INTERCROPPING OF LEAFY VEGETABLES AND *Cnidoscolus aconitifolius* WITH DIFFERENT CANOPY SIZES IN TROPICAL CLIMATES †

[CULTIVO INTERCALADO DE HORTALIZAS DE HOJA Y *Cnidoscolus aconitifolius* CON DIFERENTES TAMAÑOS DE COPA EN CLIMAS TROPICALES]

Fitra Gustiar[1], Benyamin Lakitan[1,2*], Dedik Budianta[1], Zaidan Panji Negara[1], Rofiqoh Purnama Ria[1] and Strayker Ali Muda[1]

[1]Universitas Sriwijaya, Facultad de Agricultura, Carretera Palembang-Prabumulih Kilómetro 32, Indralaya, Ogan Ilir 30662, Sumatra del Sur, Indonesia. Email: fitragustiar@unsri.ac.id; blakitan60@unsri.ac.id; Dedik_budianto@yahoo.com ; zaidan@unsri.ac.id; rofiqohpurnamaria@unsri.ac.id; straykerali@gmail.com
[2]Centro de Investigación de Tierras Subóptimas, Sriwijaya.Universitas Carretera Padang Selasa No. 524, Bukit Besar, Palembang 30139, Sumatra del Sur, Indonesia.
[*] Corresponding author

SUMMARY

Background. Chaya (*Cnidoscolus aconitifolius* **)** is a perennial leafy vegetable that is widely known for its year-round harvest potential. Several studies have also shown that it has distinct canopy and root morphology, making chaya an ideal candidate for intercropping with short-duration leafy vegetables for enhancing crop diversity and intensifying production. **Objective.** To examine the growth of short-duration leafy vegetables in an intercropping pattern with chaya using different canopy sizes. **Methodology.** The experimental design was a split-plot design with 2 main factors (planting patterns), 3 sub-plots (leafy vegetable crops), and 3 replications. Planting patterns monoculture (conventional) and intercropping with chaya having 80 cm (DC 80) or 120 cm (DC 120) canopy diameters. Leafy vegetables were water spinach, mustard greens, and lettuce. **Results.** Chaya canopy restricted sunlight intensity, leading to temperature changes in the cultivation area. This situation was proven by observing that cultivated land under chaya canopy (DC 80 and DC 120) had a lower air temperature than without chaya canopy (monoculture). Short-duration leafy vegetables grown through intercropping showed suboptimal growth under intercropping because of limited sunlight availability, causing lower yields compared to monoculture systems. Chaya canopy with a diameter of 120 cm reduced the leaf number and the fresh weight of intercropped leafy vegetables. **Conclusion.** Even though intercropping reduced leafy vegetable plant growth, intercropping is a viable option for using vacant spaces in chaya cultivation. Optimal growth could be achieved by pruning chaya leaves, allowing sunlight to reach the intercropped plants, when chaya diameter canopy is ≤ 80 cm.
Key words: Chaya; leafy vegetable; monoculture; olericulture; polyculture.

RESUMEN

Antecedentes. La Chaya (*Cnidoscolus aconitifolius***)** es una verdura de hoja perenne ampliamente conocida por su potencial de cosecha durante todo el año. Varios estudios también han demostrado que tiene una morfología de raíces y dosel distinta, lo que convierte a la chaya en un candidato ideal para el cultivo asociado con hortalizas de hoja de corta duración para mejorar la diversidad de cultivos e intensificar la producción. **Objetivo.** Examinar el crecimiento de hortalizas de hoja de corta duración en un patrón de cultivo asociado con plantas que utilizan diferentes tamaños de dosel. **Metodología.** Para la realización de los procedimientos se adoptó un diseño de parcela dividida con 2 factores principales. Los patrones de plantación sirvieron como parcelas principales, incluido el monocultivo (P1) y el cultivo asociado con árboles con diámetros de copa de 80 cm (P2) y 120 cm (P3). Las subparcelas designadas fueron verduras de hoja de corta duración, como espinacas de agua, hojas de mostaza y lechuga, lo que dio lugar a un total de 9 combinaciones de tratamientos con 3 repeticiones cada una. **Resultados.** Los resultados de la luz solar mostraron que el dosel de chaya restringió la intensidad, lo que provocó cambios de temperatura en el área de cultivo. Esta situación se comprobó al observar que las tierras cultivadas bajo dosel de chaya (P2 y P3) tuvieron una temperatura del aire más

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ORCID = F. Gustiar: http://orcid.org/0000-0003-1281-8371; **B. Lakitan**: http://orcid.org/0000-0002-0403-2347; **D. Budianta**: http://orcid.org/0000-0002-0418-2441; **Z.P. Negara**: http://orcid.org/0000-0001-9067-5869; **R.P. Ria**: http://orcid.org/0000-0003-3703-7539; **S.A. Muda**: http://orcid.org/0000-0001-9687-8114

baja que sin dosel de chaya (monocultivo). Las hortalizas de hoja de corta duración cultivadas mediante cultivos intercalados mostraron un crecimiento subóptimo con recursos limitados de luz solar, lo que provocó menores rendimientos en comparación con los sistemas de monocultivo. El dosel con un diámetro de 120 cm reduce el número de hojas y el peso fresco de las plantas intercaladas. **Conclusiones.** Sin embargo, el cultivo intercalado sigue siendo una opción viable para utilizar espacios baldíos en el cultivo de chaya. Según los resultados, se podría lograr un crecimiento óptimo podando las hojas, permitiendo que la luz del sol llegue a las plantas intercaladas, específicamente cuando la longitud de las hojas de chaya era ≤ 80 cm.
Palabras clave: Chaya; hortaliza de hoja; monocultivo; olericultura; policultivo.

