BIOVALENTIA: BIOLOGICAL RESEARCH JOURNAL
e-ISSN: 2477-1392
Vol. 9 No. 2, Nov 2023

Suitable Substrate Volumes and Cultivars for Enhancing Growth and In-Creasing Yield of Yard-Long Bean in Urban Ecosystems

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Peer review under responsibility of Biology Department Sriwijaya University

Abstract

Yard-long bean, a favored vegetable known for its taste and nutritional value, holds economic importance. Its climbing nature and environmental resilience make it ideal for urban cultivation in pots and climbing frames. This study, conducted in a limited urban space, aimed to determine optimal pot size and cultivars for yard-long bean cultivation, emphasizing growth and yield. Two pot sizes were used: a larger one (30 cm diameter x 37 cm height, M1) and a smaller one (30 cm diameter x 30 cm height, M2), alongside three commercial cultivars: Kanton Tavi (V1), Camellia (V2), and Arafi (V3). Results indicated that a larger pot size increased pod number and total pod weight per plant, facilitating root development, vine growth, and enhanced yield. The larger substrate volume retained moisture and boosted plant biomass. Cultivar treatment affected branch length and flowering time, with Camellia exhibiting the longest harvest period (14 harvests). Hence, for Camellia varieties, cultivation using larger pots (30 cm diameter x 37 cm height) is recommended.

Keywords : Vigna unguiculata; climbing vegetable; commercial cultivar; pot size; inhibited root growth.

Received: September 11, 2023, Accepted: November 29, 2023

1. Introduction

Yard-long bean (*Vigna unguiculata (L). Walp. Ssp. Sesquipedalis Verdc.* is an economically important legume crop. It is a member of the Fabaceae family and is distinguished by its long, draped pods and climbing growth pattern [1]. It is cultivated for its immature pods which are consumed fresh or cooked [2]. This plant is good for consumption because it can improve health and nutrition and it helps prevent significant health issues including diabetes, obesity, and some forms of cancer [3]. In 100 g yard-long beans contains 6.20-8.33 g carbohydrates, 0.10-0.18 g fat, 1.52- 2.37 g sugar, 2.72-3.22 g protein, 1.17-1.79 g crude fiber and 45.86-37.21 Kcal calories [4]. Therefore, this plant is popular for consumption because of its nutritional value and delicious taste.

This warm-season plant, native to Southeast Asia, is distributed across Asia, Europe, Oceania, and North America [5]. Renowned for its heat and drought resistance, it is employed in diverse cropping systems globally [1]. Its climbing traits enable cultivation in restricted spaces, including urban ecosystems.

The development of urban agriculture is based on the increasing need for food in urban areas and decreasing fertile land as well as sustainable conventional agricultural practices [6]. Urban agriculture has many benefits, namely high productivity, increased sustainability, availability of fresh food throughout the year [7], and optimizing the efficiency of small urban land areas. In addition, the health and welfare of the community and the surrounding environment benefit from urban agriculture [8].

In urban farming yard-long beans can be cultivated in pot. The pot used must be of a suitable size. A pot that is too large will take up a lot of space on limited land, but using a smaller pot can limit root development. Limitations in substrate volume have the potential to affect plant growth by chemically inhibiting root growth [9]. Plant development and carbon partitioning are affected by limited roots in too small a pot, which can also interact with other stressors [10]. Megersa et al. [11] explained that a smaller pot volume limits plant height while a larger pot volume allows plants to grow taller. Different pot sizes affect how plants respond

[12]. Therefore, it is necessary to carry out studies to find a suitable substrate volume for the development of yard-long bean.

For optimal harvest results, high-quality seeds are essential. Various cultivars, developed for maximum yields and pest/disease tolerance, are available in the market. Pidigam et al. [5] highlighted the use of pure line selection in creating significant commercial cultivars. However, there are differences in each cultivar in relation to environmental changes. Therefore, it is necessary to test several cultivars cultivated in urban ecosystems. This research aims to find suitable pot volumes and cultivars for yard-long bean cultivation with optimal growth and yield in urban ecosystems.

2. Materials and Methods

Research site

This research was carried out at the Jakabaring Research Facility (104°46'44"E, 3°01'35' S), Palembang, South Sumatra, Indonesia. The research was carried out during the rainy season in a tropical urban area. Monthly data on relative humidity and rainfall events are presented in Figure 1.

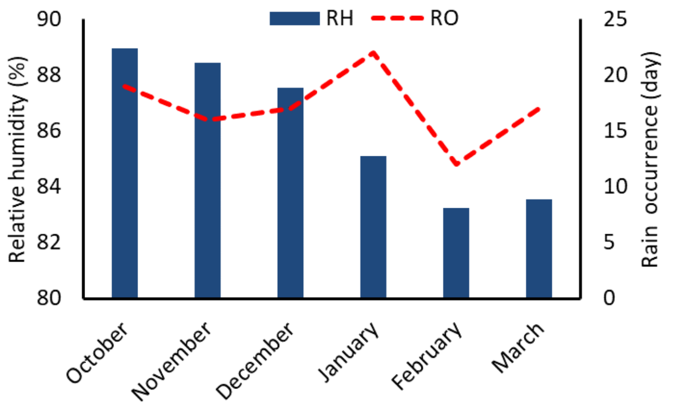

Figure 1. Monthly average relative humidity (RH) and rain occurrence (RO) during the research conducted (Source: Indonesian Meteorological, Climatological, and Geophysical Agency [13])

Research setup and design

This research used a factorial randomized block design with the first factor being substrate volume consisting of the bigger pot with a diameter of 30 cm x a height of 37 cm (M1); and smallest pot with a diameter of 30 cm x height 30 cm (M2). The second factor is the yard-long bean variety which consists of 3 varieties, namely Kanton Tavi (V1); Camellia (V2); and Arafi (V3). The seeds used in this research are commercial seeds.

Planting is done by sowing long bean seeds. Transplanting is carried out at the age of 7 days after sowing (DAS). Seedlings are planted in plastic pots according to each treatment and 5 cm is left from the surface of the pot for water drainage. The planting media used is topsoil and manure (3:1). The planting medium is then sterilized with bio fungicide which has been dissolved in 2g/l (200 ml/pot) water. Fertilization is carried out at the beginning of the vegetative period, the beginning of the generative period, and after the peak harvest period at a dose of 5 g/plant using NPK fertilizer.

