leaf width, petiole length, and canopy diameter. The mature plants were harvested at 49 DAS or 35 DAP (Fadilah et al., 2022). Variables measured at harvest included organs above the soil surface, namely total plant fresh weight, leaf blade fresh and dry weight, leaf blade water content; petiole fresh and dry weight, petiole water content; stem diameter, stem fresh and dry weight, stem water content; below ground components were root length, root fresh and dry weight, root water content. Measurements of all dimensional variables were measured using a transparent ruler and variables related to weight were measured using a digital scale.

Analysis of purple pakchoi leaf characteristics was developed based on direct measurement data on leaf length and width use of coefficient determination values from power regression models with multiple predictors (Fadilah et al., 2022), namely leaf length and width. The variables analyzed included leaf length and width ratio, leaf length and stem length ratio, specific leaf area, and specific leaf weight. Measurements of agroclimatology parameters were carried out to support the research data. Data collected included air temperature and humidity measured using a Wireless Thermo Recorder RTR-502, soil temperature using a Digital Thermometer Krisbow KW06-308, soil moisture using a Lutron PMS-714 Soil Moisture Meter, and leaf temperature measured using a FLIR C3-X Nessaku.

Data analysis

Data were analyzed using Analysis of Variance (ANOVA) based on a split-plot design with cultivation system as the main plot and plant population density as the subplot. Statistical analysis was performed using SAS Software (SAS 9.0; SAS Institute Inc., USA). Significant differences among treatments were tested using the Least Significant Difference (LSD) test at $P \leq 0.05$. The interaction effects between cultivation system and plant population density were also evaluated. Regression and correlation analyses were performed to determine the relationships among observed variables, and the coefficient of determination (R^2) was used to describe the strength of these relationships.

RESULTS AND DISCUSSION

The number of leaves was significantly affected by the cultivation system from 14 DAP until harvest (Fig. 2). Plants grown under the floating system consistently produced a higher number of leaves compared to those grown under the conventional system. The result indicates that continuous water availability in the floating system supports better vegetative growth. The floating system consisted of a water layer approximately 5–13 cm, allowing continuous capillary water supply to the planting media. This condition is particularly beneficial for young plants, which have limited root systems and a reduced capacity to absorb water from a restricted substrate volume (Kartika et al., 2021).

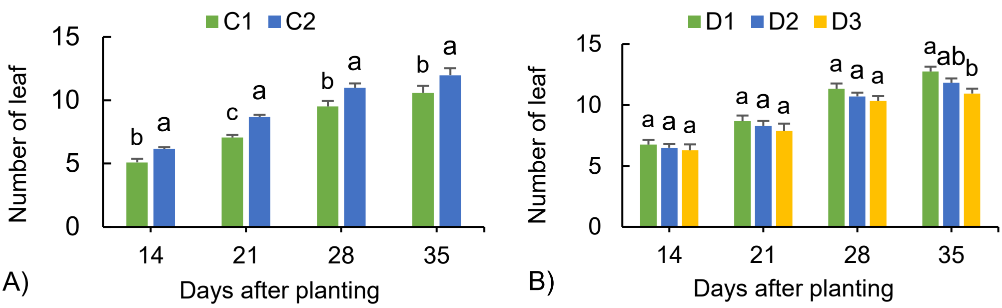

Figure 2. Effect of cultivation system (A) and plant population density (B) on the number of leaves in purple pakchoi.

Adequate water supply enhances cell expansion and leaf initiation, which are essential for leafy vegetable growth. Optimal water availability also accelerates physiological processes and overall plant growth. Similar findings were reported in previous studies showing that floating systems improve vegetative development in Brassica (Kartika et al., 2021). Overall, the cultivation system affected most growth variables of purple pakchoi, except leaf length at 28 DAP and stem length at 21–35 DAP. The difference in the number of leaves between cultivation systems began two weeks after planting (WAP) and continued until harvest.

These differences are primarily attributed to water availability. Floating cultivation systems provide a more stable water supply because water is continuously available without the need for regular irrigation. As a result, plants grown under the floating system exhibit a greater number of leaves and improved leaf and petiole development. Similar responses were observed in tatsoi *(Brassica rapa* subsp. *narinosa)* (Kartika et al., 2021) and green mustard (Siaga & Lakitan, 2021), which grow well under floating cultivation systems. Conversely, limited water availability reduces plant growth and negatively affects physiological, ecological, and morphological processes (Chadha et al., 2019).

The cultivation system also affected the increase in leaf blade length, leaf blade width, and petiole length of purple pakchoi (Fig. 3). Plants grown under the floating system showed a tendency for slower growth as harvest approached. This occur because the growing media becomes excessively moist over time, potentially reducing aeration and inhibiting root activity. The results of this study are consistent with those of Kartika et al. (2021), who observed better early growth in tatsoi under floating cultivation. However, plants are able to adapt well to both floating and conventional systems provided that sufficient nutrients are available. Limited water availability during early growth stages can inhibit leaf formation and reduce leaf number in *Brassica* species (Ackah & Kotei, 2021). Previous studies on floating cultivation also showed higher mineral nutrient content (Ca, Mg, and Fe) compared to other cultivation systems (Giro & Ferrante, 2016), which is beneficial for consumption.

