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Bok choy *(Brassica rapa* L.) growth and yield in a floating system on freshwater swamps with various substrate composition and number of wicks

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Abstract: Bok choy (*Brassica rapa* L.) is commonly cultivated using a floating system, a sustainable agricultural method suitable for flooded areas. This study aimed to evaluate the growth and yield of Bok choy grown using different substrate compositions and numbers of wicks. This study implemented following Randomized Block Design (RBD) with two factors. The first factor was the substrate composition: topsoil (M1), soil + cow manure + sand (4:2:1) (M2), and soil + cow manure + rice husk biochar (4:2:1) (M3). The second factor was the number of wicks: two (S2), three (S3), and four (S4). The results demonstrated that substrate composition and the number of wicks significantly influenced water mobilization, soil moisture, and plant performance. Substrates containing manure with sand (M2) or rice husk biochar (M3) showed superior growth and yield compared to topsoil (M1). Additionally, using three wicks (S3) optimized water absorption, resulting in the best plant growth. The combination of soil + cow manure + rice husk biochar (M3) with three wicks (S3) produced the highest growth and yield of Bok choy in floating systems within freshwater swamp conditions. These findings provide practical applications for improving sustainable Bok choy cultivation in swampy and flood-prone areas.

1. Introduction

Population growth and the continuous reduction of arable land have raised serious concerns regarding global food security. Technologies continues to be evolved in efforts to enhance sustainable productivity through the utilization of marginal land (Gustiar *et al.*, 2025; Lakitan *et al.*, 2025). Freshwater swamps are suboptimal lands that hold great potential to be utilized as agricultural land. In Indonesia, approximately 1.8 million ha of swamp land have been developed, consisting of 1,452,569 ha of tidal marshes and 347,431 ha of non-tidal marshes. Qualitative descriptive and quantitative assessments conducted in Central Kalimantan, Indonesia, indicated that swamp lands cover around 33.4 million hectares, with approximately 9.5 million hectares having potential for agricultural use (Fahmid *et al.*, 2022). Despite this potential, agricultural utilization of swamp lands is constrained by seasonal flooding and prolonged waterlogging, which limit the application of conventional cultivation systems. Floating cultivation has emerged as a promising alternative to overcome these constraints. The floating vegetable cultivation technique is a vegetable production system on swampy land that uses rafts as a solution during flooding or inundation (Siaga and Lakitan, 2021). This system aligns with the principles of sustainable agriculture by enabling the use of marginal lands, reducing pressure on fertile soils, maintaining ecosystem balance, and supporting long-term food security. One major advantage of floating cultivation is that plants do not require manual irrigation, as moisture is continuously supplied through capillary movement from the underlying water body (Jaya *et al.*, 2021; Susilawati *et al.*, 2024). Efficient water management without intensive watering contributes to water conservation and enhances system sustainability, particularly under increasingly unpredictable climate conditions.

Brassica rapa L. (Bok choy) is a leafy vegetable with a relatively short growth cycle and high nutritional value, making it suitable for cultivation in adaptive production systems. Bok choy has shown adaptability to diverse growing environments, including soilless and floating cultivation systems. Previous studies reported that plants grown under floating cultivation exhibited higher leaf numbers and better leaf and petiole development, particularly in tatsoi and green mustard (Siaga and Lakitan, 2021; Ria *et al.*, 2025). Bok choy is also among the most widely consumed leafy vegetables, with steadily increasing market demand, making it economically attractive for cultivation in marginal environments (Muslimah *et al.*, 2024). Bok choy contains nutrients including protein, fat, carbohydrates, calcium, phosphorus, magnesium (Mg), iron (Fe), and vitamins A, B, and C (Veazie *et al.*, 2020).

The increasing demand for vegetables driven by population growth necessitates the expansion of cultivation areas beyond conventional agricultural land. Utilization of freshwater swamps offers a strategic option to meet this demand (Hidayatulah *et al.*, 2022). However, swamp agriculture faces dual challenges of drought during dry seasons and flooding during rainy seasons. Floating cultivation systems have been shown to produce yields comparable to, or even higher than, conventional land-based cultivation under such conditions (Lakitan *et al.*, 2018). Cultivation on water surfaces, either using terrestrial or aquatic crops, has therefore been proposed as a sustainable agricultural strategy for tropical regions with extensive flooded areas (Radulovich *et al.*, 2015).

