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Assessing the impact on growth and yield in different varieties of chili pepper (*Capsicum frutescens*) intercropped with chaya (*Cnidoscolus aconitifolius*)

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Abstract. *Gustiar F, Lakitan B, Budianta D, Negara ZP. 2023. Assessing the impact on growth and yield in different varieties of chili pepper (*Capsicum frutescens*) intercropped with chaya (*Cnidoscolus aconitifolius*). Biodiversitas 24: 2639-2646.* Intercropping chaya and chili plants is advantageous as it can boost land productivity and increase farmer income. However, the growth of the chili plant is more likely to be hampered by the shade formed by the canopy of the chaya plant. Therefore, this study aimed to investigate the response of chili to the shade of the chaya plant canopy and identify varieties that can thrive in intercropping systems. The experiment was arranged based on a split-plot design with a planting pattern as the main plot, consisting of chili monoculture, intercropping of chaya-chili, and intercropping of pruned-canopy chaya with chili. Three chili varieties, i.e., Rajo, Taruna, and Bara, were the subplots with four replications. Chaya plants were planted at a distance of 200 x 200 cm. Chaya-chili intercropping was done by inserting two rows of chili plants with a distance of 50 x 50 cm between rows of chaya plants. The results showed that chili pepper planted in an intercropping system exhibit an etiolation effect as indicated by a taller stem but with fewer leaves than the chili plants cultivated with a monoculture system. The shading effect of the chaya plant resulted in lower leaf temperature of the chili peppers in intercropping system. Pruning treatment on the shoots of chaya plants positively impacted the growth and yield of chili plants, which was indicated by an increase in biomass weight and fruit yield. The Bara variety was harvested two weeks earlier and produced higher fruit yields compared to Rajo and Taruna varieties. The growth and yield of chili plants were relatively comparable between the monoculture and intercropping system if the canopy pruning in chaya plants was carried out, especially in the Bara variety.

Keywords: Canopy trimming, etiolation, intercropping, monoculture, shading effect

INTRODUCTION

Chaya, also known as *Cnidoscolus aconitifolius* (Mill.) I.M.Johnst., is a native plant of Yucatan, Mexico, and is a member of the Euphorbiaceae family. Compared to other leafy vegetables, chaya is a perennial plant rich in vitamins and minerals that benefit health. According to Amaya et al. (2020), chaya is a significant source of polyunsaturated fatty acids, calcium, iron, zinc, phosphorus, and vitamins A and C. Chaya is a flexible crop that can be cultivated in a variety of unfavorable soil conditions and has a bush-like morphology with a height of up to 2.5 meters (van Welzen and Fernández-Casas 2017; Gustiar et al. 2023). However, chaya has been viewed as having low economic value due to the lack of knowledge about the advantages of chaya leaves. Since chaya has not been widely cultivated, efforts to increase land productivity for intensive farming are necessary. The intercropping system used in this strategy has been found to increase yield and improve the efficiency of land usage (Harsono and Pratiwi 2017; Nievola et al. 2017; Li et al. 2020). Therefore, to boost land productivity and farmer incomes (Widiwurjani et al. 2018), two crop commodities should be grown in an intercropping system (Hu et al. 2019; Li et al. 2020). Planting more than one crop in intercropping systems will reduce economic risk and market fluctuations (Gebru 2015).

Simultaneously planting two crop commodities in the same area will probably lead to symbiosis. Therefore, good cultivation practices are essential, especially in selecting lower-ground crops to intercrop with chaya and cultivating strategies to implement an intercropping system successfully. Several elements limit lower-ground plants in intercropping systems, such as light intensity and temperature, and the chosen commodities should be able to compete favorably between plant species. The main crop provides shade for the lower-ground plants in the intercropping system. However, it is crucial to remember that shading can drastically reduce the amount of light available to the plant, having a noticeable effect on the surrounding temperature and plant growth. Reduced light levels and temperature fluctuations can substantially impact the efficiency of enzymes and photosynthesis, ultimately hindering plant development (Shin et al. 2001; Hariyono et al. 2021; Still et al. 2021).

Chili pepper is a spicy vegetable widely cultivated worldwide and has an economic worth due to its high demand (Widuri et al. 2020; Arumingtyas et al. 2023). Therefore, it is considered that chili pepper is suitable to intercrop with chaya. Chaya and chili pepper can be intercropped to provide two valuable vegetable products, as the upper-ground canopy will provide shade to the chili plant. Pruning can therefore be used to improve light intensity that reaches the intercropping plants. An earlier study showed that chili production is possible in more than 25% of shaded areas (Hariyono et al. 2021). Another study reported that the yield and growth of cayenne pepper in sheltered greenhouses significantly affected growth parameters (plant height and the number of chili flowers) compared to the unsheltered ones (Hassanien et al. 2022). Most studies on how shade affects plant development rely on artificial shading, which dismisses how shade affects the intercropping systems. Research on intercropping chili peppers, particularly under the shade of chaya plants, is still limited.

