The Effect of Moringa Leaf Extract Application on the Growth of Red Chili Pepper (*Capsicum annuum* L.)

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Abstract: The productivity of red chili pepper (*Capsicum annuum* L.) continues to face various challenges, particularly due to declining soil fertility and the heavy reliance on inorganic fertilizers, which may have adverse environmental impacts. One promising alternative is the utilization of *Moringa oleifera* Lam. leaf extract as a natural biostimulant because of its rich nutrient content and plant growth-promoting compounds. This study aimed to analyze the effect of *Moringa oleifera* leaf extract application on the growth of red chili pepper based on plant height, number of leaves, and stem diameter. A true experimental design was employed using a Completely Randomized Design (CRD) consisting of seven treatments: P0 (0 mL), P1 (10 mL), P2 (20 mL), P3 (30 mL), P4 (40 mL), P5 (50 mL), and P6 (60 mL), with five replications for each treatment. Data were analyzed using normality and homogeneity tests, followed by one-way analysis of variance (One-Way ANOVA) and the Least Significant Difference (LSD) post hoc test at a 5% significance level. The results indicated that all data were normally distributed and homogeneous. ANOVA revealed that *Moringa oleifera* leaf extract had a significant effect on plant height ($p = 0.046$), number of leaves ($p = 0.044$), and stem diameter ($p = 0.037$). The P6 treatment (60 mL) produced the best vegetative growth, with a mean plant height of 13.20 cm, 10.40 leaves, and a stem diameter of 0.72 cm. These findings suggest that *Moringa oleifera* leaf extract has considerable potential as a natural organic biostimulant to enhance the vegetative growth of red chili pepper in a sustainable cultivation system.

Keywords: *Capsicum annuum* L., *Moringa oleifera* leaf extract, vegetative growth, natural biostimulant.

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Introduction

Red chili pepper (*Capsicum annuum* L.) is one of the most economically important horticultural commodities because of its extensive use as a vegetable, spice, and raw material in the food processing industry. Market demand for red chili remains consistently high throughout the year, making it a strategic commodity for strengthening food security and increasing farmers' income. Indonesia possesses favorable tropical agroclimatic conditions that enable chili cultivation across a wide range of agroecosystems. Nevertheless, despite increasing cultivation areas, productivity remains below its genetic potential in many production regions, indicating the need for more effective and sustainable crop management strategies (Aini, 2019; Anoviansyah et al 2019; Arini, 2019).

One of the primary constraints limiting red chili productivity is the decline in soil fertility associated with intensive agricultural practices (Banu et al, 2018; Chrissanty et al., 2011). Environmental stresses, including climate variability, pest and disease incidence, and deterioration of soil physical, chemical, and biological properties, further reduce crop performance (Diantoro et al., 2015; Dima et al., 2016). To compensate for nutrient deficiencies, farmers frequently rely on synthetic fertilizers because they provide readily available nutrients and promote rapid plant growth. However, long-term and excessive application of inorganic fertilizers has been associated with soil degradation, disruption of beneficial soil microbial communities, nutrient imbalance, and increased environmental pollution, ultimately threatening the sustainability of agricultural production systems (Hala et al., 2017; Karim et al., 2018; Krisno et al., 2008).

Growing concerns regarding sustainable agriculture have encouraged the exploration of environmentally friendly alternatives capable of improving crop productivity while reducing dependence on chemical fertilizers. Among various natural resources, *Moringa oleifera* Lam. has attracted considerable scientific attention because its leaves contain substantial concentrations of macro- and micronutrients, amino acids, vitamins, antioxidants, phenolic compounds, and naturally occurring phytohormones, particularly zeatin, which functions as a cytokinin promoting cell division, chlorophyll formation, and vegetative growth (Mahanani & Kogova, 2018; Manggara & Shofi, 2018). Consequently, *Moringa* leaf extract has been increasingly recognized as a natural biostimulant capable of enhancing nutrient uptake, photosynthetic efficiency, and plant resilience under diverse environmental conditions (Maulana & Yoseven, 2015; Moekasan et al., 2016).

Numerous studies have demonstrated the positive effects of *Moringa* leaf extract on the growth and productivity of horticultural crops. Nasir et al. (2010) reported significant improvements in vegetative growth, nutrient status, and

yield following foliar application of *Moringa* leaf extract. Likewise, Nugroho (2018) found that *Moringa* leaf extract significantly increased plant height, leaf number, and fresh biomass of lettuce. Similar findings have also been reported in tomato, onion, maize, and several leafy vegetables, suggesting that *Moringa* leaf extract functions effectively as a natural biostimulant capable of stimulating plant metabolism and growth through both nutritional and hormonal mechanisms (Nurwulan, 2018).

