International Journal of Horticultural Science and Technology
Journal homepage: https://ijhst.ut.ac.ir

Liquid Organic Fertilizer Derived from Black Soldier Fly Frass Improve Yield and Quality of Tropical Vegetables, Shallot, and Red-Hot Chili Peppers

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ARTICLE INFO

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Article history:

Received: 6 March 2024,
Received in revised form: 11 August 2024,
Accepted: 14 August 2024

Article type:

Research paper

Keywords:

Black Soldier Fly Frass,
Chili,
Liquid organic fertilizer,
Shallot

ABSTRACT

This study investigated the innovative potential of black soldier fly (BSF) frass as a potassium source and its suitability as a raw material for liquid organic fertilizer (LOF). Two experiments were conducted to assess the effects of LOF on the growth and yield of shallots and chili peppers. The research took place in Lembang, West Java, Indonesia, with the first experiment running from September to December 2022 and the second from March to December 2023. The first experiment, a pot study, used a factorial design with nine shallot varieties and three LOF application rates. The second experiment, a field study, examined two factors: the LOF application method and its dosage. Results indicated that shallot growth and yield varied by variety, with 'Bima Brebes' and 'Lansuna' producing the highest yields. LOF application improved shallot biomass, increased total soluble solids in 'Batu Ijo' and 'Tajuk', and boosted vitamin C levels in 'Batu Ijo' and 'Maja'. Additionally, applying LOF at rates of 5–10 mL L^{-1} increased the marketable yield of chili peppers, while higher rates reduced unmarketable yield. In conclusion, BSF frass appeared as a promising source of liquid organic fertilizer as it enhanced vegetable growth, yield, and quality when applied at rates of 5–10 mL L^{-1}.

Introduction

As populations increase in number, education levels improve, and incomes rise, so does the demand for high-quality, environmentally friendly agricultural products (Thompson, 1998). A key aspect of sustainable agriculture is the use of organic fertilizers, particularly liquid organic fertilizers (LOFs). Among the promising organic sources, black soldier fly (BSF) frass stands out (Murtiningsih et al., 2023). The larvae of the Black Soldier Fly (*Hermetia illucens*) have a unique ability to convert organic waste into both animal feed and frass, which has significant potential as an organic fertilizer. On average, BSF larvae can break down 33% to 36% of the wet weight or 40% to 43% of the dry weight of organic substrates (Ermolaev et al., 2019; Mason, 2016; Salomone et al., 2017; Xiao et al., 2018).

BSF frass is rich in nitrogen, phosphorus, potassium, organic matter, and chitin from the larvae's exoskeleton, and it can be used as a fertilizer, soil amendment, or even for biogas production (Bulak et al., 2020; Hol et al., 2022). Its nutrient composition varies depending on the larvae's feed substrate (Palma et al., 2020), with average values of 3.4% nitrogen, 2.9% phosphate, and 3.5% potassium oxide, and a pH range of 6.80 to 7.75 (Gärttling and Schulz, 2021).

The effectiveness of BSF frass as a fertilizer depends on its dosage and the crop type. High concentrations should be avoided due to the risk of ammonia toxicity, which can result from the bioconversion process that produces excess ammonia through nitrogen mineralization (Green and Popa, 2012). For instance, maize grown with high frass concentrations showed reduced height and fewer leaves (Alattar et al., 2016). However, positive effects have also been reported. A combination of composted frass and NPK fertilizer significantly improved yields of French beans (*Phaseolus vulgaris* L.), tomatoes (*Solanum lycopersicum* L.), and kale (*Brassica oleracea* L. var. acephala) compared to NPK alone (Anyega et al., 2021).

Despite the potential of BSF frass, research on its use as a liquid organic fertilizer remains limited. Other organic materials, such as *Leucaena* sp., *Pennisetum purpureum*, as well as rabbit and goat manure, have shown high nutrient content and positive effects on plant growth. The application of LOF made from these materials increased organic tomato yields by up to 83% and organic vitamin C content by up to 78% (Sopha and Lukman, 2019). Additionally, the same LOF formulation increased both the number of fruits and the yield of hydroponic tomatoes by up to 18% (Sopha and Murtiningsih, 2021).

