Journal of Horticultural Research 2023, vol. 31(1): 81–90
DOI: 10.2478/johr-2023-0022

SEARCHING FOR SUITABLE CULTIVATION SYSTEM OF SWISS CHARD (*BETA VULGARIS* SUBSP. *CICLA* (L.) W.D.J.KOCH) IN THE TROPICAL LOWLAND

Rofiqoh P. RIA[1], Benyamin LAKITAN*[2,3], Firdaus SULAIMAN[2], Yakup YAKUP[2]
[1]College of Agriculture, Sriwijaya University, Palembang 30139, Indonesia
[2]College of Agriculture, Sriwijaya University, Indralaya 30662, Indonesia
[3]Research Center for Suboptimal Lands, Sriwijaya University, Palembang 30139, Indonesia

Received: July 2022; Accepted: December 2022

ABSTRACT

Swiss chard as a leafy vegetable (*Beta vulgaris* subsp. *cicla* (L.) W.D.J.Koch) is rarely cultivated in the tropical climate zone because this plant has not been recognized by local farmers. The purpose of this study was to compare the performance of three cultivation systems, i.e., conventional, floating, and bottom-wet culture systems on three Swiss chard cultivars with different petiole colors, i.e., 'Red Ruby', 'Yellow Canary', and 'Pink Passion'. The best result was obtained if the Swiss chard was cultivated using the floating system since the water was continuously available by the capillarity force through the bottom hole of the pots, as indicated by the highest number of leaves, total fresh weight, leaf blade dry weight, and petiole dry weight. Fresh weight amongst the three cultivars cultivated in each system did not show a significant difference. 'Yellow Canary' produced a larger petiole and heavier fresh weight of individual leaves, but a lesser number of leaves per plant. The leaf area estimation model using the leaf length × width as the predictor, and the zero-intercept linear regression was accurate for all Swiss chard cultivars, as the coefficient of determination was considerably high in 'Red Ruby' (0.981), 'Pink Passion' (0.976), and 'Yellow Canary' (0.982), respectively.

Key words: bottom-wet system, leaf area estimation model, floating system, tropical climate

INTRODUCTION

Swiss chard is a perennial, leafy vegetable crop commonly cultivated as an annual crop. Swiss chard leaves are a healthy source of nutrients, including vitamins, minerals, fiber, and various other natural phytochemicals (Ivanović et al. 2019). Swiss chard also contained betalain, fats, flavonoids, nonflavonoids phenolics, terpenes, and derivatives (Gamba et al. 2021). Cömert et al. (2020) suggested consuming a variety of colorful vegetables because leaf color is related to antioxidant activities.

In addition to its health benefits, the Swiss chard plant can also increase aesthetic value in outdoor green spaces due to its colorful leaves (Chen et al. 2009; Lindemann-Matthies & Brieger 2016). Colorful plants in urban green spaces were seen as more attractive and preferred by urban park users (Rahnema et al. 2019). Therefore, this plant can bring double benefits, namely as a source of healthy food and enhancing the aesthetic value of urban areas.

Swiss chard has a promising value for cultivation in urban areas. During the pandemic, the demand for fresh vegetables was increasing, while the production and distribution of fresh vegetables were limited by the unavailability of labor (Zhou et al. 2020). In addition, the rate of urban population growth continuously increasing. Eigenbrod and Gruda (2015) predicted that more than half of the world's population will live in urban areas and is estimated to reach 70% by 2030. Khoo and Knorr (2014) estimated that two-thirds of the world's population will live in cities by 2050. Due to this demographic shift, the effort to meet the food needs of urban communities is the most formidable challenge in the near future.

The air temperature in the tropical lowlands during the day is higher than 30 °C. Swiss chard plants are most often cultivated at lower air temperatures, ranging from 13 to 21 °C (Rana & Rani 2017). The existence of liquid water is known to lower the temperature of the air above the surface of the water because water has a high heat capacity (Nhan & Tuan 2020).

*Corresponding author
e-mail: blakitan60@unsri.ac.id

Based on these encountered challenges, this study was designed to compare three different types of cultivation systems, i.e., conventional, bottom-wet, and floating culture in search of the most suitable system for Swiss chard cultivation in the tropical lowlands. The three cultivation systems were applied to three different cultivars of Swiss chard, i.e., ‘Red Ruby’, ‘Yellow Canary’, and ‘Pink Passion’.

MATERIALS AND METHODS

The study was carried out at the outdoor research facility in Jakabaring (104°46′44″E; 3°01′35″S), Palembang, Indonesia, within the tropical lowland climate zone. The average day temperature was 33 °C and relative humidity was 80%. Three Swiss chard cultivars were used: ‘Red Ruby’, ‘Yellow Canary’, and ‘Pink Passion’. Seeds were soaked in warm water for 15 minutes to initiate imbibition.

The growing substrate was pretreated with the commercial biofungicide and aerobic decomposer (Decoprima, Prima Agro Tech, Jakarta, Indonesia). The biofungicide consists of a consortium of *Streptomyces* sp., *Geobacillus* sp., and *Trichoderma* sp. The biofungicide was dissolved in water at a concentration of 2 g per liter. Each pot was sprayed with 200 ml of the solution.

Two weeks after the biofungicide treatment, the seeds were sown in seedling trays filled with a mixture of soil and chicken manure (2 : 1 v/v). The seedlings with two leaves were transplanted 14 days after sowing from seedling trays to plastic pots with 27.5 cm in upper diameter, 20 cm in base diameter, and 20 cm in height. In each pot, three seedlings were planted. The pot was filled with a mixture of the tropical Ultisol soil and chicken manure (2 : 1 v/v). Swiss chard plants were fertilized 2 weeks after transplanting using the commercial compound NPK (16 : 16 : 16) fertilizers in doses of 5 g per plant.

