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Vegetative Growth Response of Cayenne Pepper (*Capsicum frutescens* L.) to Different Concentrations of Pineapple Peel Liquid Organic Fertilizer

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Abstract: Pineapple peel has potential as a raw material for liquid organic fertilizer (LOF), providing an alternative strategy for organic-waste management while supporting plant nutrition. This study evaluated the vegetative growth response of cayenne pepper (Capsicum frutescens L.) to different concentrations of pineapple peel LOF. An experimental study with a descriptive quantitative approach employed a one-factor completely randomized design comprising four treatments: P0 (0 mL L^{-1}), P1 (10 mL L^{-1}), P2 (20 mL L^{-1}), and P3 (30 mL L^{-1}). Each treatment was replicated five times, resulting in 20 experimental units. Each plant received 200 mL of treatment solution every four days. Plant height, stem diameter, number of leaves, and leaf width were measured every three days until 65 days after planting. The data were analyzed descriptively using treatment means. P3 showed the highest mean values for plant height (6.886 cm), stem diameter (2.724 mm), number of leaves (6.536), and leaf width (2.948 cm). The lowest mean plant height was recorded in P2 (5.950 cm), while P1 produced the lowest stem diameter (2.462 mm), number of leaves (5.326), and leaf width (2.684 cm). The response was not linear because P1 and P2 produced lower means than the control for several parameters. Within the tested concentration range, 30 mL L^{-1} showed the most favorable descriptive tendency for supporting the vegetative growth of cayenne pepper. However, statistical significance cannot be inferred because no inferential analysis was conducted.

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INTRODUCTION

Cayenne pepper (*Capsicum frutescens* L.) is a horticultural commodity with high economic value and consumption, particularly in tropical countries. Its fruit is used as food, a spice, a raw material for the processing industry, and a source of various bioactive compounds. Peppers contain vitamins, minerals, carotenoids, phenolic compounds, flavonoids, and capsaicinoids that contribute to antioxidant, anti-inflammatory, and antimicrobial activities, as well as other health benefits (Olatunji & Afolayan, 2018; Batiha et al., 2020). These economic and nutritional benefits make improvements in cayenne pepper productivity important. However, productivity is strongly influenced by early growth conditions, particularly the plant's ability to develop healthy vegetative organs before flowering and fruit formation.

Vegetative growth is a critical phase in the life cycle of pepper plants because it determines their capacity for photosynthesis, water and nutrient uptake, and biomass formation to support reproductive growth. Plant height, stem diameter, leaf number and area,

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root development, and fresh and dry weights are commonly used to describe vegetative responses to environmental conditions and nutrient availability. Growth and biomass accumulation in pepper plants are closely related to fertilizer management, particularly the availability of nitrogen, phosphorus, and potassium. Pepper growth models indicate that dry-matter production and nutrient uptake are strongly affected by fertilization rate and by soil and environmental conditions (Tang et al., 2023). Adequate nitrogen can increase leaf area, root growth, shoot biomass, and productivity, whereas nitrogen deficiency or excess may disrupt the balance between vegetative and reproductive growth (Albornoz, 2016; de Ávila Silva et al., 2019; Grasso et al., 2020; Chemweno et al., 2025).

The response of pepper plants to fertilization does not necessarily increase linearly with fertilizer dose or concentration. Subedi et al. (2023) showed that different nitrogen levels and carbon amendments produced different responses in plant height, leaf area, root length, branch number, and pepper yield. Under nutrient-deficient conditions, leaf, stem, and root growth may be restricted because chlorophyll, protein, metabolic energy, and new tissues cannot be formed adequately. Conversely, excessive nutrient levels may increase salt concentrations in the root zone, reduce nutrient-uptake efficiency, promote excessive shoot growth, and disrupt the allocation of photosynthates between vegetative and reproductive organs. Determining an appropriate fertilizer concentration is therefore an important aspect of cayenne pepper cultivation.

Pepper production still relies heavily on inorganic fertilizers because their nutrients are readily available and can be absorbed quickly by plants. However, continuous and imbalanced use of inorganic fertilizers may increase production costs, reduce soil organic matter, contribute to soil acidification, and increase nutrient losses through leaching and surface runoff. Organic fertilizers can be used as alternatives or supplements because they supply nutrients while improving the physical, chemical, and biological properties of soil. They may increase soil water-holding capacity, improve soil aggregation, provide substrates for microorganisms, and enhance plant nutrient-use efficiency.

Liquid organic fertilizer is one form of organic fertilizer with potential applications in horticultural production. Because it contains nutrients and organic compounds in dissolved form, it can be applied relatively easily to the soil or root zone. Its effectiveness depends on the raw materials, fermentation process, maturity, nutrient content, pH, electrical conductivity, concentration, application frequency, and application method. Liquid organic fertilizers have been reported to improve plant growth, nutrient uptake, and rhizosphere soil characteristics (Ji et al., 2017; Martínez-Alcántara et al., 2016). In addition to supplying nutrients, liquid organic materials may contain organic acids, amino acids, humic substances, and other metabolites that exert biostimulant effects on plant growth (Rouphael & Colla, 2020).

