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Utilization of Fishery Processing Waste as Liquid Organic Fertilizer to Enhance the Growth of Red Chili Peppers (Capsicum annuum L.)

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ABSTRACT

Fluctuating red chili production in West Sulawesi and the potential availability of fishery waste highlight the need for environmentally friendly fertilization alternatives. This study evaluated the effects of fish-waste liquid organic fertilizer (LOF) on red chili growth and identified the concentration that produced the best response among the tested levels. A Completely Randomized Design was used with four LOF concentrations: P0 (0%/control), P1 (10%), P2 (20%), and P3 (30%), each with three replications, resulting in 12 experimental units. LOF was produced by fermenting 1 kg of fish waste (heads, bones, and viscera) with 100 g of palm sugar and 1 L of water for 10–14 days. Plant height, leaf number, fruit number, and fresh weight were measured. Data were analyzed using ANOVA followed by the Least Significant Difference (LSD) test at $\alpha = 0.05$ for significant parameters. LOF significantly affected plant height, leaf number, and fresh weight ($p < 0.05$), but did not significantly affect fruit number ($p > 0.05$). P3 (30%) produced the highest plant height (38.00 cm) and fresh weight (12.30 g), P1 (10%) produced the highest leaf number (26.00 leaves), and P2 (20%) showed the highest fruit number (12.00 fruits), although the latter was not statistically significant. These results indicate that the best LOF concentration differed among growth parameters. Fish-waste LOF therefore has potential as an organic fertilizer alternative while supporting the utilization of fishery-processing waste.

INTRODUCTION

The agricultural sector plays a strategic role in national development and contributed 13.57% to the Gross Domestic Product in the third quarter of 2023 (BPS, 2023). One horticultural commodity with high economic value is red chili (Capsicum annuum L.), which is widely used as a cooking spice and raw material in the food industry, thereby influencing the stability of national food prices (Harpenas & Dermawan, 2010). The average consumption of chili peppers among Indonesians is 0.15 kg per capita per month (Muflikh, Y. N., & Kiloes, A. M., 2024), so demand tends to continue rising throughout the year. Red chili pepper production in West Sulawesi has fluctuated: 33,357 quintals in 2021, rising to 37,099 quintals in 2023, and then declining to 32,753 quintals in 2024 (West Sulawesi Provincial BPS, 2024). These fluctuations are influenced by climate change, extreme rainfall, high temperatures, pest and disease outbreaks, and poor cultivation techniques (Sari et al., 2021; Gehlot et al., 2026). On the other hand, the sustained excessive use of chemical fertilizers can damage soil structure, reduce soil microorganism activity, and increase the risk of environmental pollution (Chemweno, 2025; Mulyani & Samosir, 2017).

The fisheries sector generates large amounts of waste—estimated at 20–30% of the total fish weight—in the form of heads, bones, guts, and scales (Nainggolan et al., 2013). In coastal areas such as West Sulawesi, particularly at fish auction sites (TPI), this waste is generally disposed of directly into the environment, potentially causing pollution (Cabel et al., 2024). In fact, fish waste still contains high levels of organic matter in the form of nitrogen (N), phosphorus (P), and potassium (K), which are essential elements for fertilizer production (Ibrahim, 2005). Zahroh et al. (2018) reported that fish waste POC contains 0.30% total N, 0.65% P_2O_5, and 0.17% K_2O, and that variations in its concentration have a significant effect on the stem height and number of leaves of red chili peppers. Previous studies have shown that fish waste POC can enhance the growth of horticultural crops during both the vegetative and generative phases (Lee et al., 2004; Wickham, A., & Davis, J. G., 2024). However, the effectiveness of POC is highly influenced by the concentration used (Wickham, A., & Davis, J. G., 2024), and studies on the effects of various concentrations of fish waste POC on red chili pepper growth remain limited. Therefore, this study aims to (1) determine the effect of fish waste POC application on the growth of red chili peppers and (2) identify the most effective POC concentration for enhancing plant growth and yield, while supporting the environmentally friendly utilization of fishery waste.

