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# BREEDING OF LOCAL GARLIC *(Allium sativum L.)* VARIETIES USING THE CHEMICAL MUTAGEN SODIUM AZIDE

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***ABSTRACT***

*The demand for garlic in Indonesia continues to rise annually; however, the market remains dominated by imported garlic due to its larger bulb size compared to local varieties. One approach to improving the quality of local garlic is through mutation breeding using chemical mutagens such as sodium azide. This study aimed to evaluate the effects of sodium azide on morphological traits, stomatal index, and chlorophyll a and b content in local garlic (Allium sativum L.). The experiment was conducted using a Randomized Block Design (RBD) with a single treatment factor, sodium azide concentrations of 0.1%, 0.2%, 0.3%, and 0.4%. Observations revealed that the 0.4% concentration produced the best performance in plant height (24.20 cm), number of leaves (3.40), leaf length (22.10 cm), and leaf width (2.60 cm). The highest stomatal index (0.35) was also observed at this concentration. In contrast, the longest root length (2.320 cm) and highest fresh weight (0.8040 g) were found at the 0.3% concentration. The highest chlorophyll a and b content was recorded at the 0.1% concentration. These findings indicate that sodium azide induces significant variation in plant traits. Therefore, chemical mutagenesis is recommended as a promising breeding strategy to develop superior and competitive local garlic varieties.*

**Keywords**: *Mutation Breeding, Sodium Azide, Allium Sativum, Morphological Traits*

## INTRODUCTION

Indonesia is known as a country with an agrarian-based economy, where the majority of the population still relies on the agricultural sector and natural resource management for their livelihood (Sujana, 2020). Within this sector, agriculture not only supports the basic needs of the population by providing food, but also serves as a pillar of economic resilience, especially in the face of global fluctuations. As the population continues to grow each year, the demand for food commodities has also increased significantly (Aryawati, 2018). This puts pressure on agricultural productivity, including horticultural commodities such as garlic. Garlic (*Allium sativum L.*) is one of the most widely consumed horticultural crops in Indonesia, commonly used as a flavoring and taste enhancer in various traditional and modern dishes (Fadila & Respatijarti, 2018). Unfortunately, national garlic production is still unable to meet domestic demand. Data from the Ministry of Agriculture of the Republic of Indonesia shows that garlic consumption has increased by approximately 1.38% annually during the 2020–2024 period, while domestic production can only supply less than 10% of total national consumption (Dihni, 2022). This imbalance has led to a high dependence on imports, particularly from China.

One of the factors contributing to the low productivity of local garlic is its uncompetitive morphological characteristics. Small clove size, relatively long harvesting period, and low yield per hectare discourage farmers from planting local varieties (Bani et al., 2022). On the other hand, local garlic has advantages in terms of taste and aroma, which are stronger and more distinctive compared to imported garlic, giving it potential competitiveness from an organoleptic quality perspective (Bani, 2022). To enhance the competitiveness of local varieties, innovations in plant breeding are needed,

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one of which is through mutation induction approaches. Mutation induction is a technique used to create new genetic diversity by altering the DNA structure of plants, either through physical agents such as radiation or chemical agents such as mutagens (Husain, 2022). One commonly used chemical mutagen is sodium azide ($NaN_3$), due to its effectiveness in inducing mutations without causing severe damage to plant chromosomes and tissues (Nurhidayah, 2017; Amin et al., 2006).

Sodium azide works by modifying nitrogenous bases in DNA, causing genetic changes that can lead to desirable phenotypic variations. These mutations can be observed in various aspects of plant growth, such as plant height, number of leaves, root length, photosynthesis efficiency, and chlorophyll content (Marcu et al., 2013; Afify et al., 2011). This effect is highly promising for improving the agronomic performance of vegetatively propagated crops like garlic, which typically have low genetic diversity (Mensah et al., 2005). This study was conducted to evaluate the effects of sodium azide application on various important growth parameters in local garlic, including morphology, stomatal index, and chlorophyll a and b content. The results of this study are expected to offer an alternative strategy for improving the quality of local seed stock through mutation breeding technology, while also contributing to the expansion of genetic diversity in garlic varieties in Indonesia.

## RESEARCH METHODOLOGY

This study used a one-factor Randomized Complete Block Design (RCBD) to evaluate the effect of different concentrations of the chemical mutagen sodium azide ($NaN_3$) on local garlic (*Allium sativum L.*). The treatment factor consisted of four sodium azide concentrations: 0.1%, 0.2%, 0.3%, and 0.4%. Each concentration was replicated five times, resulting in a total of 20 experimental units. The research was conducted over six months, from January to June 2024. Cultivation and plant character observations were carried out in Baturiti Village, Tabanan Regency, while stomatal and chlorophyll analyses were conducted at the Basic Laboratory of Dhyana Pura University and the Integrated Service Laboratory of the Faculty of Agricultural Technology, Udayana University.

### Preparation of Materials and Mutagen Solution

Local garlic cloves were first soaked in distilled water (aquadest) for 6 hours for initial hydration, followed by immersion in sodium azide solution at the designated concentrations for 4 hours. After soaking, the cloves were rinsed with clean water and then soaked again in distilled water for 30 minutes, followed by two rinses to remove any residual mutagen solution (Sari, 2015). The solution formulation followed the procedure of Fazilatul (2023), where sodium azide and ethanol were mixed into distilled water to obtain a homogeneous mutagen solution.

### Nursery and Maintenance

The treated garlic cloves were sown in 20x10 cm polybags filled with sterilized soil media. During the growth period, watering was done twice a day (morning and evening), and liquid fertilizer along with botanical insecticides was applied weekly to support plant growth and protection (Fadila & Respatijarti, 2018).

### Observation of Plant Morphology

Morphological parameters observed included time of shoot emergence, plant height, number of leaves, leaf length and width, number and length of roots, fresh bulb weight, as well as visual descriptions of bulbs and leaves. Measurements were taken in the 11th week after planting. Leaf and bulb colors were identified using the RHS Colour Chart as the standard color reference (Friska, 2017).

### Stomatal Observation

The stomatal index was calculated using the stomatal impression method, in which the lower leaf surface (abaxial) was coated with a clear acetone-based nail polish. Once dried, clear adhesive tape was used to lift the epidermal imprint. The imprint was mounted on a microscope slide and observed under a light microscope (Fauziah, 2019).

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The stomatal index was calculated according to the formula by Pharmawati (2015):

$$\text{Stomatal Index: } \frac{S}{(S + E)}$$

Where:

- I = Stomatal index
- S = Number of stomata
- E = Number of epidermal cells

**Chlorophyll Content Analysis**

The analysis of chlorophyll a and b levels was conducted using an extraction method with 96% alcohol. A total of 0.1 grams of leaf tissue (excluding leaf veins) was crushed using a mortar, mixed with alcohol, and filtered. The filtrate was placed into a cuvette, and its absorbance was measured using a UV Spectrophotometer to determine the chlorophyll concentration (Amrullah, 2019).

**RESULTS AND DISCUSSION**

**Morphological Characteristics**

Observations of early sprout growth in garlic showed that treatment with sodium azide concentrations of 0.4% and 0.3% induced earlier shoot emergence, occurring on the 4th day after planting. In contrast, shoots in the control plants (without mutagen treatment) appeared later, as shown in Figure 1. This phenomenon indicates that chemical mutagen application can accelerate the shoot initiation process. According to Mutmainnah (2016), this accelerated growth is suspected to be related to the influence of mutagens on the activity of the plant's endogenous hormones. Sodium azide may trigger physiological changes that affect the balance of hormones such as auxin and cytokinin, which play a key role in stimulating cell division and shoot growth. Variations in plant response may also be due to natural differences in endogenous hormone content among individual plants, causing the response to mutagen treatment to vary depending on each explant's sensitivity level to sodium azide.

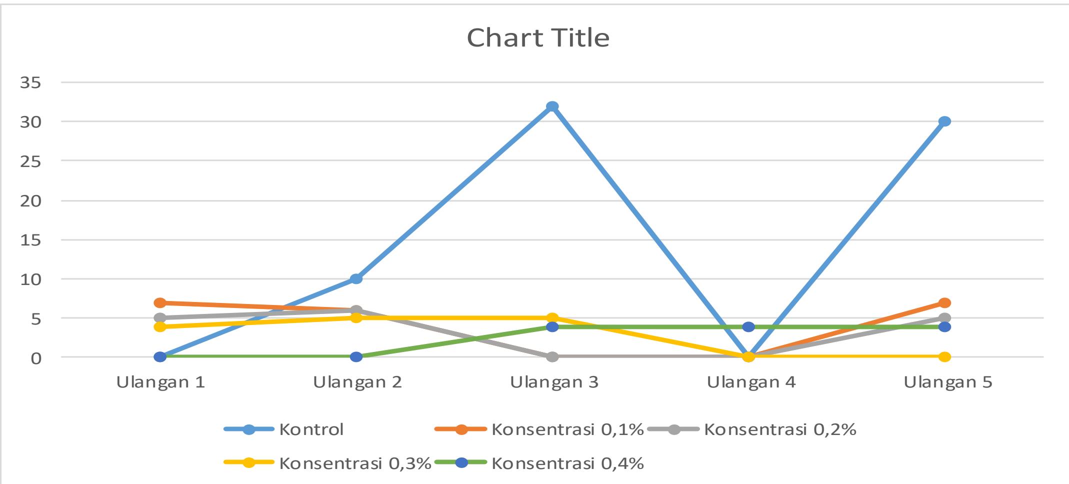


Figure 1. Days of Shoot Emergence

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Based on the application of chemical mutagens, it was proven that the early growth process of garlic plants was influenced, as indicated by the fastest growth rate in the highest concentration treatment (0.4%). This treatment accelerated shoot initiation compared to lower concentrations. This is supported by Randi (2015), who stated that without mutagen intervention, plant growth processes can significantly slow down or even fail to occur. This finding is consistent with the control treatment, where shoot emergence only began between days 10 and 32, which was much slower compared to the sodium azide treatments. The absence of a mutagen in the control group hindered the physiological activity needed for shoot initiation, resulting in suboptimal growth compared to the sodium azide-treated plants. A similar study by Endang (2017) on *M1* generation rice (variety "kulit manis") showed that a sodium azide concentration of 4.0 mM resulted in the highest germination rate (81.50%) during early observations, whereas 2.0 mM produced only 60.00%. This indicates that the effectiveness of a mutagen depends on the dosage used and that certain concentrations can significantly accelerate germination. However, excessively high doses may inhibit the biological and physiological activity of seeds, including enzyme activity, hormonal imbalances, and mitotic disturbances caused by disruptions in the cellular respiration chain. Sodium azide contains azide anions, which are strong inhibitors of cytochrome oxidase enzymes, disrupting oxidative phosphorylation and inhibiting energy metabolism (Endang, 2017).

Differences in shoot emergence timing and plant mortality rates are likely influenced by the physiological capacity of cells in the explant tissue following mutagenic treatment. Internal factors such as genetic variation and the sensitivity of meristematic cells to mutation largely determine how explants respond to treatment. Each meristem cell has regenerative potential to form shoots, but mutagen effects may cause uneven physiological changes depending on the stability and resilience of the cells under chemical stress. This is explained by Qosim (2019) as an individual genotypic response that determines the success of shoot regeneration. In addition to genetic factors, environmental influences (external factors) also play a role in vegetative plant growth. Variables such as sunlight intensity, water availability, nutrients, temperature, and humidity affect key physiological processes like photosynthesis and transpiration. According to Vinanda (2020), light is one of the dominant factors in stimulating vegetative growth, as it directly affects photosynthetic efficiency, which ultimately influences shoot growth rate and overall plant development.

**The Mutagenic Effect of Sodium Azide on Garlic Growth**

Sodium azide ($NaN_3$) is one of the effective chemical mutagens used to increase plant genetic diversity through mutation induction. The use of $NaN_3$ in garlic has shown significant effects on various growth parameters. Research by Mahajan et al. (2015) demonstrated that treatment of garlic variety G-41 with 0.01% $NaN_3$ for 12 hours resulted in optimal plant growth compared to higher concentrations. At concentrations of 0.04% and 0.08%, there was a decline in plant height and leaf number, as well as increased plant mortality. Concentrations of 0.10% and above even caused total plant death. Another study by Türkoğlu et al. (2022) on wheat indicated that $NaN_3$ can cause genomic instability and polymorphisms, showing high mutagenic potential. However, these effects are highly dependent on the concentration and duration of treatment. In the context of garlic, using $NaN_3$ as a mutagen can accelerate shoot initiation and increase genetic variation, which is crucial for plant breeding programs. However, it is essential to determine the appropriate dosage to avoid harmful toxic effects. The use of sodium azide as a chemical mutagen in garlic can enhance genetic diversity and accelerate shoot growth, but its effectiveness depends heavily on treatment concentration and duration. Excessively high concentrations can cause toxicity and plant death. Therefore, determining the correct dosage is critical in the application of mutagenesis for garlic plant breeding.

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Table 1. Morphological Analysis Results of Garlic Plants

| Treatment Concentration | Plant Height | Number of Leaves | Leaf Length | Leaf Width | Number of Roots | Root Length |
|---|---|---|---|---|---|---|
| Control | 14,34[a] | 2,00[a] | 12,60[a] | 0,94[a] | **11,60[a]** | 1,920[a] |
| 0,1% | 21,70[a] | 2,60[a] | 19,94[a] | 1,64[a] | 5,40[a] | 1,180[a] |
| 0,2% | 22,28[a] | 2,80[a] | 20,28[a] | 1,90[a] | 10,80[a] | 1,560[a] |
| 0,3% | 22,40[a] | 3,20[a] | 20,40[a] | 2,32 [a] | **11,60[a]** | **2,320[a]** |
| 0,4% | **24,20[a]** | **3,40[a]** | **22,10[a]** | **2,60[a]** | **11,60[a]** | 2,220[a] |

Note: Different letter notations in the same column indicate significant differences ($P < 0.05$).

The morphological analysis results of local garlic presented in Table 1 show varying plant responses to the application of sodium azide mutagen at different concentrations. In general, morphological parameters of the upper plant parts, such as plant height, number of leaves, leaf length, and leaf width experienced significant increases under sodium azide treatments, with the 0.4% concentration yielding the most optimal results (Nurhidayah, 2017; Sari, 2015; Fajriyah, 2019). This increase is assumed to result from the activity of sodium azide as a mutagenic agent stimulating the production of plant growth hormones, especially auxin. This hormone is known to play a key role in cell division, tissue elongation, and vegetative organ formation (Sari, 2022; Viana, 2019). Similar findings were reported by Nurhidayah (2017) in rice, and by Sari (2015, 2022) in chili and tomato plants, showing that chemical mutation treatments can accelerate growth and increase the size of vegetative organs compared to control plants.