Each variety of chili pepper has a distinct potential to thrive under the shades of chaya due to its particular morphology. Therefore, using chili varieties to intercrop with chaya will be advantageous. Thus, this study aimed to investigate the response of chili peppers to the shade of chaya plants and identify chili varieties that can thrive in intercropping systems.

MATERIALS AND METHODS

The research was conducted during the rainy season in a humid tropical climate zone in Indralaya (104°46'44" E; 3°01'35" S), South Sumatra, Indonesia, from July 2021 to October 2022. Typical agroclimatic conditions at the outdoor research facilities are shown in Figure 1.

Experimental design

This research employed a split-plot design to evaluate the effects of planting patterns as the main plot and chili pepper varieties as a subplot. Specifically, the varieties of chili pepper used in this study were Bara, Taruna, and Rajo. Three cultivation systems used were the chili monoculture, intercropping of chaya-chili, and intercropping of pruned-canopy chaya with chili, resulting in nine distinct treatment combinations. Each treatment was replicated four times.

Chaya plants (*Cnidoscolus aconitifolius* (Mill.) I.M.Johnst.) previously planted in pots were transferred to the field at the age of 2.5 months with planting holes measuring 30x30x30 cm at spacing 200x200 cm. Raised beds were constructed at a width of 80 cm, covered with black plastic mulch. The plastic mulch was drilled to create holes with a diameter of 10 cm. The holes spaced at 50x50 cm were positioned on the raised bed where chili seedlings were planted (Figure 2).

Chili seedlings were transplanted three weeks after sowing, and watering was carried out periodically. In the intercropping with pruning system, chaya plants were pruned when their canopies touched, approximately four months after planting or 55 days after chili transplanting. The canopy was pruned to create a 50 cm diameter and 100 cm height from the ground, making it easier to harvest the leaves. Furthermore, pest and disease control was performed by applying the chemical insecticide diafentiuron 500_{SC} for controlling *Spodoptera litura* (Fabricius, 1775) and fungicide Mankozeb 80_{WP} for curling yellow leaves disease. The application was carried out when symptoms of the disease occurred.

Data collection

The variables observed included soil temperature, environment, leaf growth, and yield of chili. The ground temperature was measured using a digital thermometer (Krisbow KW0600308), the field air temperature was measured using UNI-T UT333, and the chili pepper canopy temperature was measured using an Infrared thermometer. Measurements were carried out 75 days after chili planting. Parameters observed included plant height, number of leaves, leaf area, leaf thickness, SPAD (Konica Minolta 502), stem diameter, and canopy diameter. Yield parameters include fruit number, weight, diameter, fresh weight, and dry weight. The collected data were analyzed using the statistical analysis R Studio software.

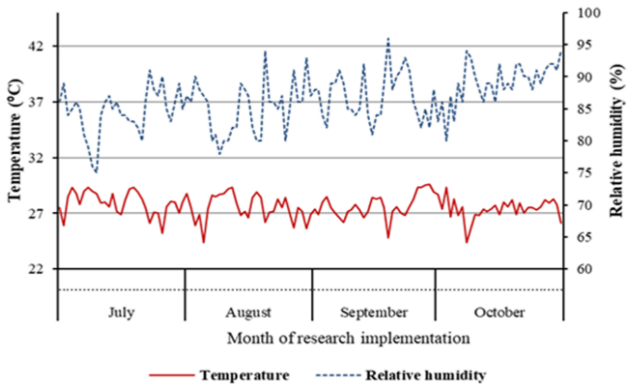

Figure 1. Air temperature and relative humidity at the nearest climatological station to the research location. Source: https://www.bmkg.go.id/