Several studies have examined the use of fish waste as liquid organic fertilizer. Zahroh et al. (2018) reported that fish waste-based POC contained 0.30% total N, 0.65% P_2O_5, and 0.17% K_2O, and that variations in its concentration had a significant effect on the stem height and number of leaves of red chili peppers. Lee et al. (2004) and Wickham & Davis (2024) obtained consistent findings in other horticultural crops, namely an increase in vegetative growth with the application of fish waste-based liquid organic fertilizer. These three studies demonstrate a consistent pattern that fish waste-based liquid organic fertilizer can improve plant growth; however, they also reveal three unresolved limitations. First, the plant response to POC is dose-dependent, but previous studies generally compared several concentration levels without identifying the optimum point or the concentration threshold at which growth begins to decline; thus, dosage recommendations for farmers are not yet available. Second, most observations have focused on vegetative parameters, while the effects of POC on the generative phase and yield components of red chili peppers remain rarely reported. Third, the nutrient content of POC is highly dependent on the composition of the raw materials, whereas waste from fish auction sites (TPI) in the coastal region of West Sulawesi has a different fish species composition compared to the raw materials used in previous studies. Unlike previous studies, this research tested POC made from West Sulawesi TPI waste across a range of graded concentrations and examined both vegetative parameters and yield components, thereby enabling the development of concentration recommendations applicable to local agroecological conditions. This study aims to (1) determine the effect of fish waste-based POC application on the growth and yield of red chili peppers, and (2) identify the most effective POC concentration, while supporting the environmentally friendly utilization of fishery waste.

RESEARCH METHODS

Time and Location

The study was conducted from June to July 2026 at the Agrocomplex Laboratory of Muhammadiyah University of Mamuju, West Sulawesi. The series of activities included the production of liquid organic fertilizer through fermentation for 10 to 14 days, preparation of the growing medium, planting of seedlings, and observation of plant growth up to 42 days after planting. The plants were placed in [a greenhouse/paranet shade/open field] to ensure that all experimental units were exposed to relatively uniform environmental conditions. The selection of these locations was based on the availability of laboratory facilities for the fermentation process and their proximity to a fish auction as a source of raw materials for the liquid organic fertilizer.

Tools and Materials

The tools used in this study are presented in table 1 while the materials used are presented in table 2

Table 1. Tools Used

NO.	TOOLS	FUNCTION
1	Fermentation Containers	Storage Container During Fermentation
2	Blender	To Puree Fish Waste
3	Measuring Tools	To Measure The Length Of The Stems And The Width Of The Leaves Of Red Chili Peppers
4	Plant Labels	To Mark The Plants
5	Books and Pens	To Record Observation Results
6	Potting Soil	To Grow Red Chili Pepper Seedlings

7	BUCKET	To Store Clean Water

Table 2. Materials Used

NO.	INGREDIENTS	FUNCTIONS
1.	Fish Waste	Main Ingredients For Poc Production
2.	Brown Sugar	Carbon Source For Fermentation
3.	Clean Water	Solvent
4.	Red Chili Seeds	Research Materials
5.	Growing Medium	Growth Medium

Experimental Design

The study used a Complete Random Design (RAL) with four POC concentration treatments and three replicates resulting in 12 experimental units. The concentration was calculated based on the comparison of POC volume to the total solution volume of 1,000 mL (Table 3). The 10–30% level was used to evaluate the response of plants at low to high application levels within the treatment range of this study, taking into account that plant responses to fish-based fertilizers may differ according to the concentration or dose given (Zahroh et al., 2018; Wickham & Davis, 2024).

Table 3. Composition of POC concentration in 1 liter of solution

Treatment	POC (mL)	Water (mL)	Total (mL)
P0 (0%)	0	1000	1000
P1 (10%)	100	900	1000
P2 (20%)	200	800	1000
P3 (30%)	300	700	1000

Production of Liquid Organic Fertilizer

One kilogram of cleaned fish waste is finely chopped, then mixed with a solution of 100 g of brown sugar and 1 L of clean water until homogeneous. The mixture is fermented in a sealed container for 10–14 days; the container is opened periodically every 2–3 days to release fermentation gases. At the end of fermentation, the liquid organic fertilizer is assessed based on color, aroma, gas formation, and pH, then filtered before use in treatments. The process of fermenting fish waste into liquid organic fertilizer is one approach to utilizing fishery waste that has been previously reported (Rafidah et al., 2023; Domínguez et al., 2024).

