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Enhancing Tomato Productivity by Determining the Planting Time and Intercropping System

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Abstract: Tomatoes are plants that are highly susceptible to cultivation. Intercropping systems can enhance tomato and land productivity. However, selection of unsuitable intercrop types for tomatoes can cause competition among plants. Therefore, this study determined planting times and suitable intercrop types to increase tomato and land productivity in intercropping systems. The experiment was conducted using a split-plot design from December 2022 to April 2023 in Poncokusumo, Malang Regency. The main plots (planting times) consisted of four levels: 0 week after planting tomato (simultaneously with tomato), 1 week after planting (WAP), 2 WAP, and 3 WAP. The sub-plots (intercrop types) consisted of three levels: pakcoy, cabbage, and cauliflower. The results show that planting time and intercrop type significantly influence yield and components of tomato intercropping systems. Tomatoes planted simultaneously with pakcoy or 1 WAP demonstrated improved yield when intercropped. Tomato intercropped with cabbage and cauliflower showed superior growth and harvests at 2 or 3 WAP. Furthermore, treatment with pakcoy produced a higher land equivalent ratio (LER) of 2.09 than other treatments.

Keywords: cabbage, cauliflower, intercropping, planting time, tomato.

通过确定种植时间和间作系统来提高番茄产量

摘要：番茄是一种极易受栽培影响的植物。间作系统可以提高番茄和土地的生产力。然而，选择不适合番茄的间作类型会导致植物之间的竞争。因此，本研究确定了种植时间和合适的间作类型，以提高间作系统中番茄和土地的生产力。该试验于2022年12月至2023年4月在玛琅摄政区蓬乔库苏莫采用裂区设计进行。主地块（种植时间）包括四个级别：番茄种植后0周（与番茄同时种植）、种植后1周（无线应用协议）、2无线应用协议和3无线应用协议。子地块（间作类型）包括三个级别：小白菜、卷心菜和花椰菜。结果表明，种植时间和间作类型显著影响番茄间作系统的产量和成分。与小白菜或1无线应用协议同时种植的番茄在间作时产量有所提高。番茄与卷心菜和花椰菜间作在2或3无线应用协议时表现出优异的生长和收成。此外，使用帕克伊处理产生的土地当量比(最低射程)高于其他处理，为2.09。

关键词：卷心菜、花椰菜、间作、种植时间、西红柿。

1. Introduction

Tomato plants are widely cultivated horticultural products and are categorized as high-risk due to potential failures in cultivation, harvest, and economics. Tomato harvest failures can be caused by reduced soil fertility, unpredictable climate changes, and pest and disease attacks, with economic risks arising from price fluctuations. A major factor contributing to this phenomenon is the implementation of inappropriate planting systems. The application of a monoculture system with high inputs led to a significant decrease in soil properties [1]. These include soil fertility, pH, organic carbon content, other nutrients, and increased compaction. Unsuitable microclimate conditions, including higher temperatures and low humidity, around the plants have also been identified as contributing factors [2]. Monoculture systems increased pest and disease attacks, indicating the need to improve planting systems to enhance the sustainable production of horticultural plants.

Intercropping systems can enhance tomato and land productivity. The utilization of these systems has the potential to enhance soil structure, moisture content, aeration, pH level, and microbial activity, which can subsequently optimize the efficiency of nutrient absorption by plants [3]. The advantages of intercropping over monoculture systems include the enhancement of climatic conditions surrounding the plants. Low temperature and high soil moisture have been established as factors contributing to nutrient loss in plants due to evaporation [4]. Intercropping systems can also reduce pest and disease attacks, thereby minimizing the risk of crop failure by approximately 73% [5].

Timing is an essential factor in the success of tomato intercropping systems. Timing is applied to avoid competition for resources such as nutrients, water, light, and growing space [6], [7], [8]. Timing aimed at enhancing complementarity effects among intercrop plants, showing the need for proper synchronization with tomato growth for successful intercropping systems [9].