INTRODUCTION

The increasing global population has heightened the demand for food, placing a specific emphasis on the consumption of vegetables, such as chaya to meet nutritional requirements for essential vitamins and minerals. Chaya (*Cnidoscolus aconitifolius*) is a leafy vegetable native to the Mexican, that is widely known for its rich content of essential nutrients vital for the human body (Ebel *et al.,* 2019). In addition, it contains various bioactive compounds, including phenolic acids, alkaloids, saponins, and flavonoids. Apart from its role as a vegetable, chaya has also been reported to serve several purposes, functioning as a supplement, animal feed, and medicinal plant. In the context of medicine, it exhibits antioxidant effects, anti-diabetic properties, antimicrobial activities, hematopoietic characteristics, an impact on erectile dysfunction, antifertility activities, as well as protective effects against Alzheimer, neurodegenerative diseases, and liver damage (Simi *et al.,* 2023). The diverse benefits of chaya as a food and medicinal resource have led to increased cultivation efforts. According to previous studies, chaya is a perennial vegetable adaptable to various types of land and available for harvest throughout the year (Gustiar *et al.,* 2023a). However, vacant spaces between crop rows are often underutilized for planting short-lived vegetables. Intercropping offers a solution to maximize these spaces and enhance the economic value of chaya cultivation (Gustiar *et al.,* 2023b). An intercropping approach comprises cultivating more than one crop type and optimizing agricultural resources efficiently, thereby maximizing resource use, and ensuring sustainable land productivity through increased planting intensity (Maitra *et al.,* 2019).

Several studies showed that intercropping also comprised the integration of crops to use space more efficiently and optimize environmental factors. In addition, it enhances the overall output of land units, even with low input levels, as dual planting maximizes the efficient use of soil nutrients and water. Intercropping has been reported to provide various benefits for small-scale farming, generating diversified crop with minimal input usage (Maitra *et al.,* 2021). In intercropping cultivation, crop commodities compete for access to growing space, sunlight, water, and nutrients. This condition illustrated that further regulation was needed to ensure that the plants grow well, including selecting the most suitable plant species. However, competition for available resources through companion planting systems can be balanced by plants that mutually benefit each other (Maitra *et al.,* 2019). The success of this cultivation approach is also dependent on the careful selection of the second-layer crop commodities. Selecting plants with different root capabilities and canopy structures can reduce the potential for competition among crop commodities, leading to optimal growth (Nyawade *et al.,* 2019). The structure and spacing of the main crop play an essential role in determining the distribution of sunlight and the use of growth resources available to the second-layer crop.

Short-lived vegetable commodities are potential crop for intercropping with chaya. Some short-duration leafy vegetables with small canopy structures and shallow roots suitable for intercropping include water spinach, mustard greens, and lettuce. Each of these commodities has different tolerance levels and adaptive abilities to resource requirements for growth. According to Sulistiani *et al.* (2023), leafy vegetables exhibit adaptation to shade. Several studies also showed that shading with a density of 45-80% reduced the growth and yield of purple pak choy (*Brassica rapa* subsp. *Pekinensis*) (Fadilah *et al.,* 2022). Studies on the influence of sunlight radiation and temperature as intercropping conditions are still limited to laboratory investigations with artificial shading. Further studies are needed concerning microclimate, growth, and yields of the main crop and short-duration leafy vegetables cultivated through intercropping.

Previous studies reported that the size of the main crop canopy affected sunlight intensity and temperature in the planting area. In addition, sunlight and temperature are crucial components of the microclimate that significantly influence growth and development. The availability of solar energy serves as the basis for considering the selection of intercropping companion plants and sustainability (Waman *et al.,* 2019. The combination of maintaining the canopy size of chaya as the main crop and selecting the appropriate second-layer crop can lead to optimal growth and yield for both plants. Therefore, this study aims to examine the growth of short-duration leafy vegetables in an intercropping pattern with chaya, considering various sizes of canopy maintenance.

MATERIAL AND METHODS

This study was conducted on an acid-tuff plain soil type with shallow topsoil depth located in Indralaya District (104º46'44" E; 3º01'35" S), South Sumatra, Indonesia, from March to May 2023. The research location is a tropical ecosystem with agroclimatic characteristics, as represented in Figure 1.

Chaya (*Cnidoscolus aconitifolius* (Mill.) I.M. Johnst.) plants were 1 year old, spaced at 200 x 200 cm, with a north-south orientation of planting path. The 3 types of short-duration leafy vegetables used, water spinach (*Ipomoea aquatica*), mustard (*Brassica juncea*), and lettuce (*Lactuca sativa*). Chaya plant aisles were arranged to create beds measuring 0.5 x 12 m, while each treatment unit comprised beds with dimensions of 0.5 x 2 m. To prepare the fertilizer, chicken manure of 50 kg was mixed with tillage. Chaya plant was pruned with a crown diameter of 80 cm and 120 cm 2 weeks before planting leafy vegetables. Mustard greens and lettuce seedlings were transplanted at 10 Day After Transplanting (DAT) with a spacing of 15 x 15 cm. Subsequently, harvesting of water spinach, mustard greens, and lettuce was carried out at 25 DAT, 35 DAT, and 40 DAT, respectively.

Data collection

The parameters observed were the growth and yield of short-duration leafy vegetables and chaya crop as well as the microclimate of the plant area. The growth of short-duration leafy vegetables consisted of plant height, number of leaves, leaf width, leaf length, SPAD value, leaf thickness, total leaf area, stem diameter, root length, spesific leaf area (SLA), and fresh weight and dry weight of each organ (leaf, stem, and root). Meanwhile, chaya growth consisted of number of shoots, plant height, number of branches, stem diameter, edible and non-edible organ, rhizosphere diameter, rhizosphere depth, and rhizosphere. The edible organ was categorized as marketable organ with the characteristics of young and less infested by pests and diseases. Moreover, the microclimate observed consisted of soil temperature (ºC), air temperature (ºC), and sunlight intensity (lux).

Soil temperature and air temperature were measured using a Krisbow KW06003 digital thermometer, while sunlight intensity was measured using a Benetech GM1030 luxmeter. The measurement of the parameters were carried out during the day at 07:00 - 17:00. Soil temperature was determined at a depth of 15 cm.