Pots were placed on either side of the 4 m x 2 m experimental pond. The propagation frame, constructed from 1-inch PVC pipes, measured 4 m x 2 m x 2 m (length x width x height). Nylon fishing lines, 0.5 mm thick, were woven vertically and horizontally at 25 cm x 25 cm intervals to facilitate vine growth upwards and horizontal branching.

Data collection

Vegetative parameters include vine length, vine diameter, number of vine nodes and number of leaves observed 7 days after planting (DAP). Water availability parameters were observed 4 weeks after planting (WAP) which included substrate moisturizer. Destructive observations were carried out by measuring leaf length, leaf width, leaf fresh weight, leaf dry weight to determine leaf relative water content (LRWC), leaf specific water content (LSWC), specific leaf area (SLA). To get LRWC, the leaves are soaked in water until the leaves are saturated. Harvest parameters were measured by the number of pods per plant and the total fresh weight of the pods per plant. Pod development is measured based on the length and diameter of the pod every day until the pod reaches the harvest criteria.

Destructive observations were carried out in the 9th week after planting to obtain information on plant growth. The parameters measured are vine length, vine diameter, number of vine nodes, vine fresh weight, vine dry weight, number of productive branches, number of non-productive branches, branch length, branch fresh weight, branch dry weight, leaf total fresh weight , leaf total dry weight, flowering time, pod diameter per plant, pod length per plant, pod fresh weight per plant, number of seeds per plant, total pod number per plant, total pod fresh weight per plant, root length, root fresh weight, and root dry weight. All plant components were dried in an oven at 100°C for 24 hours to obtain dry weight data. Pod and vine diameters were measured using a digital caliper with a resolution of 0.01 mm. Substrate moisture were measured using soil 154 moisture meter (PMS-714, Lutron Electronics Canada, Inc., Pennsylvania, USA).

Data analysis

All data collected in this study was analyzed using RStudio software version 1.14.1717 for Windows (developed by RStudio team, PBC, Boston, MA). Significant differences among treatments were tested using the least significant difference (LSD) procedure at $p<0.05$.

3. Results and Discussion

Vegetative growth on yard-long bean

The increase in vine length on yard-long beans was observed to be quite rapid, both in the substrate volume treatment and the cultivar treatment. Differences in substrate volume do not affect vine length and number of vine nodes. However, on the other hand, cultivar treatment affected vine length on days 7, 11, and 15 days after planting (DAP). During the vine elongation process, internodes are also added to the vine. This can be seen in the cultivar treatment which influences the increase in the number of nodes on the vine on days 7, 11 and 15 DAP as the vine elongates. Both treatments did not affect vine diameter in yard-long bean.

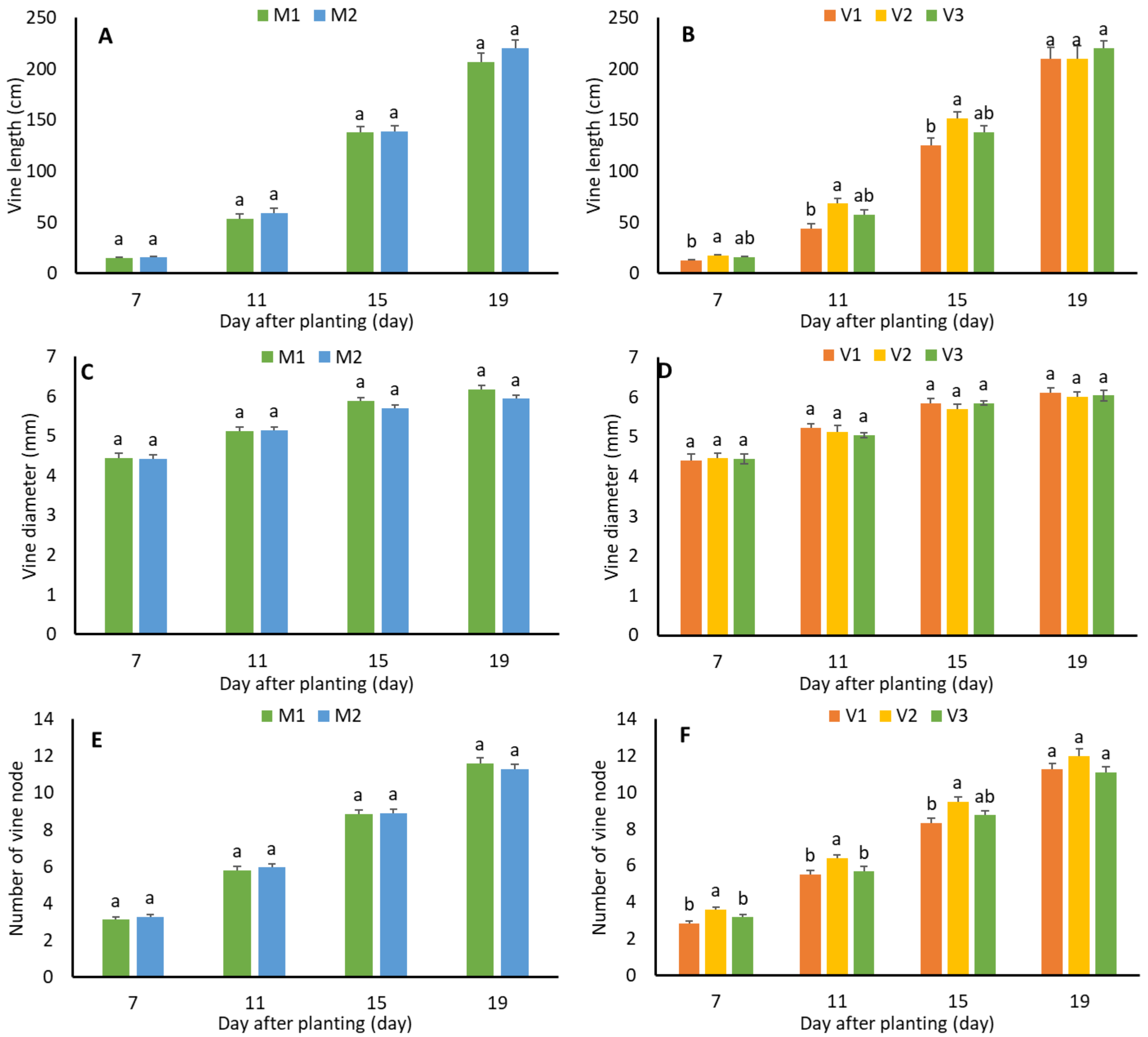

Figure 2. Vine elongation (A, B), vine diameter (C, D), and number of vine nodes (E, F) on yard-long bean based on substrate volume (left column) and cultivar (right column).