Selecting suitable intercrop types can enhance the efficiency of resources such as nutrients, water, and light [10]. The selection of unsuitable intercrop types can cause competition among plants. Plants generally have a tall habit, indicating that suitable intercrop types possess low canopies and shallow roots [11]. Previous research has shown that intercropping two different types of plants with different root systems can improve soil structure and pores [12]. The selection of plants with low canopies accelerates soil surface coverage, reducing temperature and increasing soil moisture [1]. Significant improvements in soil properties and microclimate can also reduce the risk of nutrient loss in soil and increase efficiency.

The selection of intercrops is based on several factors. These factors include morphology, age, and the critical time of the plant. Pakcoy is a short-lived plant (20-35 days), has a shallow root system (12 cm), has 7-10 cm leaf diameter, and can grow of 7-12 cm. Cabbage has an average height 7-15 cm, and root length of 4-13 cm. Cabbage can be harvested 85-90 days after planting. Cauliflower, with an average plant height ranging from 45 to 60 cm, boasts 16-18 leaves and a flower diameter measuring 10-14 cm. It requires 12-20 days for optimal flower formation, after which it can be harvested 50-51 days after planting. This is the crucial period for flower development. Different types of plants are needed to identify which types of plants are suitable as intercrops for tomato intercropping. Therefore, this study determined planting times and suitable intercrop types to increase tomato productivity in intercropping systems.

2. Materials and Methods

This research was conducted from December 2022 to April 2023 in Poncokusumo, Malang Regency, with an average temperature of 17-27.6°C, 99% humidity, and annual rainfall ranging from 15.3 to 485 mm. The planting materials comprised seeds of the tomato variety Corona 402, pakcoy variety Green, cabbage Grand 11, cauliflower Forum 23, water, manure, inorganic fertilizers (Phonska and Urea), pesticides (insecticides and fungicides), and glyphosate herbicide. The experimental setup used a split-plot design, with main plots representing planting times (T), consisting of simultaneous tomato planting (T0), 1 WAP (T1), 2 WAP (T2), and 3 WAP (T3). Meanwhile, the sub-plots were intercrop types, consisting of three levels: pakcoy (P1), cabbage (P2), and cauliflower (P3).

The experiment was carried out by preparing soil to ensure that the required plant texture was achieved. Subsequently, nursery seeding was conducted using trays filled with fine and loose soil, which was mixed with manure at a 1:1 ratio. Before sowing, seeds were evenly mixed with insecticide (carbosulfan) and fungicide (dimetomorph). The land formed into beds was covered with mulch and punctured according to planting distance. The spacing between tomato plants was 60 x 50 cm, while intercrop plants were punctured at a distance of 12 x 7 cm. During planting, seedlings were carefully transplanted along with the soil from the tray and inserted into holes to prevent root damage. Plant selection was based on several criteria: healthy, free from wounds, and uniform in size. Fertilization was performed using manure and inorganic fertilizers such as Phonska and urea, along with the addition of PGPR. This was followed by observations of various parameters, including plant height (cm), leaf count, and leaf area (cm^2). Nine harvesting operations were carried out, with a 1-week gap between each one, commencing from 8 WAP and concluding at 17 WAP, as shown in Fig. 1.