Sodium azide has been proven to enhance plant genetic diversity through the induction of positive mutations, thereby accelerating the selection of superior traits in the plant breeding process (Fajriyah, 2019; Viana, 2019). However, a negative response was detected in root system parameters. Although the number of roots did not differ significantly from the control, root length tended to decrease in the 0.1%, 0.2%, and 0.4% treatments, indicating signs of physiological stress due to sodium azide toxicity (Mshembula, 2017). This phenomenon is likely related to disturbances in enzymatic activity and inhibition of cell mitosis in root tissues, leading to slower development of the plant's lower organs (Endang, 2017). Therefore, the use of sodium azide as a mutagen must be applied carefully with optimal dose adjustments to ensure that the improvement of above-ground plant parts does not come at the expense of root health or the overall root system (Sari, 2022).

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Table 2. Average Fresh Weight of Garlic Plants

| Treatment Concentration | Average Fresh Weight Results |
|---|---|
| Control | 0,6060[a] |
| 0,1% | 0,4300[a] |
| 0,2% | 0,3320[a] |
| 0,3% | **0,8040**[a] |
| 0,4% | 0,6680[a] |

Note: Different letter notations in the same column indicate significant differences (P < 0.05).

The analysis of fresh weight in local garlic plants showed that sodium azide treatment at concentrations ranging from 0.1% to 0.4% did not result in statistically significant differences compared to the control. Interestingly, the highest average value was observed at the 0.3% concentration (0.8040 grams), but further analysis using Duncan's test at a 5% significance level indicated that the difference was not statistically meaningful (Husain, 2021). Although sodium azide demonstrated significant effects on morphological aspects such as plant height, leaf length, and number of leaves, the fresh weight parameter did not follow the same trend. This indicates that phenotypic transformation in vegetative organs is not necessarily accompanied by an increase in fresh biomass (Sari et al., 2015). The decrease or non-significant changes in fresh biomass are most likely related to the physiological effects of the mutagen that disrupt the plant's metabolism (Kharde, 2017). Sodium azide is known to act as a mutagen by inducing point mutations in DNA, but not all resulting genetic changes are beneficial from an agronomic perspective (Girija, 2019). Random mutations can disrupt the expression of genes responsible for cellular respiration and energy metabolism, such as ATP synthesis, which directly impacts biomass accumulation (Kharde, 2017; Girija, 2019). A reduction in fresh weight may also result from impaired photosynthesis and respiration, which are essential for the formation of new tissues (Nurhidayah, 2017).

Nurhidayah (2017) reported that at high concentrations, sodium azide is toxic because it can inhibit mitochondrial enzymes such as cytochrome oxidase. This enzyme is crucial for oxidative phosphorylation, and when inhibited, the plant's ability to generate energy through aerobic respiration becomes compromised. As a result, biomass growth is suboptimal, even if other growth parameters show improvement. Furthermore, visual observations using the RHS Colour Chart (2017) indicated phenotypic variations in leaf color and bulb shape across different treatments. These changes may be due to disruptions in the expression of genes regulating pigment biosynthesis, such as chlorophyll, anthocyanins, or carotenoids, which are often indicators of physiological stress from mutagen exposure (Girija, 2019). Darker leaf colors or changes in surface glossiness in plants treated with mutagens also suggest a decrease in photosynthetic efficiency and plant adaptation to stress (Kharde, 2017).

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Table 3. Plant Characterization Results

| Treatment Concentration | Bulb Shape | **Bulb Color** | Leaf Color |
|---|---|---|---|
| Control | Oval | 156C (*Linen*) | 140A (*Forest green*) |
| 0,1% | Oval | 155D (*Antique white*) | 134A (*Dark green*) |
| 0,2% | Oval | 155D (*Antique white*) | 140A (*Forest green*) |
| 0,3% | Round | 156D (*Linen*) | 140A (*Forest green*) |
| 0,4% | Oval | NN155C (*Beige*) | 140A (*Forest green*) |

Note: Different letter notations in the same column indicate significant differences (P < 0.05).

**Morphological Characterization and Stomatal Index of Garlic Plants**

The morphological characterization of garlic plants treated with sodium azide showed variations in bulb shape and color as well as leaf color, indicating mutagenic effects on phenotypic gene expression. The 0.3% concentration treatment resulted in round bulb shapes and consistently dark green leaf color (RHS code 140A), differing from the control and other treatments, which mostly produced oval bulbs (RHS, 2017). This change in shape suggests a possible mutation in genes regulating cell division in the bulb tissues (Girija, 2019). Changes in bulb color, such as turning beige (NN155C) or antique white (155D), indicate potential alterations in pigment and phenolic compound synthesis, which may also reflect adaptations to mutagenic stress (Kharde, 2017). Furthermore, the stomatal index observations indicated that sodium azide at a concentration of 0.3% produced the highest stomatal index value. This suggests that at an optimal dose, the mutagen can increase stomatal density, contributing to the plant's physiological efficiency in $CO_2$ uptake and photosynthesis (Taiz & Zeiger, 2010; Pharmawati, 2015). However, increasing the mutagen concentration to 0.4% resulted in a decrease in the index, possibly due to toxic effects that reduced epidermal cell division and stomatal size (Setyowati, 2015).

Setyowati (2015) emphasized that mutations can enlarge stomatal size, but this often leads to a reduced stomatal density per unit leaf area, thereby decreasing the stomatal index. This phenomenon is frequently observed in plants that have undergone polyploid mutation. In the context of this study, variations in the stomatal index also correlated with the time of observation. Anni et al. (2018) showed that observations made in the morning, as light intensity begins to rise, will show more stomata in an open state. This stomatal response to light allows increased photosynthesis when plants are in optimal conditions. Cambaba et al. (2019, 2022) added that stomatal density and activity are strongly influenced by environmental factors such as temperature and humidity. High stomatal density can accelerate transpiration rates and $CO_2$ uptake; however, if not accompanied by efficient water regulation, plants may experience water stress. Therefore, mutations that can regulate the stomatal index to an optimal level—not too high

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or too low—will be an added value in mutation-based breeding programs (Pharmawati, 2015).

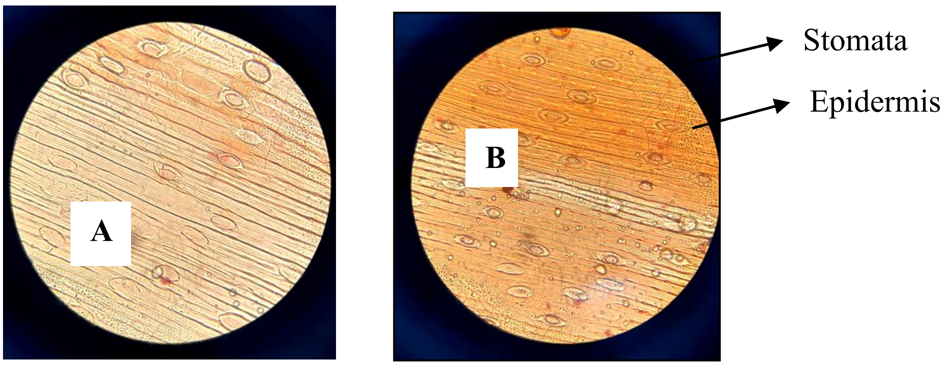
**Stomatal Index**

The analysis of the stomatal index showed that treatment with sodium azide at various concentrations did not result in statistically significant differences in the stomatal index values of garlic plants. However, the treatment with a 0.3% concentration showed the highest average stomatal index compared to the other treatments, as listed in Table 4. A higher stomatal index reflects an increase in stomatal density on the leaf surface, which physiologically may accelerate the plant's transpiration rate. Leaf sampling for stomatal observations was conducted in the morning between 09:00 and 10:00 WITA, a time when stomata tend to be open. This is due to the relatively low light intensity in the morning, which has not yet triggered the plant's active stomatal closure mechanisms.

Table 4. Average Stomatal Index Results

| Treatment Concentration | Average Stomatal Index |
|---|---|
| Control | 0,334[a] |
| 0,1% | 0,342[a] |
| 0,2% | 0,329[a] |
| 0,3% | **0,349[a]** |
| 0,4% | 0,341[a] |

Note: Different letter notations in the same column indicate significant differences (P < 0.05).



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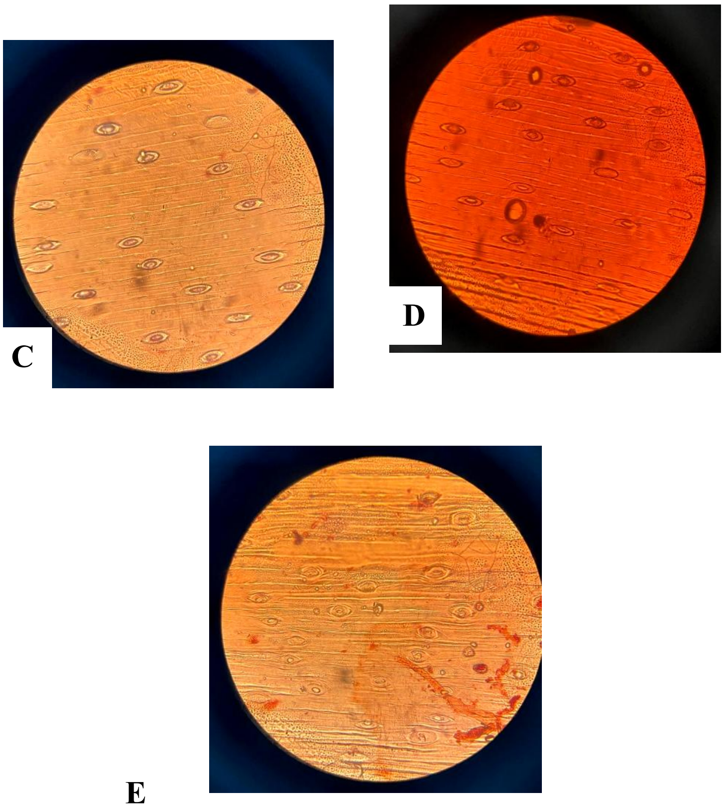


Figure 2. Stomatal Index Results.
Description: A. Control, B. 0.1% Concentration, C. 0.2% Concentration, D. 0.3% Concentration, E. 0.4% Concentration
Source: Personal Documentation

Observations of the stomatal index in garlic plants showed that sodium azide treatments at different concentrations did not produce a statistically significant effect on the average stomatal index (see Table 4). However, the treatment with a 0.3% concentration yielded the highest average value (0.349), while the lowest value was found at the 0.2% concentration (0.329), which was even lower than the control (0.334). This indicates a fluctuating physiological response of the plant to sodium azide mutagen, particularly in its effect on stomatal density (Pharmawati, 2015). Stomata are important epidermal structures in the form of pores controlled by two guard cells, functioning in the regulation of transpiration and photosynthesis (Izza et al., 2015; Taiz & Zeiger, 2010). Changes in the stomatal index can serve as an indirect indicator of ploidy level alterations or physiological conditions resulting from mutagenic treatment (Setyowati, 2015). A higher stomatal index means more stomata per unit leaf area, which can enhance transpiration and the efficiency of gas exchange ($CO_2$ and $O_2$) during photosynthesis.

Pharmawati (2015), in her study on garlic plants, showed that high concentrations of colchicine significantly reduced the stomatal index compared to the control. A similar phenomenon was observed in this study, where treatment with a high concentration of sodium azide (0.4%) produced a lower index than the moderate concentration (0.3%). This finding supports the hypothesis that optimal mutagen concentrations can improve or stimulate physiological traits, while excessive doses may be toxic. Setyowati (2015) emphasized an inverse relationship between stomatal size and density. Chemical-induced mutations can enlarge stomatal size, which in turn leads to a decrease in the index. Therefore, the higher average stomatal index at the 0.3% concentration may be associated with smaller stomatal size and higher density.

Stomatal observations were conducted in the morning between 09:00 and 10:00 WITA, when light intensity was still low and the stomata were generally open. This is consistent with the findings of Cambaba et al. (2019), who reported that in *Syzygium oleina* (red shoot) plants, the highest number of open stomata was recorded at 08:00 a.m., with a drastic decrease occurring at midday due to increased temperature and light intensity. Cambaba (2022) further explained that environmental factors such as temperature, light, and water availability greatly influence the daily rhythm of stomatal opening and closing. Based on these findings, it can be concluded that sodium azide mutagen concentration affects the stomatal index in a fluctuating manner, with 0.3% as the optimal point. However, the lack of a statistically significant effect suggests that external factors and the plant's physiological interactions also influence stomatal responses.

**Chlorophyll A and B Analysis**

Table 5. Results of Chlorophyll A and B Analysis

| Treatment Concentration | Chlorophyll A (mg/L) | Chlorophyll B (mg/L) |
|---|---|---|
| Control | 600,8818 | 328,646 |
| 0,1% | **839,8024** | **392,562** |
| 0,2% | 714,9737 | 325,880 |
| 0,3% | 603,6393 | 277,375 |
| 0,4% | 457,7534 | 228,135 |

Note: Different letter notations in the same column indicate significant differences (P < 0.05).

**Chlorophyll Content Analysis Results**

The analysis of chlorophyll content in garlic leaves showed that the application of sodium azide mutagen significantly affected chlorophyll A and B levels. Treatment with a 0.1% concentration resulted in the highest chlorophyll A content at 839.80 mg/L and chlorophyll B at 392.56 mg/L, indicating stimulation of photosynthetic pigment biosynthesis at low concentrations (Novitasari, 2023). Conversely, a 0.4% concentration showed a significant decline, with chlorophyll A levels at only 457.75 mg/L and chlorophyll B at 228.13 mg/L, indicating toxic effects of the mutagen at high concentrations (Dahot, 2017). Correlation analysis between the two types of chlorophyll showed a strong relationship, with a Pearson value of 0.939 (p = 0.018), suggesting that an increase in chlorophyll A is generally followed by an increase in chlorophyll B, and vice versa. This confirms a metabolic link between the two pigments in the plant photosynthetic system (Rahmawati, 2018).

According to Novitasari (2023), colchicine treatment in garlic at appropriate doses can increase chlorophyll levels depending on the variety and growth stage. Chemical mutations are known to modify gene expression involved in chlorophyll biosynthesis pathways, thereby enhancing pigment synthesis to a certain extent. However, these results are not universal. Dahot (2017) reported that sodium azide significantly reduced chlorophyll levels, especially in legumes, showing susceptibility to oxidative stress due to mutation. Meanwhile, Gnanamurthy (2015) stated that sodium azide was ineffective in increasing chlorophyll levels, although it had a positive effect on other metabolite contents such as protein and reducing sugars. The distribution of chlorophyll A and B in plant tissues is physiological and functionally distinct. Chlorophyll A is the primary pigment in photosynthesis and

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tends to dominate in older leaf tissues, while chlorophyll B acts as an accessory pigment that aids in light absorption at specific wavelengths and is more abundant in young leaves (Rahmawati, 2018). The decrease in chlorophyll content in high-concentration sodium azide treatment is likely triggered by disruptions in chlorophyll biosynthesis enzyme activity, oxidative stress, or adaptive mechanisms of the plant to environmental pressure (Amrullah, 2019). Additionally, chlorophyll content is strongly influenced by environmental factors such as light intensity, temperature, humidity, and water availability. Under environmental stress conditions like drought, plants tend to reduce chlorophyll content to lower energy and water consumption, which directly affects photosynthesis efficiency and growth (Amrullah, 2019).