The vines on the yard-long bean plant are important plant organs that act as support for the plant's structure. Monitoring vine growth is important to see the vegetative growth of the plant. Studies on vine growth parameters have previously been carried out on sweet gourd [14], zucchini [15] and pumpkin [16].

Substrate volume treatment did not af-fect the increase in the number of leaves. Furthermore, the cultivar treatment did not affect the increase in the number of leaves on the 7th day and the 11th day after plant-ing (DAP) but did affect the increase in the number of leaves on the 15th day and the 19th day after planting (DAP), which is thought to have occurred due to the addition of plant organs that occurred along with in-creasing planting age. The Camelia cultivar confirmed to have the highest leaf number at 15th DAP (9.3) and 19th DAP (14.2) than other cultivars.

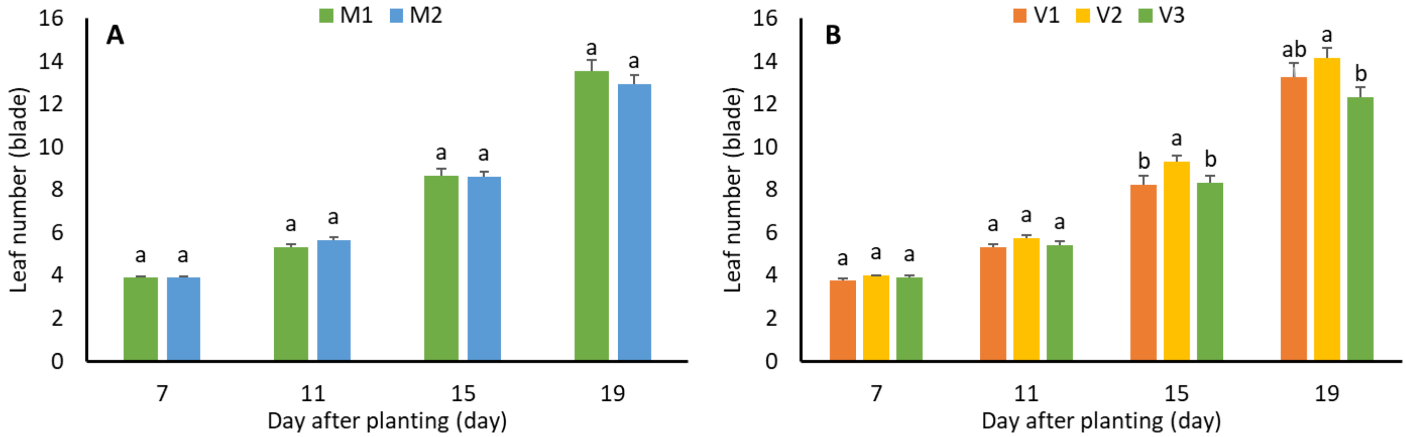

Figure 3. Increasing the number of leaves in the substrate volume (A) and cultivar (B) treatments on yard-long bean.

Influence of substrate volume and cultivar on water availability

The results showed that the substrate volume treatment did not affect the relative water content of the leaves and the specific leaf water content. This shows that differences in substrate volume are not affected by water stress. Substrate volume can cause plant stress due to limited root growth and water availability in the substrate. In several earlier studies, LRWC measurements were carried out to evaluate plant tolerance in water deficit conditions [17, 18].