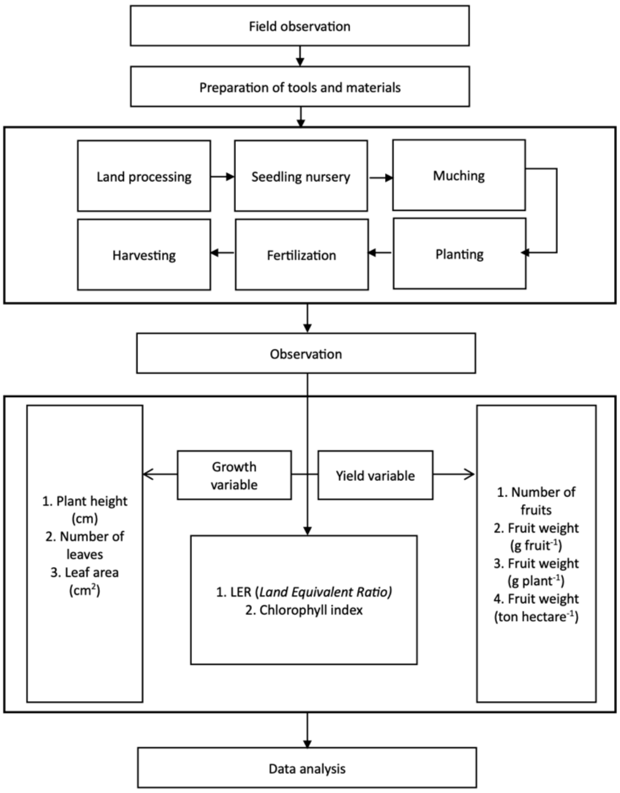

Fig. 1 Flow chart of the research (The authors)

The observed variables are shown in Fig. 1. They included plant height (cm), number of leaves, leaf area (cm^2), number of fruits, fruit weight (g $fruit^{-1}$, g $plant^{-1}$, and ton $hectare^{-1}$), chlorophyll index, and land equivalent ratio (LER). LER was calculated using the following formula according to Beets [13]:

$$LER = Cx + Cy = \frac{Ax}{Px} + \frac{Ay}{Py}$$

Description:

Cc - combined yield of plant *x*

Cx - combined yield of plant *y*

Ax - yield of plant *x* with intercropping

Px - yield of plant *y* with intercropping

Ay - yield of plant *x* with monoculture

Py - yield of plant *y* with monoculture

2.1. Data Analysis

The analysis of variance was utilized to examine the observation data, and when a significant treatment effect was identified, the HSD test was conducted at a level of 5%.

3. Results and Discussion

3.1. Growth Variables

This research showed a significant impact of the planting time and intercrop type on the height, leaf number, and leaf area at 8 WAP. Based on the results, intercropping with pakcoy produced substantial growth improvement, whereas cabbage and cauliflower showed no significant difference at 3 WAP (Fig. 2).

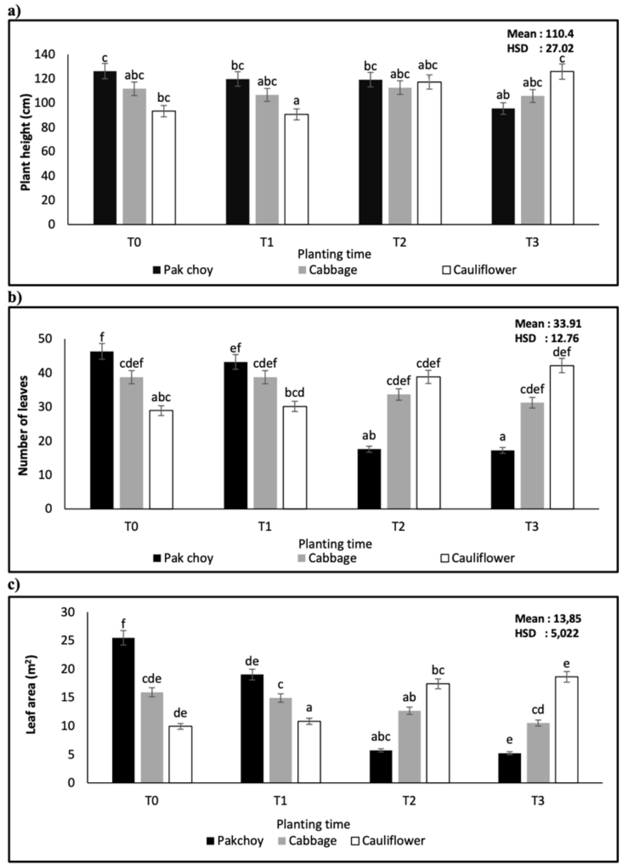

Fig. 2 Histogram of the relationship between intercrop planting time and (a) plant height, (b) number of leaves, and (c) tomato leaf area (The authors)