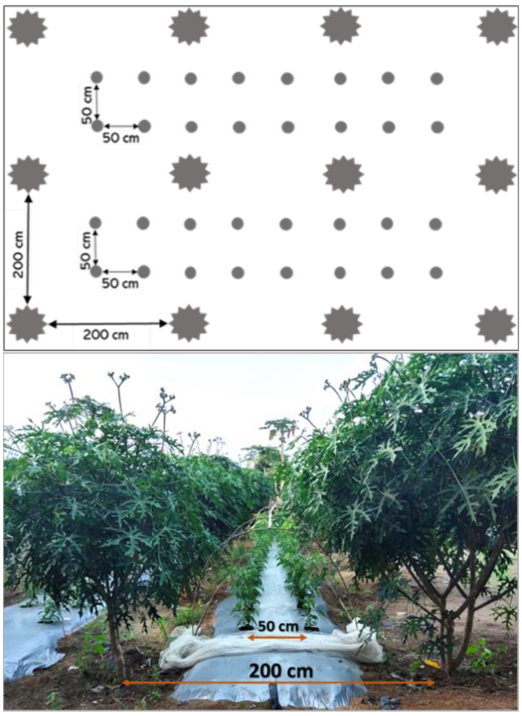

Figure 2. The layout of research on intercropping between chili and chaya plants

RESULTS AND DISCUSSION

Morphology trait of chili pepper

The results found that intercropped chili pepper has higher plant height and leaf area than those in a monoculture system. However, monoculture chili exhibited a higher stem diameter and number of leaves, as outlined in Table 1. This difference is attributed to the chaya plant canopy, which restricts sunlight to chili plants. Pruning main plants in the intercropping system can increase Photosynthetic-Active Radiation (PAR) for lower-ground plants (Della et al. 2019). The cultivation pattern system had no significant effect on the parameters of chili canopy diameter, SPAD, and leaf thickness. Monoculture and intercropping are not significant in canopy diameter variables. It is suspected that the chili varieties used have the potential to form the same canopy diameter with a different number of leaves.

The primary crop in an intercropping system acts as a shade, affecting intermediate plants' growth and increasing stem segment length, plant height, and specific leaf area (Liu et al. 2017; Sevirasari et al. 2022). In addition, the influence of low light intensity can decrease photosynthesis, reducing plant growth, such as the number of leaves and branching (Fiorucci and Fankhauser 2017; Ulinnuha and Syarifah 2022). These morphological changes enable plants to absorb relatively lighter, and shading enhances the utilization efficiency. In addition, the area and number of leaves play a critical role in forming the plant canopy, which intercepts solar radiation and boosts plant productivity (Sinclair et al. 2004).

Plants in intercropping system with pruning have showed better morphological characteristics compared to the ones without pruning, as impact of chaya canopy was reduced. Pruning increases light intensity reaching chili plants, resulting in the more rapid growth of plant area, the number of leaves, and the canopy. The physiological and anatomical properties of the leaf reach the same level as those grown in monoculture planting patterns. However, the morphological features of the stem do not change after the shade is reduced (Wu et al. 2016).

The Rajo varieties exhibited the highest plant height, reaching 122.39 cm, with the fewest leaves, but each leaf was larger than the Bara and Taruna varieties. Therefore, varieties with large leaf sizes had the smallest leaf thickness and SPAD value. In contrast, the Bara varieties had a shorter height, measuring only 69.67 cm, with the largest number of leaves. Meanwhile, the Bara varieties had the smallest leaf area with the greatest thickness and SPAD value, as shown in Figure 3.

Table 1. Comparison of the growth of three chili varieties cultivated with a monoculture system or intercropped with or without pruning at 75 days after planting

Treatment	Plant Height (cm)	Stem diameter (mm)	Leaf area (cm^2)	Number of leaf	Canopy diameter (cm)	SPAD	Leaf thickness (mm)
Cultivation system							
Monoculture	91.57 b	16.57 a	6.92 C	310.61 a	64.48 a	54.06 a	0.39 a
Intercropping	108.58 a	14.01 b	7.65 B	204.78 b	59.75 a	51.33 a	0.39 a
Intercropping with pruning	107.81 a	14.97 ab	8.39 A	246.74 b	65.68 a	53.01 a	0.41 a
$LSD_{.05}$	11.60	2.40	0.44	46.17	7.27	3.91	0.05
Varieties of chili							
Rajo	122.39 a	15.53 b	10.93 A	191.61 b	65.07 a	46.00 c	0.48 a
Taruna	115.90 a	17.00 a	7.84 B	263.26 a	66.78 a	52.73 b	0.39 b
Bara	69.67 b	13.01 c	4.19 C	307.26 a	58.06 a	59.68 a	0.33 c
$LSD_{.05}$	10.78	1.40	0.47	59.50	9.33	2.65	0.06

