



***Azolla microphylla* Liquid Organic Fertilizer and Red Onion Peel as an Environmentally Friendly Alternative to Increase the Growth of Tomatoes**

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Abstract

Intensive use of chemical fertilizers in the cultivation of rampai tomatoes (*Solanum lycopersicum* L. var. *cerasiforme*) has the potential to reduce environmental quality and soil fertility, so that environmentally friendly and sustainable fertilizer alternatives are needed. This study aims to examine the effect of liquid organic fertilizer (POC) made from *Azolla microphylla* and shallot skin on the growth and yield of rampai tomatoes. The study used an experimental method with a completely randomized design (CRD) consisting of six treatments, namely the control without fertilizer (P0), the positive control of POC Ratu Biogen 2 ml/L (P1), and a combination of POC *Azolla microphylla* and shallot skin with a concentration of 25 ml/L (P2), 35 ml/L (P3), 45 ml/L (P4), and 55 ml/L (P5), each with three replications. The parameters observed included plant height, number of leaves, flowering time, number of fruits, and fruit weight. Data were analyzed using ANOVA at a significance level of 5% and continued with Duncan's test. The results showed that the application of POC significantly affected all growth parameters and yield of tomato plants ($p < 0.05$). Treatment P5 (55 ml/L) gave the best results with a plant height of 46.8 cm, the number of leaves 26 strands, the fastest flowering time of 21 days after planting, the number of fruits 25 pieces, and fruit weight 25 grams. The high phosphorus and potassium content as well as bioactive compounds in POC are thought to play an important role in increasing the vegetative and generative growth of plants. Thus, POC made from *Azolla microphylla* and shallot skin has the potential as an effective environmentally friendly alternative fertilizer to increase the productivity of tomato plants.

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1. Introduction

Tomatoes (*Solanum lycopersicum* L. var. *cerasiforme*) are a strategic horticultural commodity with high economic and consumption value in Indonesia (Ramlan *et al.*, 2024). As a fresh food ingredient and cooking spice, tomatoes are highly sought after by the public due to their nutritional content, which is rich in vitamins, minerals, and antioxidants such as lycopene, which are beneficial for health (Xena *et al.*, 2025). Market demand for tomatoes continues to increase along with public awareness of healthy lifestyles, so this commodity has great potential to increase farmers' incomes and contribute to national food security (Semboaho, 2025). However, the productivity of tomatoes in Indonesia still faces various obstacles, especially related to suboptimal vegetative growth in small and medium-scale cultivation. Suboptimal vegetative growth has a direct impact on flower and fruit formation, resulting in suboptimal harvests and reducing farmers' economic profits.

Current tomato cultivation practices at the farmer level are still dominated by the use of synthetic chemical fertilizers or inorganic fertilizers as the primary source of nutrients (Bukhori *et al.*, 2025). Although chemical fertilizers can provide a rapid response to plant growth, their excessive and continuous use over the long term has had significant negative impacts on agricultural ecosystems (Rukmana *et al.*, 2024). Uncontrolled application of inorganic fertilizers causes soil structure degradation, reduces organic matter content, disrupts the balance of soil microorganisms, and increases the risk of groundwater pollution and water eutrophication (Kadiana *et al.*, 2025). Furthermore, farmers' dependence on chemical fertilizers also results in increasing production costs, which are increasingly burdensome, especially amidst unstable fertilizer price fluctuations. This condition not only threatens the ecological sustainability of the agricultural system but also reduces the economic competitiveness of tomato farming businesses, so that more efficient, economical, and environmentally friendly fertilizer alternatives are needed.

In the context of sustainable agriculture, the development of organic fertilizers is a crucial priority to reduce dependence on synthetic chemical inputs. Sustainable agriculture demands the use of locally available resources that are inexpensive, readily available, and environmentally friendly, as part of efforts to maintain ecosystem balance and long-term productivity (Utami, 2024). Liquid organic fertilizers (POCs) are a promising alternative because they offer several advantages over solid organic fertilizers, including more readily available nutrients, easier plant absorption through leaf stomata and roots, and more practical and efficient application (Fariz *et al.*, 2025). POCs provide macronutrients such as nitrogen, phosphorus, and potassium, as well as essential micronutrients that plants require in small amounts but are essential for optimal metabolism and growth (Muthiah *et al.*, 2024).

Azolla microphylla is a tropical water fern that has great potential as a raw material for making liquid organic fertilizer due to its very rich nutritional content. *Azolla* is known as an aquatic plant capable of symbiosis with *Anabaena azollae*, namely atmospheric nitrogen-fixing cyanobacteria that can fix nitrogen up to 20-30 kg N/ha/year (Wijayanti *et al.*, 2024). The nitrogen content in *Azolla* biomass reaches 3-5% dry weight, supplemented by phosphorus, potassium, calcium, magnesium, and various microelements such as iron, manganese, and zinc that are essential for plants. In addition to being rich in nutrients, *Azolla* also contains amino acids, vitamins, and other bioactive compounds that function as biostimulants to increase vegetative plant growth such as plant height, number of leaves, and stem diameter (Anam, 2025). *Azolla's* ability to grow quickly with a biomass doubling rate of only 3-5 days makes it a source of organic material that is easy to propagate and sustainable. However, the use of *Azolla* as a liquid organic fertilizer is still relatively limited, especially in horticultural crops such as tomatoes, so further research is needed to optimize its potential in increasing the productivity of cultivated plants (Farida *et al.*, 2023).

Onion skin is rich in potassium, which plays an important role in photosynthesis, carbohydrate formation, and improving fruit quality. Furthermore, onion skin also contains flavonoids, quercetin, and other antioxidant compounds that function as natural growth regulators (phytohormones) that can stimulate cell division and elongation, increase plant

resistance to environmental stress, and improve crop quality (Gifridus *et al.*, 2024). The content of B-complex vitamins and minerals such as calcium, magnesium, and phosphorus in onion skin also supports plant metabolism and increases the efficiency of nutrient absorption (Gunawan *et al.*, 2025). The use of onion skin waste as a liquid organic fertilizer is in line with the principles of a circular economy that prioritizes waste reduction, resource reuse, and organic material recycling to create a more efficient and sustainable production system.

Although various studies have examined the benefits of *Azolla microphylla* and shallot peel as organic fertilizers, most of these studies were conducted separately, focusing on only one type of fertilizer. Research on *Azolla liquid fertilizer (POC)* generally evaluated its effectiveness on rice, leafy vegetables, or forage crops, while studies on shallot peel have focused more on chilies, mustard greens, or as a solid compost. Scientific information on the combination of these two materials as an integrated liquid organic fertilizer applied to tomato plants is still very limited and not well documented in the scientific literature. Furthermore, it is not yet clear how effective POC made from *Azolla microphylla* and shallot peels is in increasing vegetative growth parameters of tomato plants such as plant height, number of leaves, leaf area, stem diameter, and fresh weight compared to conventional fertilizer treatments or controls. This research gap indicates the need for systematic and comprehensive experimental studies to uncover the synergistic potential of the combination of these two organic materials and to determine the optimal dosage and frequency of application to maximize the growth and productivity of tomato plants.

The urgency of this research is becoming increasingly important considering the increasing global demand for sustainable and environmentally friendly agricultural practices, especially in order to support the achievement of the Sustainable Development Goals (SDGs). This research aims to examine in depth the effectiveness of liquid organic fertilizer based on *Azolla microphylla* and shallot skin as an environmentally friendly alternative in increasing the growth of rampant tomatoes, while also providing a scientific contribution to the development of organic fertilizer technology based on local resources. The results of this research are expected to produce an effective, efficient, and applicable liquid organic fertilizer formulation for application at the farmer level, thereby reducing dependence on synthetic chemical fertilizers, lowering production costs, increasing crop productivity, and improving the quality of the agricultural environment. In addition, this research also provides innovative solutions in organic waste management and utilization of local plant potential, thus supporting the implementation of sustainable agriculture that is not only economically productive but also ecologically sustainable. Thus, this research is expected to serve as a scientific reference for researchers, academics, agricultural practitioners, and policymakers in developing a sustainable and highly competitive organic farming system.

2. Literature Review

Modern agriculture faces significant challenges related to shrinking productive land, high food demand, and environmental issues resulting from the excessive use of chemical fertilizers. These conditions have prompted the search for more efficient and environmentally friendly alternative solutions, one of which is the use of liquid organic

fertilizers. As organic farming and zero-waste trends grow, utilizing household waste as a raw material for liquid organic fertilizers (POC) has become an attractive and sustainable alternative. Red onion skins (*Allium cepa L.*) are a potential source of household organic waste due to their high nutrient content. They contain nitrogen, potassium, magnesium, phosphorus, and natural hormones such as gibberellins and cytokinins, which can accelerate root and leaf growth.

Research (Bukhori *et al.*, 2025) shows that the administration of POC made from shallot skin waste and chicken eggshells at a concentration of 60 ml/L gives the best results on hydroponic lettuce plants with a wick system, producing a leaf width of 11.67 cm, a number of leaves of 10.75 strands, a root length of 10.32 cm, and a fresh weight of 79 grams. Although laboratory test results show that the macro nutrient content in shallot skin POC is relatively low (N-total 0.03%, P₂O₅ 0.01%, and K₂O 0.07%), its use still has a positive impact on plant growth in the long term because it helps increase soil fertility naturally.