Planting and Maintenance

The soil was sieved, mixed thoroughly, placed in poly bags, and allowed to settle for 3–4 days before planting. One red chili seedling was planted per poly bag, and the treatment assignments were randomized according to the RAL. Maintenance included routine watering in the morning and evening, manual weeding, and mechanical pest and disease control without chemical pesticides. POC was applied according to the concentration of each treatment, namely P0 (0%), P1 (10%), P2 (20%), and P3 (30%).

Observation Parameters and Data Analysis

The parameters observed were plant height (cm) and the number of leaves (sheets), measured weekly starting 14 days after planting (DAP) through 42 DAP, the number of fruits, and fresh weight (g), which was measured at the end of the study. The data were analyzed using analysis of variance (ANOVA); if a significant effect was found ($P < 0.05$), it was followed by a Least Significant Difference (LSD) test at a significance level of $\alpha = 0.05$.

Conceptual Framework

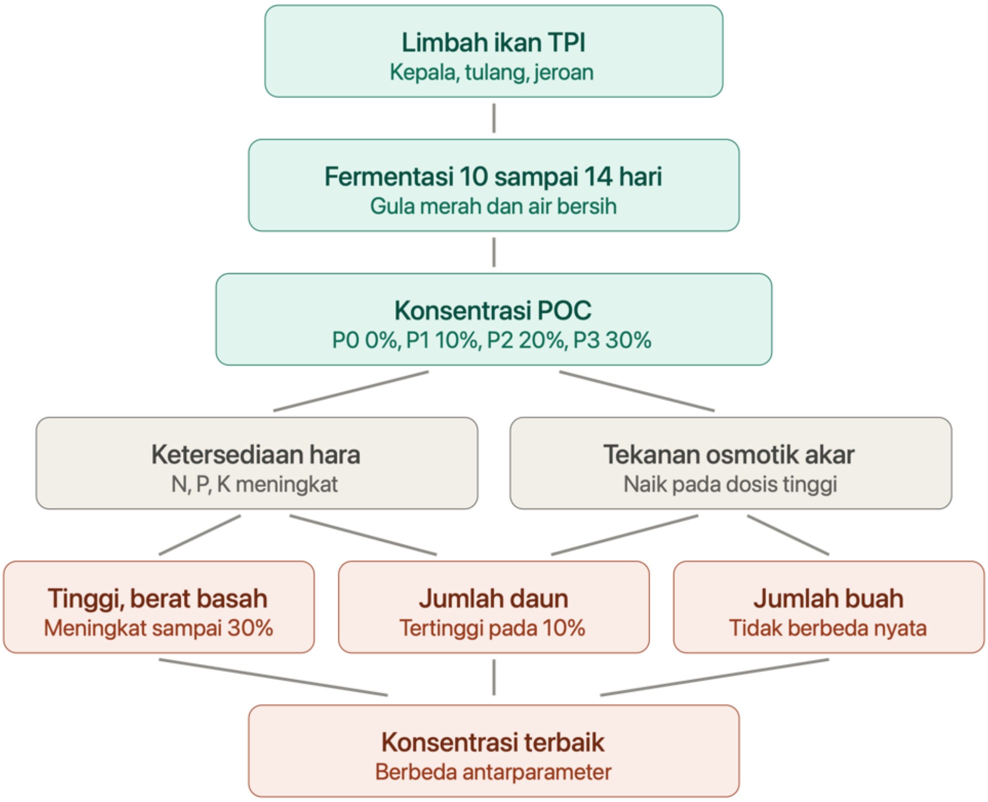

Figure 1. Conceptual Framework

RESEARCH RESULT

Observation Results

Observations were conducted weekly from 14 to 42 HST. The average observation results at 42 HST, along with the results of the BNT follow-up test, are presented in Table 4, while a summary of the variance for each parameter is presented in Table 5.