The use of organic fertilizers and organic biostimulants in Capsicum crops has produced promising results. Corn-steep-liquor-based organic extracts can improve pepper growth and nitrogen-use efficiency under nitrogen-limited conditions (Navarro-Morillo et al., 2024). Biofertilizers combined with organic fertilizers have also been shown to increase the uptake of nitrogen, phosphorus, potassium, and micronutrients and to support bell pepper productivity (Sini et al., 2024). Stoleru et al. (2023) reported that organic and biological fertilizers may affect yield, mineral content, phytochemical compounds, and the nutritional quality of bell pepper fruit. These findings indicate that organic materials can be important components of pepper nutrient management, although their effectiveness depends on the type of material and the application rate.

Pineapple peel is a locally available organic material that could be developed into liquid organic fertilizer. Pineapple processing and consumption generate waste in the form of peel, crowns, cores, leaves, stems, and residual fruit flesh. Pineapple peel is often discarded without treatment even though it contains organic matter, carbohydrates, fiber, minerals, and potentially useful bioactive compounds. Direct disposal of pineapple waste may generate odors, increase the organic load, produce acidic leachate, and contribute to environmental pollution. By contrast, this waste can be converted into value-added products through fermentation, composting, vermicomposting, biochar production, bioactive-compound extraction, and anaerobic digestion (Banerjee et al., 2018; Aili Hamzah et al., 2021).

Converting pineapple waste into organic fertilizer is an application of circular-economy principles in agriculture. This approach returns nutrients and organic matter from waste to the crop-production system. Composting and vermicomposting can increase the stability of pineapple-derived organic matter and produce safer soil amendments (Castillo-González et al., 2019). Controlled vermicomposting systems can also recover part of the nutrient content of pineapple waste and generate organic products with potential agricultural value (Zziwa et al., 2021). The use of these processed organic-waste products can reduce the amount of discarded material while decreasing farmers' dependence on external fertilizer inputs (Chen et al., 2020).

Pineapple-waste-based organic materials have been investigated in several forms. Pineapple-waste biochar and compost have been reported to improve plant growth and yield by enhancing soil quality and nutrient availability (Hanyabui et al., 2024). A combination of pineapple-leaf biochar and *Trichoderma*-based biofertilizer also affected the growth, yield, and nutrient content of habanero pepper (Mahdian et al., 2025). In continuously cultivated pepper, biochar and vermicompost applications can improve nitrogen, phosphorus, and potassium uptake, fertilizer efficiency, soil quality, and plant growth (Zhang et al., 2023). Nevertheless, biochar, compost, and vermicompost differ from pineapple-peel liquid organic fertilizer in their properties and nutrient-release patterns. Findings obtained with these solid organic materials therefore cannot be used directly to predict plant responses to pineapple-peel liquid organic fertilizer.

Pineapple-peel liquid organic fertilizer has been tested on several crops, but information regarding its application to cayenne pepper remains limited. Cristina et al. (2022) reported that the concentration and application frequency of pineapple-peel liquid organic fertilizer affected shallot growth. Their findings suggest that this fertilizer can serve as a nutrient source, although its effectiveness depends on the application concentration. In pepper cultivation, poultry manure can affect the growth, yield, and quality of cayenne pepper (Kusumiyati et al., 2024), whereas combinations of rabbit-urine organic fertilizer and NPK fertilizer produce particular responses in the growth and production of red pepper (Rismayanti et al., 2024). Liquid biofertilizer derived from cocoa-shell waste has also been reported to affect the plant height, stem diameter, and chlorophyll content of *Capsicum chinense* differently at different application rates (Solórzano et al., 2025). Collectively, these findings show that both the source and concentration of liquid organic fertilizer influence the growth response of Capsicum plants.

The concentration of pineapple-peel liquid organic fertilizer requires careful consideration because it determines the quantities of nutrients, organic compounds, acidity, and fermentation products received by the plant. A concentration that is too low may not supply enough nutrients to improve leaf formation, stem elongation, root development, and biomass accumulation. An appropriate concentration may increase nutrient availability and support plant metabolism. However, an excessively concentrated solution may increase osmotic pressure, electrical conductivity, organic-acid levels, or the concentration of unstable fermentation products. These conditions may restrict water and nutrient uptake, interfere with root activity, or create nutrient imbalances. Consequently, the highest fertilizer concentration does not always produce the greatest plant growth.

Although research on pineapple-waste processing and the use of organic fertilizers in pepper cultivation continues to expand, evidence remains limited regarding the vegetative response of *C. frutescens* to different concentrations of pineapple-peel liquid organic fertilizer. Previous studies have generally used pineapple waste as compost, vermicompost, or biochar, or have tested pineapple-peel liquid organic fertilizer on crops other than cayenne pepper. Fertilization studies on pepper have more commonly examined inorganic fertilizers, animal manure, animal urine, biofertilizers, or other organic materials. Few studies have specifically evaluated how increasing concentrations of pineapple-peel liquid organic fertilizer affect cayenne pepper plant height, stem diameter, leaf number and area, root development, and biomass.