## CONCLUSIONS AND RECOMMENDATIONS

Based on the research findings, it can be concluded that the application of sodium azide mutagen at concentrations of 0.1%, 0.2%, 0.3%, and 0.4% had an effect on the morphological and physiological growth characteristics of garlic plants, although not all parameters showed significant differences compared to the control. The best morphological treatment was observed at the 0.4% concentration, which resulted in the highest plant height, number of leaves, leaf length, and width, while the longest root and highest fresh weight were achieved at the 0.3% concentration. On the other hand, the stomatal index did not show significant differences among treatments, with the highest value at 0.4% and the lowest at 0.2%. The analysis of chlorophyll a and b content showed that the 0.1% concentration resulted in the highest chlorophyll levels, while the 0.4% concentration significantly decreased chlorophyll content. These findings indicate that the use of chemical mutagens like sodium azide can selectively influence garlic plant growth depending on the concentration used. The novelty of this study lies in its application to vegetative crops such as garlic, which have been relatively understudied in the context of chemical mutagenesis. It also provides preliminary information on the potential of sodium azide to enhance genetic variability and initial morphological traits for plant breeding purposes. To obtain more significant and applicable results, it is recommended that future research explore sodium azide concentrations higher than 0.4%, while still considering the safety threshold for plants. Furthermore, observation of the next generation is strongly advised to evaluate the stability of mutated traits, along with molecular testing and other agronomic parameters such as the number and size of bulbs, to support the development of superior garlic varieties more comprehensively.

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# EFFECTIVENESS OF CITRONELLA (CYMBOPOGON NARDUS) EXTRACT IN CONTROLLING PESTS AND DISEASES ON SURI 4 SORGHUM IN THE DRYLANDS OF NORTH CENTRAL TIMOR

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*Sorghum variety Suri 4 is an alternative food crop known for its adaptability to dryland conditions. However, its productivity is often constrained by pest and disease infestations. Lemongrass (Cymbopogon nardus) contains natural active compounds with potential as an environmentally friendly botanical pesticide. This study aims to examine the effects of various concentrations and application frequencies of lemongrass leaf extract on the growth, yield, and levels of pest and disease incidence in Suri 4 sorghum. The research was conducted in Lapeom Village, Insana Barat Subdistrict, North Central Timor Regency, using a two-factor Randomized Block Design (RBD). The first factor was extract concentration (0, 50, 75, and 100 g/l), and the second was spraying frequency (3, 5, and 7 times), resulting in 36 experimental units. Data were analyzed using analysis of variance (ANOVA), followed by Duncan's Multiple Range Test (DMRT) at a 5% significance level. The results indicated that the application of 100 g/l lemongrass extract combined with seven sprayings yielded the best performance in enhancing plant growth and sorghum yield, while effectively reducing aphid infestation and leaf spot disease incidence. Thus, lemongrass extract is recommended as a biological control strategy in sorghum cultivation under dryland conditions.*

***Keywords***: Botanical Pesticide, Cymbopogon Nardus, Pest Control, Suri 4 Sorghum

## INTRODUCTION

Sorghum (*Sorghum bicolor* L.) is one of the cereal commodities that has been gaining attention due to its ability to grow in unfavorable environments such as dry areas with poor soil fertility (Putri, 2022). As a member of the Gramineae family, sorghum holds great potential for supporting food diversification in tropical and subtropical regions, especially as an alternative to rice in the face of climate change and food crises (Wahida et al., 2011). Its physiological advantages, such as efficient water use, drought tolerance, and adaptability to marginal lands, make sorghum suitable for development in areas like North Central Timor (TTU) Regency, East Nusa Tenggara (BPS TTU, 2014). Despite its many advantages, sorghum productivity in TTU remains low, averaging around 1 ton per hectare per planting season, far below its maximum potential yield of 5–7 tons/ha (Nurhayati, 2011). This low productivity is caused by various factors, one of which is pest and disease attacks, including soil-borne diseases and major pests that damage the vegetative and generative phases of the crop (Suswanto et al., 2018).

One of the most detrimental diseases is root rot caused by the fungal pathogen *Rhizoctonia solani*, which can survive in the soil as sclerotia or dormant mycelia and infect the plant from the seedling to the generative stage (Endang, 2017). Infection by this fungus leads to root tissue damage, characterized by wilting, stunted growth, chlorosis, and even death (Nurhayati, 2011). This pathogen is difficult to control due to its complex life cycle and long survival in the soil without a host (Suswanto et al., 2018). In addition to diseases, *Spodoptera frugiperda* (fall armyworm) poses a serious threat due to its ability to attack more than 100 plant species, including sorghum, maize, and rice

(Sharanabasappa et al., 2018). This polyphagous pest has a short life cycle, and a single female can lay 1,500–2,000 eggs during her lifetime, enabling rapid population explosions (Deshmukh et al., 2021). Symptoms of attack include perforated leaves, damaged growing points, and ear damage, which directly reduce yields (Ganiger et al., 2018; Hruska, 2019). In addition, aphids (Aphididae) are also significant vectors of plant viruses. These pests damage plants by piercing and sucking plant sap, disrupting growth and spreading viruses such as mosaic and yellowing viruses (Millatinassilmi, 2014; Pabbage et al., 2007). The combined attacks of pests and pathogens can accelerate crop damage and significantly reduce harvests (Saragih, 1994).

Synthetic pesticides such as Abamectin, Deltamethrin, and Beta-cyfluthrin remain the primary method of pest and disease control among farmers due to their practicality and immediate visible effects (Purwanto et al., 2009). However, long-term use of these pesticides can lead to pest resistance, population resurgence, soil and water contamination, and negative effects on human health and natural enemies (Ismail & Tenrirawe, 2011). Therefore, more sustainable and environmentally friendly pest control approaches are being developed, including the use of botanical pesticides derived from local plants (Orr & Suh, 2000). One promising plant for botanical pesticide production is citronella (*Cymbopogon nardus*). This plant is known for its essential oil content rich in active compounds such as citronellal, geraniol, and citronellol, which function as natural insecticides, repellents, and contact poisons against various pests (Susetyo et al., 2008; Bassolé & Juliani, 2011). These compounds disrupt insect nervous systems, inhibit feeding, or damage pest cell membranes (Anugrah, 2021). Research by Nopriansyah & Rustam (2023) demonstrated that citronella extract effectively reduced *Spodoptera exigua* populations in shallots, with a mortality rate of 77.5% at 100 g/L concentration. Anugrah (2021) also reported a repellency rate of up to 82% against *Tribolium castaneum*, a common postharvest pest. Moreover, Kotambunan et al. (2020) found that at a 40% concentration, citronella extract caused 93.3% larval mortality in *Crocidolomia pavonana*, a major cabbage pest.

In rice cultivation, botanical pesticides from citronella have also proven effective in reducing brown planthopper and grasshopper populations and improving vegetative growth (Telaumbanua et al., 2021). Additionally, Ningsih & Wahyuni (2016) found that citronella extract significantly killed black ants (*Dolichoderus thoracicus*), which are known as secondary pests in horticulture. The advantages of citronella-based botanical pesticides lie not only in their biological effectiveness but also in their eco-friendly nature, safety for humans, biodegradability, and affordability, as they can be locally produced (Bassolé et al., 2011). However, their effectiveness can be influenced by factors such as extract concentration, application timing, plant age, and microclimatic conditions in the field (Rahmawati, 2018). Therefore, further research is needed to determine the optimal dosage, stable formulation methods, and potential combinations with biocontrol agents such as *Trichoderma* spp. to synergistically control soil-borne pathogens like *Rhizoctonia solani* (Suswanto et al., 2018). If developed and widely applied, citronella-based botanical pesticides have the potential to become part of an integrated pest management (IPM) strategy aligned with the principles of sustainable agriculture in dryland areas like TTU and similar regions.

## RESEARCH METHOD

This study aimed to evaluate the effectiveness of plant-based extract from citronella (*Cymbopogon nardus*) in controlling pests and diseases in Suri 4 sorghum variety. To support the implementation of the experiment, several primary materials were used, including Suri 4 sorghum seeds as the test crop, citronella extract as the active botanical pesticide, and manure as an organic soil amendment. The research was conducted from December 2023 to April 2024 in Lapeom Village, Insana Subdistrict, North Central Timor Regency, East Nusa Tenggara Province. This location was

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selected as it represents a typical dry tropical area and has historically been a site of sorghum cultivation by local communities. The climate and soil characteristics at the site are well-suited to testing the adaptability of sorghum and the effectiveness of biological control treatments. This study employed an experimental method using a Randomized Complete Block Design (RCBD) with two treatment factors, each consisting of multiple levels:

- The first factor was citronella extract concentration, with four levels:
  - V0: No treatment (control, 0 grams of citronella extract per liter of water),
  - V1: 50 grams per liter of water,
  - V2: 75 grams per liter of water,
  - V3: 100 grams per liter of water.
- The second factor was the frequency of extract application, also with three levels:
  - K1: Spraying three times during the growth period,
  - K2: Spraying five times,
  - K3: Spraying seven times.

The combination of these two factors resulted in 12 treatment combinations (e.g., V0K1, V0K2, V0K3, ... up to V3K3). Each combination was replicated three times, and each block consisted of 12 experimental plots, resulting in a total of 36 plots.

**Observed Parameters**

- The study measured both morphological and physiological variables, including:
- Plant height (cm)
- Number of leaves per plant
- Panicle length (cm)
- Fresh and dry weight of panicles (grams)
- Number of grains per panicle
- Dry weight of grains per panicle (grams)

Two primary indicators were used to assess treatment effectiveness:

1. Pest attack intensity
2. Disease incidence on sorghum plants

Pest attack intensity was measured by calculating the percentage of plant parts infested compared to the total observed, as formulated by Syahrawati et al. (2009).

All collected data were analyzed using Analysis of Variance (ANOVA) to determine the significance of treatment effects on each variable. If significant differences were found, the results were further analyzed using Duncan's Multiple Range Test (DMRT) at a 5% confidence level. This statistical approach follows the methodology described by Gomes & Gomes (2010), which is commonly used in agronomic research to ensure the validity and reliability of experimental results.

## RESULTS AND DISCUSSION

### Plant Height (cm)

There was a significant interaction between citronella extract concentration and spraying frequency on the height of Suri 4 sorghum plants, particularly during the early growth phase observed at 14, 28, and 42 Days After Planting (DAP). This finding indicates that the effectiveness of treatment depends not only on the amount of extract applied but also on how frequently the solution is sprayed onto the plants. The treatment combination of 100 grams of citronella extract per liter of water with seven spray applications proved to be the most optimal in increasing plant height at all three observation intervals. It is presumed that the high concentration and more frequent application effectively suppressed pest populations (plant-disturbing organisms), allowing the plants to undergo faster and more stable vegetative growth.

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Table 1. Plant Height (cm)

| Observation Time | Lemongrass Extract Concentration (g/liter of water) | Spraying Frequency | | | Average |
|---|---|---|---|---|---|
| | | 3 times | 5 times | 7 times | |
| 14 DAP | Control | 18.44b | 21.34ab | 20.57ab | 20.12 |
| | 50 grams | 19.22ab | 19.44ab | 18.33b | 19.00 |
| | 75 grams | 19.56ab | 19.78ab | 20.11ab | 19.82 |
| | 100 grams | 20.89ab | 21.89a | 22.22a | 21.67 |
| | Average | 19.53 | 20.61 | 20.31 | (+) |
| 28 DAP | Control | 29.78b | 32.89ab | 35.22ab | 32.63 |
| | 50 grams | 32.89ab | 28.78b | 31.44ab | 31.04 |
| | 75 grams | 30.55ab | 32.11ab | 33.00ab | 31.89 |
| | 100 grams | 38.55a | 35.55ab | 36.67ab | 36.92 |
| | Average | 32.94 | 32.33 | 34.08 | (+) |
| 42 DAP | Control | 47.89bc | 52.44abc | 55.33abc | 51.89 |
| | 50 grams | 56.44abc | 47.11c | 49.88abc | 51.14 |
| | 75 grams | 51.22abc | 54.00abc | 52.67abc | 52.63 |
| | 100 grams | 60.33abc | 61.45ab | 62.44a | 61.41 |
| | Average | 53.97 | 53.75 | 55.08 | (+) |
| 56 DAP | Control | 85.11 | 91.45 | 99.00 | 91.85a |
| | 50 grams | 91.78 | 82.22 | 84.00 | 86.00a |
| | 75 grams | 77.99 | 77.22 | 101.78 | 85.66a |
| | 100 grams | 94.67 | 98.55 | 98.00 | 97.07a |
| | Average | 87.39a | 87.36a | 95.70a | (-) |
| 70 DAP | Control | 132.33 | 134.11 | 141.45 | 135.96ab |
| | 50 grams | 139.56 | 148.89 | 136.22 | 141.56ab |
| | 75 grams | 135.66 | 127.56 | 133.78 | 132.33b |
| | 100 grams | 153.67 | 141.44 | 148.56 | 147.89a |
| | Average | 140.31a | 138.00a | 140.00a | (-) |

Note: Numbers in rows and columns followed by the same letter indicate no significant difference at the 5% level ($\alpha$ = 0.05) according to DMRT; (+) Indicates interaction between factors.

**Observation Results**

These findings align with the concept that plant pests and diseases (organisms harmful to plants/OPT), whether attacking plant tissues directly or indirectly, can inhibit the physiological activities of plants, such as photosynthesis and nutrient absorption. By reducing biotic stress from the early growth stages, plants are provided with a more stable environment to adapt and carry out optimal meristematic growth. From a physicochemical perspective, lemongrass (*Cymbopogon nardus*) is known to produce secondary metabolite compounds, particularly citronellal, citronellol, and geraniol, which possess natural insecticidal and repellent properties. Lemongrass essential oil contains active components that act as antibiosis agents—disrupting the nervous system of insect pests and inhibiting pathogenic microbial activity (Bassolé & Juliani, 2011; Susetyo et al., 2008). Therefore, the use of lemongrass extract as a botanical pesticide provides biological protection to plants from the early growth stages, which in turn promotes increased plant height. Interestingly, on the 56th and 70th days after planting, no significant interaction was observed between the two treatment factors. However, individually, the high concentration treatment (100 g/L) still resulted in the tallest plant growth compared to other treatments. This suggests that even though the interaction effect between frequency and concentration does not persist continuously, the cumulative effect of early treatments still provides growth benefits during the late vegetative phase.