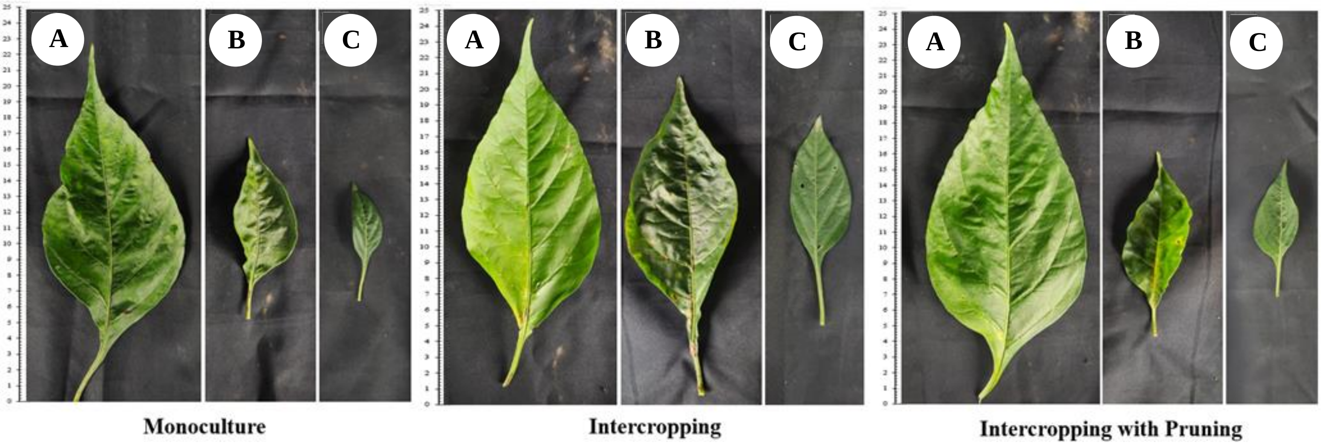

Figure 3. A. The shape and size of leaves in Rajo, B. Taruna, and C. Bara varieties exposed to different cultivation systems

The use of high-yielding varieties is one way to increase the production of chili pepper. Various varieties of chili have different advantages such as production potential, fruit size, and spiciness levels. Furthermore, varieties of chili pepper are an option for growing good types according to needs. The environmental condition of the land, soil and market demand are the main considerations in making a choice, and growth of different varieties is strongly influenced by climatic factors and the soil.

All varieties exhibited greater plant height when cultivated in intercropping compared to monoculture system. Among varieties, Bara exhibited the smallest height in monoculture system compared to others. On the other hand, Bara, Rajo and Taruna varieties were more likely to experience leaf reduction when cultivated in intercropping system than in monoculture. However, the reduced number of leaves was accompanied by leaf thickening, as shown in Figure 4. The intercropping system of Taruna and Bara varieties can lead to good growth when the main plant is pruned properly. The findings of (Ulinnuha and Syarifah 2022) suggested that the Bara variety is shade tolerant, based on its morphological characteristics.

Each varieties have different adaptability to the environment, including climatic elements and growing media. According to (Rahman et al. 2021), the nature of varieties introduced from outside through the introduction method is expected to be superior to the region of origin. However, the character of the introduced high-yielding varieties may not be identical to that of the region of origin due to agroclimatic differences between the two regions.

Ambient temperature of chili pepper

The results showed that cultivation system and chili varieties exert a significant influence on the temperature changes in the area. The soil temperature ranged from 30.20-33.34°C and was lower than air at 38.1-42.0°C. The results showed that the area's temperature changes significantly affected the cultivation system and chili peppers varieties. The air temperature exceeded the Indonesian Meteorology, Climatology, and Geophysics Agency (BMKG) data. The difference was believed to occur because BMKG data represents regional data, whereas measurement data was directly observed in a single research location. Chili peppers in the monoculture system had higher soil and air temperatures than the intercropping system with the chaya plant, as shown in Figure 5. This was due to the influence of the chaya canopy, which has blocked the sun's irradiation, affecting the lower surrounding environment plant temperature. The cultivation system can also affect the temperature of the chili pepper leaf. In monoculture planting, the leaf temperature of the Rajo and Taruna chili varieties was higher than that of intercropping with a pruning system. This differed for Bara varietie, where the leaf temperature in the intercropping system was higher than in monoculture. That is thought to influence the shape of the leaves of smaller Bara varieties so that the temperature changes faster. It was assumed that the smaller Bara cultivars' shaped leaves impacted how quickly the temperature changed.