All three Swiss chard cultivars were cultivated using three different procedures, i.e., conventional, floating, and bottom-wet culture (BWC) systems. The floating culture system was conducted in an experimental pool (4.0 m × 2.0 m inner dimension) using three identical rafts. The water depth in the experimental pool was kept stable by opening the control valve so that the rainwater will be automatically discharged. The raft dimensions were 2 m (length) × 1 m (width) × 0.08 m (thickness), made of 66 units of 1500 mL used plastic (polyethylene terephthalate, PET) mineral water bottles (Fig. 1). This raft is a revised version of our patented raft (Granted Patent No. IDP000065141). Pots filled with growing substrate were evenly distributed on the upper surface of the raft. The total weight of the filled pots was adjusted to set the depth of the water-saturated substrate layer (WSSL) to 1–2 cm. Direct contact between the water surface and the bottom part of the growing substrate is crucial for facilitating upward water movement by capillarity force for continuously wetting the substrate.

The BWC system adopts a similar principle of upward water movement by capillary force. Pots filled with growing substrate were placed directly on the pool floor, where the water layer was set at 5.0 cm, allowing free outflow of excess water on rainy days, and refilling was made when the water layer fell below 5.0 cm due to evaporation.

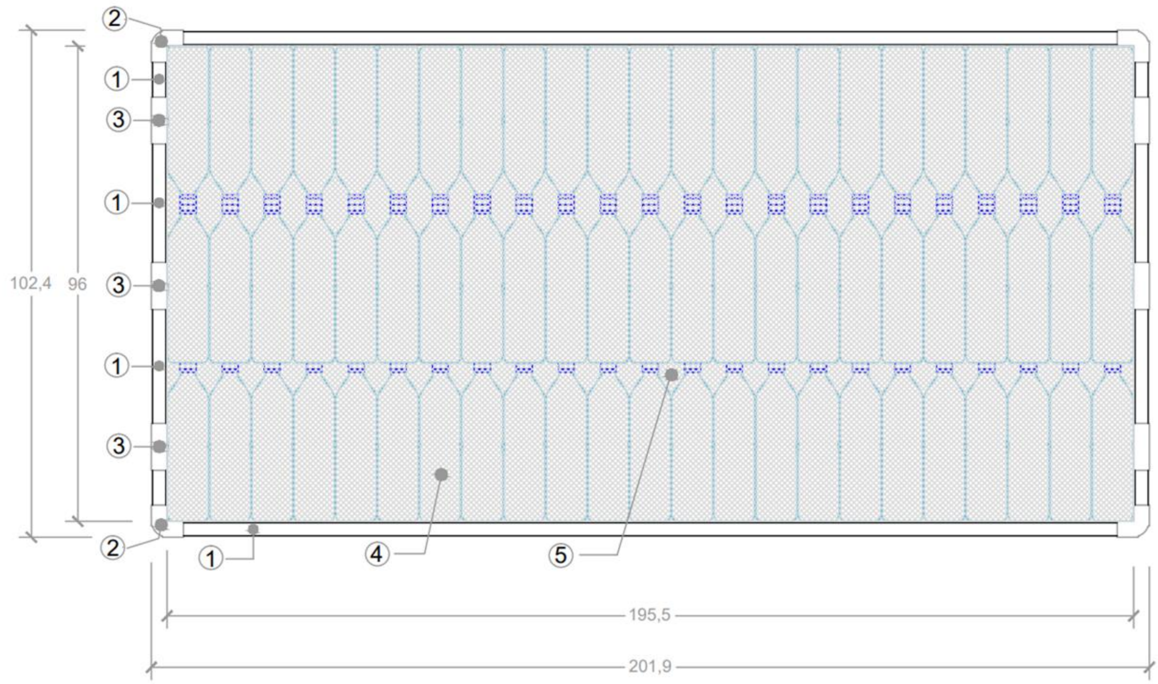
In the conventional system, which is common practice in the cultivation of potted plants, water is obtained from precipitation onto the top surface of the growing substrate.

Data collection

Soil moisture was measured using a soil moisture meter (Lutron PMS-8714) at a depth of 5 cm below the upper surface of the substrate. The dry weight of plant materials was measured after drying in an oven at 100 °C for 24 to 48 hours, depending on the size or thickness of the samples. The harvest was carried out three times, i.e., 22, 25, and 28 days after transplanting (DAT). The essential data that have to be collected destructively were carried out during the final harvest.

For the development of the leaf area (LA) estimation model, a range of leaf sizes from the smallest to the largest was deliberately selected and the distribution of the leaf size was sought to be as even as possible. The length of the midrib of the leaf (L) as the length of the blade, the width of the blade measured as its dimensions at its widest point (W), and the L×W multiplication were used as predictors in the development of the LA estimation model. Two regression models were used, i.e., the zero intercept linear regression using

L×W as a predictor and the power regression using L, W, and L×W as predictors (Kartika et al. 2021; Meihana et al. 2017). The goodness of fit of statistical models was proxied based on the coefficient of determination (R^2) value to the value of LA measured using the digital image analysis software (LIA32, Kazukiyo Yamamoto, Nagoya University, Japan).



