

Evaluating The Suitability of Sunflowers as Companion Plants in an Intercropping System with Tomatoes

Ratna Yuniati*, Siti Zahrotul Karimah and Niarsi Merry Hemelda

Abstract: The intercropping system involves growing multiple crop species simultaneously on the same land to reduce the risk of crop failure. One such example is the co-cultivation of sunflowers and tomatoes, where sunflowers function as living mulch. However, studies on the function and impact of sunflower–tomato intercropping systems, particularly in relation to weed management and productivity enhancement in Indonesia, remain limited. This study aims to evaluate the suitability of sunflower plants as companion and living mulch species in intercropping systems with tomatoes, and to assess the performance of both crops when grown individually or together. A randomized block design with two replications per treatment was employed using raised beds. Both crops were transplanted simultaneously in alternating arrangements for 13 weeks at a 1:1 ratio. Results showed that intercropping effectively suppressed weed growth and reduced pest and disease incidence. The Mann–Whitney test ($P < 0.05$) revealed significantly lower sunflower yields in the intercropping system than in monocropping. A Land Equivalent Ratio (LER) of 0.65 (< 1) indicated higher productivity under monocropping, due to intense belowground interspecific competition and rhizosphere interactions. Competition analysis showed that tomatoes dominated the system (Aggressiveness, $A = +0.165$; Competition Ratio, $CR = 1.677$). Therefore, sunflower and tomato plants can be effectively intercropped, provided that planting times are staggered to minimize competition and aggressiveness between species.

Keywords: Intercropping, monocropping, sunflower, tomato, weed.

1. Introduction

Tomato cultivation frequently encounters challenges associated with weed interference, leading farmers to adopt diverse control methods such as herbicide application and plastic mulching. While herbicides are convenient and cost-effective, they may harm non-target plants and pose environmental and health risks due to chemical residues contaminating soil and water (Jurado et al., 2011). Plastic mulch, on the other hand, effectively suppresses weed growth by blocking sunlight (Freitas et al., 2021), but its use can contribute to plastic waste accumulation and soil degradation (Wu et al., 2020). Consequently, sustainable and environmentally friendly alternatives, such as the use of living mulch within intercropping systems, have gained increasing attention.

Intercropping involves planting multiple types of crops together in one area, offering benefits beyond weed reduction, including decreased crop failure risk, improved soil and water conservation, and reduced pest populations. Intercropping promotes plant diversity by incorporating multiple plant species into the same area, thereby supporting a broader range of flora and fauna. This increased diversity facilitates more efficient resource use, can reduce damage caused by diseases and pests as interactions among diverse species enhance the overall health and productivity of the system. (Boudreau, 2013). Many plants can be effectively used as companion plants in intercropping systems, including legumes (beans, peas), marigolds, basil, corn, and sunflowers, which are commonly employed in such systems

(Makoi & Ndakidemi, 2012).

Sunflowers are commonly integrated into intercropping systems with various primary crops such as soybeans (Saudy & El-Metwally, 2008), sorghum, and cotton (Kandhro et al., 2014). The sunflower-soybean, sunflower-sorghum, and sunflower-cotton intercropping systems, as reported by Saudy and El-Metwally (2008) and Kandhro et al. (2014), have demonstrated abilities to suppress weed growth and enhance plant characteristics such as height, sunflower diameter, fresh weight, and seed yield. Another benefit highlighted in research by Kestha & El-Baz (2004) conducted in Giza, Egypt during the summer season indicates that sunflower and tomato intercropping can improve tomato fruit quality by providing shade and enhancing land use efficiency. Land use often involves optimizing the use of resources such as water, nutrients, and space. When resources are used efficiently, plants can grow more healthily, which can lead to higher fruit quality. The primary determinant of a viable intercropping system is the compatibility of crops. Therefore, the effectiveness of any intercropping setup relies on carefully selecting crop species that minimize competition for light, space, moisture, and nutrients between them (Fukai & Trenbath, 1993). In Indonesia, tomatoes are generally cultivated with chillies, soybeans, winged beans, lettuce, cauliflower and Chinese broccoli to reduce pest attacks such as the cabbage leaf-eating Diamondback moth (*Plutella xylostella*) (Asare-Bediako et al., 2010). However, research evaluating the suitability of sunflowers as companion plants in intercropping systems with tomatoes in Indonesia in controlling weeds and increasing productivity is still limited. In addition, until

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now, the intensity of competition between component plants in the intercropping system is still unclear.