More frequent spraying (7 times) also had a positive effect on plant height, although the effect tended to diminish once the plant entered the reproductive phase. This highlights that the timing of botanical pesticide application is crucial, especially during the early stages, which are critical for determining plant height and structural formation. These results are consistent with the study by Tahir et al. (2019), which stated that intensive application of botanical pesticides during the early growth phase of tomato plants could accelerate growth and increase plant height due to reduced thrips attacks. Another study by Sari et al. (2021) also supports that botanical pesticides effectively enhance the vegetative growth of long beans by significantly reducing armyworm infestation. Thus, it can be concluded that the application of lemongrass extract-based botanical pesticides has great potential in promoting plant height growth in sorghum, especially when applied at high concentrations and with sufficiently intensive spraying frequency. The application of botanical pesticides is not only environmentally friendly but also presents an efficient alternative approach for farmers to reduce reliance on synthetic chemical inputs.

**Number of Leaves (Blades)**

There was a significant interaction between lemongrass extract (*Cymbopogon nardus*) concentration and spraying frequency on the number of sorghum leaves, particularly on the 14th and 28th days after planting (DAP). The treatment combination of 100 grams per liter of water and a spraying frequency of 7 times resulted in the highest number of leaves during the early growth phase. This indicates that intensive and repeated application of lemongrass extract can create more optimal vegetative growth conditions. The increase in leaf number can be attributed to the reduced pressure from plant-disturbing organisms (OPT). Lemongrass extract, which contains active compounds such as citronellal and geraniol, is known to have insecticidal, antifungal, and antibacterial activities, thereby acting as a natural protector against insect and pathogen disturbances (Bassolé & Juliani, 2011; Susetyo et al., 2008). In a biotic stress-free environment, plants can undergo more optimal cell division and elongation, particularly in the meristematic tissues of the leaves.

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Table 2. Number of Leaves (Blades)

| Observation Time | Lemongrass Extract Concentration (g/liter of water) | Spraying Frequency | | | Average |
|---|---|---|---|---|---|
| | | 3 times | 5 times | 7 times | |
| 14 DAP | Control | 3.00b | 3.11b | 3.11b | 3.07 |
| | 50 grams | 3.44ab | 3.00b | 3.11b | 3.18 |
| | 75 grams | 3.33ab | 3.22b | 3.22b | 3.26 |
| | 100 grams | 3.22b | 3.33ab | 3.78a | 3.44 |
| | Average | 3.25 | 3.17 | 3.31 | (+) |
| 28 DAP | Control | 3.22ab | 3.44ab | 3.33ab | 3.33 |
| | 50 grams | 3.77a | 3.33ab | 3.11b | 3.40 |
| | 75 grams | 3.33ab | 3.33ab | 3.33ab | 3.33 |
| | 100 grams | 3.22ab | 3.33ab | 3.78a | 3.44 |
| | Average | 3.39 | 3.36 | 3.39 | (+) |
| 42 DAP | Control | 4.11 | 4.33 | 4.56 | 4.33a |
| | 50 grams | 4.22 | 4.11 | 4.00 | 4.22a |
| | 75 grams | 4.11 | 4.11 | 4.44 | 4.22a |
| | 100 grams | 4.56 | 4.33 | 4.56 | 4.37a |
| | Average | 4.25a | 4.22a | 4.39a | (-) |
| 56 DAP | Control | 6.56 | 6.00 | 6.78 | 6.45a |
| | 50 grams | 6.44 | 6.33 | 6.11 | 6.29a |
| | 75 grams | 6.67 | 6.33 | 6.11 | 6.37a |
| | 100 grams | 6.44 | 6.67 | 6.89 | 6.67a |
| | Average | 6.53a | 6.33a | 6.47a | (-) |
| 70 DAP | Control | 7.00 | 6.56 | 7.22 | 6.93a |
| | 50 grams | 7.00 | 6.67 | 6.78 | 6.82a |
| | 75 grams | 7.22 | 6.88 | 6.45 | 6.85a |
| | 100 grams | 6.78 | 6.78 | 7.55 | 7.04a |
| | Average | 7.00a | 6.72a | 7.00a | (-) |

Note: Numbers in rows and columns followed by the same letter indicate no significant difference at the 5% level ($\alpha = 0.05$) according to DMRT; (+) Indicates interaction between factors.

Based on the research results, in addition to its direct effects on pests (OPT), the metabolite compounds in lemongrass also play a role in strengthening plant physiology. According to Wijayakusuma (2000), the essential oil compounds in lemongrass have bioactive effects that can inhibit the development of pest larvae and adult insects, including aphids and leaf caterpillars. As the intensity of pest attacks decreases, plants are able to use nutrients more efficiently and allocate them to the formation of vegetative organs such as leaves. It is important to note that in subsequent observations (at 42, 56, and 70 days after planting), the interaction between concentration and spraying frequency no longer showed significant differences, but the treatment with 100 g/L concentration still resulted in the highest individual number of leaves. This reinforces the assumption that the early growth

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phase is a critical period for plants in determining their vegetative capacity, and pest control during this phase is essential to support the development of plant structure in the following stages (Taiz & Zeiger, 2010).

These findings are consistent with research by Rahni (2012), who reported that an increase in leaf number in horticultural plants is closely related to the availability of beneficial microbes in the rhizosphere that support root exudate production and enhance physiological activity in plants. Meanwhile, research by Nik (2023) demonstrated that high concentrations of biobased insecticides can suppress aphid development on bitter melon plants, which in turn increases both the number and size of leaves. Therefore, the use of lemongrass extract as a botanical pesticide not only functions as a pest control agent but also indirectly enhances the vegetative growth performance of sorghum. Applying high concentrations and maintaining consistent application during the early growth phase is an effective strategy for environmentally friendly pest management that supports increased productivity.

**Fresh Panicle Weight (g)**

There was a significant interaction between the lemongrass extract (*Cymbopogon nardus*) concentration and the spraying frequency on the fresh panicle weight of sorghum plants. The best combination was achieved with the treatment of 100 g/L concentration and 7 sprayings, which produced the highest fresh panicle weight, amounting to 44.85 grams. This increase in fresh panicle weight is believed to be closely related to the decreased intensity of pest attacks, particularly aphids (Aphididae), which are one of the main pests of sorghum. The application of lemongrass extract at high concentrations with frequent and consistent spraying can function as a natural bioinsecticide, reducing pest populations from the early vegetative stage. With minimal pest pressure, the plants are able to perform photosynthesis more efficiently because the leaf surface remains undamaged and the stomata function properly (Bassolé & Juliani, 2011; Wijayakusuma, 2000).

Table 3. Fresh Panicle Weight (g)

| Lemongrass Extract Concentration (g/liter of water) | Spraying Frequency | | | Average |
|---|---|---|---|---|
| | 3 times | 5 times | 7 times | |
| Control | 30.41abc | 32.65abc | 29.27abc | 30.78 |
| 50 grams | 19.20c | 31.38abc | 40.08ab | 30.22 |
| 75 grams | 26.56bc | 32.78abc | 33.90abc | 31.08 |
| 100 grams | 27.63bc | 28.87abc | 44.85a | 33.78 |
| Average | 25.95 | 31.42 | 37.03 | (+) |

Note: Numbers in rows and columns followed by the same letter indicate no significant difference at the 5% level (α = 0.05) according to DMRT; (+) Indicates interaction between factors.

According to the research results, an efficient photosynthesis process produces assimilates (photosynthetic products) that are then translocated to the reproductive organs, in this case, the panicle. The accumulation of these photosynthates influences seed formation and filling, thus directly contributing to the increase in fresh panicle weight (Taiz & Zeiger, 2010). Therefore, panicle weight can serve as one of the indicators of sorghum plant productivity, as explained by Kurniasari et al. (2023), who emphasized that panicle biomass is positively correlated with harvest yield and seed recovery. A study by Susetyo et al. (2008) also supports the notion that lemongrass extract has the potential to reduce leaf pest populations and improve plant health, allowing generative organs such as panicles to develop more optimally. Low concentration treatments and infrequent spraying still have some effect, but they are not as effective as the combination of high concentration and more frequent applications. In the results table, the control treatment without lemongrass extract only produced average panicle weights of 29–32 grams. In contrast, the 100 g/L concentration with seven applications significantly increased fresh panicle weight to more than 44 grams, demonstrating the effectiveness of this treatment in improving the physiological performance of the plant.

**Dry Panicle Weight (g)**

There was a significant interaction between the concentration of lemongrass extract and spraying frequency on the dry panicle weight of sorghum. The best treatment combination was found at a concentration of 100 grams per liter of water with a spraying frequency of 7 times, resulting in the highest dry panicle weight of 20.56 grams among all treatment combinations. Dry panicle weight is an important parameter in evaluating productivity because it reflects the accumulation of dry biomass in the plant's generative parts. This weight increase indicates that the allocation of photosynthetic products (assimilates) from the leaves to the reproductive organs was effective, supported by healthy plants experiencing minimal biotic stress. In this context, lemongrass extract acts as a biocontrol agent that reduces pressure from pests such as aphids and armyworms (Susetyo et al., 2008; Bassolé & Juliani, 2011).

In line with these findings, Kurniasari et al. (2023) stated that dry panicle weight positively correlates with sorghum seed yield potential. The successful transfer of photosynthates to the panicle is not only influenced by internal physiological factors but is also highly dependent on external environmental conditions, such as the presence of plant-disturbing organisms (OPT). Under pest-free conditions, photosynthesis runs more efficiently, and the products are effectively mobilized to the seeds. The essential oils contained in lemongrass include active compounds such as citronellal and geraniol, which possess insecticidal, antifungal, and repellent properties, capable of repelling or killing plant pests without leaving chemical residues (Wijayakusuma, 2000; Taiz & Zeiger, 2010). With spraying carried out seven times during both the vegetative and generative phases, plants receive continuous protection, especially during the critical phases of panicle formation and grain filling.

Table 4. Dry Panicle Weight (g)

| Lemongrass Extract Concentration (g/liter of water) | Spraying Frequency | | | Average |
|---|---|---|---|---|
| | 3 times | 5 times | 7 times | |
| Control | 13.62abc | 17.51abc | 12.98abc | 14.70 |
| 50 grams | 10.73c | 11.81bc | 20.41a | 14.32 |
| 75 grams | 9.93c | 19.50ab | 18.33abc | 15.92 |
| 100 grams | 13.70abc | 12.58abc | 20.56a | 15.61 |
| Average | 12.00 | 15.35 | 18.07 | (+) |

Note: Numbers in rows and columns followed by the same letter indicate no significant difference at the 5% level ($\alpha = 0.05$) according to DMRT; (+) Indicates interaction between factors.

The data in the table show that the combination of 50 g/L concentration with seven sprayings also resulted in a relatively high outcome (20.41 g), although it was not as effective as the 100 g/L treatment. This confirms that increasing the concentration of the extract plays an important role in maximizing the potential of plant-based bioinsecticides, especially when combined with the appropriate application frequency. Research by Sharma et al. (2022) also found that the use of botanical pesticides based on essential oils significantly improved the dry biomass yield of legume crops by reducing leaf pest infestations and enhancing photosynthetic efficiency during critical periods. Thus, the combination of high extract concentration and optimal spraying frequency of lemongrass extract has been proven to positively contribute to the increase in dry panicle weight, ultimately impacting sorghum yield potential and farming efficiency in dryland areas.

**Panicle Length (cm)**

There was a significant interaction between the concentration of lemongrass extract (*Cymbopogon nardus*) and spraying frequency on the panicle length growth of sorghum variety Suri 4. The most effective treatment combination was found at a concentration of 100 g/L of water with seven sprayings, resulting in the longest panicle length of 21.78 cm. This value was significantly higher than other treatments and indicates the positive impact of optimal use of plant-based bioinsecticides. Panicle length is an important indicator in determining yield potential, as it influences the number of seeds that can form per panicle. The development of good panicle length greatly depends on the physiological health of the plant during the generative phase. In this context, treatment with lemongrass extract provides effective protection against pest attacks, especially aphids and leaf caterpillars, which can damage plant tissues and interfere with the processes of flower and seed formation.

Table 5. Panicle Length (cm)

| Lemongrass Extract Concentration (g/liter of water) | Spraying Frequency | | | Average |
|---|---|---|---|---|
| | 3 times | 5 times | 7 times | |
| Control | 17.44bc | 17.45bc | 17.78bc | 17.56 |
| 50 grams | 17.44bc | 17.33bc | 17.89bc | 17.55 |
| 75 grams | 17.45bc | 19.77ab | 20.67a | 19.30 |
| 100 grams | 16.67c | 21.55a | 21.78a | 20.00 |
| Average | 17.25 | 19.03 | 19.53 | (+) |

Note: Numbers in rows and columns followed by the same letter indicate no significant difference at the 5% level (α = 0.05) according to DMRT; (+) Indicates interaction between factors.

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ased on the research results, lemongrass extract contains active compounds such as citronellal and geraniol, which have been proven to possess natural insecticidal and antimicrobial properties. These compounds are capable of repelling or inhibiting the development of plant-disturbing organisms (Bassolé & Juliani, 2011). Through this mechanism, plants remain healthy and are able to optimize the photosynthesis process and the allocation of assimilates to reproductive parts such as the panicle (Taiz & Zeiger, 2010). Moreover, the longer panicle length observed in treatments using lemongrass extract with higher spraying frequency indicates that application intensity also plays an important role. More frequent spraying provides continuous protection to the plant during the critical period of panicle formation. This aligns with the findings of Susetyo et al. (2008), which stated that routine application of botanical pesticides increases pest control effectiveness and supports generative organ development. Treatments with moderate concentrations (75 g/L) also showed positive results, especially with 5–7 sprayings. However, the highest values were still achieved at the maximum concentration and frequency, indicating that optimal use of botanical pesticides must consider both dosage and application schedule.

**Number of Seeds per Panicle**

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There was a significant interaction between the two treatment factors, lemongrass extract concentration (*Cymbopogon nardus*) and bioinsecticide spraying frequency, on the number of seeds per panicle in sorghum variety Suri 4. The treatment combination with a high concentration, namely 100 grams per liter of water, and seven sprayings consistently produced the highest number of seeds, reaching 323.78 seeds per panicle. This reflects the effectiveness of the treatment in quantitatively increasing yield. This increase can be explained through plant physiological mechanisms related to tissue health during the generative phase. When pest attacks are successfully suppressed through regular application of botanical pesticides, the plant can undergo the processes of seed formation and filling without mechanical or metabolic disruption (Bassolé & Juliani, 2011). Active compounds such as citronellal, geraniol, and citronellol found in lemongrass essential oil possess antibacterial and insecticidal properties, which play a crucial role in protecting the plant's reproductive organs from damage and pathogen infection (Susetyo et al., 2008).