Notes: T0 - with tomato; T1 - 1 WAP; T2 - 2 WAP; T3 - 3 WAP

At 8 WAP, intercropping with pakcoy produced taller plants, more leaves, and larger leaf areas compared with 1-3-WAP plants. Cabbage planted simultaneously with tomatoes showed no significant difference in growth at all planting times. Meanwhile, cauliflower cultivated at 2 or 3 WAP produced higher growth than at 1 WAP, as shown in Fig. 2a, 2b, and 2c. Short-term intercrop plants such as lettuce could be planted simultaneously with tomato [14]. The use of intercropping with plants that have the same or longer lifespans, such as eggplant and cabbage, yielded more favorable results at 2-3 WAP.

Cauliflower plants exhibit broader leaf morphology, which suggests a possible decrease in light absorption during initial planting. Meanwhile, pakcoy demonstrates narrower leaf morphology, which can augment the efficacy of the intercropping technique involving corn and soybeans. The results of the study on intercropping revealed that the growth rate of the plants was influenced by factors such as duration, nutrient requirements, and leaf morphology, which differ among plant species [15]. These differences could minimize competition between intercrop types and main plants. In this study, intercropping with pakcoy minimized tomato-intercrop competition.

Planting time is closely connected to the presence of crucial periods for plants, which represent the duration during which disturbances and financial losses can be averted [16]. In tomato cultivation, disturbances can originate from interfering plants, organisms, or natural resources, which disrupt plant growth [17]. Critical periods play a significant role in decision-making during intercrop planting times. The critical periods vary among plants, with tomato requiring high nutrients at 42 DAP [18]. Meanwhile, intercropping with pakcoy requires high levels of nutrients at 35 DAP [19], cabbage at 25 DAP [20], and cauliflower at 20 DAP [7]. Management of high nutrient requirements during these periods is essential to minimize competition between tomato and intercrop plants.

3.2. Yield Variables and Crop Yield Components

This study shows that the interaction between planting times and intercrop types significantly influences yield and its components. Based on the results, intercropping with pakcoy had the highest fruit count, with 10.34 fruits per plant, whereas 6.48, 4.81, and 5.59 fruits were obtained at 1, 2, and 3 WAP, respectively. As shown in Table 1, intercropping with cauliflower at 2 and 3 WAP produced higher tomato fruit counts of 7.09 and 8.45, respectively. Competition between main crops and intercrop plants can lead to decreased yields [22].

Table 1 Relationship of the planting time and intercrop type with the number of fruits, weight per fruit, fruit weight per plant, and fruit weight per hectare (The authors)

Treatment	Number of fruits					
	Pakchoy		Cabbage		Cauliflower	
0-WAP tomato	10.34	e	6.23	abc	5.59	ab
1-WAP tomato	6.48	bc	5.99	abc	5.31	ab
2-WAP tomato	4.81	a	6.12	abc	7.09	cd
3-WAP tomato	5.59	ab	6.43	bc	8.45	d
HSD 5%	1.471					
Fruit weight (g fruit^{-1})						
0-WAP tomato	75.18	g	47.51	bcde	41.95	abcd
1-WAP tomato	49.43	de	44.30	abcde	39.70	ab
2-WAP tomato	36.73	a	45.23	bcde	51.91	e
3-WAP tomato	41.27	abc	47.22	bcde	61.08	f
HSD 5%	8.02					
Fruit weight (g plant^{-1})						
0-WAP tomato	779.16	e	296.28	bc	235.35	ab
1-WAP tomato	323.80	bc	268.43	abc	216.77	ab
2-WAP tomato	179.56	a	280.35	abc	373.71	c
3-WAP tomato	231.41	ab	304.07	bc	517.33	d
HSD 5%	115.90					
Fruit weight (ton hectare^{-1})						
0-WAP tomato	66.45	f	41.99	bcd	37.08	abc
1-WAP tomato	43.70	bcd	39.17	abcd	35.10	ab
2-WAP tomato	32.48	a	40.00	abcd	45.91	de
3-WAP tomato	36.51	abc	41.77	bcd	54.03	e
HSD 5%	8.46					

Note: Numbers in the same column accompanied by the same letter did not differ significantly in the 5% HSD test.