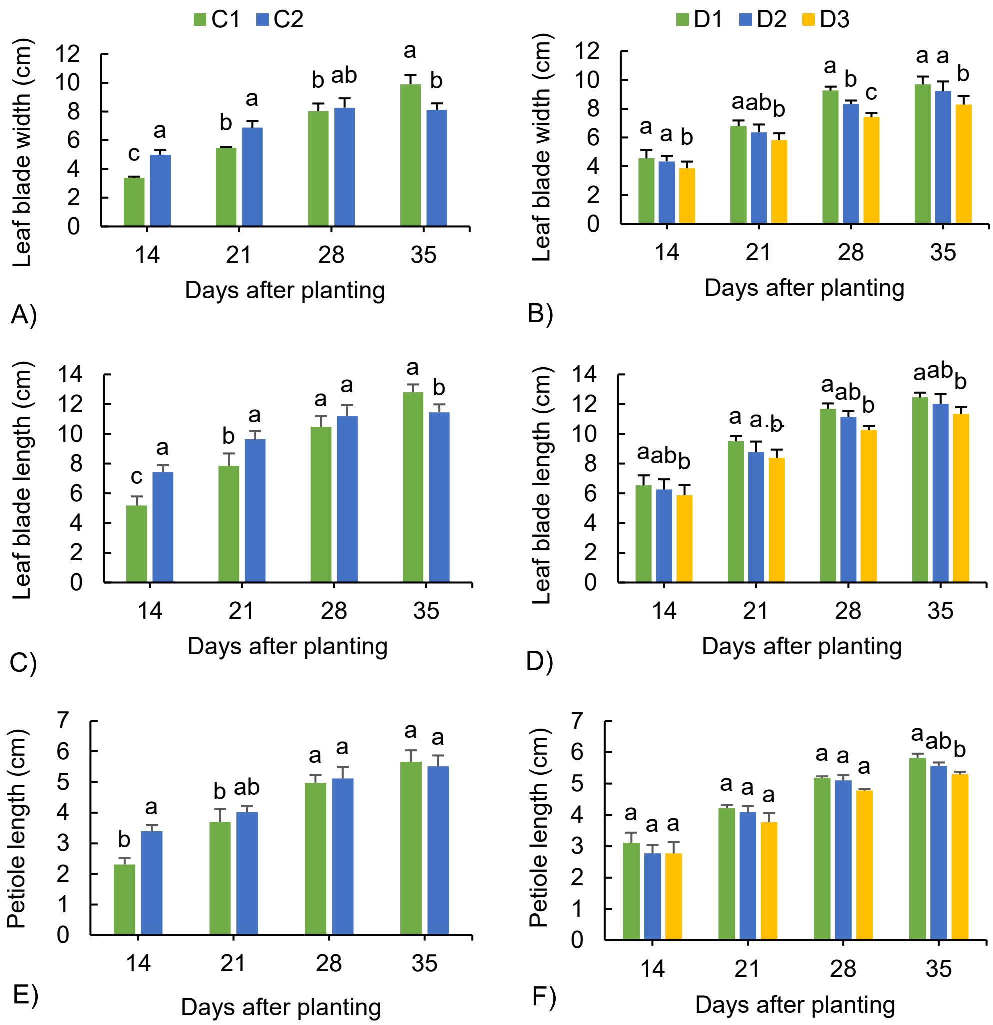

Figure 3. Effect of cultivation system and plant population density on leaf blade width (A–B), leaf blade length (C–D), and petiole length (E–F) in purple pakchoi.

Plant population density significantly affected pakchoi growth, particularly the number of leaves and leaf blade length at 28 DAP, as well as leaf blade width at most observation times (except at 21 DAP). Differences in leaf number, length, and width were mainly caused by competition among plants for root space, nutrients, and light due to limited growing area. Under wider spacing conditions, plant canopies develop more fully and intercept solar radiation more efficiently to support photosynthesis. In contrast, higher plant density reduces light availability within the canopy (Arrusy, 2021; Utari, 2021). Adequate spacing promotes vegetative development, resulting in longer and larger leaves, whereas closer spacing increases competition for water, nutrients, and light, ultimately suppressing plant growth (Hasan et al., 2017; Gashaw & Sheway, 2020). Lower planting density also enhances vegetative plasticity, leading to more vigorous plant growth (Diriba et al., 2017; Rondanini et al., 2020).

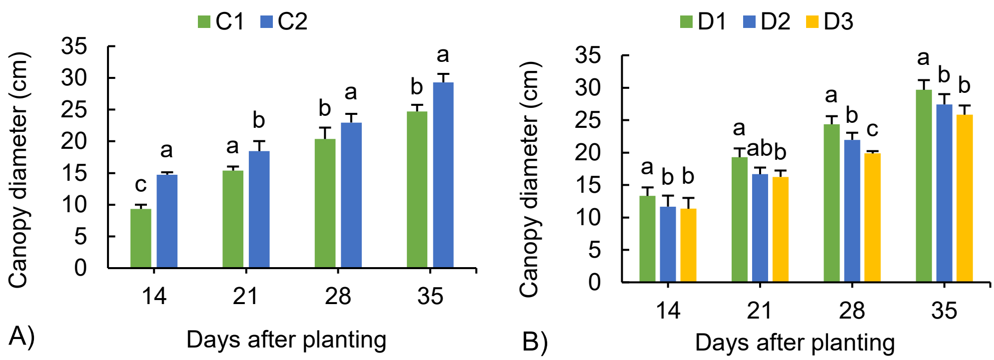

Figure 4. Effect of cultivation system (A) and plant population density (B) on the canopy diameter in purple pakchoi.