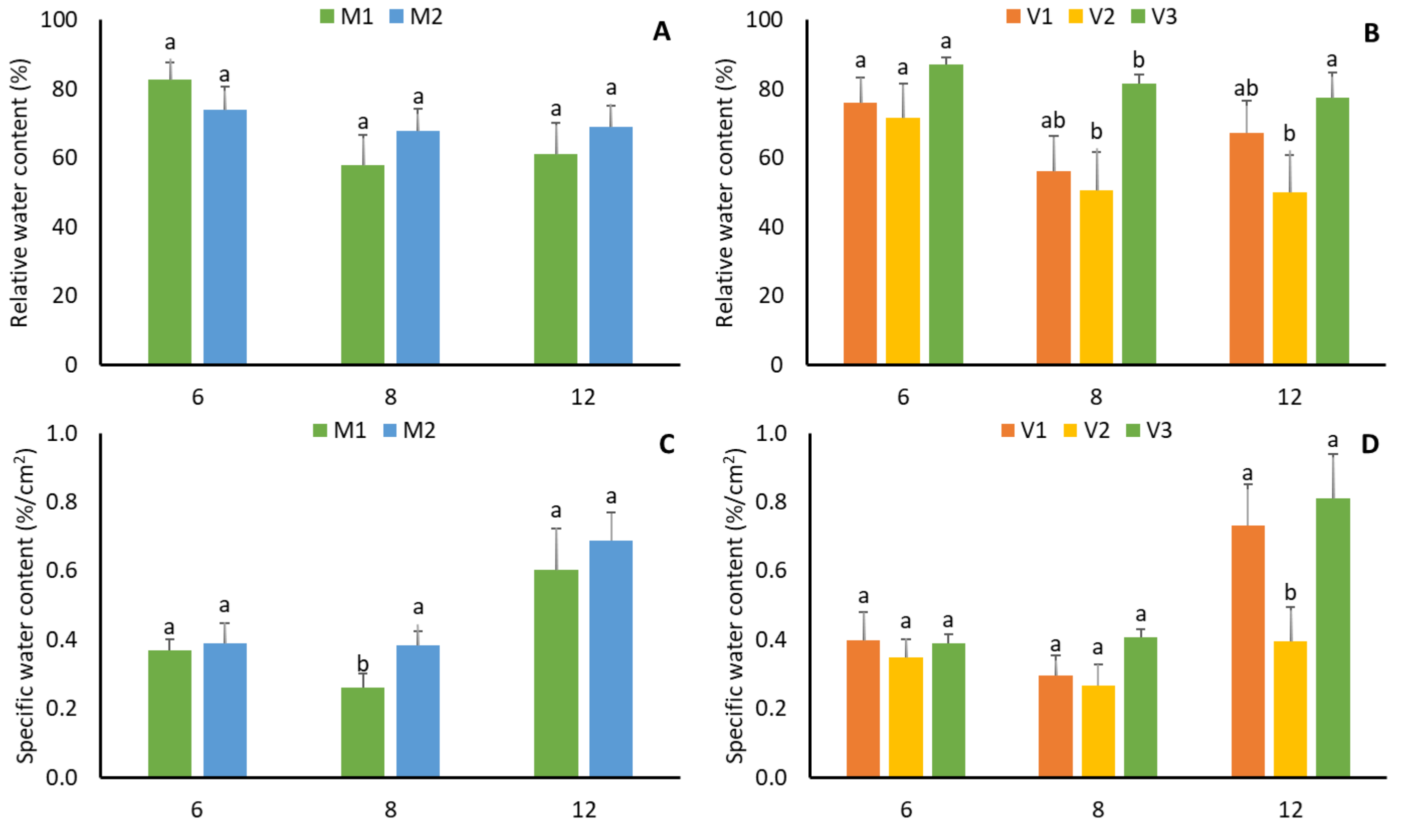

Figure 4. Leaf relative water content (A,B) and specific leaf water content (C,D) on leaves 6, 8 and 12, in substrate volume treatment (left column) and cultivar treatment (right column).

The cultivar treatments affected the relative water content on the 8th and 12th leaves and the specific leaf water content on the 12th leaf. The Arafi cultivar had the highest LRWC value among other varieties. This significant difference in relative water content is influenced by the genetic characteristics of cultivars such as cowpea [19]. A high LRWC value indicated that the plant is well hydrated. In this study, regardless of substrate volume, the Arafi cultivar was able to maintain LRWC on the leaves. Altaf et al. [20] affirmed that LRWC was well associated with drought tolerance.

The specific leaf area was unaffected by substrate volume or cultivar treatment, determined by the ratio of leaf area to dry leaf biomass. In several studies, SLA is used as an important indicator in determining plant responses to environmental factors such as drought conditions [21, 22]. The SLA value which tends to be uniform showed that differences in substrate volume do not cause drought stress in yard-long bean. A high SLA value also indicated wider leaves. The wider the leaves, the more opportunities the leaves must capture light for photosynthesis. Feng et al. [23] explained that higher N allocation to photosynthesis is correlated with higher SLA.

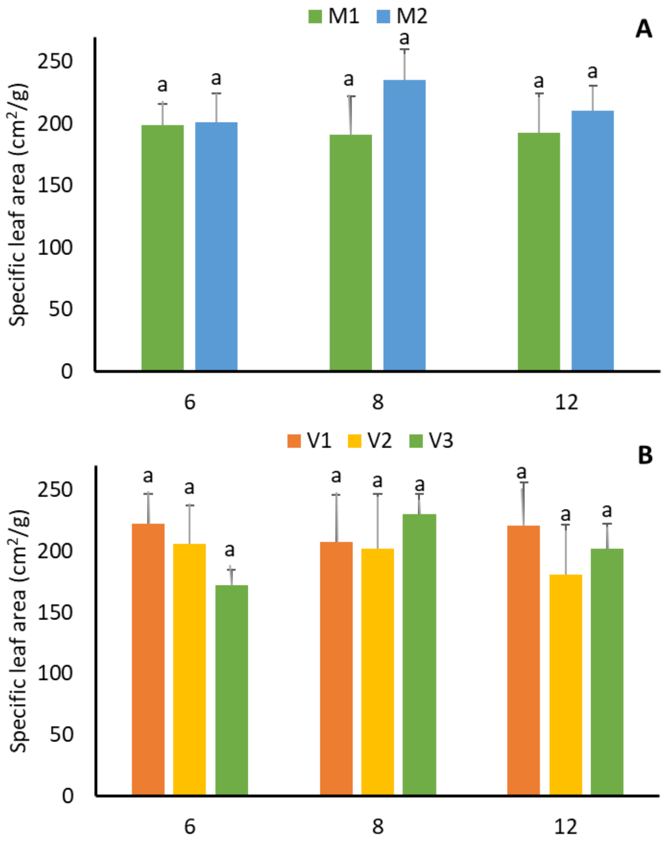

Figure 5. Specific leaf area on yard-long bean based on substrate volume (A) and cul-tivar (B).

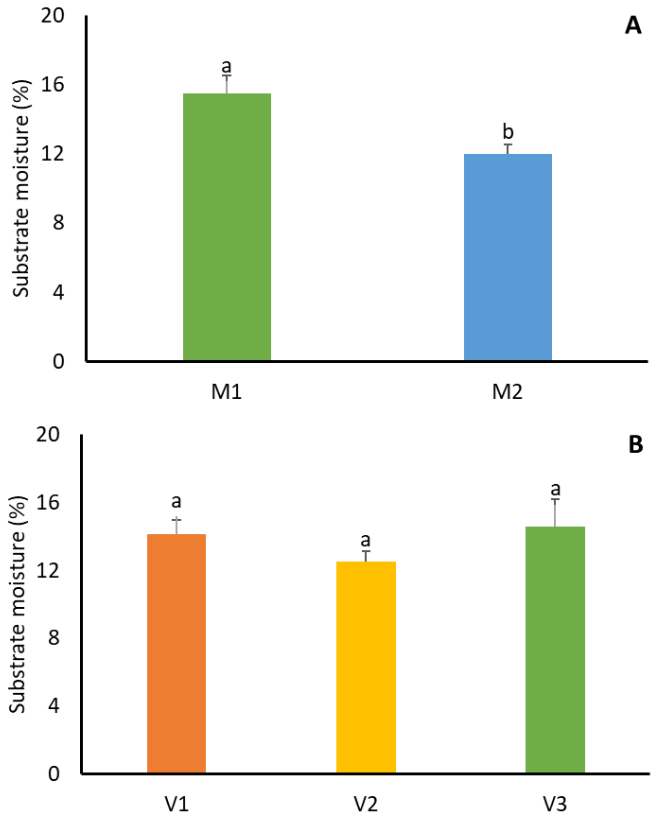

Figure 6. Substrate moisture in the yard-long bean rhizosphere based on substrate volume (A) and cultivar (B).

Substrate volume significantly influences substrate moisture, while cultivar treatments did not affect (Figure 6). A larger substrate volume has a higher moisture value, while a smaller substrate volume reduces the substrate moisture value. A larger volume allows the substrate to have higher water availability so that the substrate can support its moisture. Increased transpiration and evaporation rates accelerate water loss in the soil. According to Berretta et al. [24] water availability for substrate transpiration and vegetative vaporization is regulated by substrate moisture.