The objective of this study is to evaluate the compatibility of sunflower plants as companion plants and living mulch, and to assess the performance of sunflower and tomato plants when grown individually or intercropped. This will be achieved by evaluating competitive interactions between intercrop components and their impact on yield quality.

2. Methodology

Experimental Site

The experiment was conducted between May and September 2020, in the Tanjung Barat District of South Jakarta, situated at an altitude of approximately 26.2 meters above sea level. The average rainfall, according to Meteorological Climatological and Geophysical Agency (BMKG) ranges from 21 to 50 mm, and the soil pH is 6.5. During the experiment, temperatures fluctuated between 28 and 32 °C, with average relative humidity levels ranging from 69% to 90%.

Planting Pot Preparation

The experimental setup employed a randomized block design comprising three treatments: (i) a tomato monocrop featuring only tomato plants; (ii) a sunflower monocrop consisting solely of sunflower plants; and (iii) a sunflower-tomato intercropping system, where tomato and sunflower were planted alternately in a 1:1 ratio (3 tomato plants : 3 sunflower plants) according to the following planting arrangement (Figure 1).

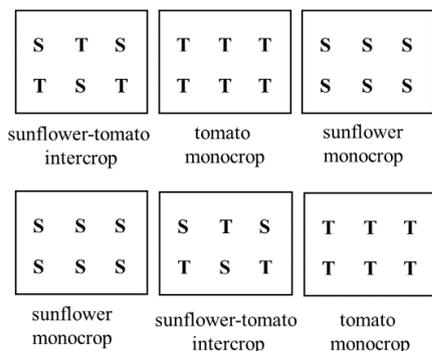


Figure 1. Planting arrangement of sunflower and tomato plants (S= sunflower, T=tomato)

Each treatment was replicated twice, resulting in six-bed plots with six plants in each plot. The plants were spaced 20 cm apart. The seeds used were the New Mutiara F1 hybrid tomato (Jawara Superior Seed) and the Giant Single Sunflower variety.

Preparation of planting plots involved land clearing, plowing, and bed setup. Land clearing aimed to remove weeds and plant residues that could harbor bacteria or fungi (Panth et al., 2020). Plowing was done to a depth of 30-40 cm. The beds were constructed with a height of approximately 10 cm, and above them, plant plots made of wood reaching 40 cm in height were installed (Naika et al., 2019). Both the sunflower and tomato plots were filled with commercial substrate (CV Tani Tangguh Perkasa),

composed of topsoil, burnt husks, and manure. Each individual plant received five grams of NPK 16:16:16 fertilizer (Rawal et al., 2022). The plant plots were left exposed to sunlight and air exchange for two weeks before further proceedings.

Germination and Seedling Preparation

The seeds were sown at different intervals, with tomato seeds planted 28 days before sunflower seeds. This discrepancy in seeding times is based on the duration each plant requires to reach the generative growth phase. Sunflower plants typically require approximately 80-95 days to produce seeds (Dagustu et al., 2012) while tomato plants need 100-140 days to bear fruit (Hossain et al., 2014). Both tomato and sunflower seeds were sown in a 54 x 28 x 5 cm seedling tray containing 50 holes. Each hole was filled with commercial planting media composed of a mixture of topsoil, burnt rice husks, and cow manure. Following sowing, the seed germination tray was sprayed with tap water, and a thin layer of rice husk was applied over the seeds to retain moisture.

Three weeks-old tomato seedlings, were transplanted into 15 x 15 cm polybags, whereas sunflower seedlings were transferred to polybags 15 days after sowing (Kestha & El-Baz, 2004). A total of 36 individuals from both the sunflower and tomato seedlings, exhibiting uniform morphology and height, were selected for transplantation into the bed plots.

Plant Transplantation and Maintenance

Tomato seedlings were transplanted three weeks after sowing, maintaining a 20 cm spacing between plants, which falls within the recommended range (NCPS, 2015). Plant maintenance, includes irrigation, fertilization, and the application of fungicides. Watering is performed twice daily to ensure adequate moisture levels for the plants. Fertilization entails the application of NPK 16:16:16 fertilizer at a dosage of 5 g per 0.5 L of water every two weeks for each treatment plot. Fungicide application treatment with Antracol (2 g/L) is administered only during the 3rd and 4th weeks after transplantation. The fungicide solution is applied by spraying the leaves of plants infected with fungi, particularly targeting powdery mildew.