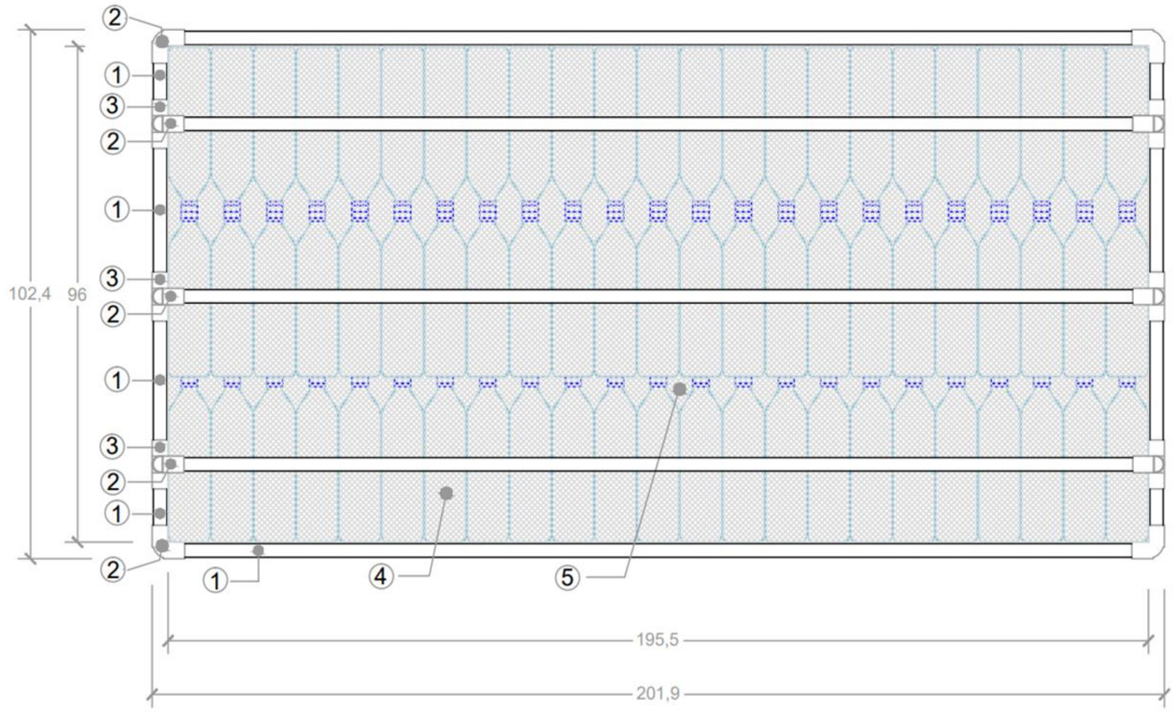


Figure 1. Upper and bottom surfaces of the PET raft for vegetable floating culture. The ¾-inch PVC pipe (1), elbow connector (2), T-connector (3), arranged PET bottles (4), and stainless mosquito net (5)

Experimental design and data analysis

This study was arranged in a randomized block design with two factors. The first factor was the cultivation systems, consisting of conventional, floating, and BWCs. The second factor was the cultivars of Swiss chard 'Red Ruby', 'Yellow Canary', and 'Pink Passion'. Each combination of two factors consisted of three replications, each replication consisted of three pots, and each pot was planted with three seedlings.

All data were organized and analyzed with the analysis of variance (ANOVA). Furthermore, significant differences between cultivars of the Swiss chard and between cultivation systems were assessed using the least significant difference (LSD) test. The value of $P < 0.05$ was referred to as statistically significant differences among cultivars or cultivation systems. Trend analysis between predictor and estimated LA was used in both the zero-intercept linear and power regressions.

RESULTS AND DISCUSSION

The effect of cultivation system

The floating culture system exhibited the best Swiss chard growth comparable to conventional growth system after 14 DAT. At 21 DAT, the leaves were mostly the largest in plants grown in the floating system (Table 1). All pot systems take up little space in urban area and are considered as easy to manage, requiring no electrical energy, and of the low cost compared to hydroponic systems (Baiyin et al. 2020); thus, it is more likely to be adopted in the urban community, including people whose financial capacity is limited.

A similar reaction to the culture conditions was observed in the analysis of fresh and dry weight. At 22 DAT, fresh and dry weight leaf blades and petioles did not differ between the conventional and the floating system, but at 25 and 28 DAT the highest values were noted in plants grown in floating culture (Table 2). Also, the leaf numbers were higher and comparable to the conventional system, except for 25 DAT (Fig. 2).

Table 1. Leaf character variation of the Swiss chard in different cultivation systems and between three cultivars measured 14 and 21 days after transplanting