In this study, pakcoy planted simultaneously with tomatoes had a lower competition level, as evidenced by the highest growth. This low competition level could be overcome by adjusting the planting time considering the varying high-resource demand periods among plants. Timing adjustments can reduce competition by preventing canopy closure in the main crop due to morphology and through strategic positioning of high-resource demand periods for both plants to improve the efficiency of resource use in the soil [23].

The difference in timing serves as a reference for appropriate planting of pakcoy when growth factor requirements are high. In this study, tomatoes planted simultaneously or at 1 WAP produced better yield components than the other treatments. Intercropping tomato with sesame plants (harvest at 2.5 months) produces higher height, branch numbers, and harvest yields [24]. This result is attributed to optimal vegetative growth and enhanced assimilation rates without delaying sesame planting. However, the results showed that competition between tomato and intercrop plants was higher due to delayed planting.

Intercropping has been found to enhance fruit weight. This is evidenced by the substantial impact on tomato yield, as demonstrated in Table 1. Based on the results, intercropping with pakcoy produced a higher tomato fruit weight than cabbage and cauliflower at 66.45 t ha^{-1} in simultaneous planting. However, there was no significant difference between the cabbage and cauliflower treatments at 1 WAP. The differences in tomato yield among intercrop types were due to variations in morphology, resource requirements, and planting times, thereby affecting competition. Intercropping tomatoes with lettuce produces a higher yield than eggplant [14], [23].

The positive interactions between intercrop plants can increase tomato productivity, including growth, plant resilience, and yield [12, 25]. Positive interactions involve situations wherein the collective presence of plants enhances the growth environment [1]. Achieving positive interaction between the main and intercrop plants can be possible when there is diversity in terms of growth duration, nutrient requirements, utilization of nutrients, regulation of height, and reducing competition for water and nutrients [15]. In intercropping systems, it is essential that the height of the tomato plants exceeds that of the intercrop plants to promote beneficial interactions between them. To achieve this, the main crop should be taller to prevent competition for light [26]. Variations in nutrient uptake have beneficial effects on soil, facilitating the success of intercropping systems.

3.3. Chlorophyll Index

Chlorophyll is an essential component, with high content serving as an indicator of photosynthesis. In this study, different chlorophyll indices were identified in various intercrop types, which affected plant growth, particularly during photosynthesis. Intercropping can increase the chlorophyll index by approximately 23.34% in corn plants [25].

The leaf chlorophyll index variable in pakcoy planted simultaneously with tomato has an index of

47.94. This value is not significantly different from intercropping with cabbage at 2 and 3 WAP (47.52), as shown in Fig. 3. The incorporation of cabbage as an intercrop demonstrated no discernible variation in all planting time treatments, suggesting a higher rate of photosynthesis. Differences in the chlorophyll index at different planting times and intercrop types may be related to plant morphology [27].