Accordingly, this study aimed to analyze the vegetative growth of cayenne pepper (*Capsicum frutescens* L.) under different concentrations of pineapple-peel liquid organic fertilizer. The study was based on the expectation that plant growth would respond differently to fertilizer concentration and that one concentration would provide more favorable conditions for vegetative development. The findings were expected to provide a scientific basis for selecting an effective concentration, support the sustainable use of pineapple waste, reduce dependence on inorganic fertilizers, and strengthen circular-economy-based nutrient management in cayenne pepper cultivation.

RESEARCH METHOD

Research Type and Approach

This study used an experimental method with a descriptive quantitative approach. Cayenne pepper plants (*Capsicum frutescens* L.) were treated with several concentrations of pineapple-peel liquid organic fertilizer, and their vegetative growth was described using plant height, stem diameter, leaf number, and leaf width.

A quantitative approach was used because plant-growth data were obtained through measurement and expressed numerically. The observations were analyzed descriptively by calculating totals and treatment means. This analysis was used to compare growth trends among the tested fertilizer concentrations without conducting statistical significance tests.

Experimental Design

The experiment employed a one-factor completely randomized design (CRD). The treatment factor was the concentration of pineapple peel liquid organic fertilizer, consisting of four levels: one control and three fertilizer concentrations. Each treatment was replicated five times, resulting in a total of 20 experimental units. Each experimental unit consisted of one cayenne pepper plant grown in an individual polybag. The treatment compositions and concentrations are presented in Table 1.

Table 1. Treatment Levels and Solution Composition of Pineapple Peel Liquid Organic Fertilizer

Treatment code	Solution composition	LOF concentration
P0	0 mL LOF + 1.000 mL water	0 mL L^{-1}
P1	10 mL LOF + 990 mL water	10 mL L^{-1}
P2	20 mL LOF + 980 mL water	20 mL L^{-1}
P3	30 mL LOF + 970 mL water	30 mL L^{-1}

At each concentration level, one liter of treatment solution was divided equally among five plants, so that each plant received 200 mL per application. The experimental units were designated P0U1-P0U5, P1U1-P1U5, P2U1-P2U5, and P3U1-P3U5. All units were positioned randomly in the greenhouse.

Time and Location

The study was conducted for 65 days after planting in the greenhouse of the Biology Education Study Program, Universitas Pendidikan Mandalika, Mataram. The research activities included preparation of the liquid organic fertilizer, seed sowing, preparation of the growing medium, planting, treatment application, plant maintenance, and observation of vegetative growth.

Population and Sample

The study population comprised all cayenne pepper seedlings available and cultivated in the greenhouse of the Biology Education Study Program, Universitas Pendidikan Mandalika. The sample consisted of 20 seedlings with relatively uniform age, leaf number, height, and overall growth condition.

Seedlings were selected on the basis of uniformity. Healthy seedlings without visible symptoms of pest or disease attack were chosen and then randomly allocated to the four treatments. Each treatment included five plants as replicates.

Equipment and Materials

The equipment included a fermentation container, bucket, knife, sieve, storage bottles, measuring cylinder, 35 x 35 cm polybags, measuring tape, ruler, vernier caliper, treatment labels, stationery, and a camera. The materials consisted of pineapple peel, cayenne pepper seeds, soil, rice husk, manure, water, sugar, and Effective Microorganisms 4 (EM4).

Preparation of Pineapple-Peel Liquid Organic Fertilizer

The liquid organic fertilizer was prepared from 10 kg of pineapple peel, 1 kg of sugar, 300 mL of EM4, and 15 L of water. The pineapple peel was washed, drained, and cut into small pieces to increase its surface area and accelerate fermentation. One kilogram of sugar was dissolved in water and stirred until evenly mixed, after which 300 mL of EM4 was added. The chopped pineapple peel was placed in the fermentation container, followed by the sugar-EM4 solution. All ingredients were mixed thoroughly, and the container was sealed tightly. Fermentation was carried out for 21 days in a shaded location protected from direct sunlight. At the end of fermentation, the liquid was separated from the solid material using a sieve. The filtered liquid organic fertilizer was stored in sealed bottles until treatment application.

Seed Sowing and Seedling Selection

Cayenne pepper seeds were sown in a nursery medium and maintained with adequate watering. After germination and seedling development, seedlings were selected for uniformity in age, plant height, leaf number, stem condition, and general health. Only healthy seedlings without physical damage or visible symptoms of pest or disease attack were used. Twenty relatively uniform seedlings were transplanted into polybags and designated as the experimental units.

Preparation of the Growing Medium and Planting

The growing medium consisted of soil, rice husk, and manure mixed uniformly. Equal quantities of the medium were placed in 35 x 35 cm polybags for all experimental units.

One cayenne pepper seedling was planted in the center of each polybag. Each polybag was then labeled according to the treatment and replicate code. The plants were maintained during an acclimatization period before liquid organic fertilizer application began.