Effect of substrate volume and yard-long bean cultivar on yield

Substrate volume treatment did not affect pod development in terms of pod diameter or pod length (Figure 7). In pod diameter, there was a significant increase every day and showed no signs of slowing down, the same thing also happened in the cultivar treatments. The continuous increase in pod diameter is caused by seed initiation and growth. The preference for consumption of yard-long beans is tender pods [1], so harvest time must be considered.

The pods showed a similar size in the substrate volume treatment until the 8th day, but there was a decrease on the 9th day in the larger substrate volume and the smaller substrate volume continued to extend until the 9th day. This difference shows that substrate volume treatment influences harvest time.

Differences in harvest time also occurred in cultivar treatments where pod elongation started with the same length and ended with a significant difference in pod length. The Arafi cultivar continued to elongate on the 9th day of observation, while the Kanton Tavi and Camelia varieties experienced a decrease on the 9th day of observation. This difference shown variation in harvest time in different cultivars after anthesis.

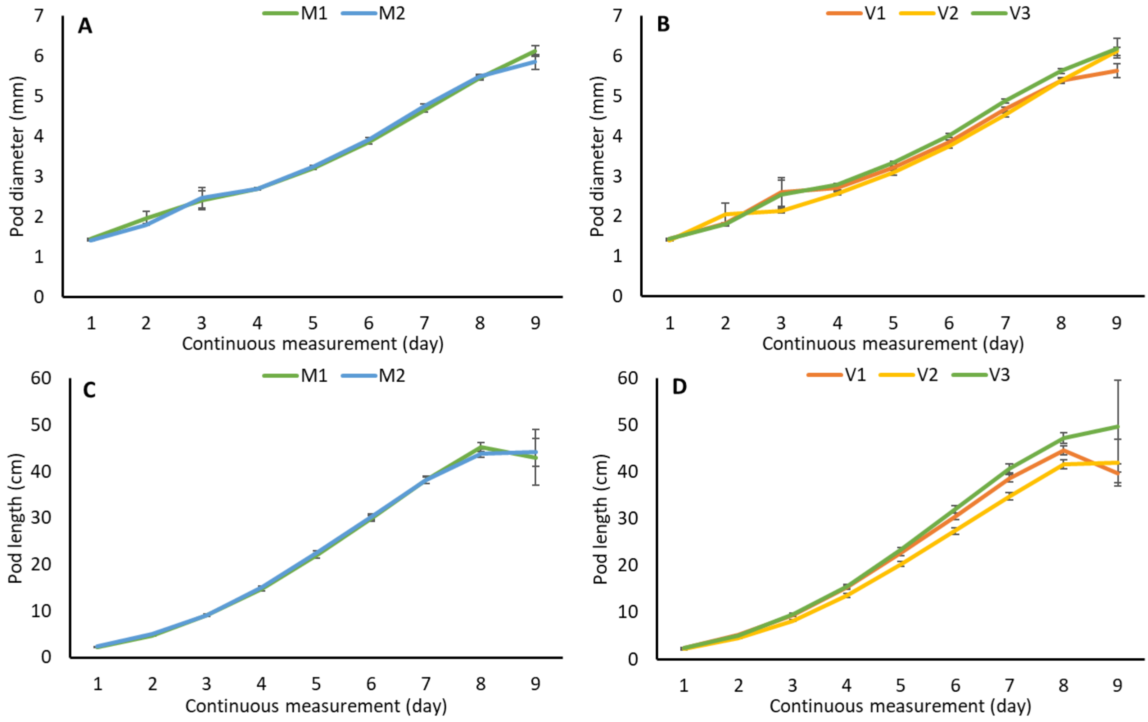

Figure 7. Development of pod diameter (A, B) and pod length (C, D) in yard-long bean based on substrate volume (left column) and cultivar (right column).

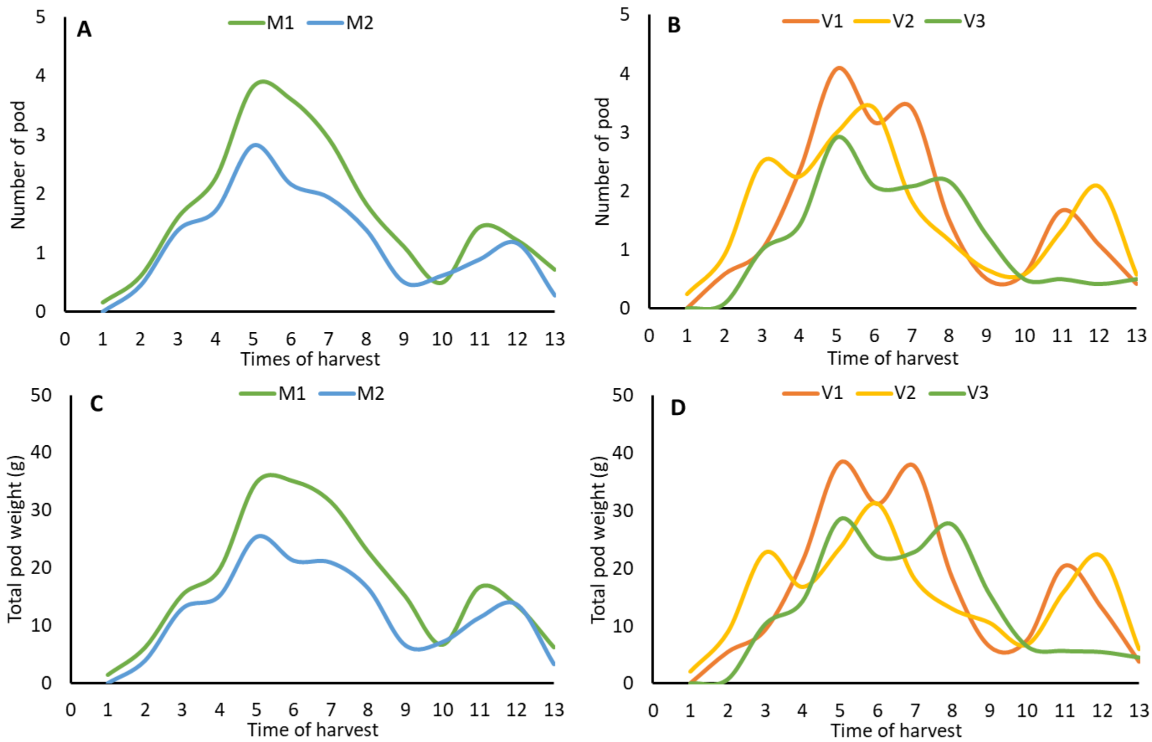

Figure 8. Number of pods (A, C) and total number of pod weights (C, D) per plant at daily harvest based on substrate volume (left column) and cultivar (right column).