	Petiole length (cm)	Leaf length (cm)	Leaf width (cm)	Leaf thickness (cm)	Number of leaves per plant	Midrib to petiole ratio
			14 DAT			
Conventional	8.28 ± 0.27 a	8.89 ± 0.37 a	5.45 ± 0.24 a	0.48 ± 0.03 a	4.08 ± 0.13 a	1.11 ± 0.06 a
Floating	8.79 ± 0.41 a	8.45 ± 0.43 ab	5.32 ± 0.26 a	0.53 ± 0.04 a	3.96 ± 0.15 ab	0.98 ± 0.05 a
Bottom-wet	8.48 ± 0.33 a	7.98 ± 0.27 b	5.18 ± 0.26 a	0.50 ± 0.02 a	3.62 ± 0.11 b	0.97 ± 0.03 a
P-value	0.49	0.06	0.65	0.26	0.03	0.11
'Red Ruby'	8.82 ± 0.31 a	8.02 ± 0.19 b	5.09 ± 0.26 a	0.43 ± 0.02 c	4.04 ± 0.15 a	0.91 ± 0.02 b
'Yellow Canary'	8.26 ± 0.32 a	9.37 ± 0.43 a	5.13 ± 0.25 a	0.59 ± 0.03 a	3.87 ± 0.11 a	1.18 ± 0.07 a
'Pink Passion'	8.47 ± 0.39 a	7.93 ± 0.25 b	5.46 ± 0.24 a	0.49 ± 0.02 b	3.81 ± 0.16 a	0.97 ± 0.06 b
P-value	0.40	<0.001	0.41	<0.001	0.33	0.003
			21 DAT			
Conventional	12.9 ± 0.50 b	13.5 ± 0.44 ab	8.90 ± 0.45 ab	0.46 ± 0.02 a	5.87 ± 0.18 a	1.07 ± 0.06 a
Floating	15.0 ± 0.56 a	14.5 ± 0.63 a	9.42 ± 0.25 a	0.46 ± 0.03 a	5.53 ± 0.10 a	0.98 ± 0.05 ab
Bottom-wet	14.1 ± 0.63 ab	12.7 ± 0.60 b	8.28 ± 0.45 b	0.40 ± 0.02 b	4.95 ± 0.20 b	0.91 ± 0.03 b
P-value	0.04	0.015	0.09	0.02	0.02	0.05
'Red Ruby'	13.1 ± 0.53 b	12.6 ± 0.57 b	8.42 ± 0.60 a	0.42 ± 0.02 a	5.59 ± 0.21 a	0.97 ± 0.03 b
'Yellow Canary'	14.1 ± 0.65 ab	15.1 ± 0.44 a	8.99 ± 0.32 a	0.45 ± 0.03 a	5.11 ± 0.17 b	1.10 ± 0.07 a
'Pink Passion'	14.8 ± 0.56 a	12.9 ± 0.42 b	9.19 ± 0.22 a	0.46 ± 0.02 a	5.66 ± 0.22 a	0.90 ± 0.03 b
P-value	0.09	0.0005	0.29	0.27	0.04	0.009

Mean ± standard error followed by the same letters within each column were significantly different based on LSD at $P \leq 0.05$ for each treatment and days of data measurement; DAT – days after transplanting

Table 2. Differences in the fresh and dry weight of leaf blades and petioles of Swiss chard cultivated using conventional, floating, or bottom-wet culture

Cultivation	Blade FW (g)	Blade DW (g)	Petiole FW (g)	Petiole DW (g)
		22 DAT		
Conventional	27.6 ± 0.25 a	2.91 ± 0.12 a	12.9 ± 0.53 ab	1.22 ± 0.05 a
Floating	31.1 ± 5.30 a	2.86 ± 0.38 a	15.3 ± 0.63 a	1.07 ± 0.07 a
Bottom-wet	19.9 ± 4.44 b	1.70 ± 0.31 b	9.9 ± 1.71 b	0.73 ± 0.04 b
		25 DAT		
Conventional	37.6 ± 2.36 ab	3.62 ± 0.07 a	18.6 ± 0.63 b	1.56 ± 0.10 a
Floating	49.6 ± 4.63 a	4.73 ± 0.51 a	31.1 ± 1.75 a	2.15 ± 0.07 a
Bottom-wet	34.2 ± 7.49 b	3.62 ± 0.36 a	20.0 ± 6.33 b	1.74 ± 0.30 a
		28 DAT		
Conventional	44.4 ± 0.41 b	5.48 ± 0.18 a	24.3 ± 2.84 b	2.39 ± 0.19 a
Floating	57.1 ± 6.56 a	5.86 ± 0.72 a	41.3 ± 2.16 a	3.10 ± 0.27 a
Bottom-wet	45.6 ± 7.82 b	5.28 ± 0.62 a	27.9 ± 3.38 b	2.91 ± 0.37 a