The canopy diameter of purple pakchoi increased with plant age (Figs 4, 5). This parameter was influenced by both the cultivation system and the number of plants per pot. Adequate water supply resulted in better plant growth. A single plant per pot allows plants to avoid competition for nutrients and light, thereby supporting optimal growth. In contrast, competition among plants (up to three plants per pot) began to occur from 3 WAP, leading to canopy overlap. However, purple pakchoi grown under relatively narrow spacing was still able to grow well (Fig. 5).

Canopy diameter showed a similar growth pattern to the number of leaves, leaf blade length and width, and petiole length. Koch et al. (2019) stated that leaf area growth can be inhibited under water stress conditions due to decreased epidermal cell activity. Reduction in leaf area is a common plant response under limited water conditions (Sacita et al., 2018). Furthermore, plants grown at lower population density (occupying larger space) tend to grow and develop faster, whereas plants at higher density compete for the same resources (Lakitan & Kartika, 2020). Similarly, excessive planting density in kaila (*Brassica oleracea* var. *Alboglabra)* has been shown to inhibit leaf expansion (Dantri et al., 2015).

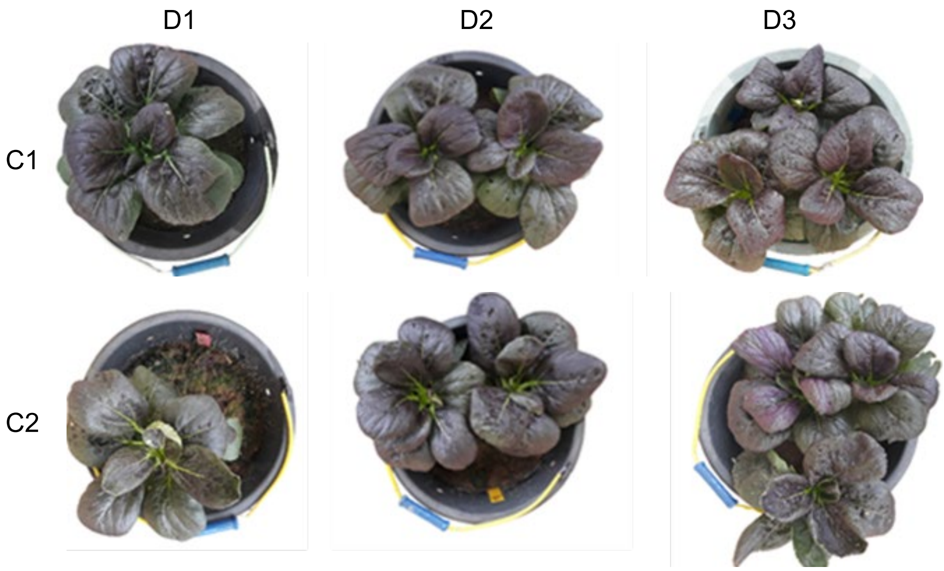

Figure 5. Effect of population density (D1; D2; D3) on conventional (C1) and floating system (C2) in purple pakchoi.

Different effects were observed on purple pakchoi yield. Plant population density significantly affected yield (Fig. 6). This effect is attributed to competition for nutrient uptake, canopy overlap, light interception, and root growth space. Increasing plant population up to three plants per pot resulted in a decrease in fresh weight per plant. However, the highest total yield per pot was achieved at the highest plant density. This indicates that higher plant density provides an advantage in maximizing the use of limited space. In other words, although individual plant performance declines, total fresh weight per pot increases with higher plant density. This reflects a trade-off between individual plant growth and overall productivity per unit area.

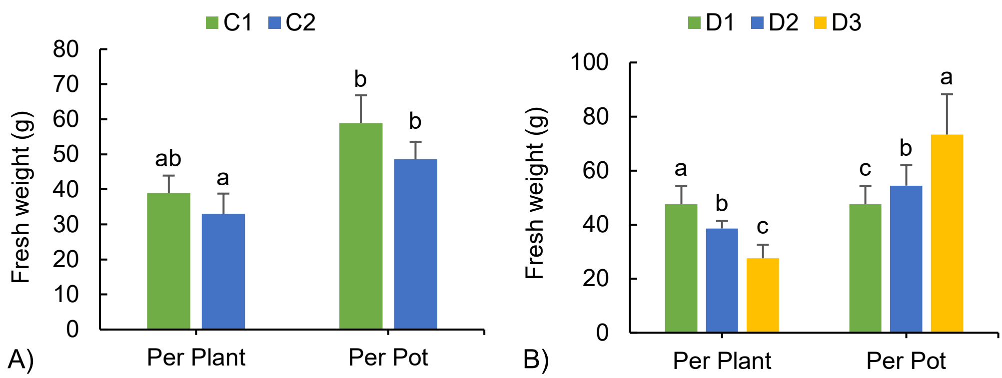

Figure 6. Fresh weight per plant and total fresh weight per pot in different cultivation systems (A) and plant population density (B).

The results of this study are in line with previous research. Although high plant density generally restricts individual plant growth, it can increase total yield per unit area (Ria et al., 2023). A similar phenomenon has been reported in kale, where individual plant performance is better at lower densities, but total yield per pot is higher under dense planting conditions (Lakitan & Kartika, 2020). Optimal plant spacing has also been shown to improve fresh leaf weight in leafy vegetables such as lettuce, beet, and spinach (Hasan et al., 2017; Pawandeep et al., 2020). These findings confirm that plant density plays a crucial role in balancing individual growth and overall yield efficiency.