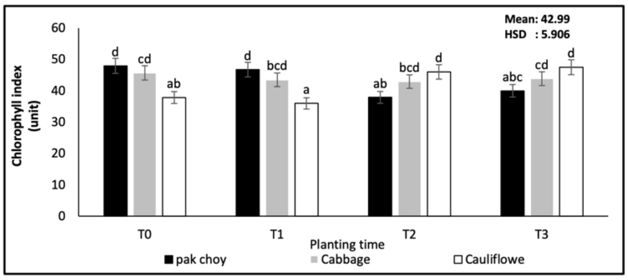

Fig. 3 Histogram of the relationship between the planting time, intercrop type, and tomato chlorophyll index (The authors)
Notes: T0 - with tomato; T1 - 1 WAP; T2 - 2 WAP; T3 - 3 WAP

Cauliflower plants possess broader leaf morphology, which can hinder light interception by tomato plants during initial planting. In contrast, pakchoy has narrower leaf morphology, enabling it to more effectively intercept light. This indicates that procrastinating the planting of pakcoy can decrease the chlorophyll index in the leaf, which suggests competition between tomatoes and pakcoy. Competition could reduce growth rates, such as plant height, leaf number, and chlorophyll index, where high values are correlated with nitrogen availability [7], [27]. In this study, nitrogen measurements showed that tomatoes intercropped with pakcoy had the highest chlorophyll index of 4.59. High nitrogen availability is associated with root morphology. Intercropping systems of different types can affect the chlorophyll index in tomato [28].

Planting times are a critical aspect of intercropping as they can help reduce competition and improve the microclimate, which can positively impact tomato yield [8]. The impacts of microclimate include temperature, humidity, and sunlight intensity, playing crucial roles in photosynthesis and the accumulation of plant dry matter [29]. Due to the high sunlight requirement of tomatoes, precise timing is essential to ensure that the canopy of intercrop plants does not reduce sunlight intensity. Plants that were cultivated previously served as a canopy, offering a layer of ground cover that protected the soil from the direct radiation of sunlight. Plant canopies function as windbreaks, reducing warm air reaching the soil surface [30]. During daylight hours, absorbed sunlight warms the leaves, creating a lower temperature in the microclimate of the soil where plants are grown. Furthermore, the canopy covering the soil has lower temperatures, creating conditions for higher relative humidity. The minimal canopy in planting patterns can also affect the microclimate, leading to increased temperature and sunlight and decreased humidity. The absence of canopy cover in tomato planting results in increased temperature and inadequate water supply for the plants, which leads to a negative impact on tomato yield [21].

3.4. LER

LER is a valuable tool in agriculture that is used to assess land use efficiency. Based on the results, all treatments had LER values >1, indicating that the farming efforts were productive. Generally, these values are obtained by comparing the intercropping and monoculture yields with the inputs applied in both systems. Based on the results, the harvest yield of monoculture tomatoes was found to be 37.71 t ha^{-1}. Among all treatments, intercropping with pakcoy resulted in the highest LER of 2.09 (Table 2).

Table 2 LER (The authors)

Treatment	Pakchoy	Cabbage	Cauliflower
0-WAP Tomato	2.09	1.85	1.86
1-WAP Tomato	1.75	1.54	1.78
1-WAP Tomato	1.35	1.61	1.71
3-WAP Tomato	1.34	1.24	1.63

All intercrop types and planting times had LER >1, indicating that intercropping tomatoes with pakcoy, cabbage, and cauliflower is viable. High LER indicates low competition between the main crop and intercrop plants. This indicates that the LER for tomato and pakcoy shows a low level of competition.

4. Conclusion

Tomato plants have high cultivation risks. Intercropping can enhance tomato crop productivity and land efficiency. However, unsuitable intercrop selection and timing can increase competition between tomato plants and intercrops. Therefore, appropriate companion crop selection and planting timing are essential to maximize tomato productivity.

The results show that intercropping tomatoes with pakcoy at 0 and 1 WAP increased tomato productivity with a yield of 66.45 tons $hectare^{-1}$. Tomatoes grown in combination with cabbage produced the highest fruit yield amounting to 41.99 tons $hectare^{-1}$. Intercropping tomatoes with cauliflower at 3 WAP produced 54.03 tons $hectare^{-1}$. This study shows the highest LER for intercropping tomatoes with pakcoy at 0 WAP. Therefore, intercropping tomatoes with pakcoy at 0 WAP is recommended for improving tomato crop productivity and land efficiency.

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