Floating vegetable cultivation is conducted by positioning substrate pots so that their bases are in direct contact with the water surface, allowing continuous water supply through capillary movement. Therefore, the raft load must be carefully adjusted to ensure sufficient submergence for water contact without compromising buoyancy and structural stability (Jaya *et al.*, 2021). In practice, maintaining a stable raft position and uniform water contact is challenging due to fluctuations in water level and changes in plant biomass. However, maintaining uniform and stable water contact under field conditions is challenging. A practical solution is the use of floating rafts combined with a hydroponic approach employing a wick irrigation system. Wick irrigation is considered a simple, low-cost, and sustainable technique capable of maintaining continuous substrate moisture through capillary action (Junejo *et al.*, 2022). In this system, water is transported from the water body to the planting medium via wicks, and substrate moisture is influenced by factors such as substrate composition, wick length, wick diameter, and the number of wicks used (Oh *et al.*, 2007). Despite its importance, information on the optimal number of wicks for floating vegetable cultivation remains limited. While increasing the number of wicks may enhance water supply, excessive wicks may reduce system efficiency and potentially impair root aeration.

In addition to wick number, substrate composition plays a critical role in regulating capillary movement, water retention, and aeration. Modifications in soil physical properties can significantly influence capillarity, with biochar addition reported to increase capillary pore space and water-holding capacity (Šimanský *et al.*, 2022). Rice husk biochar is known for its high porosity and cation exchange capacity, which may improve water retention and nutrient availability, while sand contributes to improved drainage and aeration. The planting medium is therefore a key factor determining growth and yield performance of Bok choy under floating cultivation (Rizal *et al.*, 2023). Incorporation of manure further supports nutrient supply, particularly nitrogen, phosphorus, and potassium, which are essential for vegetative growth (Bartley *et al.*, 2022). The soil-based growing medium alone does not fully meet plant nutrient requirements; therefore, manure is added as an organic nutrient source to improve nutrient availability. However, the interactive effects between substrate composition and wick number on the growth and yield of Bok choy under floating cultivation in freshwater swamps remain poorly understood. Therefore, this study aimed to experimentally evaluate the effects of different substrate compositions and wick numbers on growth and yield parameters of Bok choy cultivated under floating conditions in freshwater swamps.

2. Materials and Methods

This study was conducted at the Field Laboratory of Freshwater Swamp, Faculty of Agriculture, Sriwijaya University, South Sumatra. The implementation period of the study was from May to August 2024.

Experimental design and planting material

This study was conducted using a factorial randomized block design (FRBD) with two treatment factors. The first factor was substrate composition, consisting of M1 = soil, M2 = soil : cow manure : sand (4:2:1, v/v), and M3 = soil : cow manure : rice husk biochar (4:2:1, v/v). The second factor was the number of wicks, comprising S2 = two wicks, S3 = three wicks, and S4 = four wicks (Fig. 1A). Each treatment combination was replicated three times, and each experimental unit consisted of three plants, resulting in a total of 81 plants. Bok choy (*Brassica rapa* L.) var Nauli F1 were used in this experiment. Seedlings were grown in a nursery until reaching a uniform size prior to transplanting. Uniform seedlings were transplanted into plastic pots with a diameter of 20 cm, each filled with planting growing medium according to the assigned substrate treatment.

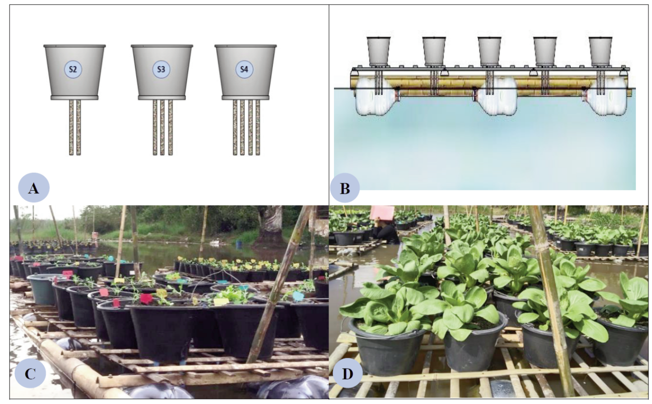

Fig. 1 - Treatment of the number of wicks (A), the appearance of the floating raft design (B), and the study of floating Bok choy cultivation activities (C, D).