The combination of organic and inorganic fertilizers has been proven to increase plant productivity and improve soil quality. Organic fertilizers play a role in continuously improving soil quality and increasing biological, chemical, structural, and physical activity of the soil. Research by Firmansyah *et al.* showed that a combination of 300 mL of onion peel POC with 4 g of NPK per plant provided the best results for the growth and yield of basil plants. The application of POC not only acts as an additional nutrient source but also contributes to increasing nutrient availability in the soil through the activity of the microorganisms it contains, such as phosphate-solubilizing bacteria and nitrogen-fixing bacteria that help decompose organic matter into forms that are more easily absorbed by plant roots.

In tomato plants, research (Fariz *et al.*, 2025) showed that the combination of 112.5 g of chicken manure fertilizer with 45 ml of shallot POC (K3P3) produced the highest tomato growth and yield, with a plant height of 127.39 cm at 7 MSPT, a stem diameter of 1.04 cm, a fruit weight per plot of 877.75 g, a number of fruits per plant of 8.09 fruits, and a fruit weight per plant of 273.25 g. This success reflects that the optimal combination of organic and inorganic fertilizers is able to optimally meet plant nutritional needs. The phosphorus and potassium content in shallot POC plays an important role in fruit formation and enlargement, while nitrogen supports vegetative growth.

Research (Sara Wales1, 2023) on tomato plants with a combination of 200 ml of shallot peel fertilizer and 150 g of coconut pulp (B2A2) provided optimal results in increasing plant height (6.6 cm), number of leaves (33.6 strands), and accelerating the flowering process. Meanwhile, research by Sulaiman and Herkules showed that the application of shallot peel waste POC with a concentration of 200 ml (P3) had a significant effect on all growth and production parameters of cherry tomatoes of the Ruby variety, with a plant height of 80.40 cm, number of branches 13.33, number of leaves 78.83 strands, number of flowers 16.83, number of fruits 10.83, and fruit weight 59.83 g in the 6th week.

The mechanism of action of onion skin POC in promoting plant growth involves several aspects. First, nitrogen plays a role in the formation of chlorophyll, enzymes, and proteins that support leaf growth and photosynthesis. Second, phosphorus plays a role in energy production (ATP), cell division, root formation, and accelerating flowering and fruit ripening. Third, potassium helps transport the products of

photosynthesis, regulates the opening and closing of stomata, and strengthens plant tissue so that leaves, flowers, and fruit do not fall off easily. Fourth, the hormones auxin and gibberellin contained in onion skin stimulate cell division and elongation, root growth, and the transition from the vegetative to the generative phase.

The integration of onion skin liquid fertilizer (POC) with other organic materials such as eggshells, coconut pulp, rice washing water, and chicken manure shows better results than single applications. Eggshells contain calcium carbonate (95%), phosphorus (3%), and other microelements that play a role in cell division and strengthening plant structure. Coconut pulp provides organic matter that can increase the soil's capacity to retain water and nutrients. Rice washing water contains vitamins B1, B2, B3, manganese, and phosphorus, which support plant growth. This combination of ingredients creates a liquid organic fertilizer with a more complete and balanced nutrient content.

Previous studies have consistently shown that onion peel extract (POC) effectively improves various plant growth parameters, including plant height, leaf number and width, stem diameter, branch number, flowering time, fruit number, and fruit weight. However, to achieve optimal results, onion peel extract needs to be combined with other nutrient sources or administered in the correct dosage according to plant needs. Environmental factors such as light, temperature, humidity, and water availability also significantly influence the effectiveness of POC in supporting plant growth.

The use of shallot peel waste as organic fertilizer (POC) offers a dual contribution to sustainable agriculture. First, it reduces environmental pollution caused by the accumulation of household organic waste. Second, it provides a more economical and environmentally friendly fertilizer alternative compared to synthetic fertilizers. Third, it supports the growing concept of organic and zero-waste farming in the community. Fourth, it empowers communities to utilize local resources and reduce dependence on expensive external inputs. Thus, the development and application of shallot peel POC has excellent prospects for supporting household food security and sustainable urban agriculture.

3. Methodology

A. Time and Place

1. Research Time

This research was conducted from August 2025 to October 2025.

2. Research Site

The location of this research will be carried out at the author's own house, namely in Wonosari Village, Gunung Sugih District, Central Lampung Regency, Lampung Province.

B. Research Approaches and Types

This study employed an experimental approach. It employed a completely randomized design (CRD) consisting of six treatments and three replications, resulting in a total of 18 subjects. The research design is as follows:

P0: Negative control (without fertilizer)

P1: Positive control (Queen Biogen ZPT Fertilizer) 2ml

P2: *Azolla microhylla* Kaulf POC combination and red onion skin with a concentration of 25 ml / liter of water

P3: Combination of POC *Azolla microhylla* Kaulf and red onion skin with a concentration of 35 ml / liter of water

P4: Combination of POC *Azolla microphylla* Kaulf and red onion skin with a concentration of 45 ml / liter of water.

P5: Combination of POC *Azolla microphylla* Kaulf and red onion skin with a concentration of 55 ml / liter of water.

Table 1: Research Design Table

P1U2	P3U1	P5U3
P0U3	P2U1	P1U1
P4U2	P5U2	P0U2
P2U3	P3U2	P0U1
P5U1	P4U3	P2U2
P3U3	P1U3	P4U1

C. Sample Population and Data Collection Techniques

1. Population

The population and this research are all tomato plants (*Solanum lycopersicum* L. var. cerasiforme) starting from the seeds that will be planted at the researcher's residence.

2. Sample

A sample is a portion of a population selected by the researcher as the object of study. The sample in this study was tomato plants obtained from purchasing tomato plants from a local agricultural store. The sample in this study was 18 tomato seedlings (*Solanum lycopersicum* L. var. cerasiforme) was divided into 6 treatments. Each treatment was repeated 3 times, so the total sample used was $6 \times 3 = 18$, the number of samples in this study was 18 tomato plants.

3. Data collection technique

This is done by means of observation and documentation. The steps for collecting data are as follows:

- Direct observation of plant growth (plant height, number of leaves, time of flower appearance, and number of fruits).
- Documentation in this research includes the sowing process, planting process, fertilization process, and harvesting process.
- Recording the results of each observation for data analysis purposes.

D. Tools and Materials

The tools used in this study were trowels, polybags, metal rulers, scales, watering cans, measuring jugs, label paper, sieves, cameras, and stationery. The materials used in this study were tomato seeds, liquid organic fertilizer from *Azolla microphylla* Kaulf, red onion skins, ZPT Ratu Biogen air fertilizer, and EM4 solution.

E. How to Make POC

Liquid organic fertilizers must undergo a fermentation process during the manufacturing process. Fermentation is the process by which chemical compounds are converted into organic compounds using microorganisms in the organic materials selected for the liquid organic fertilizer. Fermentation can also be defined as the process by which chemical compounds are converted into organic compounds. The goal is to accelerate plant nutrient absorption.

To produce liquid organic fertilizer, the fermentation of organic materials is driven by the activity of microorganisms, which occurs anaerobically, or in conditions that do not require oxygen. Anaerobic fermentation is typically carried out in a closed container, preventing air from entering. The steps in the process of making liquid organic fertilizer

are as follows:

- The materials and tools prepared were 2 grams of *Azolla microphylla* Kaulf, 400 grams of shallot skin, 300 grams of brown sugar, 50 ml of EM4, and 10 liters of clean water. The tools used included a 10-liter covered bucket, a knife, a blender or crusher, a basin, a stirrer, and a sieve.
- Activated EM4: Mix 50 ml of EM4 with 300 grams of brown sugar and 500 ml of warm water, stir until dissolved, and let it sit for 7 days until the microorganisms are active. Active EM4 is characterized by a sweet and sour smell.
- Process organic materials by chopping *Azolla microphylla* Kaulf into small pieces and grinding the shallot skin using a blender or pounding it until it is softer to speed up the decomposition process.
- Put *Azolla microphylla* Kaulf and red onion skin into the fermentation container, then add clean water until it reaches a volume of 10 liters.
- Pour the activated EM4 solution into a container containing organic materials and water, then stir until evenly mixed.
- Close the fermentation container tightly and store it in a cool, shady place. Fermentation is carried out anaerobically for approximately 4 weeks, and the container should not be opened too often to avoid disturbing the fermentation process.
- Stir the solution every 2 days to help distribute microbial activity evenly and accelerate the decomposition of organic materials.
- After 4 weeks, the solution is fermented until it has a sweet and sour aroma and no foul odor. It is then filtered to separate the dregs from the liquid. The fermented liquid is stored in a sealed bottle and is ready to be used as a liquid organic fertilizer (POC).

F. Implementation of Macro and Micro Element Content Tests in the Laboratory

1. Macro Test

The macro element test parameters are N, P, K content.