The cultivation system did not affect purple pakchoi yield. In conventional cultivation, water requirements are supplied regularly, preventing water deficit conditions, even though water availability is not continuous as in the floating system. This suggests that both cultivation systems are able to provide sufficient water to support yield formation, resulting in no significant differences in total production. According to the results on total fresh weight, all parts of the purple pakchoi plant were significantly affected by plant population density (Table 1, 2). Interplant competition influenced fresh weight accumulation and the distribution of organic compounds in plant tissues.

Table 1. Effect of cultivation system and plant population density on fresh weight, dry weight, and water content in purple pakchoi leaf

	Leaf fresh weight (g)	Leaf dry weight (g)	Leaf water content (%)
C1	23.11 ± 2.68^{ab}	2.17 ± 0.33^{a}	0.90 ± 0.0046^{a}
C2	20.05 ± 2.95^{b}	2.02 ± 0.39^{a}	0.90 ± 0.0060^{a}
LSD	5.19	0.48	0.01
D1	28.38 ± 3.22^{a}	2.89 ± 0.22^{a}	0.90 ± 0.0043^{b}
D2	23.26 ± 1.11^{a}	2.17 ± 0.09^{b}	0.91 ± 0.0006^{a}
D3	17.10 ± 1.44^{b}	1.54 ± 0.13^{c}	0.91 ± 0.0011^{a}
LSD	5.19	0.48	0.01

Table 2. Effect of cultivation system and plant population density on fresh weight, dry weight, and water content in purple pakchoi petiole

	Petiole fresh weight (g)	Petiole dry weight (g)	Petiole water content (%)
C1	11.27 ± 1.72^{ab}	0.55 ± 0.08^{ab}	0.95 ± 0.0008^{a}
C2	8.78 ± 1.54^{b}	0.47 ± 0.09^{b}	0.95 ± 0.0004^{a}
LSD	2.87	0.15	0.002
D1	13.17 ± 1.29^{a}	0.71 ± 0.08^{a}	0.95 ± 0.0020^{a}
D2	11.30 ± 0.78^{a}	0.59 ± 0.03^{a}	0.95 ± 0.0025^{a}
D3	7.55 ± 0.95^{b}	0.40 ± 0.06^{b}	0.95 ± 0.0021^{a}
LSD	2.87	0.15	0.002

Data were presented as mean ± standard error. The means followed by different letters within each column indicate significant difference at the $LSD_{.05}$.

In contrast, the cultivation system and its interaction with plant population density did not significantly affect water content or organic compound accumulation. This indicates that biomass allocation and tissue water status are more strongly influenced by plant competition than by differences in cultivation systems.

A different response was observed in stem diameter, which was significantly influenced by both the cultivation system and plant population density (Table 3). This indicates that stem development is sensitive to both water availability and interplant competition. However, stem diameter did not significantly affect stem fresh or dry weight. This suggests that increases in stem thickness were not directly associated with biomass accumulation. Furthermore, stem water content and organic compound accumulation were relatively similar across cultivation systems, indicating comparable physiological conditions between treatments. Competition for water and nutrient uptake under higher plant population density contributed to variations in stem fresh weight. Under dense planting conditions, limited resource availability may restrict assimilate allocation to the stem, thereby affecting its biomass despite differences in diameter.

Table 3. Effect of cultivation system and plant population density on diameter, fresh weight, dry weight, and water content in purple pakchoi stem

	Stem diameter (mm)	Stem fresh weight (g)	Stem dry weight (g)	Stem water content (%)
C1	9.46 ± 0.21^{b}	3.68 ± 0.26^{a}	0.34 ± 0.006^{a}	0.91 ± 0.0119^{a}
C2	8.86 ± 0.42^{b}	3.56 ± 0.50^{a}	0.32 ± 0.045^{a}	0.91 ± 0.0005^{a}
LSD	0.77	0.83	0.10	0.02
D1	9.98 ± 0.70^{a}	4.16 ± 0.05^{a}	0.36 ± 0.018^{a}	0.91 ± 0.004^{a}
D2	9.81 ± 0.33^{a}	3.75 ± 0.04^{ab}	0.38 ± 0.041^{a}	0.90 ± 0.007^{a}
D3	8.86 ± 0.42^{b}	3.01 ± 0.02^{c}	0.26 ± 0.022^{b}	0.92 ± 0.004^{a}
LSD	0.77	0.83	0.10	0.02

Data were presented as mean ± standard error. The means followed by different letters within each column indicate significant difference at the $LSD_{.05}$

All root variables showed no significant differences (Table 4). This result suggests that root growth was relatively stable across treatments. However, a declining trend in root growth was observed with increasing plant population density (Fig. 7) due to intensified competition for belowground resources. In addition, excessively moist soil conditions, particularly under the floating cultivation system contributed to reduced root development. High moisture levels can limit oxygen availability in the root zone, thereby inhibiting root respiration and elongation. Leafy vegetables generally have a short growth cycle, resulting in relatively limited root system development. Therefore, root growth remained relatively optimal across different cultivation systems and spacing conditions. This indicates that the short cultivation period may reduce the sensitivity of root parameters to environmental variation.