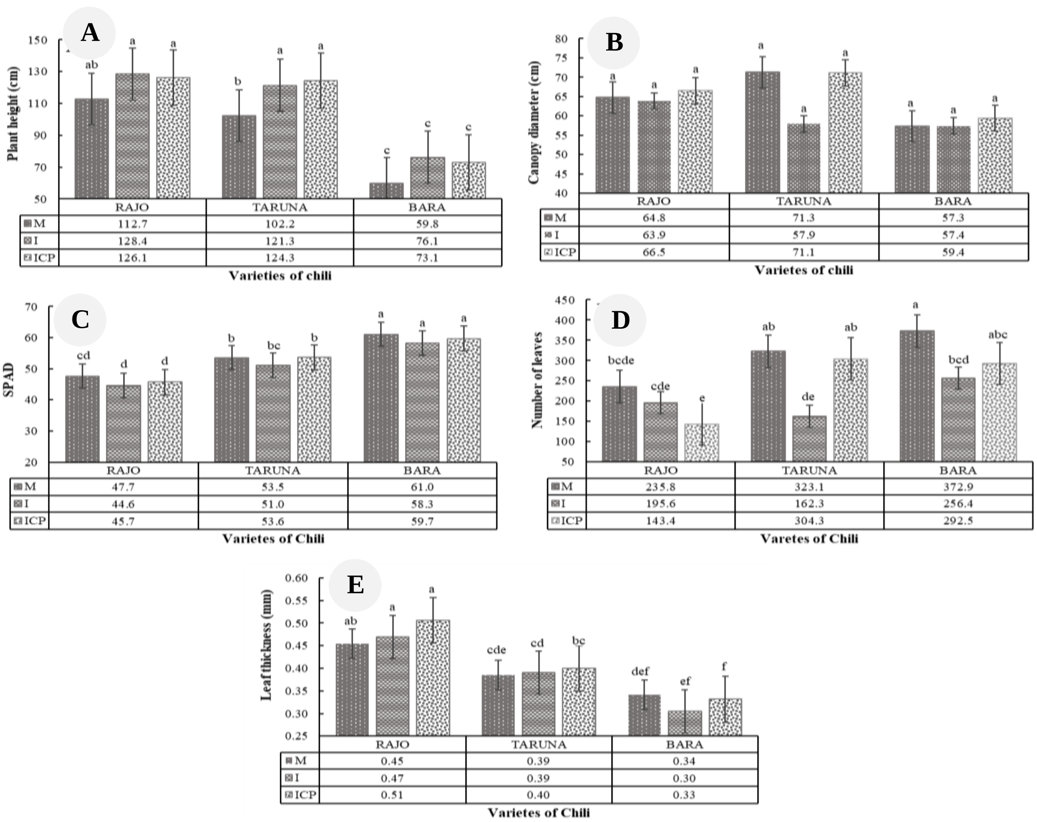

Figure 4. Morphological characteristics of 3 chili varieties in Monoculture (M), Intercropping (I), Intercropping with Pruning (ICP) for A. Parameter plant height, B. Canopy diameter, C. SPAD value, D. Number of the leaf, E. Leaf thickness

Temperature is a critical environmental factor affecting plant metabolism (Nievola et al. 2017). Leaf temperature is positively correlated with stomata conductance, which affects the water potential of the leaf, increases transpiration, elevates CO_2 concentration between cells, and ultimately influences the process of photosynthesis (Mondal et al. 2016; Jumrani et al. 2017; Urban et al. 2017). In addition, high temperatures can damage enzymes and impair metabolism, while low temperatures can render enzymes inactive, causing the metabolism to cease (Ge et al. 2017).

According to (Leuzinger and Körner 2007), plant temperature highly depends on the canopy's architecture and the leaf's characteristics. There is a strong correlation between the leaf area index of air and soil temperature and relative humidity. Canopies with a high leaf area index tend to be cooler and with higher relative humidity during the day (Hardwick et al. 2015).

The findings demonstrated a correlation between the soil and air temperatures and the temperature of the chili leaves. As shown in Figure 6, the Rajo variety's determinant coefficient (R_2) is 0.7226, Taruna's is 0.5757, and Bara's is 0.6069. Rajo variety had a higher coefficient determinant, which was assumed to be associated with their larger morphology and increased responsiveness to temperature fluctuations in the environment.

Changes in air temperature are strongly correlated with the activity of sunlight, which affects the leaf, controlling plant growth as supported by previous studies (Legris et al. 2017; Nievola et al. 2017). In particular, changes in leaf temperature are strongly influenced by the dimensions and shape of the leaf. Leaf thickness is an essential factor as it affects the heat transfer rate from the air, which is relatively slow; hence, heat convection differs between small and large leaves. Similarly, the leaf's shape can potentially affect heat transfer, where leaf lamina with different numbers are associated with temperature transfer with the size of the total area (Leigh et al. 2017). The morphological adaptation of leaf shape is influenced by temperature changes, where plants in hot environments form small, narrow, and thick leaves (Leigh et al. 2017; Zhu et al. 2018).