2. Micro Test

The micro test parameters are Fe and Ca.

G. Ways of working

1. Preparation Stage

For the preparation of liquid organic fertilizer treatment materials *Azolla microphylla* Kaulf, as much as 10 liters.

Preparation of planting media:

- Tomato plants are obtained by purchasing seeds at agricultural stores.
- Put the media into a 30x30cm polybag.

2. Randomization Stage

Randomization was performed after all plants were planted in polybags to avoid any environmental influences on the research results. The randomization steps are as follows:

- Polybags that have been planted with tomato plants are labeled according to the repetition.
- Make a number of paper pieces of the sample and then code them according to the repetition.
- Random paper drawing, the repeat code that appears will be matched with the label on the polybag
- The polybag that matches the code taken is placed.

F. Data Analysis Techniques

Azolla microphylla Kaulf liquid organic fertilizer . and soaking shallot skin (*Allium cepa* L.) on the growth of tomato plants (*Solanum lycopersicum* L. var. *cerasiforme*), the data on plant height, number of leaves, time of flower emergence, number of fruits, fruit weight and fruit diameter were tested using *Analysis of Variance* (ANOVA) at a significant level (0.05), if significant then it will be continued with the Duncan test.

4. Results

4.1. Descriptive Statistics

A. Research result

In this study, researchers used 6 treatments with 3 replications using a completely randomized design (CRD) to determine the effect of administering *Azolla microphylla* Kaulf liquid organic fertilizer (POC) . and shallot skin (*Allium cepa* L.) on the growth of tomato plants (*Solanum lycopersicum* L. var. *cerasiforme*). The treatments used consisted of a negative control without fertilizer (P0), a positive control with 2 ml/L water of Ratu Biogen ZPT fertilizer (P1), and four combination treatments of *Azolla microphylla* Kaulf POC . and soaking shallot skin with different concentrations, namely 25 ml/L of water (P2), 35 ml/L of water (P3), 45 ml/L of water (P4), and 55 ml/L of

water (P5). Each treatment was repeated three times, so that a total of 18 tomato plants were used as experimental units. Liquid organic fertilizer was given regularly according to a predetermined schedule, and observations were made on several growth parameters such as plant height, number of leaves, flowering time, and number of fruits produced. The results of this research are as follows:

1. Results of Analysis of Liquid Organic Fertilizer (POC) and Ratu Biogen Content

Before liquid organic fertilizer (POC) *Azolla microphylla* Kaulf . and shallot skin (*Allium cepa* L.) used in the research treatment on the growth of tomato plants (*Solanum lycopersicum* L. var. *cerasiforme*), laboratory tests were first carried out to determine the nutrient content in the fertilizer. The content test was carried out to ensure that the POC used had a composition of macro and micro elements that support plant growth, especially nitrogen (N), phosphorus (P), and potassium (K) which play an important role in the process of forming roots, leaves, stems, flowers, and fruit. The results of the laboratory analysis of the POC obtained became the basis for the effectiveness of the treatment on plants and also served as a reference in the discussion of the research results. The results of the analysis of the content of liquid organic fertilizer (POC) are presented in the following table:

Table 2: Results of Liquid Organic Fertilizer Content Test Analysis

No	Test Parameters	Results	Unit	SNI 7763:2018 Standard
1	Nitrogen (N)	0.13	mg/L	2
2	Phosphorus (P)	40.3	mg/L	2
3	Potassium (K)	549.6	mg/L	2
4	Calcium (Ca)	175.5	mg/L	-
5	Iron (Fe)	16.5	mg/L	5–50

Laboratory analysis results of Table 2 on liquid organic fertilizer (POC) *Azolla microphylla* Kaulf . and red onion skin (*Allium cepa* L.) obtained varied nutrient content, both macro and micro nutrients. Nitrogen (N) content was recorded at 0.13 mg/L, indicating that this POC is still below the SNI 7763:2018 standard of 2 mg/L, but still contributes to chlorophyll formation and plant vegetative growth. Phosphorus (P) has a value of 40.3 mg/L, which far exceeds the SNI standard of 2 mg/L, thus indicating excellent potential in stimulating root growth, flowering, and fruit formation. Potassium (K) showed the highest value of 549.6 mg/L, also exceeding the SNI standard of 2 mg/L, so it can support the process of strengthening plant tissue, fruit

enlargement, and improving the quality of harvest results. The calcium (Ca) element detected at 175.5 mg/L plays a role in the formation of cell walls and prevents symptoms of fruit end rot, while the micro element iron (Fe) with a value of 16.5 mg/L is still within the SNI standard range of 5–50 mg/L, so it can encourage chlorophyll formation without causing the risk of toxicity. Overall, the nutrient composition in POC shows very potential characteristics to support the growth and development of rampai tomato plants, especially through the dominant contribution of phosphorus and potassium, although the nitrogen element is detected at low levels. For comparison, the commercial Ratu Biogen fertilizer treatment was given with a content analysis as in the table below.

Table 3: Results of Analysis of the Content of Ratu Biogen Commercial Fertilizer

No	Test Parameters	Results	Unit	SNI 7763:2018 Standard
1	Nitrogen (N)	0.12	mg/L	2
2	Phosphorus (P)	38.50	mg/L	2
3	Potassium (K)	560.00	mg/L	2
4	Calcium (Ca)	170.00	mg/L	-
5	Iron (Fe)	18.00	mg/L	5–50

Table 3 shows the results of the analysis of the contents of Ratu Biogen liquid organic fertilizer, which shows that this fertilizer contains macro and micro nutrients that play an important role in supporting plant growth. The nitrogen (N) content of 0.12 mg/L, although below the SNI 7763:2018 standard, still functions as a supporting element for initial vegetative growth, especially in the formation of leaves and plant tissue. The phosphorus (P) content of 38.50 mg/L and

potassium (K) of 560.00 mg/L are considered high and exceed the SNI standard, indicating that Ratu Biogen has strong potential in supporting root development, flowering, fruit formation, and increasing plant resistance to environmental stress. The calcium (Ca) element of 170.00 mg/L plays a role in strengthening cell walls and improving the quality of plant tissue, although it is not specifically required in SNI. Meanwhile, the iron (Fe) content of 18.00

mg/L is within the SNI 7763:2018 standard range, making it quite effective in supporting the process of chlorophyll formation and plant enzyme activity. Overall, the nutrient composition of Ratu Biogen liquid organic fertilizer shows its suitability as a fertilizer to support plant growth applied as a plant growth regulator (PGR) and a complement to the main fertilizer, especially to increase the efficiency of nutrient

absorption and plant productivity.

a. Plant Height (cm)

The results of measuring the height of the tomato plants with 6 multiplications and observations for 60 days are presented in the following figure.

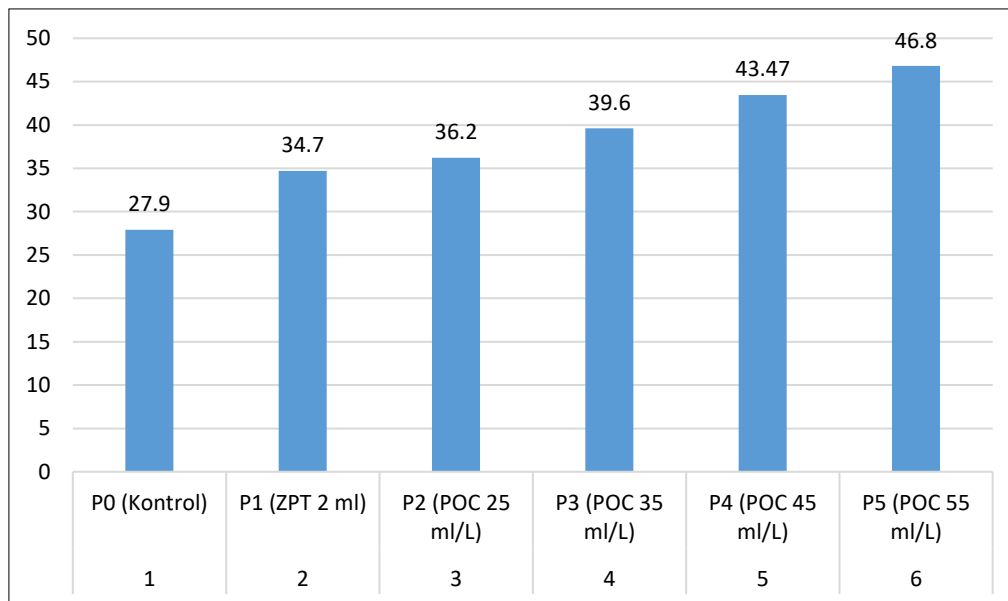


Fig 1: Results of Plant Height Observations (cm)

Plant height data showed very clear differences between treatments, reflecting the significant influence of variations in the concentration of *Azolla microphylla*-based POC and shallot skin on the vegetative growth of rampai tomatoes. The control treatment (P0) produced the lowest average height, namely 27.9 cm, which confirms that without the application of POC, the plants grew more slowly due to nutrient limitations. Treatment P1 (2 ml PGR) showed a moderate increase to 34.7 cm, but still below the effect provided by POC. Growth began to increase more strongly in P2 (25 ml/L) and P3 (35 ml/L), reaching 36.2 cm and 39.6 cm, respectively, which indicates that POC at medium concentrations began to be able to provide essential nutrients such as nitrogen, phosphorus, and bioactive compounds from shallot skin that function as growth stimulants.