Shallots and red-hot chili peppers are essential vegetables for the Indonesian population (Sopha et al., 2024; Amisnaipa et al., 2024), playing a key role in a variety of traditional dishes (Saptana et al., 2021). These crops are cultivated across diverse environments, ranging from lowlands to highlands, and in both mineral and organic soils (Sopha et al., 2021a; Sopha et al., 2021b). In addition to their culinary uses, shallots and chili peppers are valued for their nutritional content, particularly their vitamin C levels (Yaguchi et al., 2008). Indonesia is home to a wide range of superior and local shallot varieties, each with unique characteristics (Sukasih et al., 2018), making them prime candidates for testing with liquid organic fertilizers to enhance quality. However, research on improving the nutritional quality of shallots, especially their vitamin C content, remains limited. Therefore, this study aims to evaluate the effectiveness of liquid organic fertilizers derived from BSF frass, green manure, and rabbit manure on the growth and yield of different shallot varieties.

Materials and Methods

Liquid organic fertilizer preparation

The liquid organic fertilizer used in these experiments was made from a mixture of black soldier fly frass, Leucaena leaves, and manure in equal volumes (1:1:1 ratio). The studies were conducted in Lembang, West Java, Indonesia, located at an elevation of 1250 meters above sea level (107° 30' EL, 6° 30' SA). To prepare the fertilizer, fresh grass, manure, and leaves were combined in a drum, diluted with water, and supplemented with a microorganism decomposer and sugar as a carbohydrate source. The drum was then covered with textiles and secured tightly with rope, allowing the mixture to ferment for three weeks. After this period, the solution was filtered, and the liquid organic fertilizer was ready for use.

First study: the effect of liquid organic fertilizer on shallot growth and yield (pot experiment)

The study, conducted from September to December 2022, aimed to evaluate the effectiveness of liquid organic fertilizer (LOF) on shallot plants grown in polybags within a greenhouse setting. A factorial randomized complete block design was used, incorporating nine shallot varieties and three LOF concentration levels (0, 10, and 20 mL L^{-1}), with three replications per treatment. The nine shallot varieties tested were 'Bima Brebes', 'Batu Ijo', 'Tajuk', 'Maja', 'Trisula', 'Lansuna', 'Lebana', 'Sumenep', and 'Rubaru'.

Shallot seed bulbs were planted in polybags (5 kg volume) containing a substrate mixture of soil and chicken manure (1:1 ratio by volume). Dolomite (a ton ha^{-1}) and Triple Super Phosphate (TSP, 90 kg ha^{-1}) were added to the planting media, equating to 4 g of dolomite and 0.5 g of TSP per polybag. Additionally, 4 g of NPK fertilizer (16-16-16) was applied per polybag on the planting day. Pest management was implemented as needed, with a preventive insecticide application of 3% carbofuran at a rate of 2 kg ha^{-1} before planting. The plants were watered once daily using a watering can.

Agronomic parameters, such as tiller count, leaf number, plant height, and biomass, were measured seven weeks after planting. Nutrient uptake, specifically sulfur (S), calcium (Ca), magnesium (Mg), and potassium (K), was also assessed at this time. At harvest, fresh bulb yield was recorded, and the quality of the shallot bulbs, including vitamin C content and total soluble solids (TSS), was evaluated. Soil analyses, including pH and exchangeable cations (Ca^{2+}, Mg^{2+}, K^{+}), were conducted before and after planting to determine soil characteristics and nutrient status. Atomic absorption spectroscopy (AAS) was used for soil nutrient analysis (Sulaeman et al., 2005). The observational data were statistically analyzed using ANOVA, and treatment differences were further examined with Tukey's test ($P \leq 0.05$).

Second study: The effect of liquid organic fertilizer rates and application method on red-chili pepper (field experiment)

The study was conducted from April to December 2024. The evaluation of the effectiveness of LOF was carried out on red-chili plants grown in the field. A factorial randomized complete block design was used. The first factor was the application method: (i) through the leaves and (ii) drenching to the soil. The second factor was the rate of liquid organic fertilizer, (i) 0, (ii) 5, (iii) 10, and (iv) 15 mL L^{-1} and replicated four times.