Despite these promising findings, studies investigating the application of *Moringa* leaf extract in red chili cultivation remain relatively limited. Existing research has predominantly focused on leafy vegetables or evaluated only a limited number of growth variables (Putra & Sudirmatini, 2016). Furthermore, comparative information regarding the response of red chili plants to different application rates of *Moringa* leaf extract under controlled experimental conditions remains scarce (Qosim et al., 2013). This indicates a clear research gap concerning the optimization of *Moringa* leaf extract dosage and its comprehensive effects on key vegetative growth parameters, including plant height, leaf development, and stem diameter in *Capsicum annuum*.

Therefore, this study aimed to evaluate the effect of different concentrations of *Moringa oleifera* leaf extract on the vegetative growth of red chili (*Capsicum annuum* L.) using a Completely Randomized Design. The novelty of this study lies in the comprehensive evaluation of multiple vegetative growth indicators under graded application rates of *Moringa* leaf extract, providing empirical evidence for its potential use as an environmentally friendly biostimulant in sustainable red chili cultivation. The findings are expected to contribute to the development of locally available organic inputs while supporting environmentally sustainable horticultural production systems.

Methods

Study Area and Experimental Design

This study was conducted from March to May 2021 in Hilisanekhehösi Village, Onolalu District, South Nias Regency, North Sumatra, Indonesia. A quantitative approach employing a true experimental design was used to evaluate the effect of *Moringa oleifera* leaf extract on the growth of red chili pepper (*Capsicum annuum* L.). The experiment was arranged using a Completely Randomized Design (CRD) consisting of seven treatments with five replications, resulting in a total of 35 experimental units. The experimental units were randomly assigned to minimize the influence of uncontrolled environmental factors (Sugiyono, 2015).

The treatments consisted of P0 (control, without *Moringa* leaf extract), P1 (10 mL), P2 (20 mL), P3 (30 mL), P4 (40 mL), P5 (50 mL), and P6 (60 mL) of *Moringa* leaf extract. Each treatment was replicated five times, giving a total of 35 experimental plants. The independent variable was the volume of *Moringa* leaf extract applied, whereas the dependent variables were plant growth parameters, including plant height, number of leaves, and stem diameter.

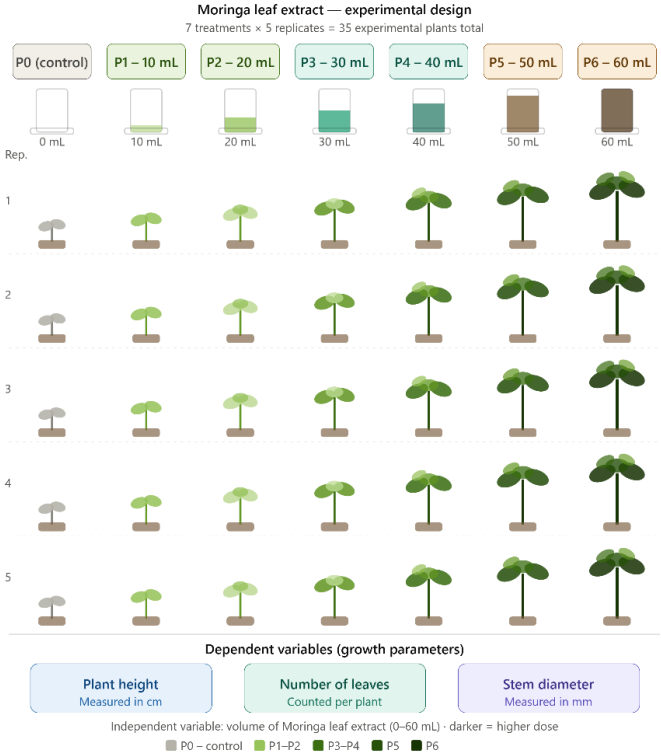

Figure 1. Moringa leaf extract — experimental design

Plant Materials and Experimental Procedures

The materials used in this study included 500 g of fresh young *Moringa oleifera* leaves, 1.5 L of water, 1 kg of rice husk, black soil as the planting medium, red chili pepper seeds, and water for irrigation. The equipment included a blender, filter, weighing balance, measuring cylinder, hand sprayer, 5-kg polybags, measuring tape, digital caliper, camera, and stationery. The planting medium was prepared by filling 35 labeled polybags with black soil. Red chili seeds were first germinated in a nursery until healthy and uniform seedlings were obtained before being transplanted into the prepared polybags.

Preparation and Application of Moringa oleifera Leaf Extract

Fresh *Moringa oleifera* leaves were thoroughly washed to remove dust and surface contaminants. The cleaned leaves were blended with water to produce a homogeneous mixture, which was subsequently filtered to obtain the liquid extract. The extract was then transferred into a sealed container and mixed with rice husk before storage in a shaded area away from direct sunlight until application (Sumarni & Muharam, 2005).