The highest response was seen at the concentration of P4 (45 ml/L) and especially P5 (55 ml/L), which resulted in plant heights of 43.47 cm and 46.8 cm, respectively. The highly significant increase in these two treatments demonstrates that the combination of *Azolla*, which is rich in protein, nitrogen, and minerals, along with phenolic compounds and natural growth regulators from shallot skin, is able to stimulate optimal stem elongation. Thus, this graph strongly indicates that the higher the concentration of POC given, the greater the positive effect on the growth of tomato plants, with the P5 treatment being the most effective concentration in supporting plant development. To support the observation results, an ANOVA test was conducted to determine the effect between treatments. The results of the ANOVA test on plant height are presented in the following table.

Table 4: Results of ANOVA Test of Plant Height (cm)

Variables	Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Plant Height	Results	1,889	2	0.945	0.638	.000

Table 4.4, the results of the ANOVA test on the height of tomato plants show that the treatment given has a significant effect on the growth of plant height. The *Sum of Squares* value of 1.889 with degrees of freedom (df) 2 produces a *Mean Square* of 0.945. The calculated F value obtained is 0.638 with a significance value (Sig.) of 0.000, which is smaller than the significance level of 0.05 ($\alpha = 5\%$). This indicates that H_0 is rejected and H_1 is accepted, so it can be concluded that there is a significant difference in the height

of tomato plants due to the administration of liquid organic fertilizer and PGR treatments. Thus, variations in the concentration of POC and PGR applied have a significant effect on the growth of tomato plants, so that the treatment is effective in increasing plant growth compared to no treatment. To see the differences between treatments, a Duncan test analysis was carried out. The results of the Duncan test are presented in the following table.

Table 5: Duncan Test Results for Plant Height (cm)

No	Treatment	Plant Height (cm)
1	P5 (55 ml/L)	46.8 ^a
2	P4 (45 ml/L)	43.5 ^{ab}
3	P3 (35 ml/L)	39.6 ^{bc}
4	P2 (25 ml/L)	36.2 ^{cd}
5	P1 (Control +)	34.7 ^{de}
6	P0 (Control -)	27.9 ^e

The results of the Duncan test showed that treatment P5 with a POC concentration of 55 ml/L produced the highest average plant height in the 6th week, namely 46.8 cm, and was in the letter group a, which means it was significantly different from most other treatments. Treatment P4 (45 ml/L) was in group ab with an average of 43.5 cm, indicating that its growth was not significantly different from P5, but better than treatments with lower concentrations. Treatment P3 (35 ml/L) was in group bc with an average of 39.6 cm, indicating a decrease in growth compared to P5 and P4, but still better than P2, P1, and P0. Furthermore, P2 (25 ml/L) was in group cd with an average of 36.2 cm, indicating that increasing the POC concentration had a positive effect, although the results were

lower than the treatments above it. Treatment P1 (positive control) was in the de group with an average height of 34.7 cm, indicating that Ratu Biogen's ZPT fertilizer still had an effect, although not as good as the combination of Azolla and shallot skin POC. Meanwhile, treatment P0 (control without fertilizer) showed the lowest average height of 27.9 cm and was in the e group, so it was very different from all other treatments.

b. Number of Leaves

Besides plant height, one important indicator of the quality of vegetative growth in tomato plants is leaf number. The results of the leaf number study are presented in the following figure.

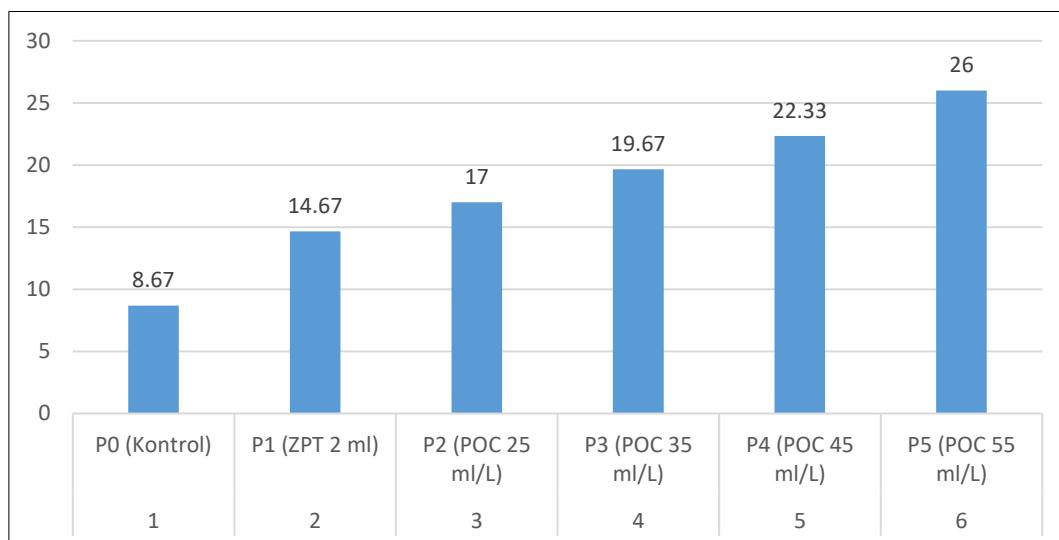
**Fig 2:** Number of Leaves

Figure 2 shows the final leaf count of tomato plants in various POC concentration treatments, and the results show a very clear pattern of increase as the concentration of the POC solution given increases. The control treatment (P0) was the group with the lowest number of leaves, namely 8.67 leaves, which indicates limited vegetative growth due to the lack of additional organic nutrient supply. Treatment P1 (2 ml PGR) showed an increase in the number of leaves to 14.67 leaves, but still lagged behind the POC treatment, indicating that PGR without the support of macro and micro nutrients is not enough to maximize leaf formation.

The growth response began to increase significantly in treatment P2 (25 ml/L) which reached 17 leaves, then increased even higher in P3 (35 ml/L) with 19.67 leaves. This

increase indicates that POC at medium concentrations has been able to provide sufficient nutrients to support the formation of new leaves. The highest increase in the number of leaves occurred in treatments P4 (45 ml/L) and especially P5 (55 ml/L), reaching 22.33 and 26 leaves, respectively. The dominance of the P5 treatment confirms that the higher the concentration of POC given, the more optimal the supply of nitrogen, organic minerals, and bioactive compounds from shallot skins that accelerate photosynthesis activity and stimulate leaf meristem growth. To see the results of differences between treatments, ANOVA and Duncan tests were carried out, which are presented successively as follows.

Table 6: Results of ANOVA Test on Number of Leaves

Variables	Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Number of Leaves	Results	2,800	2	1,400	0.268	.000

The results of the ANOVA test on the number of leaves of the tomato plant showed that the treatment given had a significant effect. The Sum of Squares value of 2.800 with degrees of freedom (df) 2 produced a Mean Square of 1.400. The calculated F value was 0.268 with a significance value (Sig.) of 0.000, which was smaller than the significance level of 0.05 ($\alpha = 5\%$). This indicates that H_0 is rejected and H_1 is accepted, so it can be concluded that there is a significant difference in the number of leaves of tomato plants due to the

treatment given. Thus, the application of liquid organic fertilizer made from *Azolla microphylla* and shallot skin has a significant effect on increasing the number of leaves of the tomato plant, because the content of nutrients and bioactive compounds in it is able to support optimal leaf formation and development. After obtaining the overall results of the observation of the number of leaves, it will be continued to the Duncan test and the following results are obtained.

Table 7: Duncan's Test Results for Number of Leaves

No	Treatment	Week 6 (Mean number of leaves)
1	P5 (55 ml/L)	26.0 ^a
2	P4 (45 ml/L)	22.3 ^b
3	P3 (35 ml/L)	19.7 ^c
4	P2 (25 ml/L)	17.0 ^d
5	P1 (Control +)	14.7 ^e
6	P0 (Control -)	8.7 ^f

The results of the Duncan Test in the 6th week showed that each treatment was in a different letter group (a–f), which means that all treatments had a significantly different effect on the number of leaves of the tomato plant. Treatment P5 (a combination of *Azolla microphylla* Kaulf. POC and 55 ml/L of shallot skin) was in the highest group (^a) with 26.0 leaves, so it can be concluded as the treatment that had the most optimal effect on the growth of the number of leaves. Treatment P4 (45 ml/L) was in the ^b group with 22.3 leaves, showing significant results but still lower than P5. Furthermore, P3 (35 ml/L) and P2 (25 ml/L) were in different groups, namely ^c and ^d, with 19.7 and 17.0 leaves, respectively. This confirms the pattern of increasing vegetative growth as the concentration of POC increases. The positive control treatment (P1) obtained 14.7 strands

recorded in the ^e group, indicating that the use of synthetic PGRs still did not provide a response as large as natural POC. Meanwhile, the negative control (P0) was in the lowest group (^f) with 8.7 strands, indicating that plants without fertilizer intervention experienced the slowest growth. Overall, the results of this further test confirmed that the combination of POC *Azolla microphylla* Kaulf . and shallot skin had a significant and graded effect on the number of leaves, with the best response achieved at the highest concentration, namely 55 ml/L.

c. Flower Appearance Time and Number of Fruits

The following diagram presents the results of observations regarding the time of first flower appearance and the number of fruits in each treatment during the observation period.