Table 6. Number of Seeds per Panicle

| Lemongrass Extract Concentration (g/liter of water) | Spraying Frequency | | | Average |
|---|---|---|---|---|
| | 3 times | 5 times | 7 times | |
| Control | 223.22b | 242.67ab | 216.78b | 227.56 |
| 50 grams | 208.55b | 253.33ab | 249.78ab | 237.22 |
| 75 grams | 190.55b | 231.78b | 259.89ab | 227.41 |
| 100 grams | 220.45b | 222.89b | 323.78a | 255.71 |
| Average | 210.69 | 237.67 | 262.56 | (+) |

Note: Numbers in rows and columns followed by the same letter indicate no significant difference at the 5% level (α = 0.05) according to DMRT; (+) Indicates interaction between factors.

In the context of plant physiology, the number of seeds per panicle strongly depends on the success of flowering, pollination, and seed filling processes, all of which are highly sensitive to biotic stress. When plants are optimally protected, metabolic energy and assimilates can be efficiently allocated toward the development of spikelets and seeds, ultimately increasing yield quantity (Taiz & Zeiger, 2010; Kurniasari et al., 2023). Spraying conducted seven times also provides continuous protection during critical periods, ensuring that pest attacks do not interfere with key stages of plant reproduction. This is consistent with research by Rahmawati et al. (2022), which stated that the intensity and timing of botanical pesticide application significantly affect the success of yield formation in cereal crops. Beyond protective effects, several studies have shown that essential oils also contain phenolic and flavonoid compounds that can act as stimulants for generative growth, including flower and seed formation. According to Sembiring et al. (2019), these compounds can stimulate plant physiological processes, thereby contributing to improved yield parameters such as the number of seeds per panicle. Thus, it can be concluded that lemongrass extract treatment at high concentrations and sufficient spraying frequency has a positive impact on crop productivity, not only through pest control mechanisms but also by enhancing plant metabolic efficiency.

**Dry Seed Weight per Panicle**

The results of the analysis of variance (ANOVA) showed no significant interaction between the lemongrass extract concentration treatment (*Cymbopogon nardus*) and the spraying frequency of the bioinsecticide on the dry seed weight per panicle in sorghum plants. However, individually, the 100 g/L water concentration treatment yielded the highest average dry seed weight of 68.41 grams, while the treatment with seven sprayings showed the best result at 73.80 grams. Dry seed weight is a key indicator of the plant's success in seed filling, which is directly related to photosynthetic capacity, efficiency of assimilate transport, and minimal biotic interference during the generative phase. Lemongrass extract, which contains active compounds such as citronellal and geraniol, has natural insecticidal and antifungal effects that are effective in suppressing pests such as *Spodoptera frugiperda* and aphids (*Aphididae*), which commonly attack leaves and panicles (Bassolé & Juliani, 2011; Susetyo et al., 2008).

Table 7. Dry Seed Weight per Panicle (g)

| Lemongrass Extract Concentration (g/liter of water) | Spraying Frequency | | | Average |
|---|---|---|---|---|
| | 3 times | 5 times | 7 times | |
| Control | 58.63 | 65.30 | 49.42 | 57.78a |
| 50 grams | 39.02 | 69.93 | 84.26 | 64.40a |
| 75 grams | 47.38 | 58.88 | 67.23 | 57.83a |
| 100 gram s | 51.29 | 59.64 | 94.30 | 68.41a |
| Average | 49.08a | 63.44a | 73.80a | (-) |

Note: Numbers in rows and columns followed by the same letter indicate no significant difference at the 5% level ($\alpha = 0.05$) according to DMRT; (+) Indicates interaction between factors.

The condition of pest-free plants during the flowering and seed-filling phases allows for the accumulation of biomass in the seeds, which is reflected in the increased dry seed weight. A high spraying frequency (seven times) enhances plant protection during this critical period, thereby maintaining the effectiveness of the bioinsecticide (Rahmawati et al., 2022). Although there was no significant interaction between treatments, the combination of high concentration and maximum spraying frequency still showed the highest absolute value 94.30 grams under the combination of 100 g/L and seven sprayings. This indicates a synergistic effect in field practice, even if statistically insignificant (Taiz & Zeiger, 2010). Several studies also note that beyond its pest control function, lemongrass essential oil contains phenolic compounds that can stimulate metabolism and protein synthesis in seeds, supporting seed formation and maturation (Sembiring et al., 2019).

**Aphid Pest Infestation Intensity (%)**

There was a significant interaction between lemongrass extract concentration (*Cymbopogon nardus*) and spraying frequency on the aphid infestation rate in sorghum plants of the Suri 4 variety. Treatments using concentrations of 75 grams/liter and 100 grams/liter of water, combined with spraying frequencies of 5 and 7 times, significantly reduced infestation intensity to as low as 0.08%. This reduction is strongly linked to the presence of active metabolites in lemongrass, such as citronellal and geraniol, which possess toxic and antifeedant properties against insects. These compounds inhibit feeding activity, disrupt metabolism, and impair the nervous system of insects, thereby reducing their aggressiveness and the extent of damage to plant tissues (Bassolé & Juliani, 2011). Repeated application of high concentrations results in an accumulation of toxic effects, leading to a significant decrease in aphid populations. This finding is supported by a study by Nik et al. (2022), which demonstrated that extracts from soursop (*Annona muricata L.*) at high doses could inhibit the development and growth of *Sitophilus* spp. in storage, through a similar mechanism involving secondary metabolite toxicity.

Table 8. Aphid Pest Infestation Rate (%)

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| Observation Time | Lemongrass Extract Concentration (g/liter of water) | Spraying Frequency | | | Average |
|---|---|---|---|---|---|
| | | 3 times | 5 times | 7 times | |
| 42 DAP | Control | 0.16abc | 0.18a | 0.17ab | 0.17 |
| | 50 grams | 0.13cd | 0.13cd | 0.13cd | 0.13 |
| | 75 grams | 0.14bcd | 0.11de | 0.08e | 0.11 |
| | 100 grams | 0.13cd | 0.08e | 0.08e | 0.10 |
| | Average | 0.14 | 0.13 | 0.12 | (+) |
| 56 DAP | Control | 0.22a | 0.19ab | 0.20ab | 0.20 |
| | 50 grams | 0.16bcd | 0.11de | 0.14cde | 0.14 |
| | 75 grams | 0.17bc | 0.10e | 0.10e | 0.12 |
| | 100 grams | 0.14cde | 0.10e | 0.11de | 0.12 |
| | Average | 0.17 | 0.13 | 0.14 | (+) |
| 70 DAP | Control | 0.23a | 0.22a | 0.22a | 0.22 |
| | 50 grams | 0.17b | 0.17b | 0.17b | 0.17 |
| | 75 grams | 0.15b | 0.08c | 0.08c | 0.10 |
| | 100 grams | 0.15b | 0.08c | 0.08c | 0.10 |
| | Average | 0.18 | 0.14 | 0.14 | (+) |

Note: Numbers in rows and columns followed by the same letter indicate no significant difference at the 5% level (α = 0.05) according to DMRT; (+) Indicates interaction between factors.

Based on the table data, observations at 42, 56, and 70 days after planting (DAP) show a declining trend in pest attacks in line with increased concentration and intensity of spraying. The control treatment without extract tended to show higher infestation rates (>0.20%), whereas treatments with 75–100 g/L and 5–7 spray applications consistently resulted in the lowest infestation rates, below 0.10%. From an agronomic perspective, effective control of aphids during the critical vegetative and generative growth phases is essential, as it helps maintain photosynthetic efficiency, prolong leaf lifespan, and maximize crop yield. Pest-free plants have better physiological capacity for seed development and filling (Taiz & Zeiger, 2010).

**Leaf Spot Disease Incidence (%)**

There was a significant interaction between lemongrass extract concentration (*Cymbopogon nardus*) and spraying frequency on the incidence of leaf spot disease in sorghum plants of the Suri 4 variety. Treatment combinations using 75 g/L and 100 g/L of water with seven sprayings were found to be the most effective in reducing disease incidence to as low as 0.06–0.08% during observations at 56 and 70 DAP. This effectiveness indicates that lemongrass-based botanical bioinsecticides can suppress pathogen infections due to their secondary metabolite content, such as flavonoids, saponins, essential oils, and polyphenols, which act as natural antimicrobial and antifungal agents (Bassolé & Juliani, 2011; Anggraito et al., 2018). These active compounds can inhibit protein synthesis, mycelium and spore growth, and damage pathogen protein structures through denaturation, ultimately leading to cell death (Achmad, 2007).

Table 9. Leaf Spot Disease Incidence (%)

| Observation Time | Lemongrass Extract Concentration (g/liter of water) | Spraying Frequency | | | Average |
|---|---|---|---|---|---|
| | | 3 times | 5 times | 7 times | |
| 42 DAP | Control | 0.17a | 0.18a | 0.16ab | 0.17 |
| | 50 grams | 0.18a | 0.16ab | 0.16ab | 0.17 |
| | 75 grams | 0.14abc | 0.10cd | 0.08d | 0.11 |
| | 100 grams | 0.11bcd | 0.10cd | 0.10cd | 0.10 |
| | Average | 0.15 | 0.14 | 0.13 | (+) |
| 56 DAP | Control | 0.19a | 0.19a | 0.19a | 0.19 |
| | 50 grams | 0.13bc | 0.13bc | 0.12bc | 0.13 |
| | 75 grams | 0.14b | 0.08cd | 0.06d | 0.09 |
| | 100 grams | 0.13bc | 0.06d | 0.06d | 0.08 |
| | Average | 0.15 | 0.12 | 0.11 | (+) |
| 70 DAP | Control | 0.22a | 0.19abc | 0.21ab | 0.21 |
| | 50 grams | 0.17bcd | 0.13de | 0.17bcd | 0.16 |
| | 75 grams | 0.16cd | 0.10ef | 0.08f | 0.11 |
| | 100 grams | 0.14d | 0.10ef | 0.08f | 0.11 |
| | Average | 0.17 | 0.13 | 0.14 | (+) |

Note: Numbers in rows and columns followed by the same letter indicate no significant difference at the 5% level (α = 0.05) according to DMRT; (+) Indicates interaction between factors.

Research findings indicate that most previous studies have generally highlighted the insecticidal activity of lemongrass extract (*Cymbopogon nardus*). However, this study reveals that its mechanism of action is also effective against pathogens causing leaf spot disease, particularly pathogenic fungi. The secondary metabolites present in lemongrass, such as essential oils, flavonoids, and polyphenols, are known to have antifungal properties that can inhibit mycelial growth, disrupt pathogen cell structures, and interfere with the synthesis of essential enzymes (Bassolé & Juliani, 2011; Anggraito et al., 2018). This effectiveness is reflected in the gradual reduction of leaf spot incidence in sorghum plants treated with lemongrass extract—from 0.13% at 42 days after planting (DAP) to 0.11% at 56 DAP, and further down to 0.10% at 70 DAP. These figures are significantly lower compared to the control group, which ranged between 0.19–0.22%, indicating that plant-based treatments with high concentrations and optimal spraying frequency can provide systemic and sustainable protection against pathogen infection. From an agronomic perspective, the low level of disease infection allows the plants to maintain healthy leaf function, enhance photosynthetic activity, and ultimately contribute directly to increased crop yields. Therefore, the use of plant-based pesticides derived from lemongrass is not only a safe and environmentally friendly alternative, but also an effective strategy within the Integrated Pest Management (IPM) program, particularly in dryland areas with limited access to synthetic chemical pesticides (Wahyuni et al., 2022; Susetyo et al., 2008).

## CONCLUSION AND RECOMMENDATION

This study demonstrates that the application of lemongrass leaf extract (*Cymbopogon nardus*) at a concentration of 100 grams per liter, with a spraying frequency of seven times, provides the most optimal agronomic outcomes for *Sorghum* variety Suri 4. This treatment significantly enhanced growth indicators such as plant height and number

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of leaves, while positively contributing to yield components including fresh and dry panicle weight, number of grains per panicle, and grain weight. Additionally, it effectively reduced aphid infestations and the prevalence of leaf spot disease to below the economic threshold (<0.10%), thereby affirming lemongrass extract's dual role as a growth enhancer and a biological control agent against plant pests and diseases.

Accordingly, it is highly recommended that farmers adopt the use of lemongrass extract at the tested dosage and frequency as part of an environmentally friendly pest and disease management strategy. This botanical pesticide can also be produced locally using simple and low-cost methods, making it an ideal solution for farmers in areas with limited access to modern agricultural inputs, such as in East Nusa Tenggara. Moreover, local governments, through relevant technical agencies, should facilitate its adoption by providing training, production tools, and policy-based incentives for farmers implementing biological control systems. To ensure sustainability, further development of lemongrass-based pesticides in ready-to-use liquid or more durable solid formulations is necessary. Follow-up research is also crucial to evaluate the long-term effectiveness and explore potential integration with other biological control agents, such as *Trichoderma spp.* and *Beauveria bassiana*, to strengthen integrated and sustainable pest and disease management systems.

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# FEASIBILITY OF BLACK RICE FARMING IN SUBAK SERASON, PITRA VILLAGE, PENEBEL DISTRICT, TABANAN

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***ABSTRACT***

*Subak Serason, located in Pitra Village, Penebel District, Tabanan Regency, holds strong potential to be developed as a center for black rice cultivation an agricultural commodity with both economic value and cultural significance. This study aims to evaluate the cost structure, revenue, and income from black rice farming, as well as to assess its economic feasibility. The research method employs a farm feasibility analysis approach. The results show that the average total cost incurred per 20 ares of land is IDR 5,838,000, while the average revenue reaches IDR 9,350,000. Consequently, the average net income obtained by farmers amounts to IDR 3,512,000. The R/C ratio of 1.60 indicates that this farming activity is profitable and economically feasible for continuation. This study recommends that farmers receive technical guidance through agricultural extension programs to improve both yield and the quality of black rice. Additionally, to enhance its economic value, harvested crops should be processed into rice before being marketed, enabling higher selling prices and significant value addition.*

***Keywords**: Black Rice, Farmer Income, Economic Feasibility*

## INTRODUCTION

The agricultural sector remains the backbone of the national economy, especially for rural communities in Indonesia. Among the various subsectors supporting the national agricultural system, the food crop subsector plays a crucial role due to its direct relevance to food security and farmer welfare. The leading commodity in this subsector is rice (*Oryza sativa*), which not only serves as the staple food for the majority of the population but also significantly contributes to farmers' incomes and the overall structure of agricultural production in the country (Mirawati, 2011; Hendayana & Maulana, 2019). Rice plays a vital role in two fundamental aspects: first, as the primary source of carbohydrates forming the foundation of national dietary consumption; and second, as a strategic commodity in the agricultural economy, providing employment and serving as the cornerstone of many farming livelihoods (Saragih, 2021). In the framework of sustainable development, improving the productivity and added value of rice commodities is a top priority, particularly through the development of superior varieties with nutritional and economic advantages.