Table 4. Average plant height, number of leaves, number of fruits, and fresh weight of red chili peppers at 42 days after transplanting following the application of fish waste-based organic liquid fertilizer

Treatment	Plant height (cm)	Number of leaves (pieces)	Number of pieces	Wet weight (g)
P0 (0%)	22.00 d	18.00 b	8.00	1.10 d
P1 (10%)	28.00 c	26.00 a	10.00	7.20 c
P2 (20%)	33.00 b	20.00 b	12.00	9.30 b
P3 (30%)	38.00 a	18.67 b	11.00	12.30 a
BNT 0.05	1.88	2.72	tn	0.34

Remarks: Numbers in the same column followed by different letters show a real difference based on the 5% BNT test; tn = unreal.

Table 5. Analysis of variance (ANOVA) summary of the effect of fish waste POC on red chili growth parameters at 42 days after sowing

Parameters	JKP	JKG	KTP	KTG	Calculated F / Table F
Plant height	422.25	8.00	140.75	1.00	140.75* / 4.07
Number of leaves	120.00	16.67	40.00	2.08	19.20* / 4.07
Number of fruits	26.25	50.00	8.75	6.25	1.40 tn / 4.07
Fresh weight	201.98	0.26	67.33	0.03	2071.62* / 4.07

Note: * = significant at $\alpha = 0.05$; ns = not significant. Degrees of freedom for treatment = 3 and degrees of freedom for error = 8.

Plant Height

Plant height increased gradually across all treatments from 14 to 42 days after sowing (DAS), but the rate of increase varied depending on the POC concentration. The control treatment P0 (0%) yielded the lowest plant height at every observation time point because the plants obtained nutrients solely from the growing medium. Based on Table 4, plant height at 42 days after sowing increased in the following order: P0 (22.00 cm), P1 (28.00 cm), P2 (33.00 cm), and highest at P3 (38.00 cm). The analysis of variance (Table 5) showed that the application of fish waste POC had a significant effect on plant height (calculated $F = 140.75 >$ table $F = 4.07$; $P < 0.05$). A post-hoc test using the 5% BNT (BNT value = 1.88 cm) revealed that all treatments differed significantly from one another, with P3 receiving the highest notation (a); thus, the 30% concentration was the best treatment for the plant height parameter. The increase in plant height as POC concentration rises is believed to be related to the increased supply of the macronutrients N, P, and K. Nitrogen stimulates chlorophyll formation as well as stem and leaf growth, while phosphorus and potassium play a role in root development, tissue strengthening, and metabolic efficiency (Lee et al., 2025; Parman, 2007). These findings are consistent with those of Zahroh et al. (2018), who reported that variations in fish waste POC concentration had a significant effect on the stem height of red chili peppers, as well as Wickham, A., & Davis, J. G. (2024), who noted an increase in chili plant height due to the application of fish waste POC.

Number of Leaves

All treatments showed an increase in the number of leaves from 14 to 42 days after sowing (DAS). Unlike plant height, the highest number of leaves was achieved by treatment P1 (10%) at nearly all observation times; at 42 DAS, P1 reached 25–27 leaves (average 26.00 leaves), while P2 ranged from 18 to 22 leaves (average 20.00), P3 was around 17–20 leaves (average 18.67), and P0 had only 17–19 leaves (average 18.00). The analysis of variance results (Table 3) indicate a significant effect on the number of leaves (calculated $F = 19.20 >$ table $F = 4.07$; $P < 0.05$). The 5% BNT test (BNT value = 2.72 leaves) showed that P1 differed significantly from all other treatments (notation a), while P0, P2, and P3 did not differ significantly from one another (notation b). This indicates that the 10% concentration provided sufficient and balanced nutrients for leaf formation, particularly nitrogen, which plays a dominant role in vegetative growth and chlorophyll formation. The lower number of leaves in P2 and P3 suggests that increasing the POC concentration does not always yield better results. Excessively high concentrations can cause nutrient imbalances or increase osmotic pressure in the root zone, thereby reducing the optimal uptake of water and nutrients. A similar phenomenon was reported by Wickham, A., & Davis, J. G. (2024), who found that there is an optimal POC concentration and that doses above this level no longer improve growth.