Data Collection Process

Data were collected from both abiotic and biotic parameters. The abiotic parameters monitored encompassed pH, temperature, and soil moisture. The biotic parameters examined included tomato plants, sunflower plants, and weeds. Sunflowers and tomatoes were both harvested 13 weeks after planting.

Abiotic (Environmental) Parameter

In this study, soil abiotic parameters such as pH, temperature, and soil moisture were recorded weekly over a 13-week period, with three repetitions. Soil moisture observations were conducted by drying 20 g soil samples from a depth of 10 cm on the soil surface. Subsequently, drying was performed using an oven set at a temperature of 40°C until the soil's dry weight remained constant (Owodoyin, 2007). The results obtained were

then calculated using the soil moisture percentage formula (Teame et al. 2017), as outlined below:

$$\text{Soil moisture (\%)} = \frac{\text{Wet soil weight} - \text{Dry soil weight}}{\text{Dry soil weight}} \times 100\%$$

Soil pH observations involved placing soil samples obtained from a depth of 10 cm into distilled water with a neutral pH. Subsequently, pH strip paper was immersed into a mixture of distilled water and soil, and the color of the pH paper was compared with the color on the pH scale to determine the pH level. Meanwhile, soil temperature measurements were conducted by inserting a thermometer to a depth of 10 cm below the soil surface (Nkansah et al., 2003).

2.4.2. Intercropping system and weed control

Weed density was observed by counting and identifying each weed present in every plot. Weeds were categorized into three groups: broadleaf weeds, grasses, and sedges. The number and density of weeds were determined using the formula outlined by Lukitasari (2018).

$$\text{Density (individual/m}^2\text{)} = \frac{\text{Number of weeds}}{\text{Area of observation plot}}$$

Plant Growth and Plant Productivity Parameters

Both sunflower and tomato plant growth parameters were observed, including various growth and productivity metrics. For tomato plants, these metrics encompassed plant height, chlorophyll content, number of fruits per plant, and fruit weight. Sunflower plant metrics included plant height, chlorophyll content, number of flowers per plant, flower diameter, and yield per plant.

The method used to measure total chlorophyll in tomato and sunflower leaves was adapted from the research conducted by Zhao et al. (2019), with modifications to the leaf disk sample size and centrifugation speed. The absorbance values obtained were then calculated using the total chlorophyll formulation provided by Wintermans & de Mots (1965), as outlined below:

$$\text{Total chlorophyll (mg/mL)} = 20.0 \times \text{OD}_{649} + 6.1 \times \text{OD}_{665}$$

Evaluation of Competitive Intensity

Plant competitive intensity in the intercropping system is assessed based on research conducted by Gitari et al. (2020), utilizing the Land Equivalency Ratio (LER) formulation. LER is defined as the land requirement in a monocropping system to produce the same crop yield as in the intercropping system. The LER value > 1 indicates that the intercropping system produces more profitable crops than monocropping. Conversely, if LER value < 1 suggests that intercropping is less profitable than

monocropping, while an LER value equal to 1 indicates that the results of intercropping are equivalent to those of monocropping.

The LER formula, according to Chipomho (2015), is as follows:

$$\text{LER} = \frac{\text{intercrop 1}}{\text{monocrop 1}} + \frac{\text{intercrop 2}}{\text{monocrop 2}}$$

The evaluation of competition between sunflower and tomato in the intercropping system involves assessing the aggressiveness value and competition ratio, as outlined by Machiani et al (2018). Plant aggressiveness in the intercropping system is calculated to gauge the impact of interspecific competition between tomato and sunflower within the intercropping setup. The aggressiveness index is computed by comparing the yields of plants in the intercropping system with those in the monocropping system, along with considering the proportion of land utilized in the intercropping system. The aggressiveness formulation (A) as used by Islam et al. (2016) is presented as follows:

$$A_{hi} = \frac{Y_{hi}}{Y_{hh} - Z_{hi}} - \frac{Y_{ti}}{Y_{tt} - Z_{ti}}$$

$$A_{ti} = \frac{Y_{ti}}{Y_{tt} - Z_{ti}} - \frac{Y_{hi}}{Y_{hh} - Z_{hi}}$$

Where A_{hi} and A_{ti} are aggressivity of sunflower and tomato respectively, Y_{hi} and Y_{ti} are yield of sunflower and tomato in the intercrop respectively; Y_{hh} and Y_{tt} yield of sunflower and tomato in monocrop plot respectively; Z_{hi} and Z_{ti} are the proportions of sunflower and tomato in the intercrop respectively.