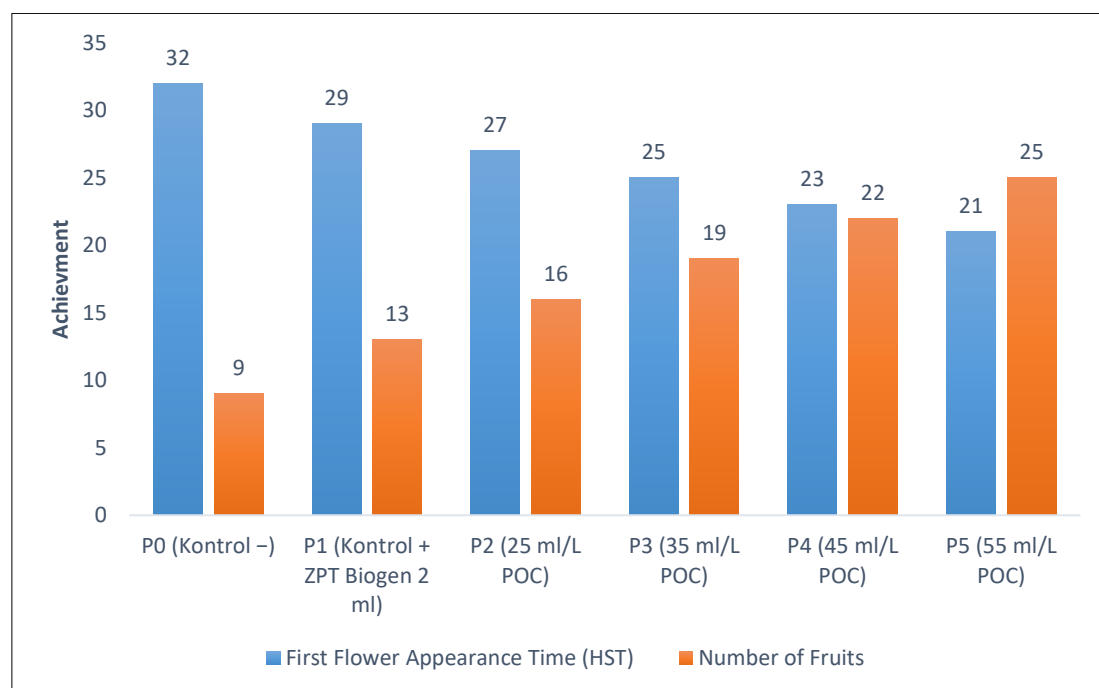


Fig 3: Flower Appearance Time and Fruits

The results of the study showed that the administration of *Azolla microphylla* Kaulf POC and shallot skin had a very significant effect on the generative phase of tomato plants, which was indicated by the acceleration of the first flower

appearance time and an increase in the number of fruits produced. Based on the first diagram, a consistent decreasing pattern was seen from treatments P0 to P5, where the higher the concentration of POC given, the faster the plants entered

the flowering phase. Plants in the P0 treatment required 32 days after planting to produce the first flower, while the P5 treatment only required 21 days after planting. This indicates that the combination of POC at high concentrations is able to accelerate the transition of plants from the vegetative phase to the generative phase. This acceleration is due to the influence of the content of nitrogen, phosphorus, potassium, anthocyanins, flavonoids, and natural phytohormones from *Azolla* and shallot skin, which synergistically improve plant metabolism and stimulate flower formation.

In line with the accelerated flowering, the second diagram shows a very significant increase in fruit number according to the treatment sequence. Treatment P0 produced the lowest number of fruits, at 9, while P5 produced 25, an almost threefold increase over the negative control. The strong correlation between flowering time and fruit number indicates that the earlier the plant enters the reproductive phase, the greater the potential for ovary formation that develops into fruit. Higher concentrations of POC provide essential nutrients and bioactive compounds in sufficient

quantities, thus giving the plant a better physiological capacity to maintain flowers, maximize pollination, and increase fruit set success. This condition is in line with the view that optimal nutrition not only accelerates flowering but also supports the continuity of fruit development until harvest.

Both diagrams show that higher concentrations of POC had the most beneficial effect, both in accelerating flower emergence and increasing the number of fruits produced. Treatment P5 (55 ml/L) was consistently the best treatment in both parameters, indicating that the combination of POC *Azolla microphylla* Kaulf . and shallot skin at high concentrations can maximize the generative potential of tomato plants. These findings confirm that this natural-based POC is effective as a biofertilizer that is not only environmentally friendly but also efficient in increasing plant productivity. The results of the ANOVA and Dunce tests for observing flowering time and fruit number are presented in the following table.

Table 8: ANOVA Test Results for Flower Emergence Time and Number of Fruits

Variables	Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Flower Appearance Time	Results	3,333	2	1,667	0.175	.000
Number of Fruits	Results	21,665	2	10,833	0.918	.000

The ANOVA test results showed that the treatment of liquid organic fertilizer and ZPT had a significant effect on the time of flowering and the number of fruits of the tomato plants. In the variable of the time of flowering, the *Sum of Squares* value of 3.333 with degrees of freedom (df) 2 resulted in a *Mean Square* of 1.667. The calculated F value was 0.175 with a significance value (Sig.) of 0.000, which is smaller than the significance level of 0.05 ($\alpha = 5\%$). This indicates that the treatment had a significant effect on the acceleration or difference in the time of flowering of tomato plants.

Meanwhile, the *Sum of Squares* value for the fruit number variable was 21.665 with a degree of freedom (df) of 2 and a

Mean Square of 10.833. The calculated F value was 0.918 with a significance value (Sig.) of 0.000, which is also less than 0.05. These results indicate that the treatment given had a significant effect on the number of fruits produced by the rampai tomato plant.

Overall, the results of the ANOVA test show that the administration of liquid organic fertilizer made from *Azolla microphylla* and shallot skins as well as ZPT not only affects the vegetative phase, but also has a real impact on the generative phase of tomato plants, which is reflected in the acceleration of flowering time and an increase in the number of fruits.

Table 9: Duncan Test Results for Flower Appearance Time and Number of Fruits

No	Treatment	Flowering Time (DAP)	Number of Fruits (fruits)
1	P0 (Control -)	32 ^f	9 ^f
2	P1 (Control +)	29 ^c	13 ^c
3	P2 (25 ml/L)	27 ^d	16 ^d
4	P3 (35 ml/L)	25 ^e	19 ^e
5	P4 (45 ml/L)	23 ^b	22 ^b
6	P5 (55 ml/L)	21 ^a	25 ^a

Duncan's test shows a significant difference between treatments in terms of flower emergence time and number of tomato fruit. Values followed by different letters indicate a significant difference at the 5% level ($\alpha = 0.05$). Plants in the negative control (P0) had the slowest flower emergence time (32 HST) and the lowest number of fruits (9 fruits), marked with the letter "f". Application of POC Ratu Biogen (P1) accelerated flowering to 29 HST and increased the number of fruits to 13, significantly different from the control. POC with various concentrations showed a significant increase in sequence: POC 25 ml/L (P2) 27 HST and 16 fruits, POC 35 ml/L (P3) 25 HST and 19 fruits, POC 45 ml/L (P4) 23 HST and 22 fruits, until POC 55 ml/L (P5) gave the best effect with the first flowers appearing at 21 HST and the highest number

of fruits, namely 25 fruits. The results of Duncan's test confirmed that the higher the concentration of POC, the faster the plant flowers and the higher the fruit production.

d. Fruit Weight

In addition to vegetative growth and generative parameters such as flowering time and fruit number, measuring fruit weight is also an important indicator in assessing tomato plant productivity. Fruit weight reflects the quality and potential yield of the crop, which is influenced by the fertilizer or growth hormone treatment applied. The following table presents the results of observations of tomato plant fruit weight in each treatment during the study period.