Table 4. Effect of cultivation system and plant population density on length, fresh weight, dry weight, and water content in purple pakchoi stem

	Root length (cm)	Root fresh weight (g)	Root dry weight (g)	Root water content (%)
C1	19.04 ± 1.36^{a}	2.63 ± 0.27^{a}	0.22 ± 0.02^{a}	0.92 ± 0.005^{a}
C2	20.06 ± 0.57^{a}	2.95 ± 0.30^{a}	0.27 ± 0.02^{a}	0.91 ± 0.001^{b}
LSD	3.46	1.50	0.12	0.008
D1	21.34 ± 0.19^{a}	4.10 ± 0.31^{a}	0.31 ± 0.03^{a}	0.92 ± 0.004^{a}
D2	18.45 ± 0.29^{a}	2.42 ± 0.22^{b}	0.22 ± 0.01^{a}	0.92 ± 0.001^{a}
D3	17.90 ± 1.15^{a}	2.52 ± 0.20^{b}	0.20 ± 0.03^{a}	0.92 ± 0.004^{a}
LSD	3.46	1.50	0.12	0.008

Data were presented as mean ± standard error. The means followed by different letters within each column indicate significant difference at the $LSD_{.05}$.

Although plant population density affected the fresh and dry weight of purple pakchoi, it did not significantly influence the water content of leaves, petioles, stems, and roots. This indicates that plant water status remained relatively stable across different population densities. Transpiration is generally balanced by water absorption through the roots (Lakitan & Kartika, 2020), even when canopy diameter varies. Therefore, no significant differences were observed in plant water content or leaf temperature across cultivation systems. The dry weight of leaves, petioles, stems, and roots followed a similar pattern to fresh weight, indicating consistent biomass allocation under different treatments. However, a different pattern was observed in stem diameter, which decreased as plant population density increased. Cabbage plants grown at low population densities exhibit better growth due to reduced competition (Erwin et al., 2015). Similarly, higher plant population density reduces stem and leaf quality due to increased competition for water, nutrients, and sunlight (Lakitan & Kartika, 2020). Such competition can also inhibit root development, thereby limiting resource uptake. These results further confirm that, although biomass production is affected, plant population density does not alter the water content of plant tissues. To minimize competition between plants, particularly in pakchoi cultivation, wider spacing can be applied to reduce both aboveground and belowground competition (Murtiawan et al., 2018).

D1 D2 D3

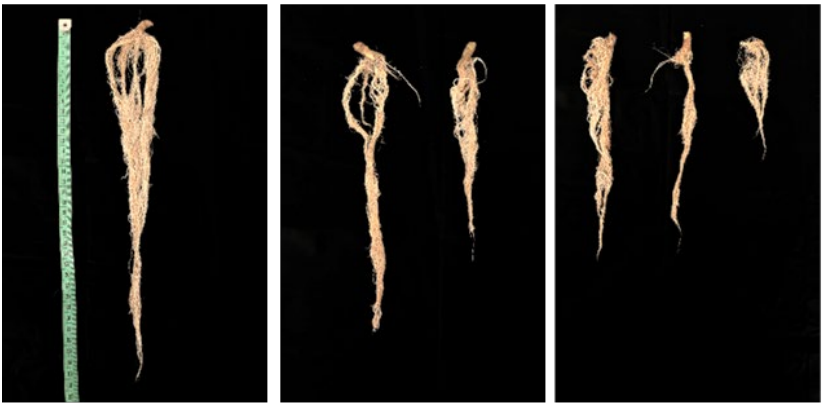

Figure 7. Effect of plant population on the root length of purple pakchoi.

Differences in cultivation system and plant population density did not affect leaf shape. From planting until harvest, purple pakchoi leaves maintained a consistent morphology (Fig. 8). The leaves are typically oval to oblong, with leaf length exceeding leaf width. Due to this characteristic shape, the ratio of leaf blade length to petiole length was analyzed. The results showed that the leaf blade length was greater than the petiole length (Fig. 8).

This indicates that assimilates from photosynthesis were predominantly allocated to leaf blade development. Consequently, purple pakchoi leaves tend to be longer than the petioles. These findings suggest that cultivation system and plant population density primarily influence plant size rather than morphological traits. Fadilah et al. (2022) reported that purple pakchoi has spoon-shaped, elliptical leaves, with leaf blade length exceeding both petiole length and leaf width. The present results are consistent with these findings, confirming that cultivation system and plant population density affect only the size of plant organs (e.g., leaf length, leaf width, petiole length, stem diameter, and root length), but not overall plant morphology.

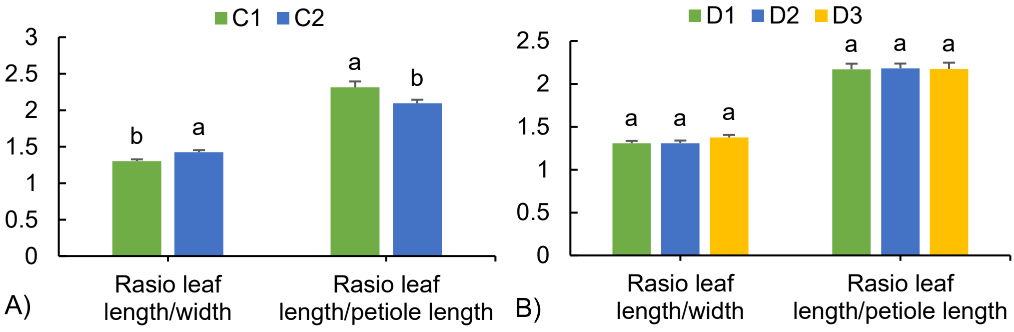

Figure 8. Effect of cultivation system (A) and plant population density (B) on the ratio leaf length/width and ratio leaf length/petiole length in purple pakchoi.