Pod elongation follows a sigmoid curve, where growth starts slowly and experiences a rapid increase and then slows down, indicating pod maturity. Similar events also occur in several crop products, such as cacao [25], soybean [26], and peanut [27].

Table 1. Vine characteristics of different substrate volume and cultivars of yard-long bean

Treatments	Vine length	Vine diameter	Number of vine node	Vine fresh weight	Vine dry weight
Substrate volume					
M1	426.67 ± 8.57	8.45 ± 0.17 a	22.50 ± 0.77	64.49 ± 2.58 a	15.52 ± 0.62 a
M2	390.33 ± 26.91	7.30 ± 0.44 b	20.72 ± 1.49	52.89 ± 3.80 b	12.25 ± 0.90 b
Significance	ns	*	ns	*	**
P-value	0.207	0.017	0.265	0.018	0.007
LSD	57.67	0.92	3.20	9.45	2.28
Cultivar of yardlong bean					
V1	390.79 ± 36.70	7.36 ± 0.70	19.67 ± 1.87 b	54.34 ± 5.55	12.95 ± 1.40
V2	448.63 ± 8.67	8.00 ± 0.15	25.08 ± 0.51 a	65.96 ± 2.83	15.36 ± 0.83
V3	386.08 ± 17.23	8.26 ± 0.24	20.08 ± 1.14 b	55.77 ± 3.44	13.36 ± 0.73
Significance	ns	ns	*	ns	ns
P-value	0.149	0.263	0.014	0.099	0.185
LSD	70.63	1.13	3.92	11.58	2.79
Substrate volume × Cultivar of yardlong bean					
M1V1	429.50 ± 16.51	8.59 ± 0.12	21.17 ± 0.79	58.13 ± 3.60	14.70 ± 1.23
M1V2	450.67 ± 7.92	8.16 ± 0.26	25.50 ± 0.76	71.62 ± 4.08	17.17 ± 1.01
M1V3	399.83 ± 12.38	8.60 ± 0.41	20.83 ± 1.45	63.73 ± 4.46	14.69 ± 0.76
M2V1	352.08 ± 71.10	6.14 ± 1.23	18.17 ± 3.72	50.55 ± 10.82	11.19 ± 2.43
M2V2	446.58 ± 16.31	7.85 ± 0.14	24.67 ± 0.71	60.31 ± 2.43	13.55 ± 0.83
M2V3	372.33 ± 32.83	7.92 ± 0.20	19.33 ± 1.86	47.82 ± 2.63	12.03 ± 1.01
Significance	ns	ns	ns	ns	ns
P-value	0.561	0.136	0.846	0.763	0.929
LSD	99.88	1.60	5.54	16.37	3.95

Remark: ns: non-significant at $P<0.05$; *: significant at $P<0.05$; **: significant at $P<0.01$.

Cultivation in urban ecosystems is expected to produce the best results to meet household food needs. In this research, harvesting was carried out every 2 days. The results showed that cultivar treatment significantly influenced the number of pods and the total weight of pods per plant. Both substrate volume treatments had the same pattern in the number of pods and total fresh weight of pods planted, where both experienced a peak harvest on the 5th harvest. Smaller substrate volumes decrease the number of pods and the total fresh weight of pods per plant. It is suspected that limited roots and minimal water availability are factors limiting harvest yields. Adequate water availability can increase pod yield per plant in lentils [28].

Cultivar treatment affected the number of pods and total fresh weight of pods per plant. The Kanton Tavi cultivar had the highest yield compared to the other two cultivars. Kanton Tavi and Arafi cultivars experienced their peak harvest period on the 5th harvest, in contrast to the Camelia cultivar which experienced its peak harvest period on the 6th harvest, then experienced a decline in yield until the 13th harvest. There were significant differences in the harvest period of the Kanton Tavi, Camelia and Arafi cultivars, namely 12 harvests, 13 harvests and 11 harvests respectively. Differences in harvest time can be caused by various biotic and abiotic factors. Differences in cultivars also influence harvest time for some plants, such as chilies [29].

Destructive observation

Destructive observations on plants provide insights into their growth and development. The substrate volume treatment impacted vine diameter, fresh weight, and dry weight, while not influencing vine length and the number of vine nodes. Although vine length did not show significant differences, variations in diameter significantly affected both fresh weight and dry weight. The study found a close relationship between vine diameter and water supply. According to Kanai et al. [30], a reduction in stem diameter expansion is more linked to decreased water supply than increased photosynthesis supply. Larger substrate containers were associated with increased biomass production by 43%, as explained by Poorter et al. [31].

Table 2. Branch characteristics of different substrate volume and cultivars of yard-long bean.

Treatment	Branch length	Number of productive branch	Number of non-productive branch	Number of branch node	Branch fresh weight	Branch dry weight
Substrate volume						
M1	132.24 ± 10.38 a	4.50 ± 0.35	1.22 ± 0.35	8.23 ± 0.45 a	13.83 ± 1.21 a	3.46 ± 0.35 a
M2	93.12 ± 10.16 a	4.00 ± 0.44	1.50 ± 0.31	6.59 ± 0.62 b	8.19 ± 0.92 b	1.91 ± 0.21 b
Significance	**	ns	ns	*	***	***
P-value	0.007	0.338	0.550	0.0342	≤ 0.001	≤ 0.001
LSD	27.46	1.05	0.94	1.51	2.98	0.78
Cultivar of yardlong bean						
V1	133.76 ± 17.63 a	3.50 ± 0.45	0.92 ± 0.23	7.83 ± 0.88	13.04 ± 1.61	3.18 ± 0.43
V2	114.56 ± 10.37 ab	4.58 ± 0.51	2.00 ± 0.52	7.97 ± 0.63	9.78 ± 0.93	2.28 ± 0.22
V3	89.73 ± 9.30 b	4.67 ± 0.47	1.17 ± 0.34	6.43 ± 0.49	10.20 ± 1.87	2.61 ± 0.53
Significance	*	ns	ns	ns	ns	ns
P-value	0.040	0.136	0.150	0.186	0.158	0.171
LSD	33.63	1.29	1.15	1.85	3.66	0.96
Substrate volume × Cultivar of yardlong bean						
M1V1	164.15 ± 18.05	4.67 ± 0.33	0.83 ± 0.31	8.93 ± 0.62	16.56 ± 1.24	4.19 ± 0.36
M1V2	124.81 ± 18.17	4.50 ± 0.89	2.17 ± 0.87	8.33 ± 1.07	10.92 ± 1.64	2.59 ± 0.36
M1V3	107.77 ± 10.46	4.33 ± 0.61	0.67 ± 0.33	7.42 ± 0.60	13.99 ± 2.75	3.60 ± 0.85
M2V1	103.37 ± 25.93	2.33 ± 0.49	1.00 ± 0.37	6.73 ± 1.60	9.52 ± 2.23	2.16 ± 0.52
M2V2	104.30 ± 10.03	4.67 ± 0.61	1.83 ± 0.65	7.61 ± 0.75	8.63 ± 0.78	1.97 ± 0.21
M2V3	71.69 ± 11.87	5.00 ± 0.73	1.67 ± 0.56	5.44 ± 0.56	6.41 ± 1.44	1.61 ± 0.35
Significance	ns	ns	ns	ns	ns	ns
P-value	0.475	0.053	0.497	0.680	0.280	0.244
LSD	47.56	1.82	1.63	2.61	5.17	1.36