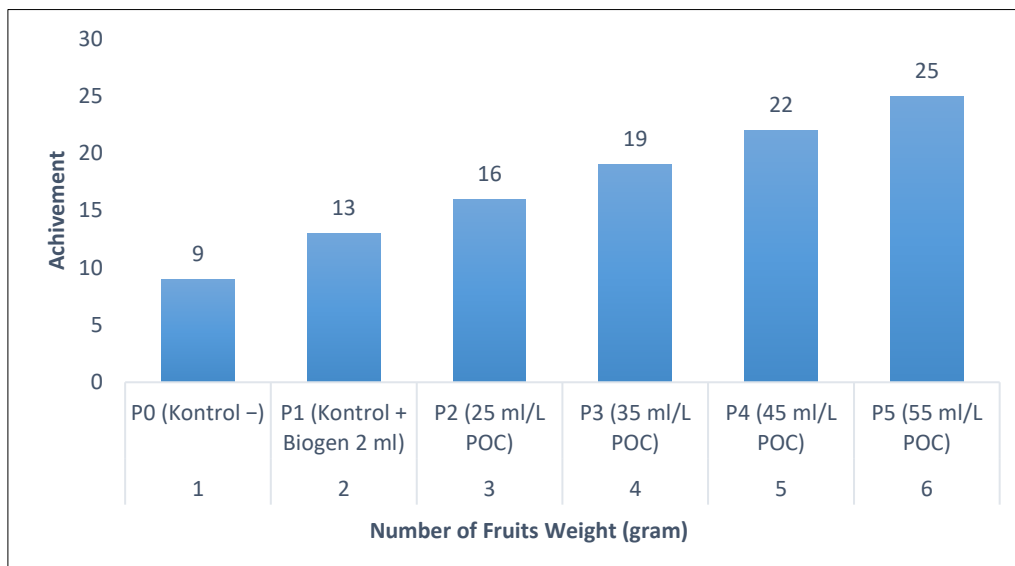


Fig 4: Fruit Weight Results

The bar chart of fruit weight shows a very clear increasing pattern, along with the increasing concentration of the combination of *Azolla microphylla* Kaulf POC and shallot skin. The treatment without fertilizer (P0) had the lowest fruit weight, namely 9 grams, which reflects the limited essential nutrients available to the plant. The application of Biogen PGR to P1 was able to increase fruit weight to 13 grams, indicating that the supply of external growth hormones provided a fairly strong physiological stimulation compared to the untreated condition. However, a much more significant increase appeared in the liquid organic POC treatment, where fruit weight continued to increase from P2 (16 grams), P3 (19 grams), P4 (22 grams), until it reached its peak at P5 with 25

grams.

This graphical pattern indicates that the combination of POC provides a more stable and richer source of nutrients than the positive and negative control treatments. The nitrogen, phosphorus, potassium, and bioactive compounds such as natural phytohormones from *Azolla microphylla* Kaulf and shallot skin play a role in strengthening the photosynthesis process, carbohydrate formation, and assimilate translocation to the fruit. This results in more optimal fruit enlargement in treatments with high concentrations. This condition also illustrates that the higher the POC concentration (up to the research concentration limit), the greater the plant's ability to utilize these nutrients to increase yield biomass.

Table 10: Results of ANOVA Test on Fruit Weight

Variables	Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Fruit Weight	Results	3,665	2	1,833	0.071	.000

The ANOVA test on the fruit weight of the rampai tomato plant showed that the treatment given had a significant effect. The Sum of Squares value of 3.665 with degrees of freedom (df) 2 resulted in a Mean Square of 1.833. The calculated F value was 0.071 with a significance value (Sig.) of 0.000, which is smaller than the significance level of 0.05 ($\alpha = 5\%$). The results indicate that H_0 is rejected and H_1 is accepted, so it can be concluded that there is a significant difference in the fruit weight of tomato plants due to the treatment of liquid

organic fertilizer and ZPT. This indicates that the application of liquid organic fertilizer made from *Azolla microphylla* and shallot skin can increase the formation and filling of fruit optimally. The content of macro and micro nutrients and bioactive compounds in POC plays a role in increasing photosynthesis results and translocation of assimilates to the fruit, thus having an impact on increasing the fruit weight of rampai tomatoes.

Table 11: Duncan Test Results for Fruit Weight

No	Treatment	Number of Fruits (fruits)
1	P5 (55 ml/L)	25 ^a
2	P4 (45 ml/L)	22 ^b
3	P3 (35 ml/L)	19 ^c
4	P2 (25 ml/L)	16 ^d
5	P1 (Control +)	13 ^e
6	P0 (Control -)	9 ^f

The results of the Duncan test showed a significant difference in the fruit weight of tomato plants between treatments. Values followed by different letters indicate significant differences at the 5% level ($\alpha = 0.05$). Plants receiving the 55 ml/L POC treatment (P5) produced the highest fruit weight, namely 25 grams, marked with the letter "a". The 45 ml/L

POC (P4) and 35 ml/L (P3) produced 22 grams and 19 grams, respectively, significantly different from the other treatments. The 25 ml/L POC treatment (P2) produced 16 grams, followed by the positive control (P1) 13 grams, and the negative control (P0) 9 grams, which showed the lowest fruit weight. The results of the Duncan test confirmed that the

higher the concentration of POC given, the greater the fruit weight of tomato plants, indicating a positive effect of POC on fruit productivity.

Research on the effect of administering liquid organic fertilizer (POC) *Azolla microphylla* Kaulf. and shallot skin (*Allium cepa* L.) on the growth of tomato plants (*Solanum lycopersicum* L. var. *cerasiforme*) was carried out for ± 6 weeks from the nursery period until the plants entered the early generative phase. The parameters observed included plant height, number of leaves, flower emergence time, number of fruits, and fruit weight.

The results of the observations showed that the growth of tomato plants in each treatment increased from the first week to the last week of observation. Tomato plants that received treatment P5 (POC concentration of 55 ml/L) showed the most optimal growth with the highest average plant height and number of leaves compared to other treatments and the control. This indicates a synergistic effect between the macronutrient content (N, P, K) contained in *Azolla microphylla* Kaulf. with bioactive compounds from red onion skin such as flavonoids, anthocyanins, and natural growth stimulating compounds (auxins and cytokinins).

Research on the effect of liquid organic fertilizer (POC) *Azolla microphylla* Kaulf. and red onion skin (*Allium cepa* L.) on the growth of rampai tomato plants (*Solanum lycopersicum* L. var. *cerasiforme*) has been carried out for ± 8 weeks from the nursery period until the plants enter the harvest phase. The parameters observed include plant height, number of leaves, flower emergence time, number of fruits, and fruit weight.

The observation results showed that the growth of tomato plants in each treatment experienced different increases. Treatments with different concentrations of POC provided varying growth responses in each observed parameter. The results of the analysis of variance (ANOVA) showed that the administration of liquid organic fertilizer (POC) *Azolla microphylla* Kaulf. and shallot skin had a very significant effect on all growth parameters of the rampai tomato plant. This is evidenced by a significance value (Sig.) of 0.000 for all observed parameters ($p < 0.05$), which means H_0 is rejected and H_1 is accepted.

Laboratory analysis results indicate that the liquid organic fertilizer (POC) used in the study contains a wide variety of nutrients, both macro and micronutrients. Nitrogen (N) content was detected at 0.13 mg/L, which, although relatively low compared to the SNI 7763:2018 standard of 2 mg/L, can still contribute to leaf growth and chlorophyll formation in the early vegetative growth phase of tomato plants. Meanwhile, phosphorus (P) in the POC showed a very high value, namely 40.3 mg/L, far exceeding the SNI standard of 2 mg/L. This high P content indicates the ability of POC to stimulate root system growth, accelerate flowering, and support the fruit formation process. Potassium (K) was even the dominant component with a value of 549.6 mg/L, also far above the SNI standard of 2 mg/L. Potassium plays an important role in strengthening plant tissue, fruit enlargement, enzyme metabolism, and improving the quality of harvest results so that it can have a significant impact on the productivity of tomato plants.

In addition, the calcium (Ca) content was measured at 175.5 mg/L, which is very useful in strengthening cell walls, preventing blossom end rot, and increasing plant tissue resistance to environmental stress. The microelement iron (Fe) was found at 16.5 mg/L, within the optimal standard

range of 5–50 mg/L so that it is sufficient to support the photosynthesis process without causing toxic effects to plants. When viewed from the overall results of laboratory tests, the POC used showed very potential fertilizer characteristics in supporting plant growth and development, especially through high phosphorus and potassium content, which are directly related to flower formation, fruit enlargement, and improving the quality of harvest results, although the low nitrogen content can be limiting in the vegetative phase if not balanced from other sources.

This finding is in line with research stating that POC made from *Azolla microphylla* Kaulf. is effective in increasing the growth of tomato plants because the high phosphorus and potassium content can accelerate flower formation and increase fruit weight (Gulo *et al.*, 2024). Similar research also shows that shallot skin as a constituent of POC is rich in mineral compounds, especially potassium, which contributes significantly to the size and quality of fruit in horticultural crops (Bani *et al.*, 2024). In addition, other research also confirms that the presence of microelements such as Fe at a balanced concentration can maximize photosynthesis thereby increasing plant vigor (Rahmawati & Widoretno, 2024).

As a comparison, this study also used commercial fertilizer ZPT Ratu Biogen, which is a liquid organic fertilizer product that has been circulating in the market and is widely used by farmers. The results of laboratory analysis of Ratu Biogen showed a nutrient composition that was relatively similar to the fermented POC, but with several differences in characteristics. The nitrogen (N) content in Ratu Biogen was recorded at 0.12 mg/L, slightly lower than POC *Azolla microphylla* Kaulf. and shallot skin (0.13 mg/L). Although these two values are still below the SNI 7763:2018 standard of 2 mg/L, both still provide sufficient nitrogen contributions to support the initial vegetative growth of plants, especially in chlorophyll formation and protein synthesis.