One such variety gaining attention is black rice, a local type of rice known for its higher nutritional content compared to white or red rice. A report from FAO (2020) indicates that black rice contains 8.5 grams of protein per 100 grams, a high fiber content, and significant levels of minerals such as iron. Its distinctive dark purple hue results from a high concentration of anthocyanins, natural antioxidants that help neutralize free radicals and support overall health (Kristamtini, 2012; Sun et al., 2022). Furthermore, black rice is recognized as a functional food, aligning with the growing dietary trends among urban, health-conscious consumers. Although its texture and taste differ from white rice, it is less soft and requires a longer cooking time, it has a unique aroma favored by certain market segments. These attributes offer farmers an opportunity to enter more profitable premium market niches (Narwidina, 2009; Wang et al., 2020). In Bali, particularly in Tabanan Regency, agriculture remains a dominant sector. One village recognized for producing black rice is Pitra Village, located in the Penebel District. Subak Serason, situated within this village, is an agrarian area actively cultivating local black rice, utilizing the traditional *subak* system, an indigenous agricultural wisdom that also attracts agrotourism (Adnyana & Putra, 2022).

Despite its great potential, many farmers in this area have yet to apply structured farm feasibility analysis, resulting in inefficient cost and income management (Astiti et al., 2021). To address this issue, an in-depth study on the financial feasibility of black rice farming is needed. This assessment is essential not only for evaluating profit and loss quantitatively but also for serving as a reference in agribusiness decision-making at the farmer level. In this context, a financial feasibility approach involving the evaluation of production cost components, business revenue, net income, and efficiency ratio (R/C ratio) is highly relevant (Prasetya, 2006; Soekartawi, 2023).

Farm business costs can be categorized into fixed costs (e.g., land rent, equipment depreciation) and variable costs (e.g., seed, fertilizer, labor), which together form the total cost (Joesron, 2003; Hernanto, 1989). Revenue is defined as the gross income from harvest sales, while net income is the difference between revenue and total cost (Soekartawi, 2006). The Revenue-to-Cost (R/C) ratio is a key indicator of feasibility, offering farmers an objective overview to evaluate input efficiency and the potential for business development. Furthermore, this approach supports farmer empowerment by providing data-driven insights and economic analysis, ultimately aiming to promote the transformation of traditional farming into market-oriented and sustainable agribusiness. Considering its nutritional benefits, economic value, and local context, black rice from Subak Serason holds strong potential to become a flagship commodity for Bali in developing a healthy, inclusive, and globally competitive agricultural sector.

## RESEARCH METHOD

This research was conducted in Subak Serason, located in Pitra Village, Penebel District, Tabanan Regency, Bali. The location was selected purposively, considering its suitable agroecological conditions for black rice cultivation and its recognition as one of the central areas of local black rice production in Bali. In addition to the fertile land and the continued operation of the traditional *Subak* irrigation system, the presence of an organized farmer group further justified its selection as the research site, as it represents a sustainable and community-based farming practice. The population of this study consisted of all farmers actively cultivating black rice in the Subak Serason area, totaling 52 individuals. Due to time, labor, and budget constraints, not all farmers could be included as respondents. Therefore, a sample of 30 farmers was selected using simple random sampling**,** which provides every member of the population an equal chance of being selected. This approach ensures that the collected data remains representative and accurately reflects the general conditions of black rice farming in the area. The research utilized both quantitative and qualitative data**.** Quantitative data included numeric values such as production volume, input costs, selling prices, income, and farm efficiency. Qualitative data consisted of narrative information explaining farmers' socio-economic contexts, decision-making patterns, and challenges faced during cultivation. Primary data were collected directly from respondents through interviews, field observations, and questionnaires. Secondary data were obtained from supporting documents such as reports from the Agriculture Office, farmer group archives, and relevant academic references. The data collection techniques used were:

a. Field observation to monitor farming activities from land preparation to post-harvest.
b. Structured interviews to obtain specific information on production inputs, labor, and technical constraints.
c. Documentation to gather historical or administrative data such as average selling prices and cultivated land size.
d. Literature review to reinforce the theoretical framework and analytical approach of this study.

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Data analysis was conducted using descriptive quantitative methods**,** aiming to simplify numerical information into easily understandable forms, as follows:

1.Total Production Cost

Calculated by summing fixed and variable costs incurred during farming operations:

**TC = TFC + TVC**

Where:

- TC (Total Cost): Total farming expenses
- TFC (Total Fixed Cost): Costs that remain constant regardless of production scale, such as equipment depreciation
- TVC (Total Variable Cost): Costs that vary with production intensity, such as seeds, fertilizer, pesticides, and labor

2.Total Revenue (TR)

Calculated by multiplying the quantity of harvested rice sold by the selling price per unit:

**TR = Hy × Y**

Where:

- TR (Total Revenue): Gross income before deducting costs
- Y: Quantity of black rice produced and sold
- Hy: Selling price per unit at the farmer level

3.Net Income (Pd)

Determined by subtracting total cost from total revenue:

**Pd = TR – TC**

Where:

- Pd: Net income from farming
- TR: Total revenue
- TC: Total production cost

4.Financial Feasibility Analysis (R/C Ratio)

Assesses profitability by comparing total revenue to total cost:

**R/C = TR / TC**

Where:

- R/C Ratio: Efficiency indicator; considered feasible if greater than 1
- TR: Total revenue
- TC: Total cost

The R/C ratio serves as a key benchmark to evaluate the financial viability of black rice farming in Subak Serason. A ratio greater than 1 indicates profitability, while a ratio below 1 indicates a loss. This analysis is widely used in agribusiness and farming studies in Indonesia and is considered a reliable method for objectively describing the economic realities faced by farmers (Soekartawi, 2006; Wahyuni et al., 2021; Trisna & Yasa, 2020).

## RESEARCH RESULTS AND DISCUSSION

In farm economic analysis, cost structure serves as a fundamental basis for understanding operational efficiency and formulating profit improvement strategies. The findings of this study reveal that the total cost incurred by farmers for black rice farming in Subak Serason amounts to IDR 6,438,000.00 per 55 ares per planting season. These costs consist of two main categories: fixed costs and variable costs, as classified in agricultural economics literature (Soekartawi, 2006; Hernanto, 1993). The fixed cost, amounting to IDR 78,000.00 per season, comes from the depreciation of agricultural tools such as hoes and sickles, which are used over multiple seasons. This amount remains unchanged regardless of production intensity, reflecting the efficiency of simple tools in traditional farming systems that still rely on manual equipment.

The variable cost is the dominant component of total expenses, comprising production inputs (seeds, organic manure, inorganic fertilizers, pesticides, sacks) and labor costs for activities such as land preparation, planting, weeding, fertilizing, pest control, and harvesting. Input costs were recorded at IDR 3,665,000.00, while labor costs amounted to IDR 2,095,000.00. These results indicate that variable costs dominate the farming expenses in small-scale black rice farming, mainly due to the high demand for manual labor (Gunawan et al., 2022; Wahyuni et al., 2021). This cost structure reflects a semi-traditional farming system still dependent on labor-intensive practices and external input purchases. Therefore, efficiency strategies should focus on optimizing input use and managing seasonal labor more effectively.

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Table 1. Cost Structure, Revenue, Net Income, and R/C Ratio of Black Rice Farming

| No | Expenditure Component | Volume | Price (Rp/unit) | Total Cost (Rp/ Cultivated Area) | Total Cost (Rp/ Hectare) |
|---|---|---|---|---|---|
| I | Input | | | | |
| A | Variable Costs | | | | |
| | 1. Production Inputs | | | | |
| | a. Organic Fertilizer) | 75 sacks | 15.000,00 | 1.125.000,00 | 2.250.000,00 |
| | b. Inorganic Fertilizer | | | | |
| | • Urea | 50 kg | 15.000.00 | 750.000,00 | 1.500.000,00 |
| | • NPK | 50 kg | 15.000,00 | 750.000,00 | 1.500.000,00 |
| | c. Pesticides | 6 bottle | 72.000,00 | 648.000,00 | 1.296.000,00 |
| | d. Storage sacks | 10 unit | 3.500,00 | 42.000,00 | 84.000,00 |
| | e. Seeds | 14 kg | 25.000,00 | 350.000,00 | 700.000,00 |
| | Subtotal 1 | | | 3.665.000,00 | 7.330.000,00 |
| | 2. Labor Costs | | | | |
| | a. Land Preparation | 8 HOK | 65.000,00 | 520.000,00 | 1.040.000,00 |
| | b. Planting | 20 are | 15.000,00 | 300.000,00 | 600.000,00 |
| | c. Tractor Usage | 20 are | 25.000,00 | 500.000,00 | 1.000.000,00 |
| | d. Weeding | 4 HOK | 40.000,00 | 160.000,00 | 320.000,00 |
| | e. Fertilizing | 4 HOK | 45.000,00 | 180.000,00 | 360.000,00 |
| | f. Pest Control | 6 HOK | 40.000,00 | 240.000,00 | 480.000,00 |
| | g. Harvesting | 3 HOK | 65.000,00 | 195.000,00 | 390.000,00 |
| | Subtotal 2 | | | 2.095.000,00 | 4.190.000,00 |
| | Subtotal A | | | 5.760.000,00 | 11.520.000,00 |
| B | Fixed Cost | | | | |
| | 1. Depreciation Costs | | | | |
| | a. Hoe | 2 units | 25.000,00 | 50.000,00 | 100.000,00 |
| | b. Sickle | 2 units | 14.000,00 | 28.000,00 | 56.000,00 |
| | Subtotal B | | | 78.000,00 | 156.000,00 |
| | Subtotal A+ B | | | 5.838.000,00 | 11.676.000,00 |
| II | Output | | | | |
| | a. Total Rice Production | 1.870 | | | |
| | b. Farm-Gate Price | | 5000,00 | | |
| | c.Total Value of Rice Production | | | 9.350.000,00 | 18.700.000,00 |
| | d. Total Costs | | | 5.838.000,00 | 11.676.000,00 |
| | e. Farmer's Income | | | 3.512.000,00 | 7.024.000,00 |
| III | R/C | | | 1,60 | 1,60 |

*Source: Processed Primary Data*

Based on the research findings, the total revenue earned by farmers comes from the sale of black rice harvests, with the farm-gate price set at IDR 5,000 per kilogram and total production reaching 2,062 kg per 55 ares. From this data, the total seasonal revenue per farmer was recorded at IDR 10,310,000.00. When compared to the total cost incurred, the net income achieved per farming season was IDR 3,872,000.00 per 55 ares. This figure is considered high for small-scale farming and indicates that the business is capable of providing a decent net profit. According to Trisna and Yasa (2020), net incomes from rice farming in *Subak* areas generally range from IDR 2 million to 3.5 million per season, depending on the variety and market price. Thus, the result from black rice farming suggests a higher economic potential than conventional rice. This reinforces the argument that developing local varieties like black rice with high functional value can be a strategic adaptation to improve farmers' incomes, particularly in agrarian regions with strong cultural traditions such as Bali.

**Financial Feasibility Evaluation**

Financial feasibility was assessed using the Revenue-to-Cost Ratio (R/C Ratio), which compares total revenue to total production cost. In this study, the R/C ratio was calculated at 1.60, meaning that for every IDR 1 spent on production, the farmer earns IDR 1.60 in revenue. According to Soekartawi (1995), a farming business is considered feasible and profitable if R/C > 1, as it indicates that the enterprise not only covers its costs but also yields a surplus or profit. An R/C value of 1.60 is relatively high compared to the general standard for rice farming in Indonesia, where the average R/C ratio typically ranges between 1.2 and 1.4 (Wahyuni et al., 2021). This finding suggests that black rice has not only a higher market value but also greater efficiency potential, particularly when managed with a well-planned agribusiness approach. Therefore, this research strengthens the conclusion that black rice farming in Subak Serason is economically feasible and has strong development potential. In addition to providing tangible benefits to farmers, this commodity is also relevant for supporting local food security and promoting healthy, functional food products that are in high market demand.

## CONCLUSION AND RECOMMENDATIONS

This study concludes that black rice farming in Subak Serason, Pitra Village, demonstrates promising economic potential. With an average production cost of IDR 6,438,000.00 per 55 ares per growing season, farmers can generate a gross revenue of IDR 10,310,000.00. The difference between total revenue and costs results in a net income of IDR 3,872,000.00. The R/C (Revenue/Cost) ratio of 1.60 indicates that every rupiah spent in the production process yields IDR 1.60 in revenue, reflecting strong business efficiency and financial profitability. These findings affirm that black rice farming can be a stable and sustainable source of income for local farmers, while also supporting the diversification of food commodities based on local wisdom. To ensure the sustainability and improve the profitability of this farming enterprise, several strategic actions are recommended, strengthening farmer institutions is essential to address both technical and non-technical challenges in cultivation. Cooperation among farmers through farmer groups, *Subak* cooperatives, or organic farming communities can enhance production efficiency and facilitate knowledge and technology transfer. Promoting downstream processing and product diversification is necessary to ensure that harvested rice is not only sold as unhusked grain but also processed into high-quality, packaged rice. This creates higher added value and strengthens the marketability of the product. Enhancing digital marketing and community outreach is vital by utilizing social media and e-commerce platforms to target premium markets, including organic product consumers, hotels, restaurants, and Bali souvenir markets. Support from local government and relevant institutions is crucial, especially in facilitating access to capital, providing farm management training, and assisting in the certification of organic or functional food products. With these efforts, black rice from Pitra Village can not only sustain its role as a flagship local commodity but also compete effectively in domestic and national markets.

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# DEVELOPMENT OF AGROTOURISM BASED ON LOCAL WISDOM IN BALI COUNTRYSIDE SIDEMEN AS AN EFFORT TOWARD SUSTAINABLE TOURISM

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***ABSTRACT***

*The Bali Countryside Sidemen area holds great potential to be developed as an agrotourism destination that combines the charm of rural landscapes, traditional farming practices, and the local wisdom of the community. Located in Sukahet Village, Sidemen District, Karangasem Regency, this area has the opportunity to become a model of sustainable agricultural tourism that supports food security, environmental education, and economic empowerment of local residents. However, the development of this destination still faces several challenges, such as limited promotion, inadequate tourism infrastructure, underdeveloped attractions, and poor accessibility. This study aims to formulate a development strategy for community-based agrotourism. A qualitative approach was used, involving interviews with five key informants consisting of tourism actors and local farmers, supported by documentation and direct field observation. The analysis was based on four key tourism elements (4A): attraction, accessibility, amenities, and ancillary services, with a focus on the agricultural context. The results show that strengthening promotion, creating educational attractions such as planting and harvesting activities, processing local agricultural products, and providing environmentally friendly accommodations rooted in farming culture are strategic steps to unlock the area's potential. The main recommendation of this study is the collaboration between farmers, tourism entrepreneurs, and village government to establish an inclusive and sustainable agrotourism system.*

***Keywords**: Agrotourism, Sustainable Agriculture, 4A Strategy, Village Collaboration*

## INTRODUCTION

The tourism sector has long been recognized as a key driver of economic development, particularly in developing countries endowed with abundant natural and cultural resources (UNWTO, 2022). Beyond contributing to national and regional revenues, tourism plays a vital role in generating employment, stimulating micro, small, and medium enterprises (MSMEs), and expanding cross-sector investment opportunities (Hernández-Mogollón et al., 2021). In Indonesia, especially in Bali the economy is highly reliant on tourism, positioning the sector as a top priority in both medium- and long-term development planning (BPS Bali, 2024). Following the COVID-19 pandemic, the recovery of the tourism sector has shown positive trends. Data from BPS Bali (2024) records that international tourist arrivals to Bali from January to September 2024 reached 4,749,449 visitors, exceeding pre-pandemic figures. This surge in arrivals has led to increased employment and investment, particularly in subsectors such as hotels, restaurants, and supporting services. Business loans to the tourism sector even reached IDR 93.59 trillion as of July 2024, reflecting the dominant role of tourism in Bali's economic structure (Bank Indonesia, 2024). A key post-pandemic strategy in tourism development is the integration of sustainability principles, encompassing environmental, social, and economic aspects (Gössling & Hall, 2021). Agritourism, which merges agricultural and tourism activities, is regarded as an innovative solution to address the uneven development of tourism, often concentrated in coastal and urban areas (Barbieri & Mshenga, 2008). Agritourism also empowers local communities to participate actively as both economic agents and custodians of cultural values that serve as key attractions (Lane, 2009).