Plants were arranged on floating rafts measuring 2.0 × 1.2 m, constructed from bamboo and supported by nine recycled 19^{-L} mineral water gallons to maintain buoyancy. Pot spacing on the raft was arranged uniformly to avoid shading effects. Each pot was connected to the underlying freshwater through flannel cloth wicks, which acted as capillary channels supplying water from the swamp to the planting growing medium. The dimensions of each wick were kept uniform across treatments to ensure consistency in water supply, with only the number of wicks varying according to treatment.

Variables and statistical analysis

The parameters observed included the planting media condition, especially humidity. Growth parameters were leaf length, width, area, and number. Leaf morphology was measured by SPAD values using Minolta 504, canopy area and leaf area using the Eazyleaf area meter device, stem diameter, root length, and plant height. Data on bok choy growth and yield were analyzed using two-way analysis of variance (ANOVA) to evaluate the effects of substrate composition, number of wicks, and their interaction. Statistical analyses were performed using R Studio software. When significant differences were detected, mean comparisons were conducted using LSD test at a 5% significance level.

Preparation of floating cultivation raft

The floating raft was made of 200 x 120 cm bamboo with the upper and lower parts separated and modified to avoid direct contact with the water in the freshwater swamps using 9 plastic gallons as floats. The design of the raft used and the study activities of the floating Bok choy is shown in figure 1. Floating cultivation was carried out using a wick system hydroponic cultivation approach where the planting media derive a water supply without direct contact with the surface of the freshwater swamps where the water depth ranged from approximately 50 to 100 cm under tropical conditions. Flannel cloth was used as a connector for water with substrate and capillary capacity, the distance between the base of the pot and the water surface was ± 10 cm.

Agroclimatic conditions at experimental site

During the study activities, rain only occurred once, at the beginning. Temperature and humidity conditions were quite fluctuating, with the highest air temperature not exceeding 30°C, and the highest humidity not exceeding 20%. Agroclimatology conditions during the study activities are shown in figure 2.

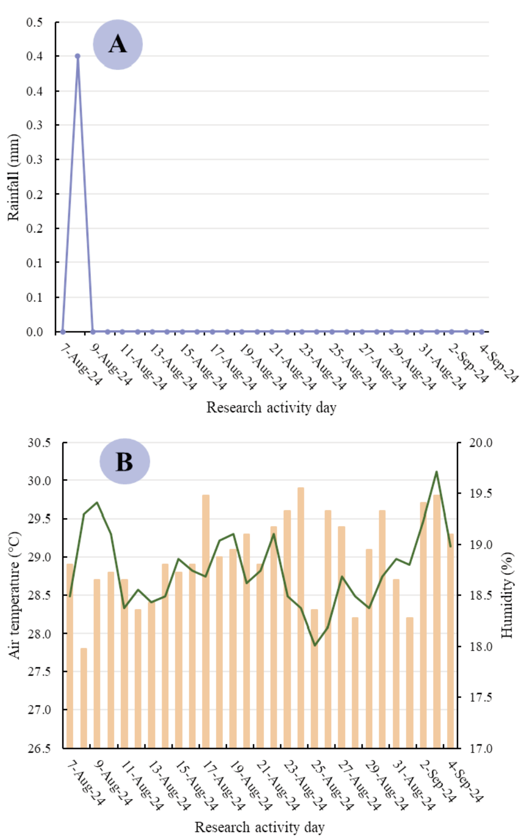

Fig. 2 - Rainfall (A), temperature, and humidity (B) patterns at experimental sites during study period (August to September, 2024). Data source: Meteorological, Climatological, and Geophysical Agency/BMKG.

3. Results and Discussion

Environment conditions and soil moisture dynamics

Freshwater swamps are characterized by alternating conditions of drought, fire, and flooding (Kurniawan, 2024). This study was conducted in a deep freshwater swamp during the dry season, when the land remained inundated despite very low rainfall. Deep freshwater swamps are land inundated throughout the year (Ratmini and Herwenita, 2021) where almost all plant cultivation activities cannot be carried out. Conducting the experiment during the dry season minimized rainfall interference, allowing the effects of substrate composition and wick number on water distribution within the floating system to be evaluated more clearly. Under these conditions, plant growth was primarily influenced by the ability of the substrate-wick system to regulate water availability rather than by external environmental fluctuations.