Chaya root rhizosphere was observed by making a cross-section of chaya root in each pruning treatment, and the deepest root was measured from the root neck. Root diameter was measured by measuring the farthest root from the stem, as shown in Figure 2. Rhizosphere volume was calculated using the truncated sphere formula presented below:

$$V = \frac{1}{3}\pi t^2 (3r - t)$$

Root density was measured by taking root samples using a sample ring with a diameter of 16 cm and a height of 30 cm. Furthermore, each plant had 3 sample point distances of 30 cm, 60 cm, and 90 cm, where each distance was taken 3 times, totaling 9 sample points per plant (Figure 2). Some of the parameters taken in this study included root diameter, weight, and volume. Root diameter observed was the greatest and representative root measured using a caliper. Whole roots were weighed, and root volume was measured using the volume of an irregular object approach using a beaker.

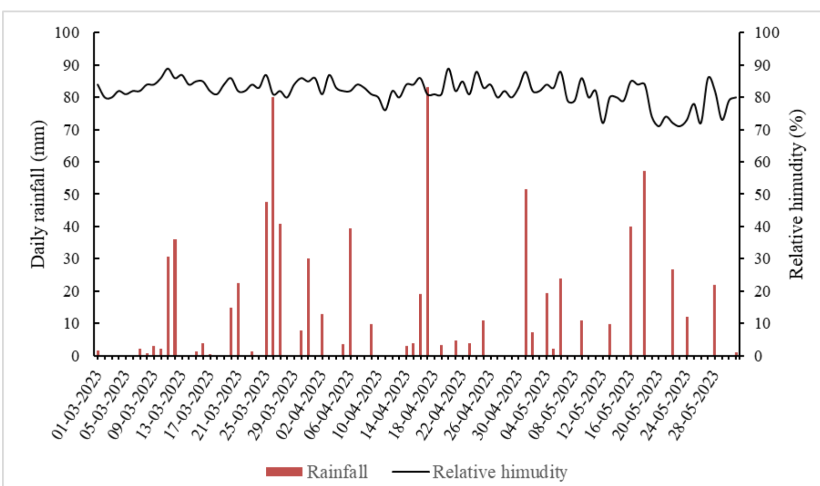

Figure 1. Daily rainfall and relative humidity in research location during the research was conducted. Source: Indonesian Agency for Meteorology, Climatology and Geophysics

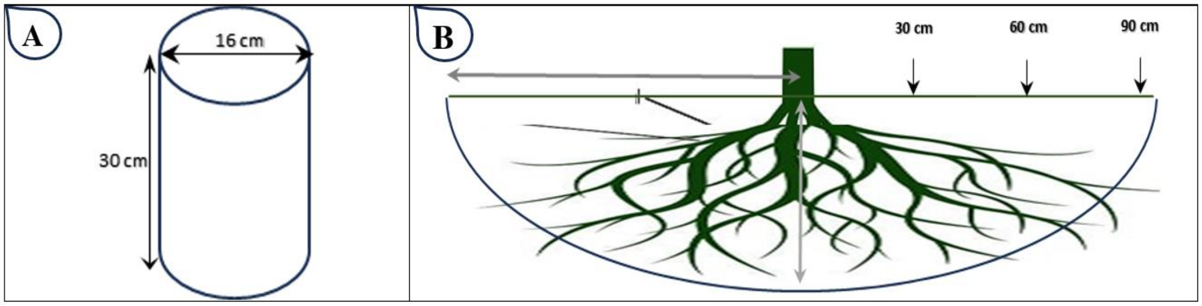

Figure 2. Sample ring size (A) and root sampling points (B).

Experimental design and data analysis

This study used the split-plot experimental design. The main plot was 3 cropping patterns consisting of monoculture systems (conventional), intercropping with chaya crown diameter of 80 cm (DC 80), and intercropping with chaya crown diameter of 120 cm (DC 120) (Figure 3). The subplots were the leafy vegetable (water spinach, mustard, and lettuce). Therefore, there were 9 treatment combinations, and each combination had 3 replications.

Data on the growth and yield of leafy vegetables and chaya were analyzed with analysis of variance using R-studio software. Least Significant Difference (LSD) at P ≤ 0.05 was used to evaluate the differences between the treatments.

RESULT

Sunlight Intensity and Temperature

The crown of chaya plant reduced sunlight intensity and air temperature. Chaya plant with a broader crown diameter was exposed to a lower sunlight intensity. From 11:30 am - 12:30 pm, sunlight intensity and temperature in the chaya plant and outside the chaya plant were relatively the same. This indicated that sunlight intensity at midday was perpendicular to soil, hence, sunlight reached leafy vegetables with minor shading (Figure 4). There were fluctuations in air temperature in the plant canopy following sunlight intensity. In the afternoon at low sunlight intensity, the air temperature was relatively still high, probably due to the storage of heat energy in the air from the solar radiation during the day.

Sunlight intensity was related to air temperature (R^2=0.772; y=7.127x - 201.62), but relatively unrelated to soil temperature (R^2 =0.237; y=9.8211x - 213.94). Soil temperature is influenced by many factors other than sunlight intensity. These factors include soil moisture, soil composition, and air circulation. If the soil is moist, the energy from unlight may be used more for evaporating water than for increasing soil temperature. Air and soil temperature had a high relationship coefficient determinant (R^2=0.546; y=0.2972x + 19.816) (Figure 5).

Figure 3. Intercropping (A) and monoculture (B) of leafy vegetables.