Uniform red chili seedlings were transplanted into the prepared polybags. The *Moringa* leaf extract was applied by foliar spraying according to the treatment volumes (0, 10, 20, 30, 40, 50, and 60 mL). Applications were carried out once daily at 08:00 a.m. for seven consecutive days with a 24-hour interval between applications. All plants received identical maintenance practices throughout the experiment, with the exception of the different extract volumes applied.

Data Collection

Data were collected through direct observation and photographic documentation. Plant growth was evaluated after treatment application using three vegetative growth parameters: plant height, number of leaves, and stem diameter. Plant height was measured from the base of the stem to the highest growing point using a measuring tape. The number of leaves was determined by direct counting, while stem diameter was measured using a digital caliper. All observations were recorded on observation sheets and documented photographically to ensure data accuracy and traceability.

Statistical Analysis

The collected data were analyzed using IBM SPSS Statistics version 20. Prior to hypothesis testing, data normality was assessed using the Kolmogorov–Smirnov test, whereas homogeneity of variances was evaluated using Levene's test. After confirming that the assumptions of normality and homogeneity were satisfied, the effects of *Moringa oleifera* leaf extract on the growth of red chili pepper were analyzed using one-way analysis of variance (One-Way ANOVA) at a significance level of 5% ($\alpha = 0.05$). When significant differences among treatments were detected, pairwise comparisons were performed using the Least Significant Difference (LSD) post hoc test to identify treatments that differed significantly. The results were presented as tables, graphs, mean values, standard deviations, and descriptive interpretations to facilitate the evaluation of the effects of *Moringa oleifera* leaf extract on the vegetative growth of red chili pepper.

Results

This study aimed to determine the effect of moringa leaf extract application on the growth of red chili plants (*Capsicum annuum* L.), measured through three parameters: plant height, number of leaves, and stem diameter. The treatments consisted of seven levels of moringa leaf extract concentration, namely P0 (0 ml), P1 (10 ml), P2 (20 ml), P3 (30 ml), P4 (40 ml), P5 (50 ml), and P6 (60 ml). Data analysis was performed using SPSS version 20 through normality tests, homogeneity tests, One-Way ANOVA, and further Duncan and LSD tests.

Plant Height of Red Chili (Capsicum annuum L.)

The normality test results showed that the plant height data were normally distributed, with a significance value of 0.064 (>0.05). In addition, the histogram showed that the data distribution followed a normal curve pattern, thus meeting the normality assumption. The homogeneity test produced a significance value of 0.090 (>0.05), indicating that the variance among treatments was homogeneous (Suwahyono, 2008).

The results of the One-Way ANOVA analysis showed that the application of moringa leaf extract had a significant effect on the height of red chili plants, with an F-value of 2.503, which was greater than the F-table value (2.45), and a significance value of 0.046 (<0.05). Therefore, the alternative hypothesis (Ha) was accepted, and the null hypothesis

(H0) was rejected. These results indicate that moringa leaf extract application significantly affected the increase in red chili plant height (Usman & Akbar, 2006).

The Duncan test showed an increasing trend in plant height as the concentration of moringa leaf extract increased. The highest average plant height was obtained in treatment P6 (60 ml) at 13.20 cm, followed by P5 (50 ml) at 10.60 cm, P4 (40 ml) at 9.40 cm, P3 (30 ml) at 8.00 cm, P2 (20 ml) at 7.20 cm, P1 (10 ml) at 6.60 cm, and the lowest height was found in the control treatment P0 (0 ml) at 6.20 cm. The LSD test results showed that treatment P6 was significantly different from P0, P1, P2, and P3 treatments, while its differences with P4 and P5 were not significant. These findings indicate that a 60 ml concentration of moringa leaf extract provided the greatest effect on increasing the height of red chili plants.

Number of Leaves of Red Chili Plants (Capsicum annuum L.)

The normality test results showed that the data on the number of leaves were normally distributed, with a significance value of 0.060 (>0.05). The homogeneity test also indicated that the data were homogeneous, with a significance value of 0.100 (>0.05).

The One-Way ANOVA analysis showed that the application of moringa leaf extract had a significant effect on the number of leaves of red chili plants. This was indicated by an F-value of 2.533, which was greater than the F-table value (2.45), and a significance value of 0.044 (<0.05). Therefore, Ha was accepted and H0 was rejected.

Based on the Duncan test, the highest average number of leaves was obtained in treatment P6 (60 ml) at 10.40 leaves, followed by P5 (50 ml) at 9.00 leaves, P4 (40 ml) at 8.40 leaves, P3 (30 ml) at 5.20 leaves, P2 (20 ml) at 4.60 leaves, P1 (10 ml) at 4.40 leaves, and P0 (0 ml) at 4.20 leaves.