Substrate composition and wick number significantly influenced soil moisture content in the floating cultivation system. The highest moisture content was recorded in the M3 substrate (soil:cow manure:rice husk biochar, 4:2:1), whereas the lowest moisture content occurred in M1 (soil only). Increasing the number of wicks resulted in higher substrate moisture, indicating enhanced capillary water supply. A significant interaction between substrate composition and wick number was observed, with the highest moisture level occurring in the M3S4 treatment (Fig. 3).

Substrate composition plays a crucial role in determining bulk density, texture, and water-holding capacity. The incorporation of organic matter, rice husk biochar, and sand altered the physical and hydraulic properties of the planting media, thereby improving its ability to absorb and retain water. A mixture of mineral soil and organic matter can cause changes in the physical and hydraulic properties (Wallach, 2019). This explains the higher moisture observed in M2 and M3 compared with M1, which relied solely on mineral soil. In particular, rice husk biochar has been shown to increase porosity, improve aeration for root respiration, and stabilize soil moisture by retaining water in micropores (Singh *et al.*, 2018). These properties support sustained water availability and microbial activity within the root zone.

Regarding wick number, treatments S3 (three wicks) and S4 (four wicks) consistently exhibited

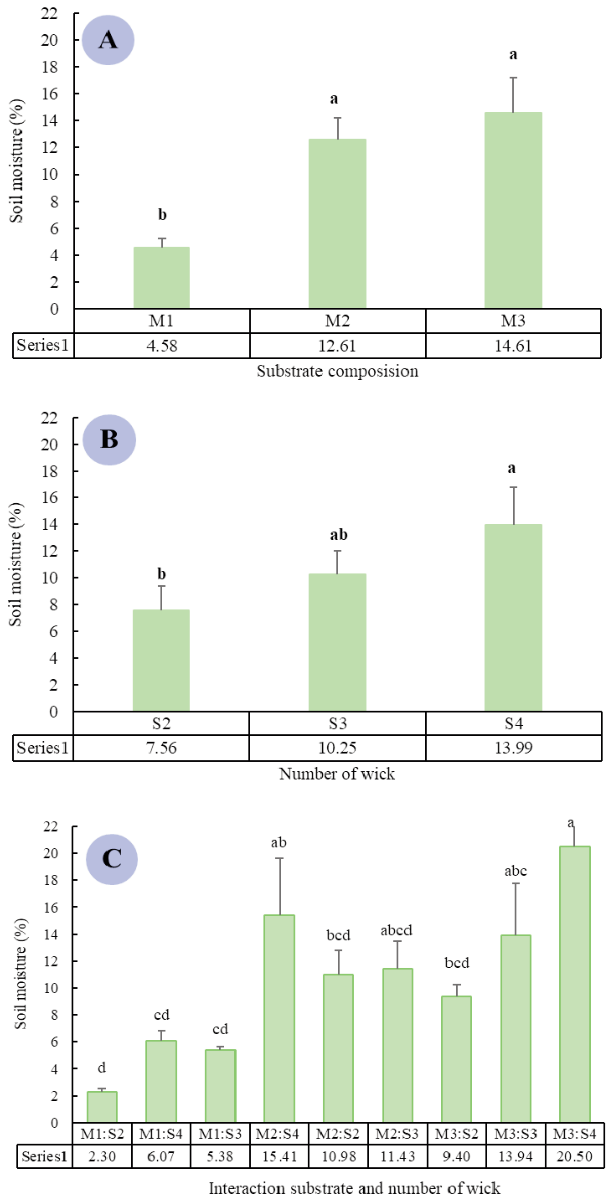

Fig. 3 - Soil moisture conditions under different planting substrate compositions (A), wick numbers (B), and combinations of substrate composition and wick number (C) in floating cultivation.

higher substrate moisture than S2 (two wicks). Increasing wick number increases the number of capillary pathways, thereby enhancing water transport from the swamp to the root zone (Ansar *et al.*, 2019). Wick irrigation functions as a subsurface capillary irrigation system, where water movement is driven by capillary forces rather than gravity (He *et al.*, 2024). However, although S4 produced the highest moisture content, excessive moisture may reduce root-zone aeration, suggesting the existence of an optimal wick number rather than a linear response. Similar studies on subsurface irrigation systems have reported benefits such as reduced evaporation, nutrient conservation, and improved plant quality, while excessive wetness may increase the risk of oxygen limitation in the root zone (Felipe and Bareng, 2022).