Remark: ns: non-significant at P<0.05; *: significant at P<0.05; **: significant at P<0.01; ***: significant at P<0.001.

Furthermore, in the cultivar treat-ments there were significant differences in the number of vine nodes but there were no significant differences in vine length, vine diameter, vine fresh weight and vine dry weight. The vine length is relatively the same, but the number of nodes is different, indicating different distances between nodes. This difference is thought to be due to genetic factors in different cultivars. This is in line with Ligarreto–Moreno and Pimen-tel–Ladino [32] who stated that genetics in-fluenced most of the variation, followed by environmental in-fluenced and genotype x environment interactions.

Branches are important organs for plants as one of the places where reproduc-tive organs are formed. Branch length, num-ber of branch nodes, branch fresh weight, and branch dry weight are influenced by substrate volume treat-ment. A larger sub-strate volume (M1) increases branch length compared to a smaller (M2) (Table 2). Long-er branches have a greater number of nodes accompanied by an increase in branch fresh weight and branch dry weight. The availabil-ity of adequate water and adequate root growth space supports the elongation of plant organs such as branches. Adequate root growth space results in longer branches on average and better branch parameters [33].

Increasing the number of nodes on branches has a positive impact on yield be-cause the growth of leaves and reproductive organs in yard-long bean plants is located at the nodes. The number of internodes and length influence important traits such as adaptability which influence plant yields [34]. Fang et al. [35] argued that yield and internode number were strongly and signifi-cantly associated. There was no significant difference in productive branches and non-productive branches in the substrate volume treatment. In the cultivar treatments, there were significant differences in branch length, but there were no significant differ-ences in other branch parameters. The Kan-ton Tavi cultivar has the longest branches, followed by the Camelia cultivar and the Arafi cultivar.

Table 3. Comparison of leaf total fresh weight and leaf total dry weight of different substrate volume and cultivars of yard-long bean.

Treatment	Leaf total fresh weight				Leaf total dry weight			
Substrate volume								
M1	72.79	±	10.75		14.44	±	2.24	
M2	67.24	±	6.71		13.50	±	1.29	
Significance	ns				ns			
P-value	0.635				0.694			
LSD	23.70				4.87			
Cultivar of yard-long bean								
V1	51.65	±	10.08	bc	10.65	±	2.13	b
V2	68.99	±	11.63	ab	12.85	±	2.20	ab
V3	89.40	±	8.52	a	18.39	±	1.81	a
Significance	*				*			
P-value	0.042				0.036			
LSD	29.03				5.96			
Substrate volume × Cultivar of yard-long bean								
M1V1	54.31	±	15.19		10.99	±	3.40	
M1V2	57.38	±	21.13		10.95	±	4.12	
M1V3	106.68	±	12.52		21.38	±	2.86	
M2V1	49.00	±	14.61		10.32	±	2.89	
M2V2	80.60	±	9.75		14.76	±	1.71	
M2V3	72.12	±	6.59		15.41	±	1.64	
Significance	ns				ns			
P-value	0.144				0.261			
LSD	41.05				8.43			

Remark: ns: non-significant at P<0.05; *: significant at P<0.05.

Measuring leaf parameters during destructive observations is important because leaves are an important organ for plant growth and development. From the research results it was found that the total fresh weight of leaves and the total dry weight of leaves were not significantly different in the substrate volume treatment.

In this study, cultivar treatment significantly influenced the total fresh weight of leaves and the total dry weight of leaves. This influence is thought to be closely related to plant age. As the plant ages, the leaves shed due to leaf senescence. Leaf senescence is the final stage of leaf development which is characterized by a functional transition from nutrient assimilation to nutrient remobilization [36]. Leaf or plant age is an endogenous stimulus that triggers leaf senescence [37]. In plants, nearly every cell, tissue, and organ age, senescence, and ultimately perishes [38].

Differences in substrate volume do not affect flowering time, pod diameter, pod length, pod fresh weight number of seeds per plant, but significantly influence the total pod number and total pod weight per plant. The total pod number per plant and total pod weight per plant are the accumulation of daily harvest results which are displayed in Figure 8. A larger substrate volume succeeded in increasing the total number of pods per plant and the total fresh weight of pods per plant. This increase is thought to be because there are no limiting factors for the roots in absorbing water and nutrients so that plant roots can develop well. Appropriate planting space can increase crop yields [39].

Cultivar differences did not affect pod diameter, pod length, pod fresh weight, number of seeds per pod, total number of pods, and total fresh pod weight per plant but did affect flowering time. The genotypic characteristics of each cultivar are thought to be a factor in significant differences in flowering time. Several studies experienced similar things like chili pepper [40].

Table 4. Pod characteristic of different substrate volume and cultivar of yard-long bean.