Treatment Application

Pineapple-peel liquid organic fertilizer was applied at four concentrations: 0, 10, 20, and 30 mL L^{-1}. Treatment P0 served as the control and received water only, whereas P1, P2, and P3 received fertilizer solutions at their respective concentrations. Each plant received 200 mL of treatment solution per application. The solution was applied to the growing medium around the root zone every four days in the morning. It was poured slowly to facilitate absorption by the medium and to avoid direct contact with the leaves. Plants were watered daily according to the moisture condition of the growing medium, except on fertilizer-application days. Water volume and all maintenance procedures were kept uniform across experimental units. Weed removal and pest and disease control were performed manually and consistently.

Data Collection

Data were collected through direct observation and photographic documentation. Direct observations involved measurements of vegetative growth in all experimental units. Measurements began after the plants had acclimatized and were conducted every three days until 65 days after planting. Photographs were used to document plant condition, treatment application, measurement activities, and changes in plant growth throughout the study. Measurements were recorded on observation sheets according to treatment code, replicate, and observation time.

Vegetative Growth Parameters

The vegetative growth parameters observed in this study included plant height, stem diameter, number of leaves, and leaf width. These parameters were measured every three days until 65 days after planting to evaluate the growth response of cayenne pepper plants to different concentrations of pineapple peel liquid organic fertilizer.

Plant Height

Plant height was measured in centimeters using a ruler or measuring tape. Measurements were taken from the surface of the growing medium to the highest growing point of the main stem every three days until 65 days after planting.

Stem Diameter

Stem diameter was measured in millimeters using a vernier caliper. Measurements were taken at the same point on the main stem, approximately 2 cm above the surface of the growing medium, every three days until 65 days after planting.

Number of Leaves

The number of leaves was determined by counting all fully expanded leaves on each plant. Leaves that were still in the bud stage or had not fully unfolded were excluded from the count. Observations were conducted every three days until 65 days after planting.

Leaf Width

Leaf width was measured in centimeters using a ruler or measuring tape at the widest part of the leaf blade. Only fully expanded and undamaged leaves were selected for measurement. Measurements were conducted every three days until 65 days after planting.

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Data Analysis

The data were analyzed using descriptive quantitative procedures. Measurements from each experimental unit were first summarized by parameter, treatment, replicate, and observation time. Treatment comparisons were based on the mean observations of the five replicates over the study period. The results were presented in tables and bar charts and interpreted by comparing the mean values of the four treatments. The treatment with the highest mean was described as showing the greatest vegetative growth, whereas the treatment with the lowest mean was described as showing the least growth. Because only descriptive analysis was used, differences among treatment means were not interpreted as statistically significant. The results therefore indicate growth trends only for the tested concentrations of pineapple-peel liquid organic fertilizer.

RESULT AND DISCUSSION

Vegetative growth was monitored for 65 days, or approximately two months. Plant height, stem diameter, leaf number, and leaf width were measured at three-day intervals throughout the observation period.

Plant Height

The mean plant heights obtained from the three fertilizer treatments and one control, each with five replicates and observed for 65 days after planting (DAP), are presented below.

Table 2. Mean Plant Height

	Plant height data					Total	Mean
Treatment	U1	U2	U3	U4	U5		
P0	8.67	6.59	6.1	6.21	5.77	33.34	6.668
P1	5.87	5.71	6.07	6.47	5.94	30.06	6.012
P2	5.52	5.71	6.54	6.03	5.95	29.75	5.95
P3	7.84	7.02	6.24	7.11	6.22	34.43	6.886
Grand total						127.58	6.379