The low nitrogen content in these two fertilizers indicates that both products rely more on other nutrients such as phosphorus and potassium as the main components in supporting plant growth. The phosphorus (P) content in Ratu Biogen is 38.50 mg/L, slightly lower than the fermented POC which reaches 40.3 mg/L, but still far exceeds the SNI standard of 2 mg/L. The high phosphorus content in both fertilizers shows excellent potential in stimulating root growth, accelerating flowering, and supporting the fruit formation process. Phosphorus is an important component in the formation of ATP (Adenosine Triphosphate) which plays a role in energy transfer for various plant metabolic processes, including photosynthesis, respiration, and biomolecule synthesis.

Calcium plays an important role as a structural component of cell walls and cell membranes, and plays a role in the process of cell division, cell elongation, and signal transmission in plants. The presence of sufficient calcium can prevent physiological disorders such as blossom end rot in tomatoes, which is often caused by calcium deficiency or impaired calcium translocation in plants. The iron (Fe) content in Ratu Biogen is 18.00 mg/L, slightly higher than the fermented POC (16.5 mg/L), but both are still within the SNI 7763:2018 standard range of 5–50 mg/L. Iron is an important component in chlorophyll synthesis and plays a role in various enzyme systems involved in the processes of photosynthesis, respiration, and nitrogen fixation.

From the comparison of nutrient composition between fermented POC from *Azolla microphylla* Kaulf. and shallot

skin with commercial fertilizer Ratu Biogen, it can be seen that both products have very similar characteristics, especially in the very high content of the main macro elements (P and K). The difference in content between the two fertilizers is relatively small and not practically significant, with fermented POC slightly superior in nitrogen, phosphorus, and calcium content, while Ratu Biogen is superior in potassium and iron content. This similarity in composition is an indicator that the fermentation process of *Azolla microphylla Kaulf* and shallot skin is able to produce liquid organic fertilizer with quality equivalent to commercial products that have gone through a standard production process.

This proves that the use of local organic materials such as *Azolla microphylla Kaulf* and red onion peel waste can be an effective and economical alternative in providing quality organic fertilizer for farmers. Although the nutrient composition of both fertilizers is relatively similar, the results of the study showed that fermented POC gave a better response to several growth parameters compared to Ratu Biogen. Treatment P5 (POC 55 ml / L) produced a higher plant height (46.80 cm), number of leaves (26 pieces), flowering time (21 HST), number of fruits (25 pieces), and fruit weight (25 grams) compared to P1 (Ratu Biogen 2 ml) with a plant height (34.70 cm), number of leaves (14.67 pieces), flowering time (29 HST), number of fruits (13 pieces), and fruit weight (13 grams). After the researcher conducted a feasibility test of the content of liquid organic fertilizer, the researcher conducted research according to established procedures.

Observations in the 6th week showed that tomato plant height showed quite significant variations between treatments. Plants in the control without fertilizer (P0) had a height of 28.3 cm, while treatment with Ratu Biogen PGR (P1) increased plant height to 35 cm. Application of POC with a concentration of 25 ml/L (P2) resulted in a plant height of 36.5 cm, which was higher than P0 and P1. Interestingly, the POC treatments of 35 ml/L (P3) and 45 ml/L (P4) showed slightly lower plant heights, 39.9 cm and 43.8 cm, respectively, compared to P2, despite the higher concentration. The POC treatment of 55 ml/L (P5) showed the highest growth, namely 47.2 cm, because at this concentration the availability of macro and micro nutrients reached an optimal point to support all plant physiological processes, including cell elongation and new tissue formation.

This phenomenon is caused by the optimal concentration factor, where at certain concentrations, plants allocate more energy to the development of root systems and generative organs, so that vegetative growth does not increase optimally. Furthermore, increasing nitrogen at moderate concentrations can affect the carbon/nitrogen (C/N) ratio, so that more plant energy is directed to metabolic processes and internal organ synthesis.

These results are in line with research stating that the administration of *Azolla pinata* POC can significantly increase the vegetative growth of mustard greens due to its high N, P, and K content as well as microelements such as Fe, Mg, and Zn which support enzyme activity and the formation of new tissue (Markus *et al.*, 2025). In addition, shallot skin also contains natural auxin and cytokinin compounds that play a role in cell elongation, as explained by research stating that bioactive compounds in shallot skin can stimulate stem and leaf growth in horticultural plants.

Treatment P3 (POC 35 mL/L) showed a plant height that was almost the same as the control, namely 53.6 cm, which was likely caused by a dose that was not optimal to meet plant nutrient needs. Thus, a concentration of 55 mL/L can be considered an effective dose to increase the height of tomato plants in this study (Riski *et al.*, 2024).

The number of leaves showed variations in plant responses to each treatment. The control treatment without fertilizer (P0) produced the fewest leaves, namely 9, indicating limited nutrients in supporting vegetative growth. Application of Ratu Biogen PGR (P1) increased the number of leaves to 15, while P2 and P3 produced 18 and 20 leaves, respectively. Interestingly, at a POC concentration of 45 ml/L (P4), the number of leaves actually decreased to 23. Meanwhile, treatment P5 with a POC concentration of 55 ml/L produced the highest number of leaves, namely 27. This is due to the availability of sufficient nitrogen to support protein and chlorophyll synthesis, plus the presence of natural cytokinins from shallot skins that stimulate cell division in meristem tissue. In addition, the balance of macro and micro nutrients at high concentrations is able to support optimal vegetative growth, so that leaf development occurs more optimally than other treatments.

The results of this study align with several previous studies that demonstrated the positive effect of liquid organic fertilizer on increasing plant leaf number. The study found that the application of liquid organic fertilizer (POC) to *Azolla microphylla Kaulf* in tomato plants it can increase the number of leaves by up to 35% compared to the control treatment, this is due to the high nitrogen content in *Azolla microphylla Kaulf* which plays an important role in the formation of chlorophyll and new vegetative tissue (Febriyanti *et al.*, 2023). In line with that, research found that administering shallot skin extract can increase the number of leaves in chili plants because it contains natural phytohormones such as auxin and cytokinin which can stimulate cell division in meristem tissue (Assadiyah *et al.*, 2023). Furthermore, research shows that a combination of liquid organic fertilizer made from *Azolla microphylla Kaulf* and organic kitchen waste (including onion peels) resulted in a 40% increase in the number of leaves in cherry tomato plants compared to without POC treatment, which indicates a synergistic effect between macronutrient content and natural phytohormones in increasing vegetative growth (Sinu *et al.*, 2024).

The flower emergence time data shows a fairly consistent pattern, with treatments P0, P1, and P2 showing flower emergence at 32, 29, and 27 days after planting (DAP), treatments P3 and P4 at 23 and 25 days after planting (DAP), and treatment P5 at 21 days after planting (DAP). This indicates that the higher the concentration of POC administered, the faster the plant's flower emergence. The nitrogen content at the P5 concentration not only supports vegetative growth but also accelerates the plant's transition from the vegetative to the generative phase. At this dose, optimal nitrogen availability helps chlorophyll formation and efficient photosynthesis, thus accelerating energy accumulation. Once basic vegetative needs are met, the plant is better prepared to enter the flowering phase. Furthermore, bioactive compounds from shallot skin, such as flavonoids and natural phytohormones, act as triggers that accelerate flower initiation. With this combination, the P5 treatment produces flowers more quickly because the plant reaches the ideal physiological condition to transition to the generative

phase. This confirms that the acceleration of flowering in P5 reflects a more efficient plant response in utilizing nutrients compared to other treatments.

Regarding the fruit number variable, the results showed very interesting findings. Treatment P0 produced the fewest fruits, namely 9, followed by P1 with 13, P2 with 16, and P3 with 19. Treatment P4 produced the highest yield, namely 22, while P5 experienced a decrease in the number of fruits to 25. These findings indicate that the concentration of POC 55 ml/L (P5) is the optimal point for fruit formation, because at this point the plant is in an ideal balance between vegetative and generative growth. Conversely, the increase in fruit number in P5 indicates that the higher nutrient concentration actually provides optimal support for the flowering and fruiting process. In this treatment, the availability of nitrogen, phosphorus, potassium, and bioactive compounds from shallot skins is at a balanced level so as not to trigger excessive dominance of vegetative growth. Plants are able to maintain good leaf and stem growth without sacrificing energy allocation for fruit formation. This results in a greater number of fruits followed by better fruit size.

This phenomenon indicates that in P5, there is no negative trade-off between vegetative and generative growth; instead, the plants are in their most ideal physiological condition. The natural phytohormone compounds in POC help increase pollination success, fruit filling, and uniform fruit shape. Therefore, P5 can be considered the most superior concentration for increasing tomato plant productivity, as it can encourage the formation of more, more uniform, and higher-quality fruit compared to other treatments.