T	Flowering time	Pod diameter per plant	Pod length per plant	Pod fresh weight per plant	Number of seed per pod	Total pod number per plant	Total pod weight per plant
Substrate volume							
M1	26.50 ± 0.50	5.59 ± 0.05	45.76 ± 1.22	10.28 ± 0.30	16.92 ± 0.45	28.06 ± 1.41 a	259.09 ± 13.26 a
M2	27.50 ± 0.49	5.64 ± 0.05	44.47 ± 0.94	10.35 ± 0.32	15.42 ± 0.93	20.56 ± 1.17 b	195.03 ± 15.95 b
S	ns	ns	ns	ns	ns	***	**
P-value	0.116	0.556	0.382	0.867	0.174	≤ 0.001	0.004
LSD	1.26	0.14	2.99	0.90	2.20	3.61	41.69
Cultivar of yardlong bean							
V1	26.67 ± 0.50 b	5.55 ± 0.05	45.23 ± 0.91	10.07 ± 0.40	15.45 ± 0.82	26.08 ± 2.47	247.56 ± 25.62
V2	25.75 ± 0.58 b	5.63 ± 0.07	43.67 ± 1.34	10.06 ± 0.38	16.43 ± 0.35	25.67 ± 1.53	240.70 ± 16.76
V3	28.58 ± 0.50 a	5.67 ± 0.06	46.44 ± 1.63	10.82 ± 0.31	16.64 ± 1.32	21.17 ± 1.34	192.92 ± 13.38
S	**	ns	ns	ns	ns	ns	ns
P-value	0.003	0.351	0.314	0.286	0.631	0.057	0.075
LSD	1.55	0.18	3.66	1.11	2.70	4.42	51.06
Substrate volume × Cultivar of yardlong bean							
M1V1	26.17 ± 0.54	5.57 ± 0.03	45.77 ± 1.36 ab	10.35 ± 0.41	16.61 ± 0.69	31.50 ± 2.86	291.98 ± 25.86
M1V2	25.00 ± 0.73	5.68 ± 0.12	41.93 ± 1.86 b	9.62 ± 0.49	16.29 ± 0.60	28.83 ± 1.89	261.65 ± 23.11
M1V3	28.33 ± 0.76	5.53 ± 0.09	49.59 ± 2.04 a	10.87 ± 0.57	17.86 ± 0.96	23.83 ± 1.54	223.64 ± 11.06
M2V1	27.17 ± 0.83	5.52 ± 0.10	44.69 ± 1.31 ab	9.79 ± 0.72	14.28 ± 1.40	20.67 ± 2.64	203.15 ± 37.81
M2V2	26.50 ± 0.85	5.58 ± 0.09	45.42 ± 1.81 ab	10.50 ± 0.56	16.57 ± 0.42	22.50 ± 1.65	219.74 ± 22.95
M2V3	28.83 ± 0.70	5.81 ± 0.05	43.30 ± 1.88 b	10.77 ± 0.29	15.42 ± 2.49	18.50 ± 1.65	162.20 ± 16.98
S	ns	ns	*	ns	ns	ns	ns
P-value	0.805	0.082	0.036	0.407	0.514	0.410	0.644
LSD	2.19	0.25	5.17	1.56	3.81	6.26	72.20

Remark: T: Treatment ; ns: non-significant at P<0.05; *: (S) significant at P<0.05; **: significant at P<0.01; ***: significant at P<0.001.

Table 5. Root characteristic of different substrate volume and cultivar of yard-long bean.

Treatment	Root length	Root fresh weight	Root dry weight	Shoot/root ratio
Substrate volume				
M1	64.24 ± 3.69 a	37.61 ± 3.05	5.63 ± 0.47	6.50 ± 0.52
M2	51.29 ± 3.98 b	36.16 ± 2.77	4.84 ± 0.35	5.50 ± 0.40
Significance	*	ns	ns	ns
P-value	0.028	0.735	0.200	0.153
LSD	11.41	8.65	1.23	1.39
Cultivar of yard-long bean				
V1	52.75 ± 6.50	34.09 ± 4.45	4.71 ± 0.62	5.49 ± 0.69
V2	59.45 ± 4.00	39.92 ± 3.82	5.32 ± 0.47	6.20 ± 0.59
V3	61.10 ± 4.21	36.65 ± 1.87	5.66 ± 0.43	6.31 ± 0.46
Significance	ns	ns	ns	ns
P-value	0.442	0.536	0.438	0.564
LSD	13.98	10.60	1.51	1.70
Substrate volume × Cultivar of yard-long bean				
M1V1	57.97 ± 7.83	37.87 ± 5.73	5.65 ± 0.77	5.69 ± 0.91
M1V2	64.37 ± 6.93	35.61 ± 7.17	5.12 ± 0.95	6.90 ± 1.15
M1V3	70.38 ± 3.72	39.35 ± 3.01	6.11 ± 0.79	6.90 ± 0.66
M2V1	47.53 ± 10.67	30.31 ± 6.97	3.78 ± 0.87	5.28 ± 1.11
M2V2	54.53 ± 3.57	44.24 ± 2.34	5.51 ± 0.21	5.50 ± 0.16
M2V3	51.82 ± 5.45	33.94 ± 1.84	5.22 ± 0.35	5.73 ± 0.59
Significance	ns	ns	ns	ns
P-value	0.776	0.253	0.321	0.824
LSD	19.77	14.99	2.14	2.40

Remark: ns: non-significant at P<0.05; *: significant at P<0.05.

It is important to study plant roots because roots are plant organs that have direct contact with water and nutrients. Good root growth will stimulate maximum growth and yields in plants. Substrate volume treatment significantly affected root length but did not affect root fresh weight, root dry weight and shoot/root ratio. Larger substrate volumes increased root length but not root weight. Meanwhile, at a smaller volume, the substrate has denser roots when calculated from its fresh weight. According to Murphy et al. [41], root weight did not increase with increasing container volume, but increased with the addition of water-soluble fertilizer. A nutrient shortage could result from competition and diffusion barriers affecting nutrient acquisition when root density increased in the limited soil volume [42]. Small differences in root density have a big impact on water uptake [43]

4. Conclusion

Results indicate that substrate volume has no impact on vegetative growth and water availability parameters like LRWC, SLWC, and SLA. Larger pot sizes increase pod number and total pod weight per plant, correlating with substrate water availability. Ample root space in larger volumes stimulates vine, branch, and yield growth, maintaining substrate moisture and enhancing plant biomass. Concurrently, cultivar treatment affects branch length and flowering time. Although there is no significant difference in yield among cultivars, the Camelia cultivar exhibits the longest harvest period at 14 harvests.

5. Conflict of Interest

The authors declare there is no conflict of interest.

6. Acknowledgement

The author would like to offer par-ticular thanks to the Editor-in-Chief and the reviewers for their constructive comments, suggestions, and corrections to our manuscript.

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