Note: see Table 1

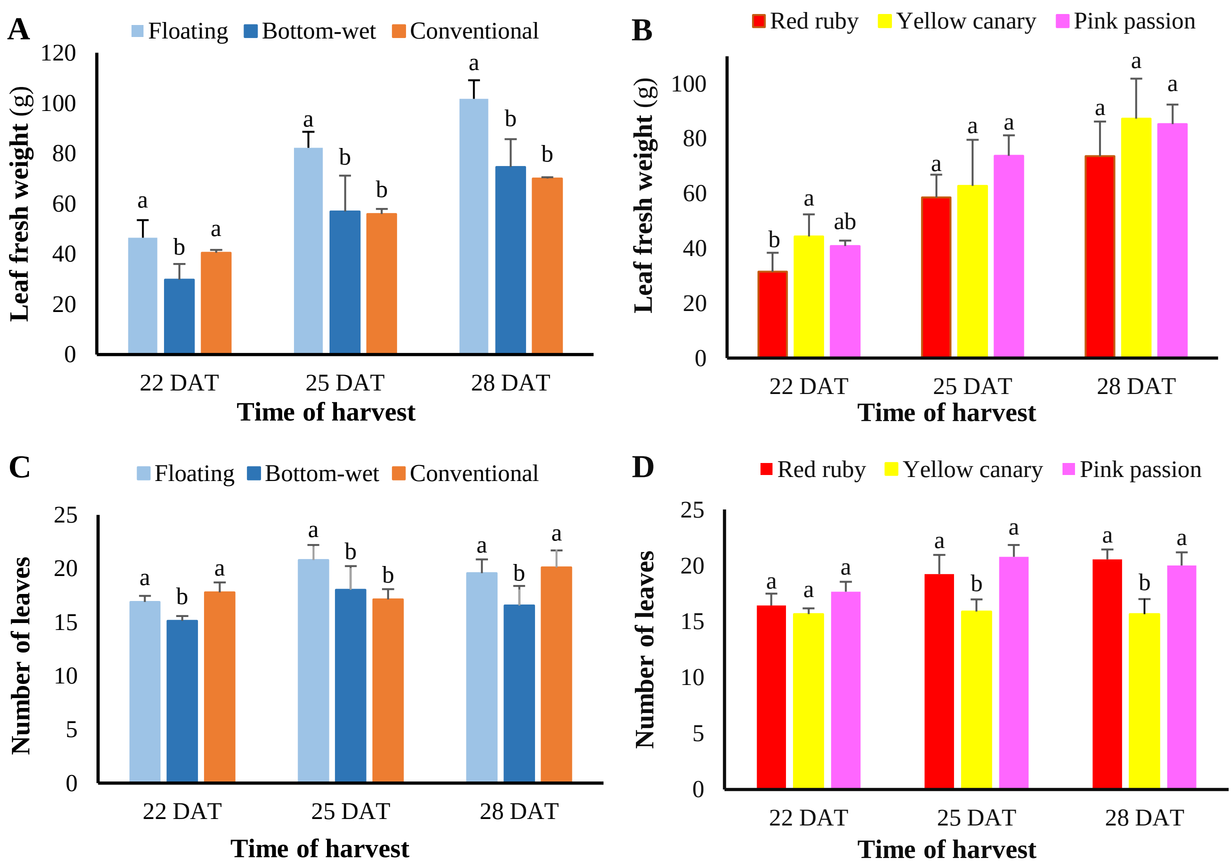


Figure 2. The effect of cultivation systems and cultivars of the Swiss chard on fresh weight (A–B) and number of leaves (C–D) at 22, 25, and 28 days after transplanting (DAT). The different letters on standard error bar are significantly different based on the LSD at $p \leq 0.05$

The growth of Swiss chard plants cultivated with the BWC system was slightly inhibited in, comparison to plants cultivated with the other two systems. However, there was no significant difference in leaf dry weight in all three cultivation systems (Table 2). Consequently, the differences between the cultivation systems were associated with leaf water content (Table 3). In other words, plants cultivated in the floating system absorbed more water than those in other cultivation systems, especially over a longer period of culture. The high water content improves the freshness of the vegetables at harvest.

Air and soil temperatures in the tropical lowlands are higher than conditions in the temperate zone where Swiss chard is generally cultivated. High air temperatures can limit plant growth and development due to disturbances in metabolic processes (Zhu et al. 2021), while the limited availability of oxygen in the growing medium due to the presence of a water-saturated soil layer limits growth and reduces yields (Sharma et al. 2018).

For terrestrial plants including Swiss chard, the presence of a water-saturated layer at the bottom of the growing substrate in floating and bottom-wet cultivation systems was a limiting factor for root growth and development. The roots of plants cultivated in the floating system and BWCs were significantly shorter at 25 and 28 DAT than the roots of conventionally cultivated plants. Nevertheless, the fresh and dry weight of the roots was higher in floating cultivated plants. This indicated that despite the short main roots, plants cultivated with a floating system formed a more intensive lateral root system (Table 4).

The same phenomena were also observed in chili pepper (Siaga et al. 2018) and common beans (Lakitan et al. 2018). Meier et al. (2020) explained that plants could modulate their root system architecture to improve water and nutrient acquisition from the soil. Nitrogen application stimulated the accumulation of shoot-derived auxin in the root vasculature and promoted lateral root emergence to build a highly branched root system. In our study, nitrogen was supplied via a compound NPK fertilizer.

The growth and yield of bottom-wet cultivated Swiss chard plants were not as good as the floating cultivated plants. This difference was likely related to the thickness of the WSSLs, i.e., the depth of the bottom substrate whose pores are saturated with water. The thick WSSL (5 cm) as in the BWC negatively affected the root weight and the fruit yield of the ‘Green Apple’ eggplant (Jaya et al. 2019) and the overall growth of the leaf celery (Jaya et al. 2020, 2021).

In pot experiments of the same substrate volume, increasing the thickness of the WSSL means reducing the volume of the aerobic substrate. Therefore, in a floating cultivation system, the thickness of WSSL needs to be minimized but the contact between the bottom of the substrate and the water surface must be continuously maintained so that the water supply by the capillarity force can still take place. The WSSL in floating culture varied from 1 to 3 cm depending on rainfall and air temperature. In the BWC, the WSSL was controlled at 5 cm by continuously opening the outflow valve, and water was added manually if the WSSL fell below 5 cm due to evapotranspiration on a hot, rainless day.

The substrate surface absorbs sunlight energy, thereby increasing the substrate temperature, triggering evaporation, and decreasing soil moisture (Dincă et al. 2018). The advantage of floating and BWC was that the water supply by the capillarity force took place continuously so that the moisture of the growth substrate could be maintained (Jaya et al. 2021), as long as the direct contact between the substrate and the water surface was not interrupted (Kartika et al. 2021).

Morphology and growth of Swiss chard dependent on cultivar

Among the tested cultivars, the petiole of ‘Yellow Canary’ Swiss chard exhibited the longest blade, the thickest leaf, and the highest ratio of the length of the midrib to the petiole, and therefore the largest leaf blade, because the leaf width was similar to the three cultivars studied. However, this cultivar produced the least number of leaves per plant, which was recorded at 21 DAT (Table 1). Smaller leaves are in some cultivars compensated with a greater number of leaves per plant.

Fresh leaf weight did not differ significantly between all the cultivars evaluated, with the exception of 'Pink Passion', which was lower at 22 and 25 DAT. In contrast, the number of leaves on 'Yellow Canary' became smaller compared to the other two cultivars at 25 and 28 DAT (Table 5, Fig. 2).