Growth rate of Bok choy (Brassica rapa L.)

In general, leaf length, width, and area increased progressively with plant age, particularly from leaf expansion until 12 days after full leaf opening. Substrate composition significantly affected the rate of leaf enlargement. In the M1 treatment, leaf growth tended to stagnate after the fifth day, whereas in M2 and M3, leaf length, width, and area continued to increase until the twelfth day with relatively similar growth rates (Fig. 4). At 25 days after planting (DAP), plants grown in M1 exhibited smaller leaves (length 6.5 cm, width 5.0 cm, leaf area 15 cm²) compared with those grown in M2 and M3. The slower leaf growth in M1 was associated with suboptimal physical and nutritional properties of the soil-only substrate. Although M1 exhibited relatively high moisture levels, the absence of organic amendments likely limited nutrient availability and

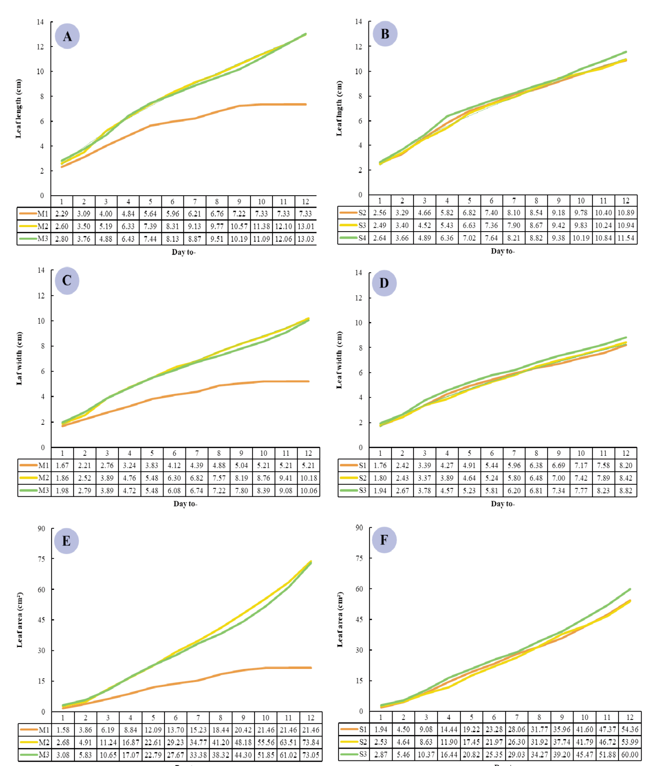

Fig. 4 - Effects of substrate composition (left) and number of wicks (right) on the daily rate of increase in leaf length (A, B), leaf width (C, D), and leaf area (E, F) of Bok choy grown under floating cultivation. Leaf traits were measured repeatedly over a 12-day cultivation period.

root development. In contrast, substrates M2 and M3, which contained cow manure, provided improved nutrient supply and better physical conditions for root growth, thereby supporting sustained leaf expansion.

The number of wicks also influenced leaf growth. The largest leaf dimensions were observed in S4, with leaf length of approximately 11 cm, width of 9 cm, and leaf area of 63 cm². However, leaf growth in S3 was statistically comparable to S4 and not markedly different from S2, indicating that increasing wick number beyond three did not proportionally enhance leaf expansion. This suggests that three wicks may provide sufficient water supply for optimal leaf growth without causing excessive moisture accumulation.

M2 and M3 treatments exhibited faster and more sustained leaf growth than M1, reflecting the combined effects of improved substrate structure and nutrient availability. The presence of organic matter in M2 and M3 likely enhanced soil pH balance, nutrient availability, and microbial activity, which are essential for vegetative growth (Ho *et al.*, 2022). Manure contributes essential nutrients and increases soil organic matter, thereby stimulating plant growth, whereas mineral soil alone is often insufficient to meet the nutritional requirements of Bok choy (Augustien and Suhardjono, 2016).