Data Analysis

Data analysis was conducted using SPSS version 26. The tomato and sunflower plant parameter data were analyzed using the T-test with a significance level of 99%. The T-test was employed to ascertain the significant effects between the monocropping and intercropping systems.

3. Result and Discussion

Abiotic Parameter

In comparison to intercropped plots, the mean soil temperature in monocropped sunflower plots was notably the highest, at 27.65 ± 1.16 °C, indicating that the intercropping system effectively lowered soil temperatures. The higher soil water content observed at 0–30 cm depth in the soil of intercropping plots correlates with the shade provided by the canopy of sunflower plants, which have wide leaf types, thereby minimizing soil evaporation. Intercropping plots exhibited the highest soil moisture percentage, whereas the soil pH was almost the same across all plots (Table 1).

Table 1. Soil parameter observation

| Treatment | Soil Parameter | | |
|--------------------|----------------|------------------|---------------|
| | pH | Temperature (°C) | Moisture (%) |
| Intercrop | 6 ± 0.37 | 27.27 ± 1.12 | 66.05 ± 15.85 |
| Tomato Monocrop | 6 ± 0.44 | 27.28 ± 0.96 | 62.50 ± 13.38 |
| Sunflower Monocrop | 6 ± 0.40 | 27.65 ± 1.16 | 60.82 ± 14.39 |

These findings are consistent with visual soil assessments, which revealed that the soil in intercropping plots had a looser structure compared to monocropping plots. Soil physical properties is influenced by various factors, including constituents and concentration of the soil components porosity, and soil moisture content (Doran & Zeiss, 2000). The increased shade generated by plants can indeed lower soil temperature, subsequently increasing groundwater viscosity and leading to elevated soil moisture levels around the shaded area (Onwuka et al., 2018). Hence, this phenomenon is believed to be the reason behind the high soil moisture observed in the intercropping system. However, the lower soil moisture in monocropping systems does not necessarily cause faster leaf aging and drying. This is because the soil moisture levels in the monocropping system are within the range of ideal soil moisture for tomato plant growth, which is

typically around 60% - 70% (Liu et al., 2009)

Intercropping System and Weed Control

The intercropping system significantly reduced weed density compared to the monocropping systems of either sunflower or tomato (Table 2). This suppression likely results from competition for light, water, and nutrients at both surface and subsurface levels, as well as allelopathic effects from sunflower roots. Sunflowers produce secondary metabolites such as sesquiterpene lactones and helinunol, which act as natural bioherbicides that inhibit weed growth (Makoi & Ndakidemi, 2012). Additionally, the dense sunflower canopy in the intercropping system reduces solar radiation reaching the soil surface, further limiting weed germination and development.

Table 2. The effectiveness of intercropping and monocropping as weed control

| Treatment | Total | Average number/plot | | | Density (individual/m ²) | | |
|-----------|-------|---------------------|--------|-------------|--------------------------------------|--------|-------------|
| | | Grasses | Sedges | Broadleaves | Grasses | Sedges | Broadleaves |
| Intercrop | 9 | 0.5 | 0 | 4 | 2.09 | 0 | 16.67 |
| Sunflower | 24 | 0.5 | 0.5 | 11 | 2.09 | 2.09 | 45.80 |
| Tomato | 19 | 1 | 0.5 | 8 | 4.17 | 2.09 | 33.35 |

The canopy architecture in the intercropping system determines the distribution of sunlight, as noted by Gao et al. (2010). The broad leaf type of sunflower plants grows vertically with various lamina and petiole tilt angles in the upper and lower canopy layers. Leaves in the upper canopy tend to lean upwards, while those in the lower canopy lean downwards, resulting in decreased light interception efficiency in the lower canopy layers (Hernandez, 2010). The obstruction of sunlight by the leaf canopy of sunflowers in intercropping plots is believed to hinder the interception of solar radiation reaching the soil surface, thereby inhibiting weed growth.