Differences in cultivation system and plant population density did not significantly affect the specific leaf area or individual leaf weight of purple pakchoi (Fig. 9). The leaf area ranged from 22.2 to 25.8 cm². An increase in leaf area is generally associated with thinner leaves, which in turn influences leaf weight. Consistent with this, individual leaf weight was relatively low (< 0.01 g). The estimation of specific leaf area and specific leaf weight was based on the coefficient of determination (R^2) obtained from a power regression model with double predictors (P × L) (Fadilah et al., 2022). Power regression has been shown to be an accurate method for estimating leaf area in vegetable crops (Lakitan et al., 2021). These results confirm that individual leaf area and weight were not influenced by cultivation system or plant population density.Leaf area plays a key role in determining leaf weight, where larger leaves tend to be flatter and thinner. A flat leaf structure allows optimal physiological function by regulating leaf initiation, shape, and polarity (Du et al., 2018). Consequently, thinner leaves have lower mass, which explains the relatively low individual leaf weight observed in this study.

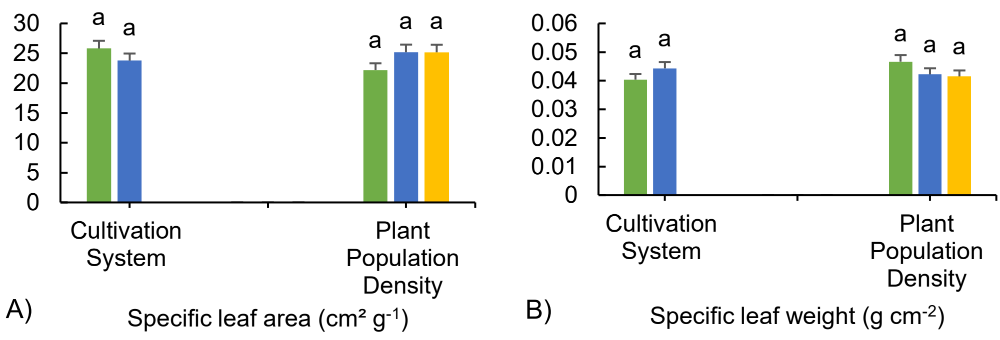

Figure 9. Effect of cultivation system and plant population density on the specific leaf area (A) and specific leaf weight (B) in purple pakchoi.

During the growing period, leaf moisture and temperature were observed to evaluate the effects of different cultivation systems and plant population densities on leaf transpiration in purple pakchoi (Fig. 10).

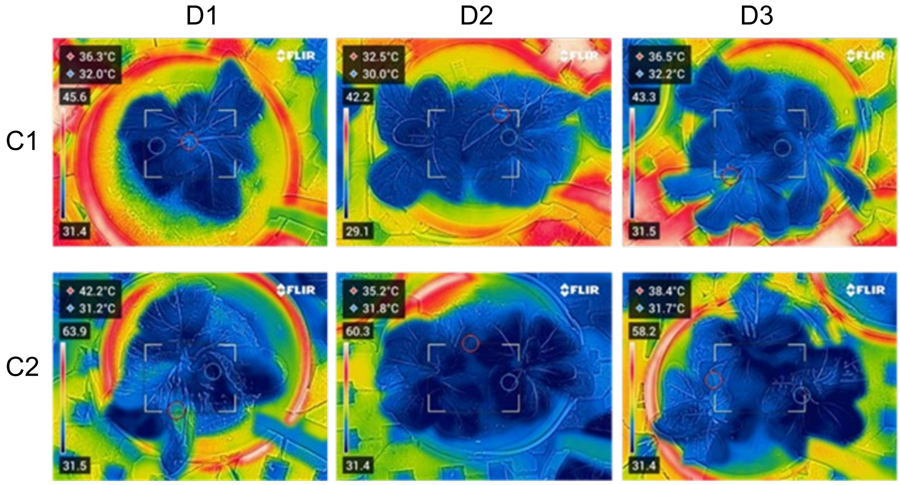

Figure 10. Leaf temperature of purple pakchoi in conventional cultivation system (C1) and floating cultivation system (C2) with different plant populations (D1, D2, D3).

Observations revealed that purple pakchoi grown under conventional cultivation exhibited higher leaf temperatures, indicating higher transpiration rates. In contrast, plants grown under the floating system showed lower leaf temperatures due to consistently moist growing conditions, which help reduce transpiration stress. Plant population density also influenced leaf temperature, as increased canopy overlap under higher densities alters the microclimate around the leaves. This condition can reduce air circulation and modify heat dissipation, thereby affecting leaf temperature. Thermal observations further support these findings, showing spatial differences in leaf temperature distribution under different treatments.

Despite these variations, purple pakchoi growth was not significantly limited by relatively high air temperatures. Pakchoi can be cultivated in both highlands and lowlands with temperatures ranging from 15 °C to 30 °C (Putri, 2019). High soil moisture conditions, particularly in floating systems, may influence root development (Fadilah et al., 2022). Excessive moisture can reduce oxygen availability in the root zone, potentially limiting root respiration and growth. However, purple pakchoi was still able to grow and produce optimal yields under these conditions. This is because pakchoi has a relatively shallow root system (Walters & Midden, 2018), which allows it to efficiently utilize water and nutrients in the upper soil layer. As a result, plant growth was not significantly affected by differences in cultivation systems or competition due to plant population density. In conventional cultivation, regular watering helps maintain adequate soil moisture, while a well-developed canopy can reduce excessive evaporation by shading the soil surface.

CONCLUSIONS

This study demonstrates that both cultivation system and plant population density play important roles in optimizing purple pakchoi production under urban farming conditions. The floating cultivation system ensures continuous water availability, which supports stable plant growth, while conventional systems can also maintain adequate production when water is properly managed. Although higher plant population density reduced individual plant growth, it significantly increased total fresh biomass per pot, indicating a trade-off between individual performance and overall productivity. This finding highlights the importance of optimizing planting density to maximize land-use efficiency in limited urban spaces.