Based on the linear regression, there was a positive trend but a very weak correlation between LA and leaf width. Although statistically insignificant, the trend shown in the 14 and 21 DAT results provided interesting findings, i.e., at a younger age, the LA was still small but thick; then, after the leaves enlarged, the thickness decreased. This phenomenon suggests that lateral growth (elongation and widening) was becoming more dominant and vertical growth (thickness) was halted.

Estimation of Swiss chard leaf area

Using length × width (L×W) as a predictor of LA was consistently more accurate compared to using length or width alone for all cultivars studied. In this case, the use of zero-intercept linear regression was consistently more accurate when L×W was used as a predictor; conversely, the use of power regression was more accurate if L or W were used separately as a predictor. Conclusively, the most accurate combination was to use zero-intercept linear regression and L×W as predictors for 'Red Ruby' (R^2 = 0.9807), 'Yellow Canary' (R^2 = 0.9821), and 'Pink Passion' (R^2 = 0.9758), as indicated by the values of their respective coefficients of determination (Table 6).

The development of LA estimation models has attracted the attention of many agronomists and biologists. The resulting models are primarily for further use in nondestructive, rapid, and accurate prediction of the LA during its development, so that leaf growth analysis can be realistically calculated as it uses the same leaves. Most LA estimation models are based on regression equations using morphological traits as predictors, such as tomatoes (Meihana et al. 2017), cocoa (Salazar et al. 2018), tatsoi (Kartika et al. 2021), celery (Lakitan et al. 2021a), and many others.

Many types and combinations of traits have been used in estimation models for the LA, but the type of trait that was always consistent and accurate was the traits that are directly related to the dimensions of the leaf, namely the length and width of the leaf blade. The dimension of the leaves' thickness is more difficult to measure and should be taken for choice for some species of succulent plants.

Although the normal leaf shape in a single plant looks the same, the length-to-width ratio of a leaf can vary significantly between leaves of the same plant. For this case, the use of the L×W combination as a predictor in the LA estimate will be more accurate than using L or W separately using linear regression. This argument had already been proved in the leaves of *Bougainvillea* (Fascella et al. 2018), Habanero chili (Lakitan et al. 2022), and Java ginseng (Lakitan et al. 2021b). Since LA should be zero if L or W is zero, then the most appropriate to use is the zero-intercept linear regression model (Lakitan et al. 2021b). If the estimation model uses only a single predictor L or W, then the most suitable regression option is the power regression. Power regression automatically sets LA = 0 if either L or W were zero.

Table 3. Water content of leaf blade and petiole amongst three different cultivation systems

Cultivation	Blade water content (%)	Petiole water content (%)
	22 DAT	
Conventional	89.4 ± 0.44 b	87.4 ± 3.75 a
Floating	90.5 ± 0.71 ab	92.7 ± 0.57 a
Bottom-wet	91.5 ± 0.33 a	92.2 ± 1.08 a
	25 DAT	
Conventional	90.3 ± 0.39 a	91.6 ± 0.61 a
Floating	90.4 ± 0.49 a	93.1 ± 0.12 a
Bottom-wet	88.5 ± 2.02 a	91.6 ± 1.31 a
	28 DAT	
Conventional	87.6 ± 0.39 b	89.9 ± 0.45 b
Floating	89.8 ± 0.16 a	92.5 ± 0.22 a
Bottom-wet	88.4 ± 1.08 b	89.8 ± 0.54 b

Note: see Table 1

Table 4. Length, fresh weight, and dry weight of the roots as affected by cultivation system in Swiss chard

Cultivation	Root length (cm)	Root FW (g)	Root DW (g)
	22 DAT		
Conventional	33.6 ± 1.43 a	5.67 ± 0.06 b	0.47 ± 0.08 ab
Floating	26.8 ± 2.48 b	9.74 ± 0.08 a	0.65 ± 0.14 a
Bottom-wet	19.6 ± 1.88 c	4.10 ± 0.05 b	0.37 ± 0.14 b
	25 DAT		
Conventional	34.4 ± 3.04 a	5.26 ± 1.31 b	0.56 ± 0.07 ab
Floating	28.7 ± 3.33 ab	8.58 ± 1.61 a	0.80 ± 0.15 a
Bottom-wet	22.7 ± 1.33 b	4.87 ± 1.00 b	0.51 ± 0.14 b
	28 DAT		
Conventional	26.8 ± 1.73 ab	7.77 ± 0.52 b	0.31 ± 0.07 b
Floating	29.2 ± 3.06 a	11.30 ± 3.04 a	0.58 ± 0.62 a
Bottom-wet	24.1 ± 1.38 b	8.28 ± 1.90 b	0.48 ± 0.36 ab

Note: see Table 1

Table 5. Fresh and dry weights of the leaf and petiole in three different Swiss chard cultivars

Cultivar	Leaf FW (g)	Leaf DW (g)	Petiole FW (g)	Petiole DW (g)
		22 DAT		
'Red Ruby'	27.6 ± 4.60 a	2.03 ± 0.50 a	10.8 ± 2.90 a	0.91 ± 2.28 a
'Yellow Canary'	31.1 ± 6.01 a	2.75 ± 0.49 a	14.8 ± 2.16 a	1.17 ± 2.08 a
'Pink Passion'	19.9 ± 0.68 b	2.70 ± 0.28 a	12.5 ± 3.00 a	1.05 ± 1.45 a
		25 DAT		
'Red Ruby'	37.6 ± 3.82 ab	3.71 ± 0.45 a	21.2 ± 3.66 a	1.68 ± 0.24 a
'Yellow Canary'	49.6 ± 10.4 a	4.28 ± 0.70 a	22.2 ± 6.21 a	1.78 ± 0.27 a
'Pink Passion'	34.2 ± 1.88 b	3.98 ± 0.18 a	28.2 ± 4.36 a	2.00 ± 0.21 a
		28 DAT		
'Red Ruby'	44.8 ± 6.95 a	5.28 ± 0.62 a	27.8 ± 5.46 a	2.51 ± 0.21 a
'Yellow Canary'	52.5 ± 8.01 a	6.12 ± 0.51 a	31.3 ± 7.47 a	2.86 ± 0.47 a
'Pink Passion'	49.8 ± 5.11 a	5.22 ± 0.34 a	33.6 ± 3.14 a	2.95 ± 0.22 a