Number of Fruits

Fruits had not yet formed at 14 DAP, began to appear at 21 DAP, and increased gradually until 42 DAP across all treatments. The highest average number of fruits at 42 HST was achieved by treatment P2 (12.00 fruits), followed by P3 (11.00), P1 (10.00), and the lowest by P0 (8.00). However, the analysis of variance (Table 3) showed that the application of POC had no significant effect on fruit number (calculated $F = 1.40 <$ table $F = 4.07$; $P > 0.05$); therefore, a post-hoc BNT test was not conducted, and the apparent advantage of P2 could not yet be declared statistically significant. The large value of the mean square for error (MSE = 6.25) relative to the mean square for treatment (MST = 8.75) indicates high variability in fruit number among replicates within the same treatment. The increase in fruit number in the treatments given POC is presumed to be due to the content of N, P, K, as well as amino acids and organic compounds resulting from the decomposition of fish waste, which support flowering, pollination, and fruit filling, while also improving soil microorganism activity (Wickham, A., & Davis, J. G., 2024; Behera et al., 2025).

Fresh Weight

Fresh weight showed a clear dose–response pattern: P3 produced the highest fresh weight with an average of 12.3 g, followed by P2 (9.3 g), P1 (7.2 g), and P0 at only 1.1 g. The analysis of variance results (Table 3) showed a highly significant difference in effects (calculated F = 2,071.62 > table F = 4.07; $P < 0.05$); the very small mean square error (MSE = 0.03) indicates relatively uniform replicate values and consistent plant responses. The 5% BNT test (BNT value = 0.34 g) showed that all treatments differed significantly from one another in the following order: P3 (a) > P2 (b) > P1 (c) > P0 (d). The P3 plants produced more than eleven times the fresh weight of the control, confirming the significant contribution of POC nutrients to biomass accumulation. Nitrogen supports chlorophyll and leaf formation, phosphorus supports root development and metabolism, while potassium aids in the translocation of photosynthates and tissue water balance (Sun et al., 2024).

The Role of Nutrients in Growth Responses

Differences in responses among treatment levels can be traced to the physiological roles of each nutrient contained in fish waste-derived POC. Nitrogen is a component of chlorophyll, amino acids, proteins, and nucleic acids; thus, its availability determines the rate of cell division and elongation in meristematic tissues. The increase in nitrogen supply as POC concentration rises is consistent with the pattern of continuously increasing plant height up to P3. Phosphorus serves as a component of ATP, membrane-forming phospholipids, and nucleic acids, thereby supporting metabolic energy transfer and root system development. A more developed root system expands the area for water and nutrient uptake, which in turn enhances the growth of the plant's aboveground parts. Potassium is not a structural component of tissues but functions as an enzyme activator, a regulator of stomatal opening, and a controller of turgor and the translocation of photosynthates from the leaves to storage organs. It is this role of potassium in tissue water status that is thought to be closely related to the pattern of fresh weight, given that fresh weight is largely determined by tissue water content in addition to dry matter accumulation. In addition to macronutrients, fish waste-based POC contains protein hydrolysis products in the form of free amino acids and short-chain peptides. These compounds can be absorbed by plants without going through the nitrate reduction pathway, which requires metabolic energy; thus, they have the potential to accelerate growth responses compared to inorganic nitrogen sources (Domínguez et al., 2024). The organic matter contained in POC also serves as a carbon source for soil microorganisms; thus, the application of liquid organic fertilizer can alter the composition of the soil bacterial community and improve nutrient mineralization processes (Lee et al., 2025; Zhang et al., 2024). It should be emphasized that this mechanistic explanation is speculative, as this study did not conduct chemical analysis of the liquid organic fertilizer nor measure the chemical and biological properties of the growing medium.