Furthermore, the stability of morphological traits across treatments indicates that purple pakchoi has strong agronomic adaptability under varying cultivation conditions. This suggests that the crop is suitable for flexible production systems in urban environments. Therefore, integrating appropriate cultivation systems with optimized plant population density is recommended as a practical strategy to enhance productivity and resource-use efficiency in urban horticulture.

Beyond the immediate findings, this study provides a practical basis for developing efficient urban farming systems, particularly for leafy vegetables with short growth cycles. Future studies are recommended to explore long-term productivity, economic feasibility, and environmental sustainability under different urban cultivation scenarios. Overall, these results contribute to the development of technical guidelines for purple pakchoi production, supporting urban food security and enhancing the economic potential of urban farming practices.

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REFERENCES

Ackah, E. & Kotei, R. 2021. Effect of drought length on the performance of cabbage *(Brassica oleracea* var. *capitata)* in the forest–savannah transition zone, Ghana. *Plant Physiology Reports* **26**, 74–83.

Akintuyi, O.B. 2024. Vertical farming in urban environments: A review of architectural integration and food security. *Journal of Biology and Pharmacy* **10**, 114–126. https://doi.org/10.53022/oarjbp.2024.10.2.0017

Arina, I.N., Martini, M.Y., Surdiana, S., Mohd Fauzi, R. & Zulkefly, S. 2021. Radiation dynamics on crop productivity in different cropping systems. *International Journal of Agronomy* **8**, 1–8. https://doi.org/10.1155/2021/4570616

Arrusy, A. 2021. Effect of watering frequency and NASA POC on lettuce *(Lactuca sativa* L.) with banana stem media (Doctoral dissertation, Universitas Islam Riau).

Badan Pusat Statistik. 2024. *Dynamics of land consumption in urban areas in Indonesia*. Badan Pusat Statistik.

Chadha, A., Florentine, S.K., Chauhan, B.S., Long, B. & Jayasundera, M. 2019. Influence of soil moisture regimes on growth, photosynthetic capacity, leaf biochemistry, and reproductive capabilities of the invasive agronomic weed Lactuca serriola. *PLoS ONE* **14**(1), 1–17.

Chowdhury, R.B. & Moore, G.A. 2017. Floating agriculture: a potential cleaner production technique for climate change adaptation and sustainable community development in Bangladesh. *Journal of Cleaner Production* **150**, 371–389.

Dantri, R., Irmansyah, T. & Ginting, J. 2015. Respons pemberian pupuk hayati pada beberapa jarak tanam terhadap pertumbuhan dan produksi kailan *(Brassica oleracea* var. *acephala). Jurnal Agroekoteknologi* **3**(2), 483–488.

Diriba, T.F.D.G., Defa, G., Gudeta, G., Iticha, G., Chimdessa, A. & Abdisa, A. 2017. Effect of plant spacing and urea fertilizer on yield and yield components of beetroot *(Beta vulgaris* L.). *Agricultural Development* **2**(1), 13–21. https://doi.org/10.20448/journal.523.2017.21.13.21

Du, F., Guan, C. & Jiao, Y. 2018. Molecular mechanisms of leaf morphogenesis. *Molecular Plant* **11**(9), 1117–1134. https://doi.org/10.1016/j.molp.2018.06.006

Erwin, S., Ramli, R. & Adrianton. 2015. The effect of various planting distances on the growth and production of cabbage *(Brassica oleracea* L.) in the middle plains of Bobo Village, Palolo District, Sigi Regency. *Agrotekbis Journal* **3**(4), 491–497.

Fadilah, L.N., Lakitan, B. & Marlina, M. 2022. Effects of shading on the growth of purple pakchoy *(Brassica rapa* var. *chinensis)* in an urban ecosystem. *Agronomy Research* **20**, Article AR.22.057. https://doi.org/10.15159/AR.22.057

Gandharum, L., Hartono, D.M., Karsidi, A. & Ahmad, M. 2022. Monitoring urban expansion and loss of agriculture on the north coast of West Java Province, Indonesia, using Google Earth Engine and intensity analysis. *Scientific World Journal* **1**, 1–16. https://doi.org/10.1155/2022/3123788

Gashaw, B. & Sheway, H. 2020. Effect of different rates of nitrogen and intra-row spacing on growth performance of lettuce *(Lactuca sativa* L.). *Advances in Agriculture* **1**, 1–6. https://doi.org/10.1155/2020/7364578

Giro, A. & Ferrante, A. 2016. Yield and quality of Corchorus olitorius baby leaf grown in a floating system. *The Journal of Horticultural Science and Biotechnology* **91**(6), 603–610.