Bali Countryside Sidemen, located in Karangasem Regency, exemplifies a region with high agritourism potential that has yet to be fully optimized. Its beautiful natural landscape, traditional farming systems such as *subak*, and rich cultural heritage make the area highly suitable for development as a local wisdom-based agritourism destination (Wiranata & Purnomo, 2022). However, previous observations and findings identify several challenges, including limited digital promotion, insufficient tourism-standard facilities, low human

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resource capacity, and the absence of institutional collaboration among community members, private actors, and the government (Sugihartini et al., 2021). Under the paradigm of sustainable tourism, each destination must be developed as part of an interactive system involving social, economic, cultural, and political components (Farrell & Twining-Ward, 2005). Thus, developing a destination like Sidemen cannot rely on a single actor. It requires synergy among three core pillars: the community, as the cultural and land owners; the private sector, as business actors and investors; and the government, as the provider of enabling policies, infrastructure, and regulatory support (Murphy, 1985; Dredge & Jenkins, 2007). Nevertheless, prior studies reveal that local communities are often treated merely as passive objects in tourism development and are excluded from meaningful decision-making and equitable benefit distribution (Tosun, 2006). This disparity fosters social resistance and undermines the effectiveness of tourism programs in improving local welfare. Therefore, a participatory approach is essential in developing an agritourism model that is inclusive, context-sensitive, and sustainable (Timothy, 2007). This study aims to design a local wisdom-based agritourism development model for Bali Countryside Sidemen. The proposed model is expected to enhance the destination's appeal and competitiveness both locally and globally while strengthening community participation in a just and sustainable tourism system.

## RESEARCH METHOD

This study employs a descriptive qualitative approach aimed at comprehensively portraying the dynamics of local wisdom-based tourism development in the Bali Countryside Sidemen area. This approach was selected for its ability to deeply explore social phenomena and provide a holistic understanding of the perceptions, experiences, and practices of tourism stakeholders within a local context (Creswell, 2014). The focus of the research is directed toward interpreting development strategies that integrate economic, socio-cultural, and environmental dimensions in alignment with sustainable tourism principles. The study utilizes both primary and secondary data. Primary data were collected through in-depth interviews, participatory observation, and field documentation. In-depth interviews were conducted with five key informants selected purposively, including three tourists and two tourism managers. These informants were chosen based on their direct involvement in destination activities and their potential to contribute valuable insights regarding service quality, attraction sustainability, and tourism management perceptions. A semi-structured interview technique was used to ensure the research had a guiding framework while remaining flexible enough to explore broader insights as prompted by respondents' answers.

Direct observations were carried out in the field to examine interactions between tourists and local communities, facility usage, attraction implementation, and accessibility conditions to the tourist location. This observational data was vital in identifying the alignment of on-site tourism practices with sustainability standards. In addition, documentation such as photos, videos, and field notes served as visual evidence to complement verbal data. Secondary data were obtained through document and literature reviews, including destination management reports, village tourism development policies, scholarly journal articles, and regional strategic plans related to sustainable tourism. Data analysis was conducted using thematic analysis to identify patterns, themes, and categories related to tourism development components based on the 4A framework (attractions, accessibility, amenities, ancillary services) as developed by Cooper et al. (2008), and sustainability indicators from UNWTO (2019). To ensure the validity and reliability of the data, source and method triangulation techniques were employed. Triangulation involved comparing interview findings with direct observations and relevant written documents to ensure consistency and objectivity in the researcher's interpretation. The analysis process followed a staged approach, starting with data transcription, coding, identifying key themes, and interpreting meaning—based on the principles of data reduction, data display, and conclusion drawing (Miles, Huberman, & Saldaña, 2014). The findings of this research are expected to contribute to the theoretical and practical advancement of community-based sustainable tourism in rural areas.

## RESULTS AND DISCUSSION

### The Potential of Bali Countryside Sidemen as an Agritourism Destination

Bali Countryside Sidemen, located in Karangasem Regency, East Bali, presents a unique and authentic potential for agritourism based on local wisdom. With its terraced rice fields, clean air, and strong traditional farming culture, the area is well-suited for the development of experiential tourism that blends education, recreation, and cultural preservation (Wiranata & Purnomo, 2022). Tourists visiting the area can actively participate in activities such as plowing fields with oxen, planting rice, and joining workshops on Balinese cooking, canang (offerings) crafting, and writing traditional Balinese script on lontar leaves. These activities make Sidemen not only a recreational destination but also a space for cross-cultural learning and understanding. Unfortunately, this extraordinary potential has yet to be fully optimized. Limited digital promotion, insufficient tourism infrastructure, and weak institutional collaboration remain major barriers to improving the destination's competitiveness. In fact, agritourism can be an effective strategy to diversify Bali's tourism offerings, which have long been concentrated in the southern region (Lane & Kastenholz, 2015). With a participatory approach and local capacity building, Sidemen has the potential to become a model for community-based and sustainable destination development in East Bali.

**Economic Dimension**

From an economic perspective, agritourism plays a significant role in strengthening local economies, particularly in rural areas. The presence of tourists generates demand for local products and services, creates new jobs, and increases family and village income. According to Biantoro (2014), tourism can provide direct impacts such as employment generation and increased economic activity, as well as indirect impacts through multiplier effects that stimulate other sectors like agriculture, trade, and services. However, the economic success of tourism can only be achieved if the benefits are equitably distributed. UNWTO (2005) emphasizes the importance of indicators such as tourism income, community investment, and contributions to poverty alleviation. One major challenge is economic leakage, when much of the profit flows out of the region. Therefore, strengthening local businesses, ensuring transparent management of tourism revenues, and providing entrepreneurship training are key strategies to promote inclusive and sustainable economic growth (Barbieri & Mshenga, 2008).

**Social Dimension**

The social aspect of sustainable tourism is closely linked to community empowerment and the preservation of local culture. The Community-Based Tourism (CBT) model positions local communities as owners and managers of the destination, allowing them to directly benefit both economically and socially from tourism activities (Asker et al., 2010). Involving the community early in the planning and management process helps build local capacity, sustain cultural identity, and enhance resilience against external changes. The success of CBT in practice depends on several factors, such as strong community institutions, participatory decision-making mechanisms, and fair benefit distribution (Tosun, 2006). UNWTO (2019) outlines key social indicators for sustainable tourism, including community participation, cultural preservation, gender equality, and protection of vulnerable groups. In the case of Sidemen, strengthening community organizations, promoting local human resource training, and fostering equal partnerships between communities and tourism businesses are strategic steps to generate inclusive and positive social impacts.

**Environmental Dimension**

The environmental dimension is a critical component of sustainable tourism, especially in relatively untouched areas like Sidemen. Ecotourism and agritourism practices aligned with ecological principles help sustain agricultural landscapes, biodiversity, and environmental quality. Environmentally friendly tourism activities such as tree-planting tours, the use of renewable energy, and community-based waste management provide effective environmental education (Honey, 2008). These practices are essential to maintaining a balance between destination use and preservation. Without wise management, however, tourism can lead to environmental degradation such as land erosion, pollution, and pressure on water resources (Gössling, 2002). Therefore, environmental management strategies based on carrying capacity, environmental audits, and tourism development regulations must be integrated into the destination's master plan. In the context of Sidemen, preserving the rice terrace landscapes and the *Subak* irrigation system is not only a matter of aesthetics but also a vital part of cultural identity that must be safeguarded through protective policies and active community participation.

**3.2. Sustainable Tourism Concept in Bali Countryside Sidemen**

Tourism development in the Bali Countryside Sidemen area is part of a region-based tourism development strategy in Karangasem Regency. In this context, Sidemen is identified as a key area with distinctive potential to offer a differentiated destination grounded in natural landscapes and local culture. The main goal of this development is aligned with the realization of sustainable tourism principles, a holistic approach that balances economic growth, environmental preservation, and the social well-being of local communities (UNWTO, 2005; UNEP, 2011). The success of developing this area is also intended to enhance the quality of tourist experiences, maintain environmental sustainability, and generate employment opportunities for local communities (Gössling & Hall, 2021).

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Figure 1. Weaving Process

Figure 2. Philosophy of Traditional Balinese House

Figure 3. Trekking through Sidemen Village

Figure 4. Education on Subak and Traditional Plowing with Oxen

Figure 5. Learning the Traditional Arak-Making Process Figure

6. Education on the Ngaben Cremation Ceremony


Figure 7. Writing in Balinese Script Figure Leaves

8. Making Canang Sari Offerings Using Lontar

To gain empirical insights into the development direction of Bali Countryside Sidemen, interviews were conducted with five informants, consisting of three tourists and two destination managers. The results indicate that building a competitive and sustainable destination must begin with strengthening the core elements of tourism destinations, known as the 4A concept: Attraction, Accessibility, Amenities, and Ancillary Services (Cooper et al., 2008; Dredge & Jenkins, 2007). These components form the foundation for improving both the competitiveness and quality of the destination.

a. Attraction (Tourist Attractions) are the primary reasons tourists choose to visit a destination. In Sidemen, the appeal lies not only in its stunning natural landscapes but also in its rich cultural heritage and preserved agrarian practices. Visitors can participate in educational activities such as traditional weaving, learning about Balinese traditional house architecture, understanding the *banjar* social structure, observing traditional *arak* distillation, and studying the UNESCO-recognized *Subak* irrigation system (Wiranata & Purnomo, 2022). Other activities include plowing rice fields with oxen, cooking local dishes, making *canang* offerings, and writing Balinese script on *lontar* leaves. These experiences highlight authenticity, direct interaction with locals, and the embodiment of local wisdom, ideally suited to the principles of experiential tourism (Lane & Kastenholz, 2015).

b. Accessibility determines how easily tourists can reach a destination. Bali Countryside Sidemen is reachable by private vehicle or tourist bus, but the condition of access roads still requires significant improvement from local authorities. Poor or damaged infrastructure can reduce comfort and safety, as well as negatively affect visitors' perceptions of the destination's quality (Dredge & Jenkins, 2007). Therefore, enhancing both physical and digital access such as road signage, pedestrian pathways, and internet connectivity should be a top priority in tourism development strategies.

c. Amenities play a vital role in improving comfort and service quality for tourists. Currently, basic facilities in Sidemen include parking areas, clean public toilets, seating areas, bamboo learning huts, community kitchens, gazebos, temples (*pura*), and small shops. These support the visitor experience but still require both quantitative and qualitative enhancement. Adequate facilities are also closely linked to destination competitiveness, especially in attracting international tourists who value comfort and safety (UNWTO, 2019).

d. Ancillary, supporting services and institutions such as ATMs, tourist information centers, money changers, emergency healthcare, and safety management are not yet fully available in the area. This highlights an urgent need to strengthen tourism institutional frameworks, including planning, risk management, and information services (Murphy, 1985). In the long term, a strong and inclusive village tourism institution can foster an independent, adaptive, and professional destination capable of addressing visitor needs and industry challenges.

Implementing the 4A concept in the development of Bali Countryside Sidemen is a strategic step toward achieving sustainable tourism goals. When supported by active community participation, cross-sector collaboration, and favorable local policies, this region has strong potential to become a highly competitive and eco-friendly agritourism model in Bali.

## CONCLUSION AND RECOMMENDATIONS

The development of the Bali Countryside Sidemen agritourism destination requires a comprehensive, context-based strategic approach. This strategy should not only focus on enhancing destination promotion through digital media and partnership networks, but also emphasize the improvement of physical facilities, the expansion of tourism service elements, and the provision of authentic and comfortable experiences for visitors. These efforts aim to create added value for the destination while supporting the core principles of sustainable tourism. The sustainability of the tourism destination is inseparable from the area's capacity to adopt eco-friendly technologies and integrate local innovations. The implementation of technologies such as alternative energy usage, sustainable waste management, and green architectural design in tourism infrastructure is crucial for environmental preservation and for strengthening the destination's image as an ecologically conscious tourism area.

Furthermore, it is essential to establish participatory mechanisms that actively involve all stakeholders in the planning and execution of development programs. To ensure sustainable progress, a regular monitoring and evaluation system based on measurable performance indicators must be implemented. Ongoing evaluation serves as a tool to assess the effectiveness of implemented strategies and provides a foundation for adjusting policies and interventions in areas needing reinforcement. As a key recommendation, this study proposes the development of eco-lodge accommodations in the vicinity of Bali Countryside Sidemen. This type of lodging not only addresses accessibility challenges due to the destination's distance from urban centers but also complements the main attraction of rural and agricultural landscapes. Accommodation design that aligns with local natural aesthetics and sustainability principles is projected to enhance the destination's image as a space for both recreation and cultural reflection, while also encouraging longer stays and higher tourist expenditures.