Weeds with vegetative reproduction are generally easier to control during soil tillage compared to weeds that produce seeds. This difference arises because the vegetative reproductive organs of weeds typically have lower tolerance to environmental changes, while seeds possess high dispersal ability and resistance to environmental fluctuations (Sastroutomo, 1990). As a result, the prevalence of broad-leaved weeds is believed to be primarily due to weed seeds being transported during land processing.

Based on the mechanism of weed photosynthesis, sedges and grasses are typically classified as C4 class weeds, which have a high requirement for light during the photosynthesis process, while broadleaf weeds are categorized as C3 class weeds, which

have a lower need for light during photosynthesis (Marsal et al., 2015). The high density of broadleaf weeds observed in each treatment plot (Table 2) is likely due to the shade provided by each plant in both the intercropping and monocropping systems. Additionally, the research area being a plantation surrounded by large trees contributes to the dominance of broadleaf weeds, with limited growth of sedges and grasses. According to Marsal et al. (2015) suboptimal light intensity hampers the growth of sedges and grasses, while broadleaf weeds can thrive and survive better under such conditions.

The sunflower and tomato intercropping system effectively reduces the growth of broadleaf weeds compared to the monocropping system. This is attributed to the more optimal canopy architecture formed by the intercropping system, which minimizes light interception on the ground surface. Consequently, not only is the growth of sedges and grasses inhibited, but the growth of broadleaf weeds is also significantly suppressed. The canopy created by the intercropping system exhibits strong chlorophyll absorption capacity, thereby reducing photon flux across all photosynthetically active wavelengths in the 400-700 nm (PAR) spectrum, which in turn suppresses physiological processes and weed development (Bilalis, 2010).

Additional parameters were also observed on both tomato and

sunflower plants to assess the impact of intercropping and monocropping systems on pest and disease management. Findings revealed a higher incidence of pest and disease infestations in the monocropping system as opposed to the intercropping system (Table 3). Specifically, pests such as

Liriomyza huidobrensis, responsible for leaf miner disease, *Bemisia tabaci*, causing leaf curl disease and the caterpillar pest *Spodoptera litura* were identified as common threats to tomato.

Table 3. Pest and diseases attack

| Treatment | Plant | % total infection of all plants | | | |
|---------------|-----------|---------------------------------|----------------|-------------------|----------------------|
| | | Leaf miner | Bemisia tabaci | Spodoptera litura | Homeosoma electellum |
| Intercropping | Tomato | 50 | 25 | 0 | 0 |
| | Sunflower | 16.67 | 0 | 0 | 0 |
| Monocropping | Tomato | 50 | 25 | 0 | 0 |
| | Sunflower | 0 | 0 | 16.67 | 8.33 |

Among all the tomato plants observed, the incidence of infestation by the leaf miner disease-causing pest *Liriomyza huidobrensis*, was higher in monocropping tomato plants compared to those in intercropping plots. Conversely, infestation by the pest *Bemisia tabaci* showed similar percentages in both monocropping and intercropping tomato plants. Caterpillar pests *Spodoptera litura* and *Homeosoma electellum* were exclusively detected on sunflowers. In monocropping sunflower plots, the incidence of *S. litura* and *H. electellum* caterpillar infestations was greater than in intercropping sunflower plots. This phenomenon is believed to result from the partitioning of populations between the main crop and companion plants. Population partitioning reduces the intensity of pest attacks on the main crop through the transmission of visual and chemical signals that alter insect behavior (González-Chang et al., 2019). Consequently, it is believed that the concurrent cultivation of tomato and sunflower plants in an intercropping system may reduce the incidence of caterpillar infestations on sunflower plants. Additionally, beneficial insects like various bee species acting as pollinators and natural pest predators such as coleoptera, dragonflies, and spiders were frequently observed on sunflowers in both intercropping and monocropping systems.

Furthermore, intercropping settings create physical barriers that impede pest movement between plants and offer floral resources

that attract natural enemies of pests (Smith and McSorley, 2000). Similar findings were reported by Degri and Samaila (2014) in the context of tomato-corn intercropping systems. The plant partitions established by the tomato-corn intercropping system were effective in reducing the population of the *Helicoverpa armigera* borer pest on tomatoes compared to monocropping systems. This reduction is attributed to changes in the microclimate of the plant canopy, increased plant diversity, and greater spacing between similar plants. Consequently, the partitions created by corn plants effectively limit the spread of borer pests on tomato plants. In this study, sunflower plants serve a similar role.