Hasan, M.R., Islam, M.N., Ali, M.A. & Uddain, J. 2017. Growth and yield of lettuce *(Lactuca sativa* L.) influenced by nitrogen fertilizer and plant spacing. *IOSR Journal of Agriculture and Veterinary Science* **10**(6), 27–31. https://doi.org/10.9790/2380-1006016271

Hussen, J.S. & Ahmed, G.E. 2025. Role of vertical farming for sustainable urban horticulture: A review. *Advances in Horticultural Science* **39**(1), 69–80. https://doi.org/10.36253/ahsc-16549

Jaya, K.K., Lakitan, B. & Bernas, S.M. 2021. Responses of leaf celery to floating culture systems with different depths of water–substrate interface and NPK fertilizer application. *Walailak Journal* **18**(12), 1–14. https://doi.org/10.48048/wjst.2021.19823

Kartika, K., Lakitan, B., Ria, R.P. & Putri, H.H. 2021. Effect of cultivation systems and split fertilizer applications on the growth and yields of tatsoi *(Brassica rapa* subsp. *narinosa)*. *Trends in Sciences* **18**(21), 1–12. https://doi.org/10.48048/tis.2021.344

Kim, H.S., Yoo, J.H., Park, S.H., Kim, J.S., Chung, Y., Kim, J.H. & Kim, H.S. 2021. Measurement of environmentally influenced variations in anthocyanin accumulation in *Brassica rapa* subsp. *chinensis* using hyperspectral imaging. *Frontiers in Plant Science* **12**, 1–9. https://doi.org/10.3389/fpls.2021.693854

Koch, G., Rolland, G., Dauzat, M., Bédiée, A., Baldazzi, V., Bertin, N., Guédon, Y. & Granier, C. 2019. Leaf production and expansion: A generalized response to drought stress from cells to whole-leaf biomass. *Plants Journal* **8**, 409.

Lakitan, B. & Kartika, K. 2020. Population density, multiple harvesting, and ability of *Ipomoea reptans* to compete with native weeds at tropical wetlands. *Biodiversitas Journal of Biological Diversity* **21**(9), 4376–4383. https://doi.org/10.13057/biodiv/d210957

Lakitan, B., Kartika, K., Widuri, L.I., Siaga, E. & Fadilah, L.N. 2021. Lesser-known ethnic leafy vegetables Talinum paniculatum grown in tropical ecosystems. *Biodiversitas* **22**(10), 4487–4495. https://doi.org/10.13057/biodiv/d221042

Li, X., Wu, Y., Li, B., Yang, Y. & Yang, Y. 2018. Selenium accumulation characteristics and biofortification potential in turnip *(Brassica rapa* var. *rapa). Frontiers in Plant Science* **8**, 1–10. https://doi.org/10.3389/fpls.2017.02207

Murtiawan, D., Heddy, S. & Nugroho, A. 2018. Study of differences in planting distance and seedling age in pakcoy plants *(Brassica rapa* L. var. *chinensis)*. *Jurnal Produksi Tanaman* **6**(2), 264–272.

Orsini, F., Gasperi, D., Marchetti, L., Piovene, C., Draghetti, S., Ramazzotti, S. & Gianquinto, G. 2014. Exploring the production capacity of rooftop gardens in urban agriculture. *Food Security* **6**(6), 781–792.

Pant, C. & Sah, S.K. 2020. Managing plant population and competition in field crops. *Acta Scientifica Malaysia* **4**(2), 57–60. https://doi.org/10.26480/asm.02.2020

Pawandeep, K., Singh, H. & Rani, P. 2020. Effect of plant spacing and nutrient management on growth and yield of spinach *(Spinacia oleracea* L.). *International Journal of Chemical Studies* **8**(3), 1245–1249. https://doi.org/10.22271/chemi.2020.v8.i3q.9368

Priadi, D. & Nuro, F. 2017. Seedling production of pak choy using organic and inorganic nutrients. *Biosaintifika* **9**(2), 217–224. https://doi.org/10.15294/biosaintifika.v9i2.8537

Putri, S.U.A. 2019. *Business feasibility study of the use of tapioca biogas reactor effluent for vegetable production* (Unpublished master's thesis). Universitas Lampung, 62 pp.

Ria, R., Lakitan, B., Sulaiman, F., Yakup, Y., Negara, Z.P. & Susilawati. 2023. Artificial shade adaptation and population density on Swiss chard in urban areas. *Biovalentia* **9**(1), 71–83. https://doi.org/10.24233/biov.9.1.2023.384

Rondanini, D.P., Menendez, Y.C., Gomez, N.V., Miralles, D.J. & Botto, J.F. 2020. Vegetative plasticity and floral branching compensate for low plant density in rapeseed. *Field Crops Research* **210**, 104–113.

Rubatzky, E.V. & Yamaguchi, M. 1998. *Vegetables of the world* (Vol. 2). Institut Teknologi Bandung, 292 pp.

Sacita, A.S., June, T. & Impron, I. 2018. Soybean adaptation to water stress. *Agrotech Journal* **3**, 42–52.

Siaga, E. & Lakitan, B. 2021. Rice nursery and mustard greens cultivation floating technique. *Abdimas Unwahas* **6**(1), 127–137.

Song, B., Xu, H., Chen, L., Fan, X., Jing, Z., Chen, S. & Xu, Z. 2020. Relationship between leaf color formation and anthocyanin metabolism in purple pakchoi. *Molecules* **25**(20), 4809. https://doi.org/10.3390/molecules25204809

Utari, U. 2021. *Effect of planting spacing and application of sawdust and cow dung on green eggplant* (Doctoral dissertation, Universitas Cokroaminoto Palopo), 67 pp.

Walters, S.A. & Midden, K.S. 2018. Sustainability of urban agriculture on green roofs. *Agriculture* **8**, 168. https://doi.org/10.3390/agriculture8110168

Wang, X. 2022. Managing land carrying capacity for sustainable food systems. *Land* **11**, 484. https://doi.org/10.3390/land11040484

Zhang, Q., Achal, V., Xu, Y. & Xiang, W.N. 2014. Aquaculture wastewater improvement using water spinach floating bed. *Aquacultural Engineering* **60**, 48–55.