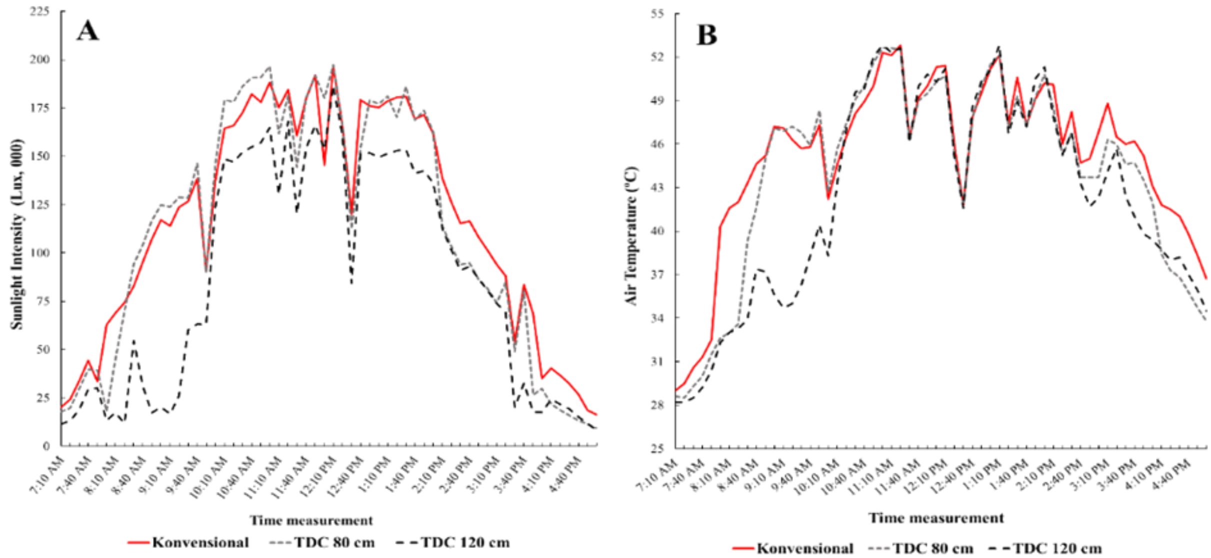

Figure 4. Monitoring of sunlight intensity (A) and air temperature (B) in vegetable growing areas.

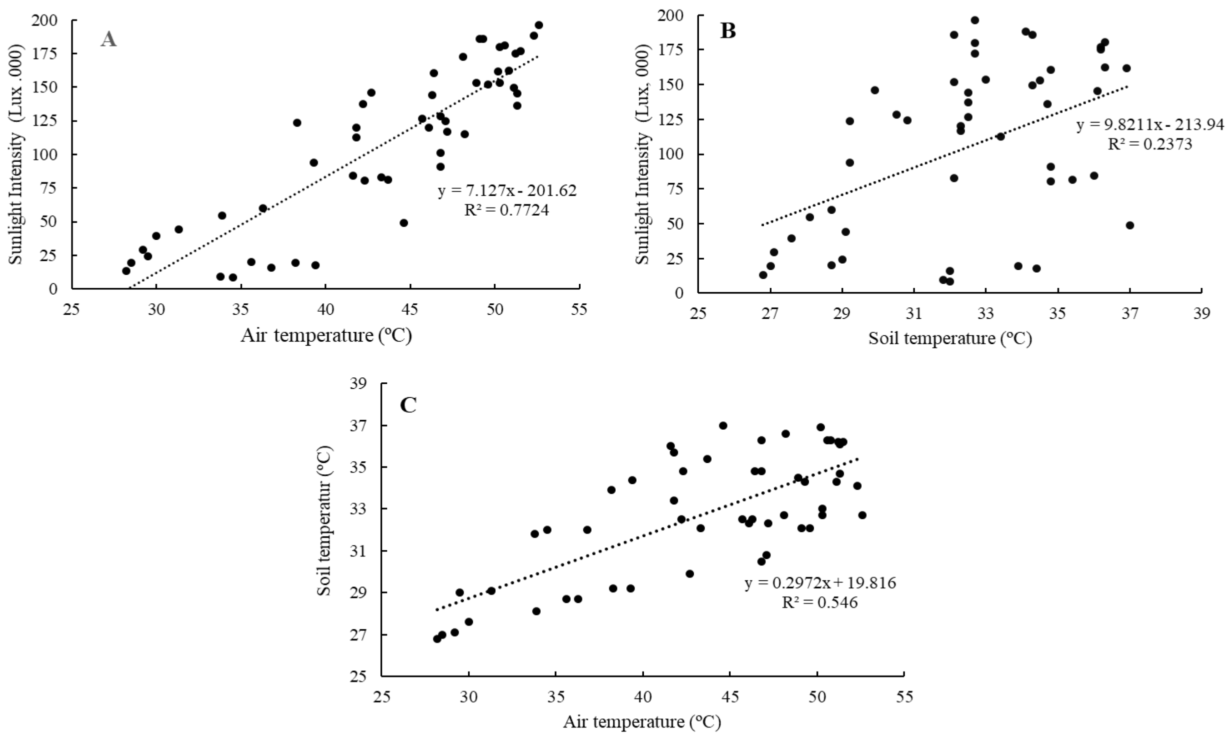

Figure 5. Regression of sunlight intensity with air temperature (A), soil temperature (B), as well as regression of air and soil temperature (C).

Growth Indicators of Annual Vegetables

Cropping pattern had no effect in plant height and number of leaves at the early stages of growth in water spinach, mustard greens, and lettuce. However, the season progressed, plant growth differences between planting patterns became more evident (Figure 6). Water spinach and mustard greens plants were shorter and had fewer leaves when intercropped with a chaya canopy diameter of 120 cm (DC-120) compared to a canopy diameter of 80 cm (DC-80) and conventional planting. In intercropping lettuce plants were tallest with DC-120 and the shortest with DC-80.