Note: see Table 1

Table 6. The leaf area estimation model and coefficient determination (R^2) for 'Red Ruby', 'Yellow Canary', and 'Pink Passion' cultivars of the Swiss chard plant

Cultivar	Regression	Predictor	Model	R^2
'Red Ruby'	Zero-Intercept Linear	Length × Width	LA = 0.695 LW	0.981
		Length	LA = 5.704 L	0.924
		Width	LA = 9.816 W	0.940
	Power	Length × Width	$LA = 0.786\ LW^{0.972}$	0.921
		Length	$LA = 0.406\ L^{1.991}$	0.856
		Width	$LA = 1.973\ W^{1.746}$	0.866
'Yellow Canary'	Zero-Intercept Linear	Length × Width	LA = 0.658 LW	0.982
		Length	LA = 6.302 L	0.931
		Width	LA = 11.887 W	0.937
	Power	Length × Width	$LA = 1.138\ LW^{0.893}$	0.934
		Length	$LA = 0.791\ L^{1.707}$	0.836
		Width	$LA = 2.759\ W^{1.631}$	0.842
'Pink Passion'	Zero-Intercept Linear	Length × Width	LA = 0.666 LW	0.976
		Length	LA = 6.021 L	0.925
		Width	LA = 10.028 W	0.927
	Power	Length × Width	$LA = 0.909\ LW^{0.937}$	0.904
		Length	$LA = 0.440\ L^{1.968}$	0.829
		Width	$LA = 2.472\ W^{1.622}$	0.817

LA – leaf area, LW – length × width, L – length, W – width

CONCLUSIONS

Of the three cultivation systems investigated, Swiss chard plants grew and developed best in the floating cultivation system, partly due to the continuous availability of water in the growing substrate. Growth responses amongst the three Swiss chard cultivars showed that the 'Red Ruby' and 'Pink Passion' produced a greater number of leaves, while the 'Yellow Canary' produced fewer leaves but of larger sizes. However, these paradoxical differences resulted in a comparable fresh weight and dry weight amongst the three cultivars studied. The successful cultivation of Swiss chard opens up opportunities to increase the cultivation of this plant in urban areas in tropical lowland conditions. Based on the LA estimation model and the predictor used, the best option is to use the zero-intercept linear regression model with a combination of length × width (LW) of leaf blades as the predictor for all cultivars used.

Acknowledgments
We appreciate all the parties who have helped us in conducting the research and preparing this manuscript. We also would like to express our gratitude to the editors and staffs of this journal. Our high appreciation goes to anonymous reviewers for their suggestions and constructive comments.

REFERENCES

Baiyin B., Tagawa K., Gutierrez J. 2020. Techno-economic feasibility analysis of a stand-alone photovoltaic system for combined aquaponics on drylands. Sustainability 12(22); 9556; 20 p. DOI: 10.3390/su12229556.

Chen B., Adimo O.A., Bao Z. 2009. Assessment of aesthetic quality and multiple functions of urban green space from the users' perspective: The case of Hangzhou Flower Garden, China. Landscape and Urban Planning 93(1): 76–82. DOI: 10.1016/j.landurbplan.2009.06.001.

Cömert E.D., Mogol B.A., Gökmen V. 2020. Relationship between color and antioxidant capacity of fruits and vegetables. Current Research in Food Science 2: 1–10. DOI: 10.1016/j.crfs.2019.11.001.

Dincă L., Badea O., Guiman G., Bragă C., Crişan V., Greavu V. et al. 2018. Monitoring of soil moisture in long-term ecological research (LTER) sites of Romanian Carpathians. Annals of Forest Research 61(2): 171–188. DOI: 10.15287/afr.2018.1188.

Eigenbrod C., Gruda N. 2015. Urban vegetable for food security in cities. A review. Agronomy for Sustainable Development 35(2): 483–498. DOI: 10.1007/s13593-014-0273-y.

Fascella G., Rouphael Y., Cirillo C., Mammano M.M., Pannico A., De Pascale S. 2018. Allometric model for leaf area estimation in *Bougainvillea* genotypes. Acta Horticulturae 1215: 449–452. DOI: 10.17660/actahortic.2018.1215.81.

Gamba M., Raguindin P.F., Asllanaj E., Merlo F., Glisic M., Minder B. et al. 2021. Bioactive compounds and nutritional composition of Swiss chard (*Beta vulgaris* L. var. *cicla* and *flavescens*): a systematic review. Critical Reviews in Food Science and Nutrition 61(20): 3465–3480. DOI: 10.1080/10408398.2020.1799326.

Ivanović L., Milašević I., Topalović A., Đurović D., Mugoša B., Knežević M., Vrvić M. 2019. Nutritional and phytochemical content of Swiss chard from Montenegro, under different fertilization and irrigation treatments. British Food Journal 121(2): 411–425. DOI: 10.1108/bfj-03-2018-0142.