Integrated Inter-Parameter Analysis

Table 6. Summary of red chili pepper growth responses to fish waste POC concentrations

Parameters	**ANOVA Results**	**Best Treatment**	**Response pattern**
Plant height	Significant (F = 140.75*)	P3 (30%): 38.00 cm	Increased by up to 30% at the tested levels
Number of leaves	Significant (F = 19.20*)	P1 (10%): 26.00 strands	Highest at a concentration of 10%
Number of fruits	Not significant (F = 1.40)	P2 (20%): 12.00 pieces	Numerically highest at 20%; not significant
Fresh weight	Significant (F = 2071.62*)	P3 (30%): 12.30 g	Increased by up to 30% at the tested levels

The summary in Table 6 shows that the POC concentration yielding the best response varied across parameters. Plant height and fresh weight increased up to a concentration of 30%; the highest number of leaves was observed at a concentration of 10%, while the numerically highest number of fruits was at a concentration of 20%, though this difference was not statistically significant. Thus, the 30% concentration can be considered the best among the tested levels for plant height and fresh weight, but it cannot yet be declared the general optimum concentration. Determining the optimal concentration requires a wider dose range and/or more closely spaced treatment levels. Differences in response among parameters are thought to be related to differences in nutrient requirements between the vegetative and generative phases, as well as the chemical and biological conditions in the root zone. Liquid organic fertilizers can influence nutrient availability and the soil microbial community (Lee et al., 2025;

Zhang et al., 2024), whereas fertilization efficiency in chili peppers depends on the balance of available nutrients (Sun et al., 2024). The N, P, and K contents reported by Zahroh et al. (2018) were derived from the liquid organic fertilizer formulation used in that study and cannot be directly considered representative of the liquid organic fertilizer composition in this study, as no chemical analysis of the liquid organic fertilizer was conducted. The small number of fruits also needs to be considered in the context of the experimental design, namely three replicates per treatment and observations up to 42 days after sowing. Future studies should increase the number of replicates, extend observations until full harvest, test intermediate concentration levels, and conduct chemical characterization of the POC. From an environmental perspective, the use of fishery residues as fertilizer supports a circular approach by converting organic waste into valuable agricultural inputs (Cabell et al., 2024; Domínguez et al., 2024).

Practical and Economic Implications

Although a 30% concentration yielded the tallest plants and the highest fresh weight, the additional yield per unit volume of POC actually decreased as the concentration increased. Each milliliter of POC at P1 produced an additional fresh weight of 0.061 g above the control, whereas at P3 it was only 0.037 g. This means that using a 30% concentration requires three times the volume of POC compared to 10%, but the additional yield obtained does not increase proportionally. For farmers with limited access to raw materials, a low concentration is potentially more efficient per unit of material, while a high concentration is more suitable when fish waste is abundant and the cost of obtaining it is low. In terms of material availability, POC production in this study requires only fish waste, brown sugar, clean water, and a closed fermentation container—without the need for specialized equipment or processes requiring high technical skills. These characteristics enable its application on a household scale and by farmers' groups in coastal areas of West Sulawesi near fish auctions. Such utilization provides dual benefits: it supplies valuable agricultural inputs and reduces the burden of organic waste that has traditionally been disposed of directly into the environment, in line with the circular economy approach to fisheries residue processing (Cabell et al., 2024; Domínguez et al., 2024). A comprehensive business feasibility analysis could not yet be conducted in this study because the experiments were carried out on a polybag scale up to 42 days after sowing (DAS); thus, the weight of the harvested fruit—the primary determinant of farm income—has not yet been measured. Further studies on a field scale through to full harvest, accompanied by calculations of POC production costs and comparisons with inorganic fertilizers at recommended doses, are needed to assess its economic feasibility.

CONCLUSION

The application of liquid organic fertilizer made from fish waste had a significant effect on plant height, number of leaves, and fresh weight of red chili peppers ($p < 0.05$), but had no significant effect on the number of fruits ($p > 0.05$).

Among the treatment levels tested, the 30% concentration (P3) yielded the highest plant height (38.00 cm) and fresh weight (12.30 g), while the 10% concentration (P1) produced the highest number of leaves (26.00 leaves). The 20% concentration (P2) showed the highest numerical fruit count (12.00 fruits), but the difference was not significant. These results indicate that the best response to POC depends on the parameter being observed; therefore, the 30% concentration cannot yet be declared the optimal concentration for all parameters. Fish waste POC has the potential to be developed as an alternative organic fertilizer while also supporting the utilization of fishery byproducts. Further research is recommended using a larger number of replicates, an observation period extending to full harvest, a more refined concentration gradient, and chemical characterization of the POC to strengthen the determination of the optimal dose and the mechanism of plant response.

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