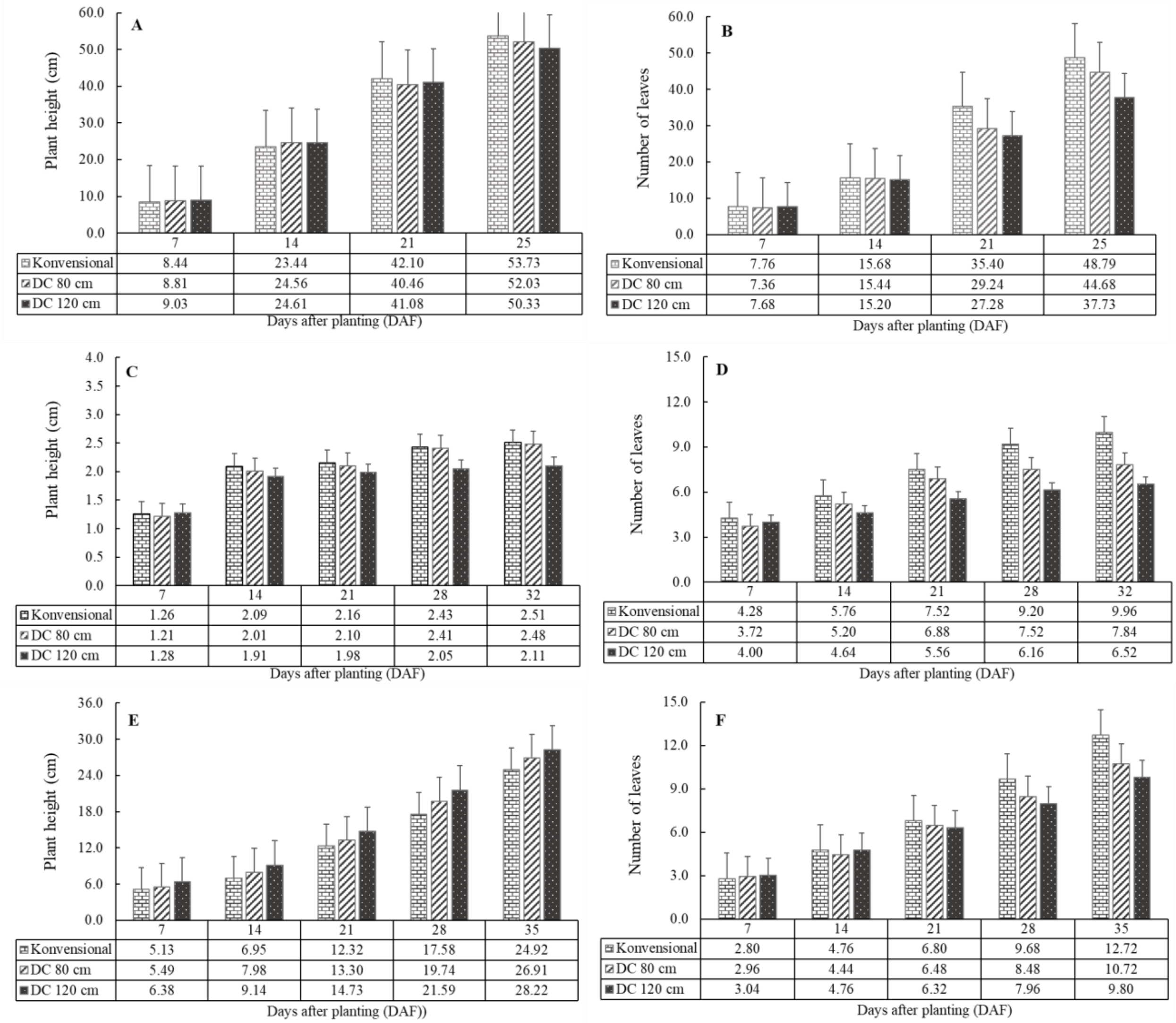

Figure 6. The increase in plant height (left) and number of leaves (right) of water spinach (A and B), mustard greens (B and C), and lettuce (E and F) in chaya intercropping with different crown diameters (CD). Conventional= monoculture, DC 80= intercropping with chaya crown diameter of 80 cm, DC 120= intercropping with chaya crown diameter of 80 cm.

Conventionally grown plants had larger leaf dimensions (length, width, and thickness), total leaf area, and longer root lengths compared to others cultivated through intercropping (Table 1). Some morphological variables of leaf like leaf width, leaf length and leaf thickness of leafy vegetables in intercropping under chaya canopy with an 80 cm diameter were not significantly different from those cultivated conventionally/monoculturally. This explanation was suspected to be due to the greater sunlight intensity under 80 cm canopy compared to 120 cm canopy. Visually, these differences can be observed in Figure 7.

Production of Short-Duration Vegetable Biomass

The biomass yield of short-duration leafy vegetables, both in fresh weight (FW) and dry weight (DW), in conventional cultivation, was higher compared to intercropping. Samples cultivated under the canopy of chaya with a diameter of 120 cm were lower than those under an 80 cm canopy, but statistically not different (Table 2). This indicated that vegetable types, such as water spinach, mustard greens, and lettuce could not symbiotically use limited resources.

Growth and Yield of Chaya Plant

Chaya cultivated while maintaining a specific canopy size exhibited different growth and yield characteristics. Various growth parameters, such as the number of shoots, plant height, branch count, and stem diameter in chaya plant with a 120 cm canopy, were higher compared to an 80 cm canopy. Yield parameters, including fresh leaf and stem weight in chaya maintained with a 120 cm canopy, were higher, as shown in Table 3.

Table 1. Morphological characteristics of water spinach, mustard greens, and lettuce planted in different planting patterns.

Treatment	Leaf width (cm)	Leaf length (cm)	SPAD value	Leaf thickness (mm)	Total leaf area (cm^2)	Bar diameter (mm)	Root length (cm)	SLA (cm^2/g)
Main Plot								
Conventional	9.13 a	15.68 a	29.57 a	0.28 a	974.17 a	10.07 a	18.67 a	302.67 a
CD 80	8.14 ab	14.30 ab	28.31 a	0.26 a	680.79 b	8.16 b	17.56 a	321.93 a
CD 120	7.35 b	13.18 b	29.75 a	0.21 b	525.77 b	7.28 b	16.46 a	325.92 a
LSD.05	1.2	1.97	1.89	0.05	238.06	0.9	2.59	35.04
Subplot								
Water Spinach	10.81 a	15.23 a	35.13 a	0.24 a	843.40 a	7.92 a	23.21 a	398.98 a
Mustard	9.72 b	14.87 a	36.37 a	0.31 b	568.00 a	7.74 b	15.23 b	227.73 c
Lettuce	4.11 c	13.05 b	16.13 b	0.21 b	769.32 ab	9.85 b	14.25 b	323.82 b
LSD.05	0.76	1.22	1.74	0.05	207.84	0.65	2.13	51.01

Remarks: Data presented as mean ± standard error. The numbers followed by different letters in the same column indicate significant differences at LSD.05. The numbers followed by same letters in the same column indicate non-significant differences at LSD.05. Conventional= monoculture, DC 80= intercropping with chaya crown diameter of 80 cm, DC 120= intercropping with chaya crown diameter of 80 cm.