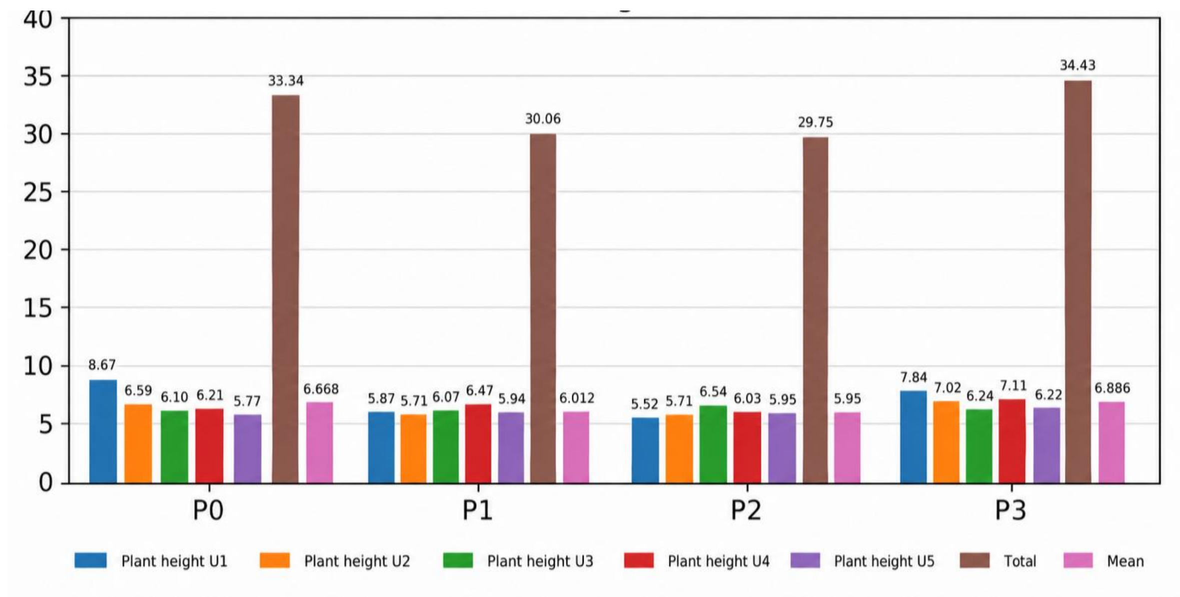

Figure 1. Plant Height Data

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Table 2 and Figure 1 shows the mean plant height over the 65-day observation period. Among the 20 experimental units, P3 produced the highest mean plant height (6.88 cm), whereas P2 produced the lowest mean (5.95 cm). The higher mean under P3 may reflect more favorable nutrient availability or other growth conditions. However, the mechanism cannot be confirmed because the fertilizer nutrient composition and relevant environmental variables were not analyzed. The low mean under P2 also shows that the response was not linear across concentrations and that 20 mL L^{-1} did not outperform the other treatments during the study period.

Stem Diameter

The mean stem diameters obtained from the three fertilizer treatments and one control, each with five replicates and observed for 65 DAP, are presented below.

Table 3. Mean Stem Diameter

	Stem diameter data					Total	Mean
Treatment	**U1**	**U2**	**U3**	**U4**	**U5**		
P0	2.93	2.67	2.57	2.64	2.42	13.23	2.646
P1	2.38	2.22	2.64	2.74	2.33	12.31	2.462
P2	2.38	2.52	2.79	2.5	2.49	12.68	2.536
P3	3	2.69	2.52	2.81	2.6	13.62	2.724
Grand total						51.84	2.592

Table 3 shows the mean stem diameter over the 65-day observation period. P3 produced the largest mean stem diameter (2.72 mm), whereas P1 produced the smallest mean (2.46 mm).

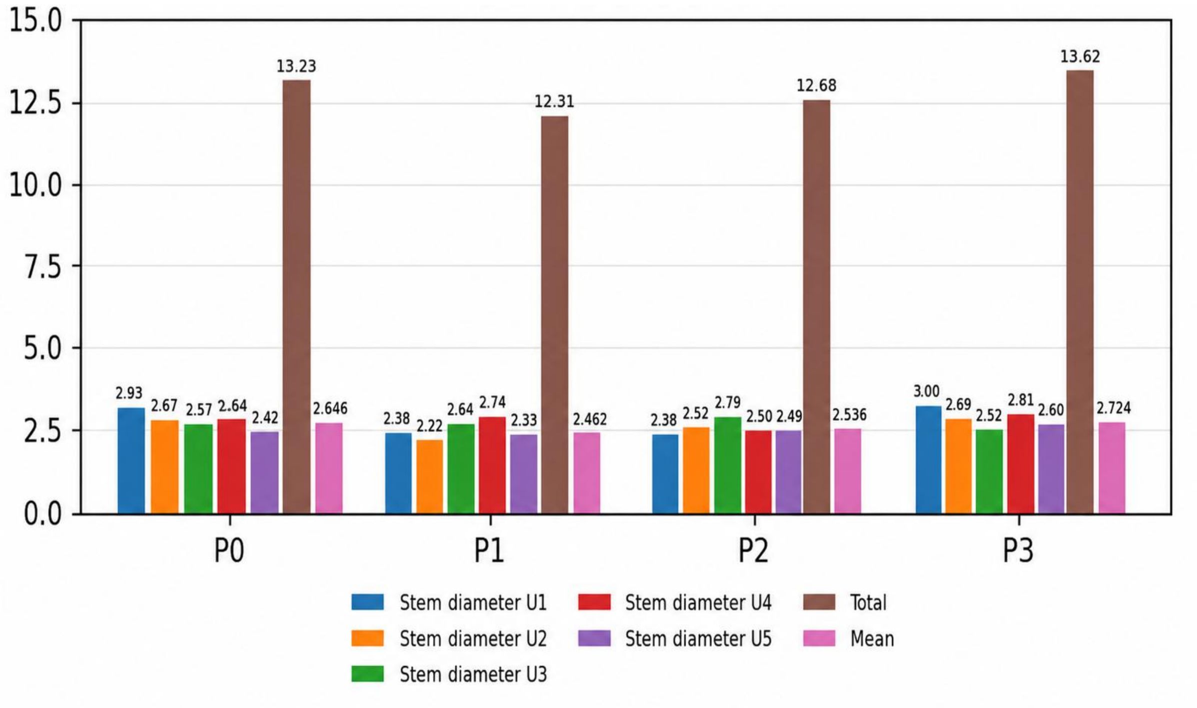

Figure 2. Stem-Diameter Data

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Figure 2 showed the largest mean stem diameter. This trend may indicate more favorable overall growing conditions under the 30 mL L^{-1} treatment. Nevertheless, explanations involving particular nutrients, such as potassium or boron, or plant-growth hormones cannot be confirmed because these components were not measured. P1 produced the smallest mean stem diameter, indicating that the 10 mL L^{-1} treatment did not improve stem thickening relative to the other treatments.