Plant growth parameters

Based on the independent samples T test analysis, plant height (0.681>0.01), fresh weight (0.083>0.01) and total chlorophyll (0.104>0.01) of tomato plant in the intercropping and monocropping systems were not significantly different. The average of all tomato plant growth parameters in the intercropping system is higher compared to monocropping (Table 4).

Table 4. Growth parameter of tomato plant

| Treatment | Growth Parameter | | |
|---------------|-----------------------------|-----------------------------|-------------------------|
| | Plant height (cm) | Fresh weight (g) | Chlorophyll (mg/mL) |
| Intercropping | 143.33 ± 23.39 ^a | 168.67± 25.36 ^a | 1.71 ±1.76 ^a |
| Monocropping | 139.17 ± 18.15 ^a | 123.08 ± 20.83 ^a | 0.69±0.24 ^a |

Parameters of plant height and total chlorophyll of sunflower plants in the intercropping system are higher than those in the monocropping system, while the fresh weight of plants in the intercropping system is lower because sunflower plants in the

intercropping system have thin stems and leaves that are much smaller than sunflower in monocropping (Table 5).

Table 5. Growth parameter of sunflower plant

| Treatment | Growth parameter | | |
|---------------|-----------------------------|-----------------------------|-------------------------|
| | Plant height (cm) | Fresh weight (g) | Chlorophyll (mg/L) |
| Intercropping | 138.17 ± 19.27 ^a | 150.5 ± 19.38 ^a | 2.43 ± 2.3 ^a |
| Monocropping | 132.5 ± 9.98 ^a | 155.17 ± 29.13 ^a | 1.15 ± 0.8 ^a |

The sunflower-tomato intercropping system results in tomato plants exhibiting higher average values for vegetative growth parameters such as fresh weight, plant height, and total chlorophyll compared to the monocropping system. This outcome is attributed to the interspecific competition effects observed in the intercropping system. The observed root structures of tomato plants reveal numerous and long lateral roots with a branched and fibrous tap root system, whereas sunflowers possess fewer lateral roots with a single large tap root. Consequently, it is presumed that tomato plants have a higher nutrient absorption capacity compared to sunflowers, thereby facilitating better growth of the tomato plants.

The vegetative growth parameters of tomato plants, including fresh weight, plant height, and total chlorophyll (Table 5), demonstrated higher average values in the intercropping system compared to the monocropping system. This phenomenon is believed to be influenced by the interspecific competition occurring within the intercropping system. Similar results were reported by Cunha-Chiamolera (2017) in an intercropping system of tomatoes with lettuce. Tomatoes exhibit better tolerance and nutrient absorption than lettuce, thus enhancing nutrient absorption efficiency and preventing reduced lettuce yields.

In the monocropping system, tomato leaves experienced a faster period of senescence and drying compared to the intercropping system by week 12. This is attributed to high exposure to direct sunlight, which accelerates leaf senescence, resulting in lower total chlorophyll levels in both tomato and sunflower plants. Consequently, the total chlorophyll in the intercropping system is higher than in the monocropping system. El-Mehy and Mohamed (2018) reported similar findings in a tomato-maize intercropping system, where reduced leaf aging of tomatoes and increased ear leaf area of maize were observed due to optimal shading on the soil surface. Additionally, shading by rows of maize plants can stimulate internode growth and plant height, thereby increasing the wet weight and dry weight of the plants.

Plant Productivity Parameters

According to the T-test results, the number of tomato fruits, diameter, and fruit weight did not exhibit a significant difference between the two systems (Table 6). However, tomatoes in the monocropping system produced more fruit with larger sizes and weights.

Table 6. Tomato plant productivity

| Treatment | Number/plant | Fruit parameter | | |
|---------------|--------------------------|--------------------------|----------------------------|-------------|
| | | Diameter (cm) | Weight (g) | Cracked (%) |
| Intercropping | 5.67 ± 3.56 ^a | 3.45 ± 0.69 ^a | 24.91 ± 13.10 ^a | 2.9 |
| Monocropping | 7.4 ± 5.9 ^a | 3.81 ± 0.55 ^a | 24.91 ± 13.10 ^a | 12 |

Additionally, based on morphological observations, tomatoes in the monocropping system tend to have an oval shape, whereas those in the intercropping system tend to have a rounded shape (Figure 2).