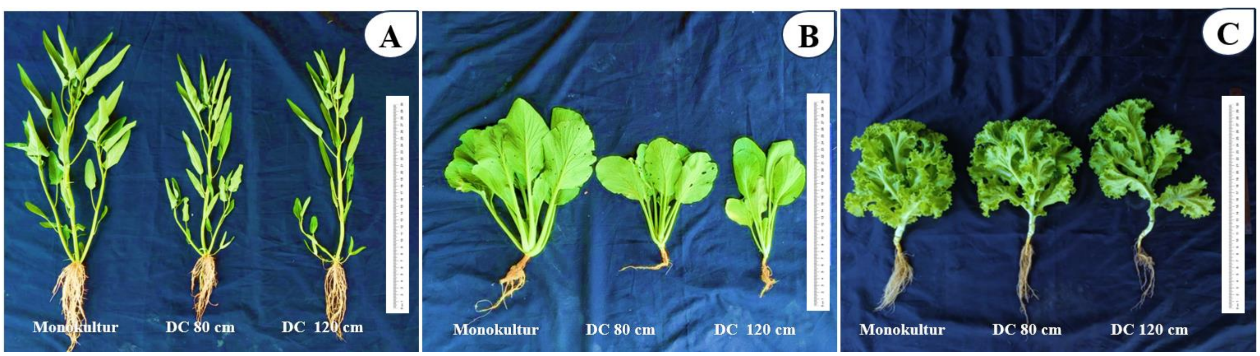

Figure 7. Plant growth of water spinach (A), mustard greens (B), and lettuce (C) in various planting patterns. Conventional= monoculture, DC 80= intercropping with chaya crown diameter of 80 cm, DC 120= intercropping with chaya crown diameter of 80 cm.

Table 2. Harvest of water spinach, mustard greens, and lettuce planted in different planting patterns.

Treatment	Fresh Weight (g)			Dry Weight (g)		
	Leaf	Stem	Root	Leaf	Stem	Root
Main Plot						
Conventional	41.32 a	17.93 a	7.41 a	3.15 a	1.41 a	0.83 a
DC 80 cm	23.94 b	13.88 ab	4.41 b	2.23 b	0.99 b	0.53 b
DC 120 cm	16.56 b	11.53 b	3.51 b	1.65 b	0.83 b	0.43 b
LSD.05	12.53	4.62	1.99	1.07	0.39	0.26
Subplot						
Water Spinach	23.60 b	25.58 a	9.19 a	2.50 a	1.72 a	0.93 a
Mustard Green	47.72 a	4.72 c	3.78 b	2.07 a	0.47 c	0.42 b
Lettuce	10.49 c	13.07 b	2.36 b	2.46 a	1.04 b	0.44 b
LSD.05	10.32	4.66	1.96	0.87	0.34	0.24

Remarks: Data presented as mean ± standard error. The numbers followed by different letters in the same column indicate significant differences at LSD.05. The numbers followed by same letters in the same column indicate non-significant differences at LSD.05. Conventional= monoculture, DC 80= intercropping with chaya crown diameter of 80 cm, DC 120= intercropping with chaya crown diameter of 80 cm.

Table 3. Growth and yield of chaya with different canopy maintenance sizes.

	Number of shoots	Plant height (cm)	Number of branches	Stem diameter (cm)	Edible			Non-edible		
					Stem (kg)	Leaf (kg)	SLA (cm²/g)	Stem (kg)	Leaf (kg)	SLA (cm²/g)
DC 80	153.6a	161.8 a	151.8a	96.4 a	0.7 a	1.0 a	288.1a	8.4 a	0.8 a	287.5a
DC 120	269.8b	193.4 a	201.2a	95.8 a	1.5 a	1.7 b	440.7a	16.5 a	2.0 b	102.1a
p-value	0.003	0.107	0.319	0.925	0.024	0.047	0.050	0.028	0.138	0.007

Data presented as mean ± standard error. The numbers followed by different letters in the same column indicate significant differences at LSD.05. The numbers followed by same letters in the same column indicate non-significant differences at LSD.05. DC 80= intercropping with chaya crown diameter of 80 cm, DC 120= intercropping with chaya crown diameter of 80 cm.

Chaya Rhizosphere

There was a difference in rhizosphere diameter, as shown in Table 4. Rhizosphere of chaya referred to the soil area around plant roots influenced by root presence and interactions with microbes, along with inherent biochemical processes occurring (Figure 8).

Chaya root generally had smaller diameter, weight, and volume as these organs extended further from the main stem. Furthermore, samples (Figure 8) maintained with a 120 cm canopy tended to have larger root sizes, as shown in Figure 9. A larger canopy allowed for greater storage of photosynthates in root area, leading to a larger root zone.

DISCUSSION

Sunlight Intensity and Temperature

This study found that plant growth and productivity were significantly influenced by environmental factors, this study found that plant growth and productivity were significantly influenced by environmental factors, particularly sunlight intensity. Different plant species require varying levels of sunlight for photosynthesis, which converts solar energy into chemical energy. Changes in sunlight intensity can impact photosynthetic processes, including photon absorption efficiency and carbon fixation (Yustiningsih *et al*., 2019).

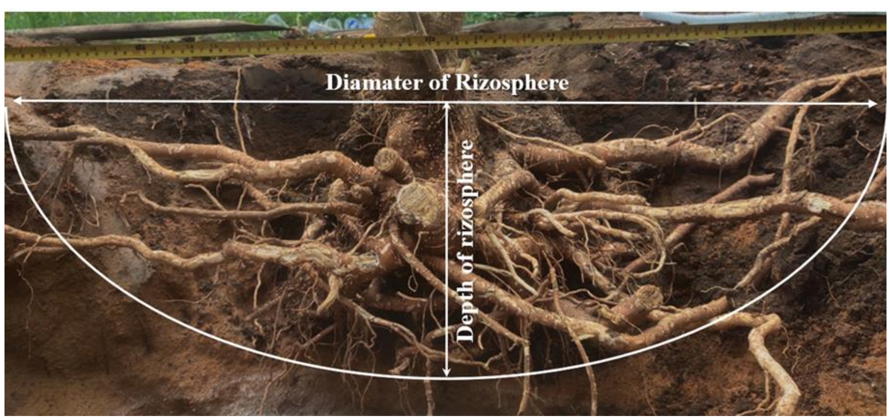

Figure 8. Diameter and depth of chaya root rhizosphere with crown diameter 120 cm treatment.