Number of Leaves

The mean numbers of leaves obtained from the three fertilizer treatments and one control, each with five replicates and observed for 65 DAP, are presented below.

Table 4. Mean Number of Leaves

	Leaf number data					Total	Mean
Treatment	**U1**	**U2**	**U3**	**U4**	**U5**		
P0	8.23	6.76	5.47	4.64	4.70	29.8	5.96
P1	4.94	5	5.82	6.64	4.23	26.63	5.326
P2	4.05	5.41	7.17	6.64	5.29	28.56	5.712
P3	7.76	5.64	5.64	7.94	5.7	32.68	6.536
Grand total						117.67	5.8835

Table 4 shows the mean number of leaves over the 65-day observation period. P3 produced the highest mean number of leaves (6.53), whereas P1 produced the lowest mean (5.32).

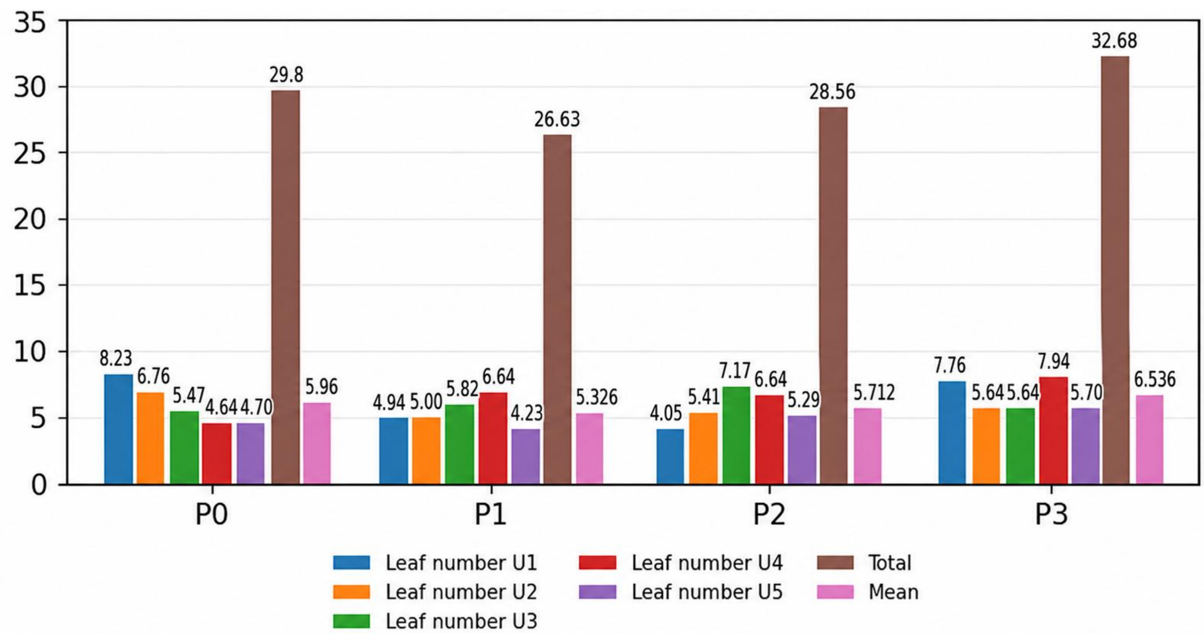

Figure 3. Leaf-Number Data

Figure 3 produced the highest mean leaf number. The result may reflect more favorable nutrient availability, including nutrients involved in leaf formation, but the nutrient content of the fertilizer and plant tissues was not measured. P1 produced the lowest mean, which may indicate that the 10 mL L^{-1} treatment provided insufficient benefit under the study

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conditions. Because no inferential test was performed, these explanations should be interpreted as possible mechanisms rather than confirmed treatment effects.

Leaf Width

The mean leaf widths obtained from the three fertilizer treatments and one control, each with five replicates and observed for 65 DAP, are presented below.

Table 5. Mean Leaf Width

	Leaf width data					Total	Mean
Treatment	**U1**	**U2**	**U3**	**U4**	**U5**		
P0	3.39	2.81	2.44	2.72	2.68	14.04	2.808
P1	2.64	2.59	2.69	3.07	2.43	13.42	2.684
P2	2.44	2.68	3.1	2.82	2.51	13.55	2.71
P3	3.35	2.91	2.75	3	2.68	14.69	2.948
Grand total						55.7	2.785

Table 5 shows the mean leaf width over the 65-day observation period. P3 produced the greatest mean leaf width (2.93 cm), whereas P1 produced the smallest mean (2.68 cm).