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# OPTIMIZATION OF THE MARKETING CHAIN OF TRADITIONAL PRODUCTS: A CASE STUDY OF SUPUTRA HERBAL INCENSE IN ABIANSEMAL DISTRICT

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***ABSTRACT***

*Dupa Herbal Suputra, a micro, small, and medium enterprise (MSME) located in Angantaka Village, Abiansemal District, Badung Regency, has great potential in developing natural and spiritually significant herbal incense products. This study aims to analyze the marketing channels and calculate the marketing margins of the herbal incense products. The research used a combination of qualitative and quantitative methods. The study was conducted at Dupa Herbal Suputra MSME in Angantaka Village, Abiansemal District, Badung Regency, over a period of two months, from November to December. Data collection instruments included interviews and recordkeeping. The results showed that there are three marketing channel patterns: (1) a one-level channel (producer–consumer), (2) a two-level channel (producer–retailer–consumer), and (3) a three-level channel (producer–collector–retailer–consumer). The marketing margin for Dupa Herbal Suputra was zero in the first channel due to direct transactions. The second channel yielded a margin of IDR 3,000, while the third channel provided a margin of IDR 5,000. This study recommends enhancing direct marketing through digital platforms to improve efficiency and producer margins. In addition, training in business management and market access is important to improve the competitiveness of local MSMEs.*

***Keywords**: Marketing Channel, Marketing Margin, Herbal Incense, MSME,*

## INTRODUCTION

In the context of an increasingly digitalized global economy, the development of information technology serves as a key catalyst in accelerating the transformation of business sectors, including micro, small, and medium enterprises (MSMEs). This advancement not only expedites production and distribution activities but also revolutionizes marketing strategies through digital platforms, e-commerce, and integrated logistics systems (Tiwari et al., 2021; Xu et al., 2020). MSMEs are required to adapt to these dynamics by building responsive and efficient supply chain and marketing systems, utilizing technology as a tool for decision-making and market expansion (Gunasekaran et al., 2017; Gadde & Håkansson, 2001). Digitalization provides opportunities to expand market reach through online channels, strengthen customer relationships via social media, and enhance operational efficiency through business process automation (Kotler & Keller, 2016; Chatterjee et al., 2021). However, it also increases competition intensity, as consumers have broader access to compare prices, quality, and services. In this context, MSMEs must optimize distribution efficiency and service quality as a form of competitive advantage (Melovic et al., 2022).

In the agribusiness sector, marketing plays a vital role as a connector between upstream producers and downstream consumers. This role goes beyond merely distributing products; it also involves value creation through packaging, branding, and crafting integrated consumer experiences (Bairagi et al., 2018; Wang et al., 2018). The effectiveness of marketing systems in agribusiness can be measured using indicators such as marketing margins, logistics costs, product damage rates, and farmer's share, the proportion of final prices received by farmers or producers (Acharya & Agarwal, 2010; Trienekens, 2011). Marketing channels, comprising various intermediaries such as agents, retailers, and distributors, determine how value and products flow along the distribution chain. The structure of these channels influences overall system efficiency and plays a role in final market pricing (Yuliardi, 2021; Gereffi & Fernandez-Stark, 2016). When the channel structure is inefficient, distribution costs rise, producers' profit margins shrink, and value gaps between supply chain actors widen (Hartono, 2020; Kurniawati et al., 2022). One of the key indicators used to evaluate distribution system sustainability is the marketing margin, the difference between the consumer's payment and the producer's receipt.

Margins that are disproportionate to the distribution functions performed lead to inequities that disadvantage producers, particularly community-based MSMEs with limited bargaining power (Kohls & Uhl, 2002; Fernandez-Stark et al., 2011). A real illustration of these challenges is the Suputra Herbal Incense MSME in Angantaka Village, Badung Regency, Bali, which demonstrates how high-value products such as herbal incense made from agarwood, masohi, and cinnamon have not yet fully benefited from their market value due to a suboptimal distribution system (Septiani, 2021). Since its establishment in 2015, this business has shown steady growth, yet the owner continues to struggle with understanding distribution channel structures, calculating margins for each marketing path, and optimizing logistics cost efficiency (Daryanto & Nurmalina, 2015).

This lack of knowledge becomes a structural barrier in developing sustainable marketing strategies. Moreover, the use of high-quality natural raw materials increases production costs, which are not matched by profit margins, especially when distribution channels are controlled by intermediaries (Hartono, 2020; Melovic et al., 2022). Therefore, an analytical approach to the structure and efficiency of distribution channels is necessary, one that considers not only technical aspects but also the political economy of value systems and market governance (Trienekens, 2011; Reardon et al., 2012). By evaluating marketing margins, farmer's share, and logistics costs, MSMEs such as Suputra Herbal Incense can design more equitable and efficient distribution models that focus on empowering local producers (Gereffi & Fernandez-Stark, 2016; Wang et al., 2018). This is essential to ensure business sustainability, enhance competitiveness in domestic and international markets, and avoid excessive dependence on external marketing institutions that are often non-transparent in value allocation (Kurniawati et al., 2022).

## RESEARCH METHODS

This study was conducted at the Suputra Herbal Incense MSME, located in Angantaka Village, Abiansemal District, Badung Regency, Bali Province. The research took place over a two-month period, from November to December. The location was selected purposively, based on the consideration that this MSME processes natural raw materials such as agarwood, benzoin, and teak wood into herbal incense products used for spiritual activities, health purposes, and as a livelihood source for the local community. Furthermore, there has been no prior research specifically examining the marketing of herbal incense in this area, thereby providing academic opportunities for further scientific exploration.

This study employed two main types of data: qualitative and quantitative. Qualitative data were collected to understand existing distribution patterns and marketing structures, and were analyzed descriptively to build a comprehensive understanding of the empirical realities encountered (Sugiyono, 2018). Meanwhile, quantitative data were used to measure variables such as selling price, production volume, marketing margins, and producers' income. These quantitative data were analyzed using mathematical methods to support the qualitative findings. The sources of data consisted of both primary and secondary data. Primary data were directly obtained from business actors and key respondents through interviews, observations, and direct field visits. The information collected included business profiles, marketing flows, and cost components. Secondary data were obtained through supporting documents, internal business reports, production records, and references from relevant literature or scientific publications (Sugiyono, 2018). The population in this study included all marketing actors in the Suputra herbal incense distribution chain, consisting of producers (the MSME owner), wholesalers, retailers, and consumers. Based on field data, the total population comprised 14 individuals: 5 wholesalers, 4 retailers, and 5 consumers. A census method was used for sampling, in which all members of the population were included as research respondents. Consumer selection focused on regular buyers who made purchases at least three to four times a week.

Several data collection methods were applied in this research. First, in-depth semi-structured interviews were conducted using open-ended questions to gather information from various key respondents. Second, field observations were conducted to obtain real-time insights into the production, transaction, and distribution activities. Third, a literature review was employed to explore relevant documents and references, both from the MSME and online sources. Lastly, documentation was used to complement visual and narrative data through photos, quotations, or other written materials that supported the validity of the findings. Data analysis was carried out using descriptive and quantitative approaches. First, to analyze the marketing channels, a distribution flow was traced from the producer to the end consumer. Information was gathered through interviews with distribution actors regarding marketing paths, selling prices, and margins at each distribution point. Second, the marketing margin was calculated to determine the price difference between the producer's selling price and the final consumer's purchase price, formulated as follows:

$$Mp = Pf - Pr$$

Description:
Mp = Marketing margin (Rp/package)
Pf = Price received by the final consumer (Rp/package)
Pr = Selling price from the producer (Rp/package)

Through this approach, the researcher can evaluate the level of marketing efficiency and identify opportunities for improving distribution strategies that are more beneficial for the producer.

## RESEARCH RESULTS AND DISCUSSION

### Marketing Channels

Marketing channels refer to the sequence of institutions or individuals involved in delivering products from producers to consumers, either directly or through various intermediaries (Kotler & Keller, 2016). The findings from the study conducted at the Suputra Herbal Incense MSME in Angantaka Village, Abiansemal District, reveal that the producer employs three primary distribution patterns to market their herbal incense products. These patterns illustrate how the product flows through different pathways before reaching the end user. The marketing channel structure adopted by the herbal incense business is presented in Table 1, which outlines the specific routes and actors involved in the product's distribution.

Table 1. The Marketing Channel Structure Adopted By The Herbal Incense Business

| Marketing Channel | Number (people) | Percentage (%)) |
|---|---|---|
| Channel I:<br>Producer<br>Consumer<br>Channel II:<br>Producer<br>Retailer<br>Consumer<br>Channel III:<br>Producer<br>Collector<br>Retailer<br>Consumer | 5 | 36% |
| **Total** | | |
| Channel I:<br>Producer<br>Consumer<br>Channel II:<br>Producer<br>Retailer<br>Consumer<br>Channel III:<br>Producer<br>Collector<br>Retailer<br>Consumer | 4 | 28% |

| | | |
|---|---|---|
| Total<br>Channel I:<br>Producer<br>Consumer<br>Channel II:<br>Producer<br>Retailer<br>Consumer<br>Channel III:<br>Producer<br>Collector<br>Retailer<br>Consumer<br>Total | 5 | 36% |
| Channel I:<br>Producer<br>Consumer | 14 | 100% |

*Source: Processed Primary Data, 2024*

Based on the research findings, Channel I is a single-level (direct) channel, where the producer sells directly to the end consumer without intermediaries. The results show that 5 respondents, or approximately 36%, use this model. This channel is typically used situationally, especially when the producer needs quick income or is fulfilling specific demands such as for religious offerings or yoga needs. This type of channel is considered the most efficient as it incurs no additional distribution costs and allows producers to obtain the maximum profit (Kohls & Uhl, 2002; Gereffi & Fernandez-Stark, 2016). Channel II is a two-level channel, involving retailers as the sole intermediary between producers and consumers. This pattern was used by 4 respondents (28%) in the study. Retailers purchase the products directly from producers and then resell them to consumers with a certain margin. This distribution model is still considered efficient, as it helps producers reach a broader market without significantly extending the distribution chain (Coughlan et al., 2006). Channel III is a three-level channel involving both wholesalers and retailers before the product reaches the final consumer. A total of 5 respondents, or 36%, reported using this distribution path. In this scheme, producers sell their herbal incense to wholesalers, who then sell them to retailers before finally reaching the end consumers. Although this channel broadens market coverage, it increases marketing costs and reduces producers' profit margins (Hartono, 2020). These results indicate that the variation in marketing channels used by the Suputra Herbal Incense MSME is influenced by factors such as production volume, the availability of distribution networks, and the producer's need to adapt to local market dynamics. Therefore, selecting an efficient marketing channel is a crucial aspect in improving the competitiveness and sustainability of MSMEs (Kotler & Keller, 2016; Barbieri & Mshenga, 2008).

### 3.2. Marketing Margin, Farmer's Share, and Marketing Efficiency

The marketing margin is the difference between the product's selling price received by the consumer and the price received by the producer at the initial level (Kohls & Uhl, 2002). This price gap reflects the accumulation of various costs incurred by marketing institutions during the distribution process, including transportation, storage, and the profit margins of each intermediary (Hartono, 2020). The longer the distribution chain, the larger the marketing margin tends to be, as more actors are involved in claiming a share of the product's selling value (Acharya & Agarwal, 2010). In the case of herbal incense produced by the Suputra Herbal Incense MSME, the marketing margin, farmer's share, and marketing efficiency are presented in Table 2.

Table 2. Marketing Margin, Farmer's Share, and Marketing Efficiency of Suputra Herbal Incense MSME

| Uraian | Saluran I | Saluran II | Saluran III |
|---|---|---|---|
| Produsen | | | |
| Harga Jual | 25.000 | 22.000 | 20.000 |
| Pedagang Pengempul | | | |
| Harga Beli | | | 20.000 |
| Biaya Transpotasi | | | 645.72 |
| Harga Jual | | | 25.000 |
| Margin Pemasaran | | | 5.000 |
| Margin Keuntungan | | | 4.354.28 |
| Pegagan Pengecer | | | |
| Harga Beli | | 23.000 | 25.000 |
| Biaya Transportasi | | 450.89 | 500 |
| Harga Jual | | 25.000 | 27.000 |
| Margin Pemasaran | | 3.000 | 2.000 |
| Margin Keuntungan | | 2.549.11 | 1.500 |
| Konsumen | | | |
| Harga Beli | 25.000 | 25.000 | 27.000 |

*Source: Processed Primary Data, 2024*

The study conducted on Suputra Herbal Incense MSME revealed significant differences in marketing margins across different distribution channels. In Marketing Channel I, producers sell directly to consumers without involving any intermediaries, meaning no marketing margin is formed. This model is categorized as a direct channel, which, according to Kotler & Keller (2016), provides the highest efficiency as the entire selling price is received directly by the producer. This offers optimal profit opportunities, particularly for small-scale producers who have direct access to consumers. In Channel II, producers sell their products to retailers, who then distribute them to consumers. Based on the data, a marketing margin of Rp3,000 is generated at the retailer level, with operational costs amounting to Rp450.89 and a net profit of Rp2,549.11. Although one intermediary is involved, this channel is still considered relatively efficient due to the low distribution costs compared to the product's selling value (Coughlan et al., 2006). This strategy also allows for a wider market reach than the direct channel.

Channel III involves two intermediaries: wholesalers and retailers. Producers sell the herbal incense at Rp20,000 to wholesalers, who then resell it to retailers for Rp25,000. Wholesalers earn a margin of Rp5,000, minus transportation costs of Rp645.72, resulting in a net margin of Rp4,354.28. Retailers then sell the product to consumers for Rp27,000, earning a net margin of Rp1,500. This distribution structure illustrates how the addition of more marketing institutions can reduce the share of profits received by the producer (Bairagi et al., 2018). In addition to marketing margin, distribution efficiency can also be assessed through the Farmer's Share, which is the proportion of the final selling price received by the producer. In Channel I, the farmer's share reaches 100%; in Channel II, it drops to 88%; and in Channel III, it further decreases to 74%. These figures indicate that the more intermediaries involved in the supply chain, the smaller the share of the final product value received by producers (Acharya & Agarwal, 2010). This imbalance could threaten the sustainability of small enterprises by reducing production incentives and weakening producers' bargaining positions in the market. Therefore, choosing the appropriate marketing channel structure should consider the balance between market reach and margin efficiency. Short channels are more suitable for preserving producers' profit margins, while longer channels can be used to expand market reach, provided they are accompanied by cost-efficiency strategies to avoid disadvantaging producers (Kotler & Keller, 2016; Gereffi & Fernandez-Stark, 2016).

## CONCLUSION AND RECOMMENDATIONS

Based on the research findings, several conclusions can be drawn as follows. The marketing system of herbal incense products at Suputra Herbal Incense MSME is divided into three distribution channel patterns. The first channel is a single-level distribution that connects the producer directly to the consumer without involving intermediaries, thus incurring no additional margins. The second channel involves one intermediary, namely the retailer, resulting in a marketing margin of Rp3,000 per package. The third channel involves two intermediaries—wholesalers and retailers—and generates the highest marketing margin of Rp5,000 per package. Therefore, it can be concluded that the longer the distribution channel used, the greater the marketing margin formed, which in turn reduces the proportion of income directly received by the producer. Based on these findings, it is recommended that Suputra Herbal Incense MSME optimize the use of direct distribution channels (single-level channels) to maximize income and reduce distribution costs. Marketing actors such as wholesalers and retailers are also encouraged to choose more efficient distribution channels, both in terms of cost and delivery time to end consumers, in order to optimize profits. To support overall marketing efficiency, it is important for all parties within the distribution chain to prioritize price transparency and strategic collaboration in designing a marketing model focused on sustainability. Furthermore, to enrich academic discourse, future research is highly recommended to not only focus on marketing aspects but also include studies on production, raw material supply chains, and innovation and development of herbal incense products moving forward.

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