Substrate composition and wick number influenced the temporal pattern of leaf production in Bok choy plants. During the early growth stage (up to 13 DAP), the highest leaf number was observed in the M2 substrate, whereas at 16 DAP and towards the end of the experiment, plants grown in M3 exhibited the greatest number of leaves. In contrast, M1 consistently produced the lowest leaf number from 10 DAP until harvest, indicating suboptimal growing conditions in the soil-only substrate (Fig. 5 A).

The number of wicks did not significantly affect leaf number during the early growth phase (≤13 DAP). However, from 16 DAP onwards, treatments S3 (three wicks) and S4 (four wicks) produced a greater number of leaves than S2 (two wicks). Although S4 recorded the highest leaf number at harvest, it was not statistically different from S3, suggesting that increasing wick number beyond three provided no additional advantage for leaf initiation (Fig. 5 B).

The delayed response of leaf number to substrate and wick treatments indicates that early vegetative growth was not limited by water availability. At the initial growth stage, the root system was still

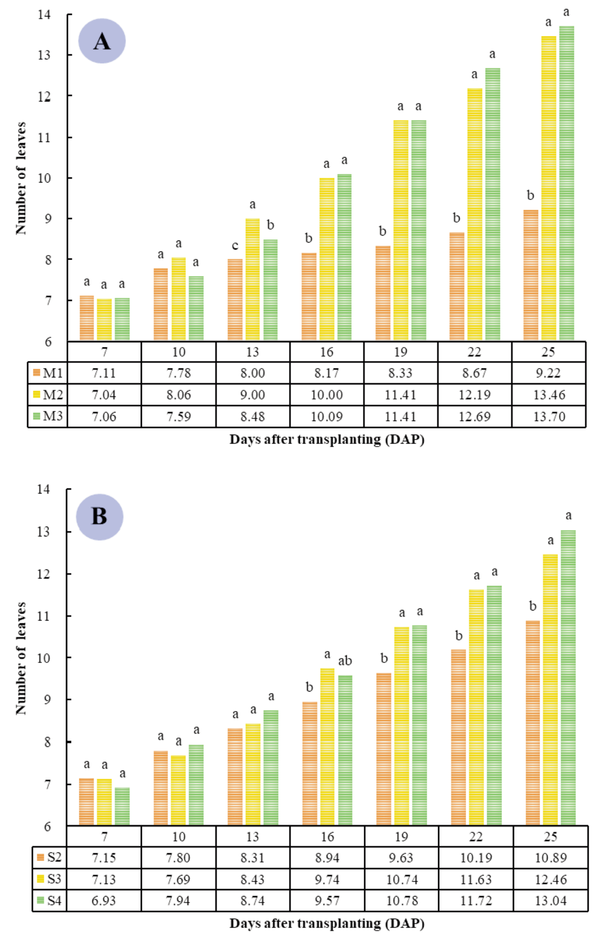

Fig. 5 - The leaf growth rate in different substrate composition (A) and number of wicks (B).

underdeveloped, limiting the plant's capacity to utilize increased water supply from additional wicks. Consequently, differences in leaf number became apparent only after root establishment, when plants could more effectively exploit substrate moisture and nutrient availability.

These findings are consistent with Maludin *et al.* (2020), who reported that significant differences in Bok choy growth parameters emerged only after 15 DAP, reflecting the transition from establishment to active vegetative growth. The superior performance of M3 at later stages may be attributed to the improved physical structure and water-holding capacity provided by rice husk biochar, which supports sustained leaf initiation under continuous moisture supply. Meanwhile, the comparable performance of S3 and S4 suggests the existence of an optimal wick number, beyond which additional water supply does not proportionally enhance leaf production and may risk excessive moisture in the root zone.

Morphology and yield of Bok choy

In general, substrate composition affects the observed SPAD and plant morphological variables, including, canopy area, total leaf area, stem diameter, root length, and plant height. Substrate treatment using only soil (M1) had the smallest value for all morphological variables. The highest value was found in M3, but not significantly different from M2. This is presumably because the addition of manure supplies the nutrient needs of Bok choy plants, thereby making plants grow better. The morphology of the plant is presented in figure 6. The number of wicks also affected plant morphological variables where the smallest value was found in the pot prepared using two wicks (S2). The largest value was found in plants with four wicks (S4) but not significantly different from plants using three wicks (S3). In the interaction of substrate composition treatment and the number of wicks, the highest value was found in the M2S3 combination, while the lowest was recorded in the M1S2 treatment. The overall data are presented in Table 1.