The increased content of nutrients such as nitrogen (N), phosphorus (P), and potassium (K) in POC is thought to be the main factor influencing the acceleration of flowering. Nitrogen plays a role in chlorophyll formation and vegetative growth, while phosphorus plays a crucial role in flower and fruit formation. Shallot skin contains flavonoids, phenols, and natural phytohormones such as auxins and cytokinins, which can stimulate faster flower formation. Meanwhile, *Azolla microphylla* Kaulf. contains a complete range of macro and micronutrients, as well as bioactive compounds that increase nutrient availability in the growing medium. The combination of the two provides an optimal nutritional balance to support the flowering of tomato plants. These results align with research showing that the application of *Azolla pinnata*-based POC accelerated flowering in red chili plants by 20% compared to the control. Other research also found that the application of shallot skin extract can accelerate flowering and increase the number of flowers in mustard plants due to the influence of its natural phytohormone compounds.

Several previous studies have shown that the application of liquid organic fertilizer (POC) made from natural ingredients *Azolla* and shallot skin has a significant effect on the generative phase of plants, especially on flower formation (Lestari *et al.*, 2023). Other studies also show that the application of *Azolla pinnata*-based POC to red chili plants can accelerate the time of flower emergence by up to 20% compared to the control treatment (Wulandari & Agroteknologi, 2023). This is due to the high content of macronutrients such as nitrogen (N), phosphorus (P), and potassium (K) as well as the presence of nitrogen-fixing microorganisms that help increase the availability of nutrients in the soil. Other studies also state that the application of shallot skin extract to mustard plants can accelerate flowering

and increase the number of flowers (Widyaningrum, E. Nanik Kristalisasi, 2023). This effect is associated with the presence of natural phytohormone compounds such as auxin and cytokinin in shallot skin which play a role in stimulating the formation of plant reproductive organs.

Several previous studies have shown that plants that flower earlier will produce more fruit; for example, one study reported that tomato fruit set is more influenced by assimilate availability, light intensity, and plant hormone balance than by the transition time from the vegetative to the generative phase (Assadiyah *et al.*, 2023). Other studies also confirmed that successful fruit set is influenced by pollen viability, environmental conditions during anthesis, and the sink strength of young fruit (Collins *et al.*, 2021). Furthermore, high doses of nitrogen or certain POCs can accelerate or delay flowering, while simultaneously affecting canopy size, photosynthetic efficiency, and carbon allocation, which are key factors in determining fruit set.

Research found that administering POC at optimal concentrations was able to increase the number of tomatoes by up to 45% compared to the control, but concentrations that were too high actually reduced fruit productivity due to the dominance of vegetative growth. (AndiPurnamaMS, JenalMutakin, 2021). This is supported by research stating that excess nitrogen in tomato plants can cause excessive leaf and stem growth, thus inhibiting flower and fruit formation (Irmawati, 2024). In line with that, research shows that the phosphorus content in liquid organic fertilizer plays a crucial role in increasing the number of tomato flowers and fruits because phosphorus is an important component in the formation of ATP (Adenosine Triphosphate) which is needed during the flowering and fruiting process (Widyaningrum, E. Nanik Kristalisasi, 2023).

Based on the research results, the acceleration of the flowering time in tomato plants was proven to be in line with the increase in the number of fruits produced. The P5 treatment, which showed the fastest flowering time (21 days after planting), also produced the highest number of fruits, namely 25. This indicates that the acceleration of the generative phase that occurs due to the high availability of nitrogen, phosphorus, potassium, and bioactive compounds from *Azolla microphylla* Kaulf and shallot skin not only accelerates flower initiation but also directly supports a more efficient fertilization process. The physiological condition of the plants in P5 is at an optimal level, where vegetative needs have been met and energy is allocated effectively towards flower and fruit formation. Natural phytohormones such as auxin and cytokinin also strengthen the success of pollination and fruit formation, so that the plants do not experience a trade-off between vegetative and generative growth.

The fruit weight parameter showed consistent results with other parameters. The P0 treatment produced the lowest fruit weight at 9 grams, followed by P1 (13 grams), P2 (16 grams), P3 (19 grams), P4 (22 grams), and the highest at P5 with 25 grams. This increase in fruit weight is in line with the better vegetative growth results in the high POC treatment, because more leaves and stronger stems support the distribution of photosynthates to the fruit. The potassium (K) element in POC plays a major role in the process of fruit formation and filling, because K functions in the transportation of photosynthesis results to the fruit and increases sugar content and fruit quality. In addition, bioactive compounds from shallot skins are also thought to improve plant metabolism, so that nutrient absorption is more efficient. Research also

shows that the use of POC made from *Azolla* and shallot skins can increase tomato fruit weight by up to 30% compared to without organic fertilizer. Although the P4 treatment produced the highest number of fruits, the highest fruit weight was obtained in the P5 treatment, which indicates a trade-off between the number and size of fruits, where different POC concentrations can optimize different production parameters in the cultivation of rampai tomato plants.

Research states that the application of POC made from *Azolla microphylla Kaulf* . is able to increase the weight of tomato fruit by up to 30% compared to the control, this is due to the increase in leaf area that supports the process of photosynthesis and the accumulation of photosynthates in the fruit (Siti nawariah, Siti Rabiatul Fajri, 2022) . In line with that, research found that the potassium content in liquid organic fertilizer plays an important role in the translocation of carbohydrates from leaves to fruit, thereby significantly increasing the weight and quality of tomato fruit (Cepa *et al.*, 2025) . Other research also shows that bioactive compounds in onion skins such as *flavonoids* and *quercetin* can increase the efficiency of plant metabolism and nutrient absorption, which has an impact on increasing fruit weight by up to 25% compared to treatments without onion skin extract (Siti nawariah, Siti Rabiatul Fajri, 2022) .

The results of this study can be explained through various theories in plant physiology. First, Justus von Liebig's theory of plant mineral nutrition states that plant growth is limited by the nutrient with the least availability (Liebig's law of the minimum). In this study, the administration of *Azolla microphylla Kaulf POC was used* . and shallot skins provide essential nutrients such as nitrogen (N), phosphorus (P), and potassium (K), which meet the minimum requirements of tomato plants for optimal growth. Treatment P5, which produced the highest plant height (68.3 cm), indicates that a concentration of 55 mL/L is able to provide sufficient nutrients to overcome growth-limiting factors.

The theory of photosynthesis and chlorophyll formation. According to this theory, nitrogen is a major component in the synthesis of chlorophyll, proteins, and nucleic acids. The structure of the chlorophyll molecule contains nitrogen atoms in its porphyrin core, so nitrogen availability significantly determines the photosynthetic capacity of plants. The results showed that the P5 treatment produced the largest number of leaves (10 leaves), which means a larger photosynthetic surface area. This is in accordance with the theory that the higher the nitrogen content, the more chlorophyll is formed, and the more efficient the photosynthesis process. This increase in photosynthesis produces more photosynthates that support vegetative growth and biomass accumulation.

Potassium (K) plays an important role in regulating osmotic pressure and opening stomata for gas exchange. In this study, the P5 treatment produced the highest fruit weight (71 grams), which can be explained by this theory: the potassium content in the POC facilitates the efficient translocation of photosynthates from leaves to fruits, so that the fruits receive sufficient carbohydrate intake for enlargement and weight gain.

The theory of flowering physiology explains that the transition from the vegetative to the generative phase is influenced by the C/N (carbon/nitrogen) ratio in plant tissue. A high C/N ratio encourages flowering, while a low ratio encourages vegetative growth. Phosphorus (P) plays an important role in the formation of ATP and nucleic acids

necessary for flower cell differentiation. The results showed that treatment P5 had the longest flowering time (32 days), indicating that high nitrogen concentrations prolong the vegetative phase. Conversely, treatment P4 produced the highest number of fruits (14.6 fruits) due to a more balanced C/N ratio, where the nitrogen content is sufficient for initial growth but not excessive so that the plant can quickly transition to the generative phase and allocate energy to flower and fruit formation.

Understanding the plant physiology theories above can be applied to biology lessons at various levels of education. For secondary school students, this research can be used as practical material to understand the concepts of plant growth and development, mineral nutrition, and photosynthesis. Students can directly observe the effects of organic fertilizer on growth parameters such as plant height and leaf number, then relate these findings to the theories learned in class.

5. Conclusion

Based on the research results, it can be concluded that liquid organic fertilizer (POC) made from *Azolla microphylla* and shallot skins has a significant effect on the growth and yield of tomato plants (*Solanum lycopersicum L. var. cerasiforme*). The application of POC at various concentrations has been proven to be able to increase vegetative growth parameters, including plant height and number of leaves, as well as accelerate the generative phase as indicated by faster flower emergence time and increased number and weight of fruit. The treatment with the highest concentration, namely 55 mL/L (P5), consistently produced the best values in all observation parameters and was significantly different compared to the control treatment and lower concentrations. The effectiveness of this POC is related to the content of macro and micro nutrients, especially high phosphorus and potassium, as well as the presence of bioactive compounds and natural phytohormones that play a role in stimulating growth and yield formation. Thus, the combination of POC *Azolla microphylla* and shallot skins has the potential to be an effective alternative environmentally friendly fertilizer to increase the productivity of tomato plants while supporting the implementation of sustainable agriculture and reducing dependence on synthetic chemical fertilizers.

6. References

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