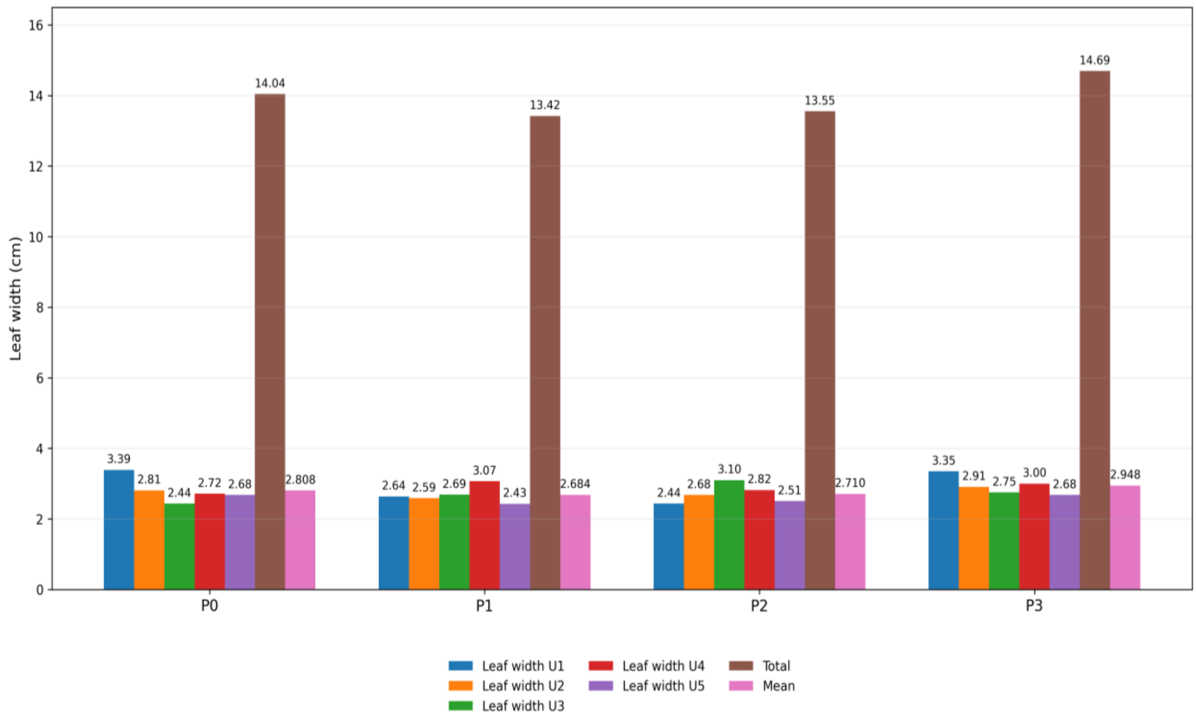

Figure 4. Leaf-Width Data

P3 produced the greatest mean leaf width, which may be associated with favorable cell expansion and plant water status. Wider leaves provide a larger surface area for light interception and potentially support greater photosynthetic capacity. P1 produced the smallest mean leaf width. Because leaf expansion is sensitive to water and nutrient limitations, the result may reflect less favorable growth conditions; however, plant water status and nutrient concentrations were not measured, so this explanation remains tentative.

Discussion

Plant Height of Cayenne Pepper (Capsicum frutescens L.)

Descriptively, P3, consisting of 30 mL of pineapple peel liquid organic fertilizer and 970 mL of water, showed the highest mean plant height (6.89 cm), followed by the control treatment (6.67 cm). This result indicates that 30 mL L^{-1} was the most favorable concentration for plant height within the range evaluated. However, because no inferential statistical analysis was performed, the difference cannot be interpreted as a statistically significant treatment effect.

A similar concentration-dependent tendency was reported by Cristina et al. (2022), who found that pineapple peel liquid organic fertilizer applied at 30 mL L^{-1} every seven days tended to support better growth and yield of shallots, although the concentration did not significantly affect most measured variables. In *Capsicum chinense*, Solórzano et al. (2025) also demonstrated that different doses of liquid biofertilizer produced different plant-height responses, with the highest doses generally resulting in greater plant height at the final observation.

The response observed in P3 may be associated with a more favorable supply of soluble nutrients and organic compounds from the fermented fertilizer. Navarro-Morillo et al. (2024) reported that an organic-derived extract improved vegetative growth and nitrogen assimilation in pepper plants grown under nitrogen-deficient conditions. Nevertheless, because the nutrient composition, pH, and electrical conductivity of the pineapple peel liquid organic fertilizer were not measured in the present study, the physiological mechanism underlying the higher plant height in P3 remains tentative.

Stem Diameter of Cayenne Pepper (Capsicum frutescens L.)

P3 also showed the largest mean stem diameter (2.72 mm), followed by P0 (2.65 mm), P2 (2.54 mm), and P1 (2.46 mm). The fact that P1 and P2 produced smaller mean stem diameters than the control indicates that the response did not increase linearly with increasing fertilizer concentration. Therefore, the results suggest that the response of stem development depended on the suitability of the applied concentration rather than simply on the amount of fertilizer supplied.