The LSD test results showed that treatment P6 was significantly different from P0, P1, P2, and P3 treatments. In addition, treatment P5 was also significantly different from the control treatment (P0). Overall, P6 produced the highest number of leaves compared with other treatments, indicating that it was the most effective treatment in increasing leaf formation in red chili plants (Wijaya et al., 2009)

Stem Diameter of Red Chili Plants (Capsicum annuum L.)

The normality test results showed that stem diameter data were normally distributed, with a significance value of 0.062 (>0.05). The homogeneity test produced a significance value of 0.101 (>0.05), indicating that the data had homogeneous variance. The One-Way ANOVA test results showed that moringa leaf extract application had a significant effect on the stem diameter of red chili plants, with an F-value of 2.643, which was greater than the F-table value (2.45), and a significance value of 0.037 (<0.05). Therefore, Ha was accepted and H0 was rejected.

Based on the Duncan test results, the highest average stem diameter was obtained in treatment P6 (60 ml) at 0.72 cm, while other treatments showed lower values, namely P5 (0.54 cm), P4 (0.54 cm), P3 (0.52 cm), P2 (0.50 cm), P1 (0.46 cm), and P0 (0.44 cm). The LSD test results showed that treatment P6 was significantly different from all other treatments (P0, P1, P2, P3, P4, and P5). In contrast, most treatments other than P6 did not show significant differences from each other. Therefore, P6 was the most effective treatment in increasing stem diameter of red chili plants.

Table 1. Growth Response of Red Chili Plants Based on Treatment

Treatment	Moringa Leaf Extract Concentration	Plant Height (cm)	Number of Leaves	Stem Diameter (cm)
P0	0 ml (Control)	6.20	4.20	0.44
P1	10 ml	6.60	4.40	0.46
P2	20 ml	7.20	4.60	0.50
P3	30 ml	8.00	5.20	0.52
P4	40 ml	9.40	8.40	0.54
P5	50 ml	10.60	9.00	0.54
P6	60 ml	13.20	10.40	0.72

Overall, the results showed that the application of moringa leaf extract significantly affected the growth of red chili plants (*Capsicum annuum* L.) across all observed parameters, including plant height, number of leaves, and stem diameter. Treatment P6 (60 ml moringa leaf extract) produced the best growth response, with an average plant height of 13.20 cm, 10.40 leaves, and a stem diameter of 0.72 cm. These findings indicate that higher concentrations of moringa leaf extract resulted in better growth of red chili plants, and therefore, a concentration of 60 ml can be recommended as the most effective treatment in this study.

The results showed that moringa leaf extract application had a significant effect on the growth of red chili plants (*Capsicum annuum* L.) based on plant height, number of leaves, and stem diameter. Analysis using SPSS version 20 demonstrated clear differences in growth between plants treated with moringa leaf extract and untreated control plants.

Generally, increasing concentrations of moringa leaf extract were followed by increased growth in all observed parameters.

The average plant height increased from 6.2 cm in the control treatment (P0) to 13.2 cm in treatment P6 (60 ml). Similarly, the number of leaves increased from 4.2 leaves in P0 to 10.4 leaves in P6, while stem diameter increased from 0.44 mm to 0.72 mm. These results indicate that treatment P6 provided the best growth response compared with other treatments. The increase in growth was presumably caused by the higher availability of nutrients, particularly nitrogen (N), supplied through moringa leaf extract, which supported optimal vegetative growth processes.

In contrast, the lowest growth was observed in the control treatment (P0), indicating that limited nutrient availability could inhibit plant physiological processes. The further test results (LSD) also showed that all treatments using moringa leaf extract produced better growth than treatments without extract application. These findings support previous studies indicating that moringa leaf extract has potential as a natural nutrient source to improve the growth of red chili plants, particularly in terms of plant height, leaf number, and stem diameter.

Conclusion

This study confirms that moringa leaf extract has potential as a natural biostimulant that can be utilized to support red chili plant growth in a more sustainable and environmentally friendly manner. These findings provide practical implications for developing alternative organic fertilizers based on locally available resources that are easily accessible and relatively economical for farmers.

However, this study has limitations because it was conducted only on an experimental scale with a relatively short observation period and focused on vegetative growth parameters without evaluating yield productivity, plant nutrient content, or physiological mechanisms underlying plant responses to moringa leaf extract. Therefore, future studies are recommended to evaluate the effects of moringa leaf extract at various growth stages until fruit production, test its effectiveness under field conditions and different soil types, and identify the optimum concentration and active compounds responsible for improving plant growth. Thus, the utilization of moringa leaf extract can be further developed as a comprehensive component of sustainable agricultural strategies in the future.

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