Changes in plant morphology also affect the variables of plant yield in the form of fresh and dry

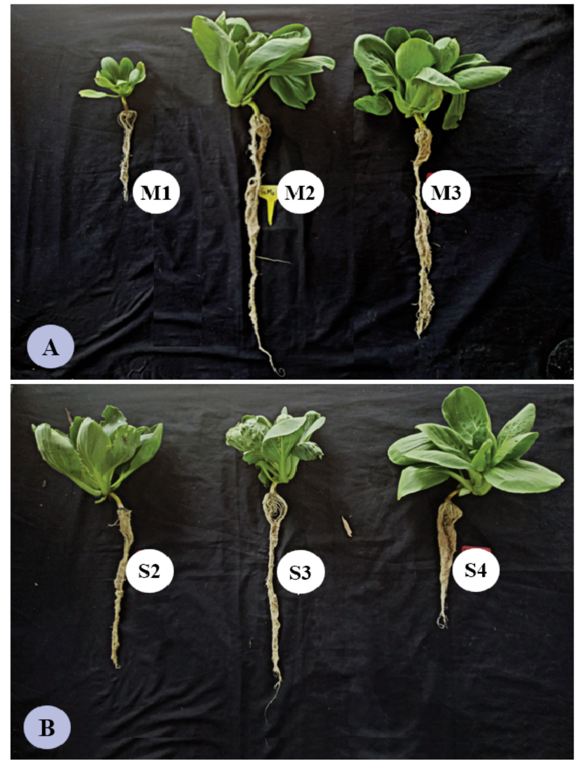

Fig. 6 - Bok choy plants grown under various substrates (A) using 3 types of wicks (B).

Table 1 - Effect of substrate composition and number of wicks on the morphology of Bok choy plants in floating cultivation

Description	SPAD value	Canopy area (cm²)	Total leaf area (cm²)	Stem diameter (mm)	Root length (cm)	Plant height (cm)
Substrate composition						
M1	38.26 b	126.28 b	130.94 b	3.96 b	28.83 b	3.79 a
M2	49.61 a	615.07 a	1056.52 a	7.80 a	45.81 a	3.85 a
M3	52.55 a	516.46 a	1079.88 a	8.14 a	43.77 a	4.07 a
LSD0.05	3.52	215.45	328.21	1.33	10.48	0.56
Number of wicks						
S2	45.57 a	257.79 b	520.10 b	5.51 b	35.52 b	3.97 a
S3	47.08 a	486.10 a	849.30 a	7.25 a	41.39 a	3.79 a
S4	47.77 a	513.93 a	897.94 a	7.14 a	41.51 a	3.95 a
LSD0.05	3.52	215.45	328.21	1.33	10.48	0.56
Interaction substrate composition and number of wicks						
M1S2	33.57 d	99.70 d	93.53 c	3.35 d	26.83 c	3.77 a
M1S3	38.23 cd	106.77 d	138.56 c	4.00 cd	27.65 c	3.68 a
M1S4	42.98 bc	172.38 d	160.73 c	4.53 cd	32.02 bc	3.92 a
M2S2	50.20 a	349.32 bcd	574.78 bc	6.15 bc	35.98 abc	3.83 a
M2S3	50.88 a	785.87 a	1275.45 a	9.02 a	48.47 ab	4.18 a
M2S4	47.75 ab	710.03 ab	1319.33 a	8.23 ab	52.98 a	3.53 a
M3S2	52.95 a	324.35 cd	892.00 ab	7.02 ab	43.73 abc	4.31 a
M3S3	52.13 a	565.67 abc	1133.88 ab	8.73 a	48.07 ab	3.50 a
M3S4	52.57 a	659.37 abc	1213.75 a	8.67 a	39.51 abc	4.41 a
LSD0.05	6.10	373.17	568.49	2.31	18.14	0.97

The means followed by different letters within each column indicate significant difference at the LSD 0.05.

leaf, stem, and root weights. The smallest planting substrate composition treatment was found in M1, and the highest weight was recorded in M3, but not significantly different from M2. The greatest wick treatment was found in S4, which was significantly different from S2 but not S3. Complete data are shown in Table 2.