The tendency observed in P3 is comparable to the findings of Solórzano et al. (2025), who reported that the highest liquid-biofertilizer dose produced the largest stem diameter in *C. chinense* at the final observation. In addition, Sini et al. (2024) found that combinations of organic fertilizer and biological fertilizers increased the uptake of nitrogen, phosphorus, potassium, and several micronutrients in bell pepper. These nutrients contribute to biomass production and the development of vegetative plant tissues.

The potential contribution of organic amendments to nutrient availability is also supported by Zhang et al. (2023), who reported that biochar and vermicompost increased nutrient uptake and fertilizer-use efficiency in continuously cropped pepper. Nevertheless, the relatively small differences among the treatments in the present study should be interpreted cautiously. Direct measurements of plant nutrient status and fertilizer composition would be required to determine whether the larger stem diameter in P3 was specifically associated with improved nutrient availability.

Number of Leaves of Cayenne Pepper (Capsicum frutescens L.)

P3 showed the highest mean number of leaves (6.54), whereas P1 showed the lowest mean (5.33). The control treatment produced an average of 5.96 leaves, which was higher than the averages obtained in P1 and P2. This pattern demonstrates that increasing the concentration of pineapple peel liquid organic fertilizer did not produce a consistently proportional increase in leaf formation.

The study by de Ávila Silva et al. (2019) demonstrated that nitrogen availability can modify leaf biomass allocation, photosynthetic activity, carbon distribution, and other growth-related characteristics in *Capsicum chinense*. Their findings also showed that an excessive nitrogen supply may reduce carbon dioxide assimilation and disturb the balance between vegetative and reproductive growth. Similarly, Subedi et al. (2023) found that different combinations of nitrogen and charcoal produced varying responses in the growth characteristics of chili plants. These findings indicate that vegetative development depends not only on nutrient quantity but also on nutrient balance and growing conditions.

The slightly higher mean number of leaves in P3 may indicate that this concentration provided more favorable conditions for leaf formation than the lower concentrations. Nevertheless, because the differences were evaluated only descriptively, P3 should be described as showing the highest tendency rather than producing a statistically significant increase in the number of leaves.

***Leaf Width of Cayenne Pepper* (*Capsicum frutescens* L.)**

The highest mean leaf width was observed in P3 (2.95 cm), followed by P0 (2.81 cm), P2 (2.71 cm), and P1 (2.68 cm). As observed for the other parameters, the response was not linear because the two lower fertilizer concentrations produced smaller mean leaf widths than the control. Therefore, the greater leaf width recorded in P3 indicates a favorable descriptive response at 30 mL L^{-1} but does not demonstrate a statistically significant treatment effect.

Leaf expansion is closely related to nutrient availability, photosynthetic capacity, and biomass allocation. The study by de Ávila Silva et al. (2019) showed that increased nitrogen availability promoted greater biomass allocation to leaves in *C. chinense*, although an excessive nitrogen supply could negatively affect carbon dioxide assimilation and reproductive performance. Navarro-Morillo et al. (2024) similarly reported that an organic-derived extract supported vegetative growth and nitrogen assimilation in pepper plants under nutrient-limited conditions.

Sini et al. (2024) further demonstrated that combining organic fertilizer with microbial biofertilizers improved the uptake of nitrogen, phosphorus, potassium, and micronutrients in bell pepper. Improved nutrient availability may support cell division and expansion during leaf development. Nevertheless, because nutrient uptake, chlorophyll content, leaf area, and fertilizer composition were not measured in the present study, the larger mean leaf width recorded in P3 cannot be attributed conclusively to a particular nutrient or physiological process.

CONCLUSION

The application of pineapple peel liquid organic fertilizer produced different descriptive vegetative-growth responses in cayenne pepper. Among the tested treatments, P3 at a concentration of 30 mL L^{-1} consistently showed the highest mean values for plant height (6.886 cm), stem diameter (2.724 mm), number of leaves (6.536), and leaf width (2.948 cm). However, the response did not increase linearly with increasing fertilizer concentration because P1 and P2 produced lower mean values than the control for several parameters. Therefore, 30 mL L^{-1} can be regarded as the concentration showing the most favorable descriptive tendency within the tested range and under the conditions of this study, rather than as a statistically confirmed optimum concentration. These findings indicate the potential use of pineapple peel liquid organic fertilizer as an organic input while supporting the utilization of pineapple waste in sustainable crop production.

RECOMMENDATIONS

Further studies should apply inferential statistical analyses, such as analysis of variance followed by an appropriate post hoc test, to determine whether the differences among treatments are statistically significant. A larger number of replicates and a wider range of fertilizer concentrations should also be used to identify the optimum application rate more reliably. The nutrient content, pH, electrical conductivity, carbon-to-nitrogen ratio, and maturity of the pineapple peel liquid organic fertilizer should be characterized before application. Future studies should additionally monitor environmental conditions and include other growth indicators, such as root development, chlorophyll content, leaf area, fresh and dry biomass, flowering, fruit production, and yield. Based on the present descriptive findings, 30 mL L^{-1} may be used as a candidate concentration for further experimental testing but should not yet be recommended as a definitive optimum rate.

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