Table 4. Chaya rhizosphere with different canopy maintenance sizes.

	Rhizosphere diameter (cm)	Rhizosphere depth (cm)	Rhizosphere volume (cm³)
DC 80 cm	210.47 a	34.00 a	328,740.10 a
DC 120 cm	273.00 b	35.60 a	484,502.42 a
p-value	0.011	0.594	0.095

Remarks: Data presented as mean ± standard error. The numbers followed by different letters in the same column indicate significant differences at LSD.05. The numbers followed by same letters in the same column indicate non-significant differences at LSD.05. DC 80= intercropping with chaya crown diameter of 80 cm, DC 120= intercropping with chaya crown diameter of 80 cm.

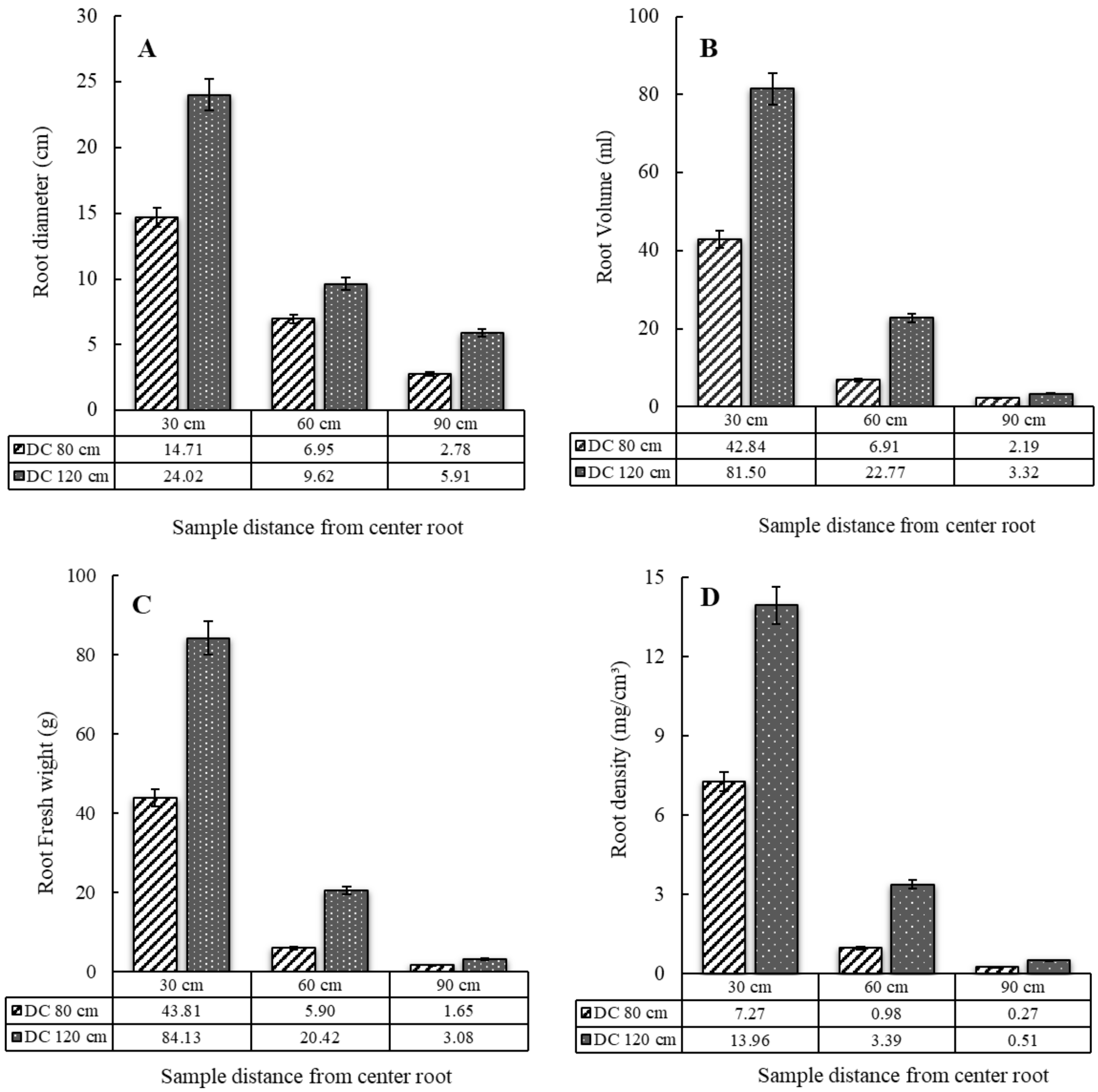

Figure 9. Distribution of chaya root with different canopy sizes, Root Diameter (A), Volume (B), Weight (C), and Density (D). Data presented as mean ± standard error. The numbers followed by different letters in the same column indicate significant differences at LSD.05. The numbers followed by same letters in the same column indicate non-significant differences at LSD.05. DC 80= intercropping with chaya crown diameter of 80 cm, DC 120= intercropping with chaya crown diameter of 80 cm.

In intercropping systems, sunlight distribution differs from conventional methods due to the height and canopy of intercropped plants. The choice of plant species and planting orientation affects sunlight access, making it challenging to simulate sunlight distribution in mixed intercropping patterns (Van Oort *et al*., 2020; Wang *et al*., 2021). A key goal of intercropping is to optimize sunlight use per unit area, allowing for the simultaneous planting of crops that require less sunlight. Shade-tolerant species often have less robust foliage and flatter crowns, which supports this approach (Niinemets, 2010).