In general, the best substrate treatments were found in M2 and M3 while the best wick treatment was found in the use of three (S3) or four wicks (S4). The interaction of substrate composition and number wicks had a very significant effect on fresh and dry weight variables. The highest fresh leaf weight was found in M2S3 at 139.07 g, the highest dry leaf weight as well as fresh and dry stem weight were found in M3S4, and the highest root weight was recorded in M2S4.

The effect of M2 was not significantly different from M3 but differed from M1 in terms of plant morphology and yield variables. This is the effect of administering manure and rice husk biochar or sand which enhance the biochemical and physical properties of the soil. Changes in the biochemical and physical properties of the soil produce better growth, which will have implications for improving plant biomass. Manure is a material with high levels of micro and macronutrients. Furthermore, the administration of cow manure to the planting media has been proven to increase microbial composition, soil enzyme activity, and soil carbon (Ozlu *et al.*, 2019). The use of rice husk charcoal or biochar as a soil conditioner has long been recognized in agriculture to improve soil productivity. Given that biochar has a high CEC, it can bind soil cations crucial for growth. Furthermore, the role of biochar in the soil is to keep moisture and improve fertility. The benefits of administering rice husk biochar to the soil include enhancing air and water circulation as well as providing nutrients to evoke growth (Setyawan, 2023).

4. Conclusions

In conclusion, the highest growth and yield performance of Bok choy was found in the substrate with soil, cow manure and sand - the ratio 4:2:1 (M2). In general, the floating cultivation system

Table 2 - Effect of substrate composition and number of wicks on the weight of Bok choy plant biomass in floating cultivation

Description	Fresh leaf weight (g)	Dry leaf weight (g)	Fresh stem weight (g)	Dry stem weight (g)	Fresh root weight (g)	Dry root weight (g)
Substrate composition						
M1	10.15 b	1.49 b	0.99 b	0.13 b	3.27 b	0.31 b
M2	101.09 a	9.56 a	2.55 a	0.32 a	13.22 a	1.35 a
M3	103.67 a	9.88 a	3.08 a	0.36 a	15.31 a	1.26 a
LSD0.05	29.79	2.42	0.65	0.08	4.92	0.45
Number of wicks						
S2	45.79 b	4.42 b	1.69 b	0.23 a	6.20 b	0.67 b
S3	84.75 a	7.68 a	2.47 a	0.27 a	12.12 a	0.98 ab
S4	84.37 a	8.82 a	2.47 a	0.30 a	13.48 a	1.27 a
LSD0.05	29.79	2.42	0.65	0.08	4.92	0.45
Interaction substrate composition and number of wicks						
M1S2	6.38 d	1.07 de	0.80 c	0.10 e	1.55 c	0.19 d
M1S3	9.31 d	1.01 e	0.94 c	0.12 de	3.57 bc	0.22 d
M1S4	14.76 d	2.38 de	1.25 c	0.17 cde	4.70 bc	0.51 cd
M2S2	50.20 cd	5.25 cd	1.66 bc	0.24 bcd	5.98 bc	0.78 bcd
M2S3	139.07 a	12.06 a	3.38 a	0.41 a	15.61 a	1.53 ab
M2S4	113.99 ab	11.38 a	2.62 ab	0.31 ab	18.08 a	1.75 a
M3S2	80.78 bc	6.97 bc	2.62 ab	0.36 ab	11.09 ab	1.04 abc
M3S3	105.87 ab	9.95 ab	3.08 a	0.30 abc	17.19 a	1.20 abc
M3S4	124.36 ab	12.70 a	3.54 a	0.42 a	17.65 a	1.54 ab
LSD0.05	51.59	4.20	1.13	0.14	8.52	0.78

The means followed by different letters within each column indicate significant difference at the LSD 0.05.

required at least three wicks (S3) to achieve satisfactory growth and yield across most substrate compositions, whereas two wicks (S2) were less effective. However, for the M2 substrate, two wicks (S2) were sufficient to provide adequate water and nutrient supply, resulting in the best performance among all treatment combinations (M2S2).

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