Yield of chili pepper

The Bara variety is typically harvested 10 weeks after planting, which is 2 weeks earlier than the Taruna and Rajo varieties. All three varieties reached their peak harvest in the sixth week and experienced a decline in production until the eighth week. Furthermore, the Bara variety yielded a larger quantity of fruits compared to the other two varieties. During the sixth week of harvest, the Taruna and Rajo varieties had a higher fresh weight than the Bara variety, although their dry weights were lower. This observation indicates that the water content of the Taruna and Rajo varieties is higher, as illustrated in Figure 7.

Intercropping systems with pruning could produce Fresh of Weight Canopy (FWC), Dry of Weight Canopy (DWC) dan yield Number of Fruit (NF), average Fresh Weight Fruit (FWF), Total Fresh Weight Fruit per plant (TFWF), Total Dry Weight Fruit per plant (TDWF) higher than monoculture and intercropping system. Rajo varieties had higher biomass (FWC, DWC) than Taruna and Bara. However, the greatest and least number of fruits were found in the Bara and Rajo varieties, as shown in Table 2. The varieties of chili pepper with large to small fruit sizes were Rajo, Taruna, and Bara, respectively, as shown in Figure 8. Even though the NF Rajo varieties were the least abundant, its fruits were characterized by a significant size. Consequently, the TFWF was found to be higher in the Rajo varieties than in other varieties. The TDWF was observed to be higher in the Bara variety. These observations suggested that the water content of the Bara variety was lower compared to Rajo and Taruna varieties.

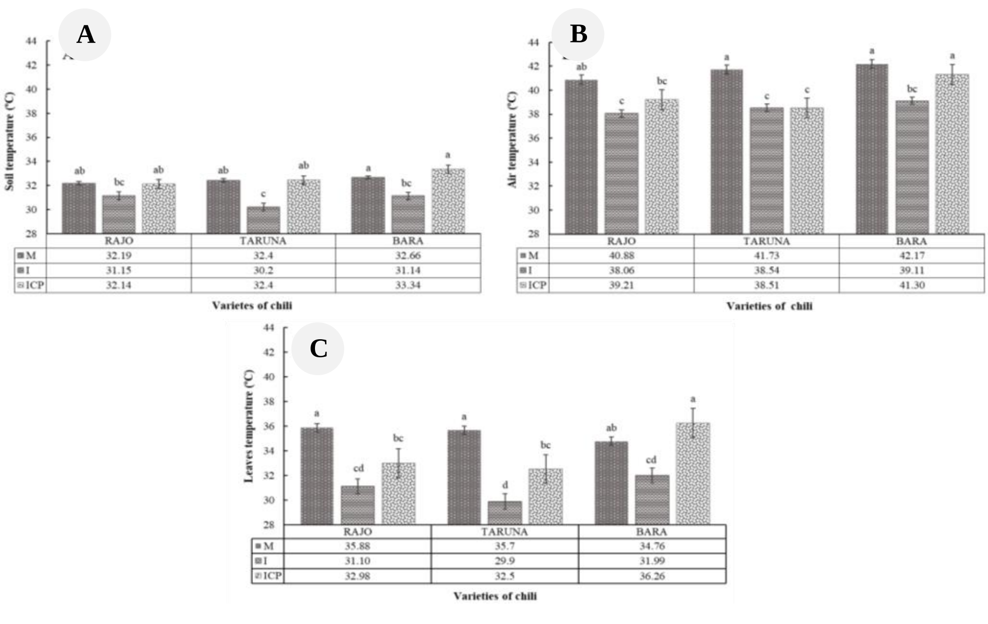

Figure 5. A. Soil, B. Air, and C. Leaf temperature for three varieties of chili 75 days after planting in Monoculture (M), Intercropping (I), and Intercropping with Pruning (ICP) systems