Jaya K.K., Lakitan B., Negara Z.P. 2019. Depth of water-substrate interface in floating culture and nutrient-enriched substrate effects on green apple eggplant. Agrivita Journal of Agricultural Science 41(2): 230–237. DOI: 10.17503/agrivita.v41i2.2235.

Jaya K.K., Lakitan B., Bernas S.M. 2020. Tiller size and water table effects in celery growth on floating cultivation system. Jurnal Lahan Suboptimal: Journal of Suboptimal Lands 9(2): 184–191. DOI: 10.33230/jlso.9.2.2020.499.

Jaya K.K., Lakitan B., Bernas S.M. 2021. Responses of leaf celery to floating culture system with different depths of water-substrate interface and NPK-fertilizer application. Walailak Journal of Science and Technology 18(12); 19823; 14 p. DOI: 10.48048/wjst.2021.19823.

Kartika K., Lakitan B., Ria R.P., Putri H.H. 2021. Effect of the cultivation systems and split fertilizer applications on the growth and yields of tatsoi (*Brassica rapa* subsp. *narinosa*). Trends in Sciences 18(21); 344; 12 p. DOI: 10.48048/tis.2021.344.

Khoo C.S., Knorr D. 2014. Grand challenges in nutrition and food science technology. Frontiers in Nutrition 1; 4; 3 p. DOI: 10.3389/fnut.2014.00004.

Lakitan B., Kadir S., Wijaya A., Susilawati 2018. Tolerance of common bean (*Phaseolus vulgaris* L.) to different durations of simulated shallow water table condition. Australian Journal of Crop Science 12(4): 661–668. DOI: 10.21475/ajcs.18.12.04.pne1047.

Lakitan B., Kartika K., Susilawati, Wijaya A. 2021a. Acclimating leaf celery plant (*Apium graveolens*) via bottom wet culture for increasing its adaptability to tropical riparian wetland ecosystem. Biodiversitas 22(1): 320–328. DOI: 10.13057/biodiv/d220139.

Lakitan B., Kartika K., Widuri L.I., Siaga E., Fadilah L.N. 2021b. Lesser-known ethnic leafy vegetables *Talinum paniculatum* grown at tropical ecosystem: Morphological traits and non-destructive estimation of total leaf area per branch. Biodiversitas 22(10): 4487–4495. DOI: 10.13057/biodiv/d221042.

Lakitan B., Susilawati S., Wijaya A., Ria R.P., Putri H.H. 2022. Non-destructive leaf area estimation in habanero chili (*Capsicum chinense* Jacq.). International Journal of Agricultural Technology 18(2): 633–650.

Lindemann-Matthies P., Brieger H. 2016. Does urban gardening increase aesthetic quality of urban areas? A case study from Germany. Urban Forestry and Urban Greening 17: 33–41. DOI: 10.1016/j.ufug.2016.03.010.

Meier M., Liu Y., Lay-Pruitt K.S., Takahashi H., von Wirén N. 2020. Auxin-mediated root branching is determined by the form of available nitrogen. Nature Plants 6(9): 1136–1145. DOI: 10.1038/s41477-020-00756-2.

Meihana M., Lakitan B., Susilawati, Harun M.U., Widuri L.I., Kartika K., Siaga E., Kriswantoro H. 2017. Steady shallow water table did not decrease leaf expansion rate, specific leaf weight, and specific leaf water content in tomato plants. Australian Journal of Crop Science 11(12): 1635–1641. DOI: 10.21475/ajcs.17.11.12.pne808.

Nhan T.T., Tuan L. 2020. Temperature independence of the heat capacity of liquid water at atmospheric pressure. Journal of Physics: Conference Series 1506; 012014; 7 p. DOI: 10.1088/1742-6596/1506/1/012014.

Rahnema S., Sedaghathoor S., Allahyari M.S., Damalas C.A., El Bilali H. 2019. Preferences and emotion perceptions of ornamental plant species for green space designing among urban park users in Iran. Urban Forestry and Urban Greening 39: 98–108. DOI: 10.1016/j.ufug.2018.12.007.

Rana M.K., Rani P. 2017. Swiss chard. In: Rana M.K. (Ed.), Vegetable Crops Science. CRC Press, USA, pp. 241–246. DOI: 10.1201/9781315116204-28.

Salazar J.C.S., Melgarejo L.M., Bautista E.H.D., Di Rienzo J.A., Casanoves F. 2018. Non-destructive estimation of the leaf weight and leaf area in cacao (*Theobroma cacao* L.). Scientia Horticulturae 229: 19–24. DOI: 10.1016/j.scienta.2017.10.034.

Sharma N., Acharya S., Kumar K., Singh N., Chaurasia O.P. 2018. Hydroponics as an advanced technique for vegetable production: An overview. Journal of Soil and Water Conservation 17(4): 364–371. DOI: 10.5958/2455-7145.2018.00056.5.

Siaga E., Lakitan B., Hasbi, Bernas S.M., Wijaya A., Lisda R. et al. 2018. Application of floating culture system in chili pepper (*Capsicum annum* L.) during prolonged flooding period at riparian wetland in Indonesia. Australian Journal of Crop Science 12(5): 808–816. DOI: 10.21475/ajcs.18.12.05.pne1007.

Zhou J., Han F., Li K., Wang Y. 2020. Vegetable production under COVID-19 pandemic in China: An analysis based on the data of 526 households. Journal of Integrative Agriculture 19(12): 2854–2865. DOI: 10.1016/s2095-3119(20)63366-4.

Zhu T., Fonseca De Lima C.F., De Smet I. 2021. The heat is on: how crop growth, development, and yield respond to high temperature. Journal of Experimental Botany 72(21): 7359–7373. DOI: 10.1093/jxb/erab308.