Figure 2. Harvested tomatoes (a) and (b) monocropping (c) and (d) intercropping.

Based on the Mann-Whitney test results, there was no significant difference between the number of flowers and the diameter of sunflowers per individual plant in the two cropping

systems. However, the yield per individual in the intercropping system was significantly different from the monocropping system (Table 7).

Table 7. Sunflower plant productivity

| Treatment | Flower parameter | | |
|---------------|--------------------------|---------------------------|----------------------------|
| | Number /plant | diameter (cm) | Weight (g) /plant |
| Intercropping | 1 ± 0 ^a | 12.99 ± 1.60 ^a | 12.17 ± 1.17 ^a |
| Monocropping | 1.17 ± 0.58 ^a | 13.52 ± 1.44 ^a | 21.00 ± 14.57 ^b |

The sunflower and tomato intercropping system effectively creates an optimal canopy, inhibiting excessive sunlight and reducing the occurrence of tomato fruit cracking. According to Jones (2002), tomato fruit cracking is caused by high differences in day and night temperatures and rapid water absorption during fruit ripening, which reduces the elasticity of the fruit exocarp (outer skin).

Evaluation of Competitive Intensity Result

The relationship between the yield obtained and intraspecific competition between sunflower plants and tomato plants in the intercropping system was evaluated by assessing the Land Equivalent Ratio (LER) ratio, aggressiveness values and competition ratios (Table 8).

Table 8. Yield evaluation

| Plant | Treatment | Yields (g/2400 cm ²) | Individual LER | LER | Aggressiveness | Competition Ratio |
|-----------|---------------|----------------------------------|----------------|-------|----------------|-------------------|
| Sunflower | Intercropping | 29 | 0.24 | 0.650 | -0.165 | 0.596 |
| | Monocropping | 119 | | | | |
| Tomato | Intercropping | 385 | 0.41 | | 0.165 | 1.677 |
| | Monocropping | 942 | | | | |

The resulting LER ratio value of 0.650 in sunflower-tomato intercropping shows that plant productivity using the intercropping system reaches 65% of the yield from a single crop. A LER ratio of less than one means that productivity with a monocropping system is higher per unit area. The aggressiveness value and competition ratio in sunflower and tomato intercropping explain why this happens. Narwal and Malik (1985) also found similar results in various intercropping systems involving sunflowers and other plants, unless when the two plants were planted at different ages. Kestha & El-Baz (2004) stated that planting sunflowers when tomato plants have entered the flowering and fruiting phase can increase the LER value >1, while planting sunflowers when transplanting tomato plants results LER value <1.

The observations of intercropped sunflowers and tomatoes indicate that tomatoes dominate when associated with

sunflowers. This conclusion is based on the negative aggressiveness value obtained by sunflower plants (A = -0.165) and the positive aggressiveness value obtained by tomato plants (A = 0.165). Additionally, the plant aggressiveness is reinforced by the competition ratio results, which serve as indicators for evaluating the plant's ability to acquire resources both vertically and horizontally. The competition ratio for tomato yields (1.677) exceeds the ratio for sunflower (0.596). Therefore, both the competition ratio and aggressiveness provide strong evidence of interspecific competition in the sunflower-tomato intercropping system, with tomato plants emerging as the strongest competitors in resource acquisition. Based on observations, tomato plants have many and long lateral roots with a branched and fibrous tap root structure (Jones 2007) while sunflower plants have fewer lateral roots with a single, large tap root structure (Gregory 2006). Thus, the absorption of nutrients in tomato plants

is thought to be higher than in sunflower plants.

Based on the results of a comprehensive evaluation, the recommendation that can be given is to pay attention to the difference in age of the two plants in the intercropping system and use inappropriate planting distances so as to minimize overlapping root systems but still accommodate the ability of sunflower plants as living mulch to inhibit weed growth.

4. Conclusion

This study demonstrates that sunflowers can serve as effective companion plants for tomatoes in intercropping systems. However, simultaneous planting of both species increases interspecific competition, resulting in overall productivity reaching only 65% of monocropped yields. Tomatoes exhibited a higher aggressiveness index and competition ratio, indicating dominance in resource acquisition. Nevertheless, sunflower plants function efficiently as living mulch, substantially reducing weed growth. Future studies should investigate optimized planting intervals and spatial arrangements to minimize competition and maximize intercropping benefits.

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