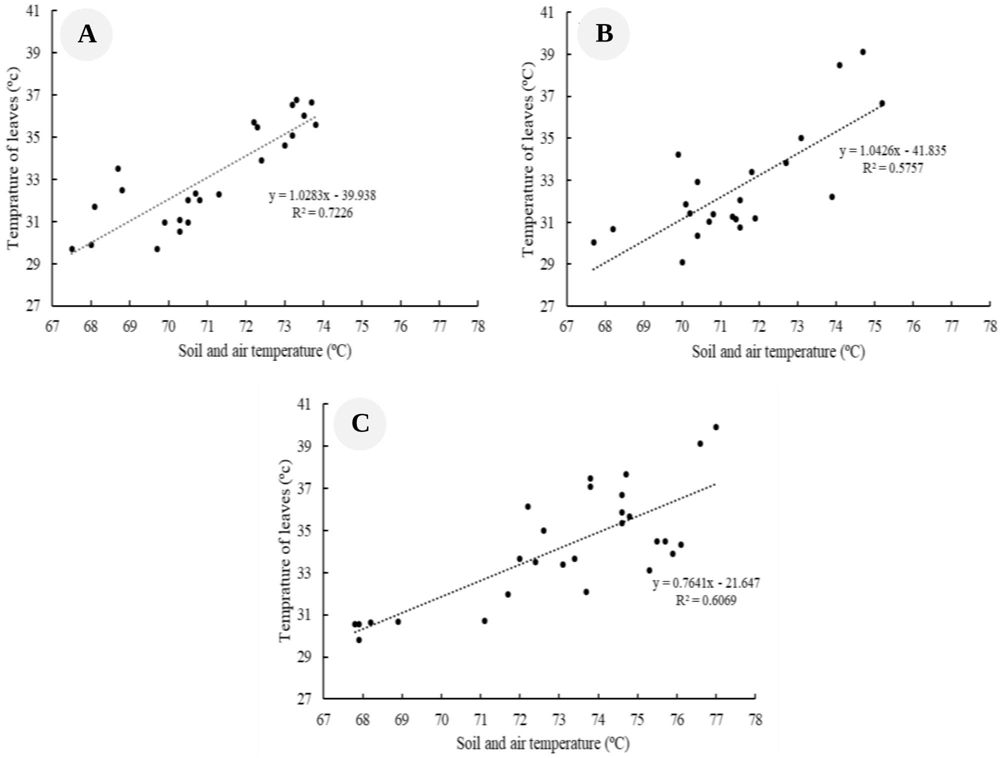

Figure 6. Correlation of soil and air temperature with chili leaf temperature in: A. Rajo, B. Taruna, and C. Bara varieties