Air temperature, strongly influenced by sunlight intensity, was shown to correlate with solar radiation (Leroy *et al*., 2019; Dalengkade, 2019). The canopy of main crops in intercropping reduced air temperatures in the planting area, subsequently lowering soil temperatures. Nyawade *et al*. (2019) reported that intercropping reduced soil temperature at a depth of 0–30 cm by 7.3°C. Temperature is crucial for plant growth, impacting physiological processes and metabolism. Each plant species has an optimal temperature range for healthy growth. For instance, Kong *et al*. (2023) found that increasing air temperature from 21 to 30°C enhanced the fresh and dry weight of lettuce and pak choy by 30%. However, temperatures above optimal levels can stunt growth or cause plant death due to stress (Salisbury and Ross, 1995). Excessively high temperatures can denature enzymes, disrupt metabolic processes, and lead to dehydration as plants close their stomata to conserve water, sacrificing evaporative cooling (Yuniati *et al*., 2020).

Growth Indicators of Annual Vegetables

The efficiency of sunlight absorption by leaves influences plant morphology and physiology. Leaf structure adaptations help plants respond to varying sunlight intensities (Yustiningsih, 2019). Plant metabolism involves generating carbohydrates through photosynthesis and breaking them down via respiration. When photosynthesis exceeds respiration, growth occurs; however, under low-sunlight conditions, the two processes can equalize, inhibiting growth. Sulistyowati *et al*. (2019) found that tomato growth rates and productivity decline under low sunlight intensity. Tomatoes grown under tree canopies or as intercrops received reduced sunlight, disrupting metabolism and decreasing photosynthesis and carbohydrate synthesis.

Research by Daniel *et al*. (2022) and Yasoda *et al*. (2018) on Brassica rapa (Pakchoi) and Brassica oleracea (cauliflower) showed that shaded plants had greater heights than those grown in full sun. Similarly, Shehata *et al*. (2013) reported that shaded tomato plants experienced better growth and higher yields. Low sunlight intensity can stimulate gibberellin (GA) synthesis, promoting node, internode, and cell elongation, enhancing the plant's ability to capture sunlight for photosynthesis (Lyu *et al*., 2021). These responses to shading were crucial in selecting plant types and varieties for intercropping. Suitable varieties must show high complementarity and minimal competition, as well as insensitivity to sunlight periods. Typically, selected intercropping varieties exhibit features such as thinner leaves, reduced branching, and shade tolerance (Maitra *et al*., 2021).

Unlight energy is crucial for plant growth and development, serving as the primary energy source for photosynthesis (Tan *et al*., 2020). Insufficient sunlight can reduce photosynthetic activity and assimilate production, negatively impacting growth (Yustiningsih, 2019). Nyawade *et al*. (2019) confirmed that sunlight radiation converted into dry matter is vital, regardless of other factors like soil temperature and water. These findings highlight the importance of sunlight availability in selecting suitable intercropping plant types and ensuring sustainable cultivation practices (Verma *et al*., 2021).

Growth and Yield of Chaya Plant

Chaya was a perennial leafy vegetable and long-term harvesting was made easier when it was accompanied by early canopy formation activities (Gustiar *et al.,* 2023a). Regular harvesting while maintaining a specific canopy height and diameter was an essential aspect of the cultivation. This differed somewhat from pruning citrus trees, where pruning was an action to regulate plant branching, shape the desired plant form and size, and play an essential role in balancing vegetative and reproductive activities (Sugiyatno *et al.,* 2020).

According to Yun *et al.* (2019), canopy diameter was directly correlated with leaf count and total leaf area. Furthermore, the parameter was also related to sunlight radiation capture and photosynthetic activity. Plant with larger canopy could achieve faster growth by increasing the amount of incoming sunlight compared to plants with smaller canopy (Jayalath *et al.,* 2021). With increased sunlight penetration, canopy photosynthesis, and plant biomass accumulation also increased when canopy photosynthesis was not sunlight-saturated. This, in turn, helped plant produce additional canopy faster than those with smaller canopy.

Chaya Rhizosphere

Chaya propagation was achieved through stem cuttings, leading to shallow roots that only penetrated the topsoil layer. The deepest root depth of chaya was found at 35.60 cm, with the widest rhizosphere diameter measuring 273.00 cm. The results showed that there was no significant difference in rhizosphere volume between chaya with canopy diameters of 80 cm and 120 cm. Understanding root rhizosphere could aid in better plant management, including appropriate fertilization, and comprehending the complexity of interactions between plants and soil microorganisms, which was crucial for sustainable agriculture. Enhanced plant growth, nutrient availability, and resistance to stress and diseases could be achieved through the use of beneficial microbes and environmentally friendly farming practices.

Furthermore, rhizosphere was an essential area that played a role in nutrient absorption, water exchange, and interactions with microorganisms that could affect plant health and productivity (Mai *et al.,* 2019).

Various complex microorganisms, including bacteria, fungi, and other organisms, interacted with plant roots. Plants were known to release organic compounds known as root exudates into rhizosphere (Wheatley *et al.,* 2020). According to previous studies, root exudates contained sugars, amino acids, organic acids, enzymes, and other organic compounds that served as a food source for microorganisms (Wulandari *et al.,* 2020). Roots served to anchor plants and acted as organs of absorption, taking up water and nutrients from the soil essential for growth. Understanding root zone relationships was crucial, specifically in intercropping patterns, to estimate the extent of competition between plant types for water and nutrients. Furthermore, different root systems and adequate fertilization could help avoid nutrient competition. Intercropping could also be adjusted based on root type and planting times. Regulating root types was essential to avoid nutrient competition, specifically when intercropping deep-rooted plants with shallow-rooted variants (Wijayanto and Nurunnajah, 2012). The growth of 2 neighboring plant populations was likely not to cause competition when soil moisture and nutrient availability were sufficient for each plant. The absorption of roots was regulated in response to supply and demand dynamics, with absorption increasing as the fraction of root system with access to nutrients decreased (Dunbabin *et al.,* 2002).

CONCLUSION

Intercropping reduced leafy vegetable growth, due to competition for sunlight and root area. However, intercropping is still a viable option for using free space in chaya cultivation. Optimal growth can be achieved by pruning chaya crown diameter ≤ 80 cm, thereby allowing sunlight to reach the intercropped plants.

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Compliance with ethical standards. Adherence to ethical standards through authorization from the Indonesian ethics or bioethics committee, i.e. autonomous, harmless, beneficial, and fair to living beings.

Data availability. The data that support the findings of this study are available from the corresponding author upon reasonable request.

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