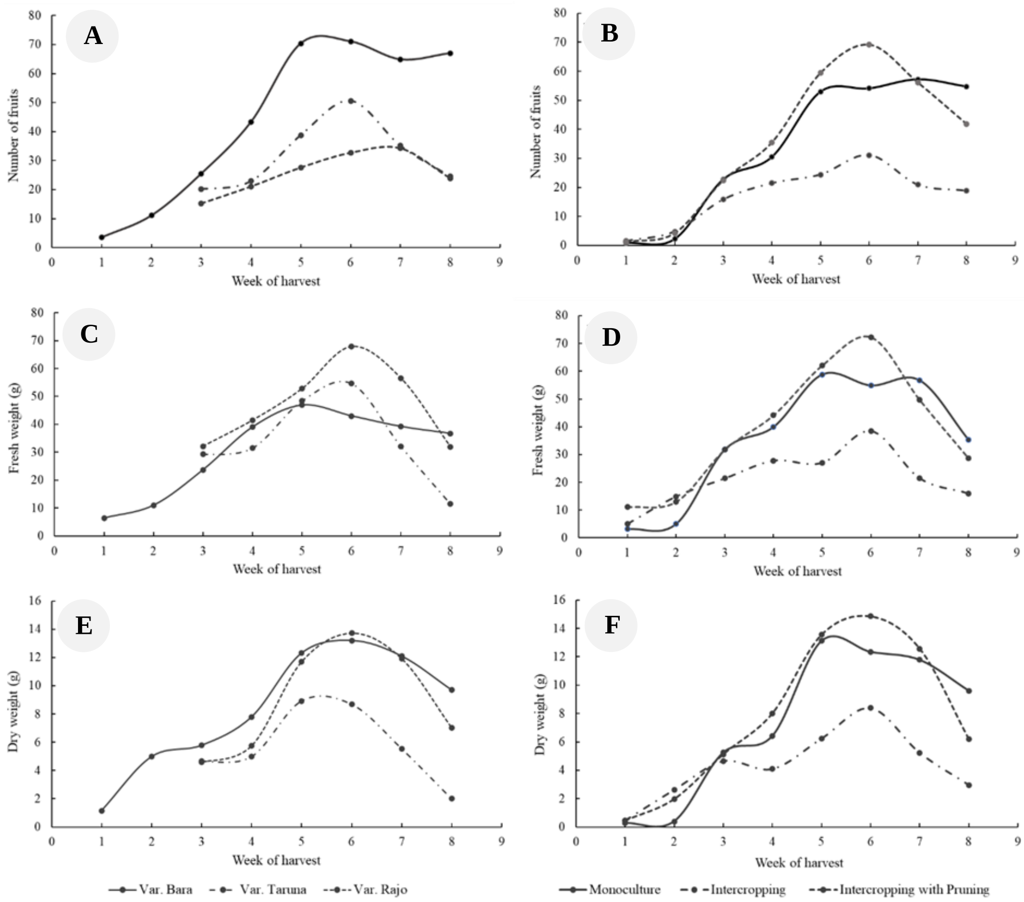

Figure 7. Continuous measurement number of fruits, total fresh weight, and total dry weight of fruits harvested on different chili varieties (left column), different cultivation systems (right column)

Table 2. Fruit yield of 3 varieties of chili pepper in different planting systems

Treatment	FWC (g)	DWC (g)	NF	FWF (g)	TFWF (g)	TDWF (g)
Monoculture	406.25 ab	121.79 ab	275.47 a	1.18 a	280.37 a	59.22 a
Intercropping	331.75 b	86.41 b	138.94 b	1.20 a	158.96 b	34.60 b
Intercropping with pruning	479.59 a	135.68 a	289.67 a	1.20 a	296.55 a	62.78 a
$LSD_{.05}$	147.79	37.26	43.78	0.04	48.00	10.53
Rajo	599.97 a	170.19 a	154.90 b	1.83 a	282.65 a	54.72 b
Taruna	336.75 b	99.98 b	192.21 b	1.07 b	207.28 b	34.81 c
Bara	280.88 b	73.71 b	356.97 a	0.69 c	245.97 ab	67.07 a
$LSD_{.05}$	113.26	33.92	45.75	0.05	55.62	11.17
Interaction						
Monoculture: Rajo	524.01ab	177.43 a	166.23 bcd	1.86 a	307.36 a	56.13 cd
Monoculture: Taruna	297.25cd	96.19 b	239.75 b	1.06 b	254.79 a	44.82 cd
Monoculture: Bara	397.50bc	91.75 bc	420.42 a	0.67 c	278.98 a	76.72 ab
Intercropping: Rajo	639.50a	166.58 a	133.48 cd	1.84 a	245.48 a	49.45 cd
Intercropping: Taruna	144.00d	37.35 c	94.08 d	1.04 b	98.66 b	15.39 e
Intercropping: Bara	211.75cd	55.31 bc	189.25 bc	0.70 c	132.74 b	38.95 d
Intercropping with pruning: Rajo	636.39a	166.56 a	164.98 bcd	1.79 a	326.18 a	58.60 bc
Intercropping with pruning: Taruna	569.00ab	166.41 a	242.79 b	1.10 b	268.38 a	44.21 cd
Intercropping with pruning: Bara	233.37cd	74.08 bc	461.25 a	0.70 c	326.18 a	85.55 a
$LSD_{.05}$	196.17	58.76	79.24	0.08	96.34	19.35

Note: FWC: Fresh of Weight Canopy, DWC: Dry of Weight Canopy dan NF: yield Number of Fruit, FWF: average Fresh Weight Fruit, TFWF: Total Fresh Weight Fruit per plant, TDWF: Total Dry Weight Fruit per plant

Figure 8. The chili pepper fruit size varies on: A. Rajo, B. Taruna, C. Bara

The increased plant height morphology in shaded conditions is an adaptation of plants to capture more light. However, this positive response cannot compensate for reduced leaf and total light interception, reducing biomass and yield (Maitra 2019). The efficiency of resource conversion to biomass depends on the total amount of light intercepted by the canopy and the leaf's net photosynthesis rate per unit area (Lestariana and Prabowo 2021). The leaf is the primary plant photosynthetic organ, and they respond to changes in its light environment by altering morphology and resource allocation patterns (Franco et al. 2018).

Plant growth and development are influenced by two factors, namely genetic and environmental (Khokhar 2017). Different varieties of chili pepper have varying morphological properties and exhibit distinct responses to planting systems. According to the findings, intercropping chili peppers with chaya will inhibit growth and decrease chili yield. However, Rajo variety in the intercropping system resulted in the most biomass and fruit weight yields. For the growth and productivity of chili peppers, intercropping followed by pruning the main crop was comparable to a monoculture cultivation system. This shows that it is very important to maintain the size of the main plant canopy. This ensures that a certain size of the canopy allows intercropping plants to receive adequate light. Based on morphological and yield properties, Bara chili variety had better growth than other varieties.

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