Results and Discussion

First study: the effect of liquid organic fertilizer on shallot growth and yield (pot experiment)

Analysis of pre-experiment soil and black soldier fly frass

The soil used in this study had an acidic pH, pH H_2O = 5.4 and pH KCl = 4.9, a high organic carbon content of 3.57%, low total nitrogen content of 0.33% and a C/N ratio of 11. The available P content was very low, Bray-P = 0.9 mg P kg^{-1} soil. The exchangeable cations concentration was low, Ca^{2+} = 1.61 cmol (+) kg^{-1}, Mg^{2+} = 0.57 cmol (+) kg^{-1}, K^{+} = 0.38 cmol (+) kg^{-1} and Na^{+} = 0.19 cmol (+) kg-1, the cation exchange capacity (CEC) value was 15.90, so that the base saturation was very low (17%). Black soldier fly's frass used in this experiment contained 42% of organic carbon, 2.2% of total nitrogen, 2.73% phosphate, 2.68% of potassium oxide, 0.32% of calcium oxide, 0.55% of magnesium oxide, 1.59% of sulfur, and 0.94% of sodium.

After the experiment, no significant differences between treatments were observed for all soil chemical properties. On average, the soil pH slightly increased to 5.6 (pH H_2O), and the concentration of base cations increased significantly. On average, the concentration of Ca^{2+} was 14.43 cmol (+) kg^{-1}, Mg^{2+} = 6.13 cmol (+) kg^{-1}, K^{+} = 5.42 cmol (+) kg^{-1}, and Na^{+} = 2.12 cmol (+) kg^{-1}. The increase in soil pH was due to the application of dolomite before planting time, while using fertilizers increased the cation concentration.

Effect of varieties and liquid organic fertilizer rates on shallot biomass

There was no interaction between the variety and the rates of liquid organic fertilizer during vegetative growth. Shallot variety significantly affected the number of tillers, leaves, and plant height (Table 1). Shallot 'Bima Brebes' and 'Tajuk' had the highest number of tillers and leaves than other varieties (Table 2). Meanwhile, 'Batu Ijo' and 'Maja' had the lowest tillers and leaves. In addition, shallot 'Lansuna' had the highest plant height, while 'Sumenep' had the shortest plant height. There was no effect of liquid organic fertilizer rates on the number of tillers and plant height. However, a high rate of liquid organic fertilizer reduced the number of leaves.

Table 1. ANOVA (mean square) of the number of tillers (NT), number of leaves (NL), plant height (PH), and plant biomass (PB) at seven weeks after planting.

Source of Variances	DF	Mean square			
		NT	NL	PH	PB
Varieties	8	27.246^{**}	603.263^{**}	401.235^{**}	7.233^{**}
LOF	2	1.940^{ns}	56.100^{ns}	16.444^{ns}	6.338^{**}
Var. X LOF	16	0.623^{ns}	20.399^{ns}	15.077^{ns}	0.361^{ns}
Error	52	0.711	16.603	10.906	0.327
CV (%)		16	15	8	15
SD		1.85	8.88	7.17	0.29

**Significance (P<0.01); ^{ns} = no significant difference (P > 0.05).

Table 2. Effect of varieties and liquid organic fertilizer rates on the number of tillers, leaves, and plant height seven weeks after planting.

Treatments	Number of tillers	Number of leaves	Plant height (cm)
Varieties:			
Bima Brebes	7.73[a]	41.62[a]	45.39[bc]
Batu Ijo	3.58[cd]	20.91[cd]	49.36[ab]
Tajuk	7.37[ab]	40.58[a]	44.11[c]
Maja	3.04[d]	20.40[d]	49.59[ab]
Trisula	4.60[c]	22.29[cd]	45.41[bc]
Lansuna	3. 69[cd]	26.09[cd]	51.43[a]
Lebana	6.69[ab]	34.00[b]	41.88[c]
Sumenep	6.11[b]	26.76[c]	28.69[d]
Rubaru	4.77[c]	24.36[cd]	43.84[c]
P-value	0.000	0.000	0.000
LOF rates:			
0 mL L^{-1}	5.49 [ns]	29.71[a]	44.92[ns]
10 mL L^{-1}	5.39	29.02[ab]	44.80
20 mL L^{-1}	4.98	26.94[b]	43.51
P-value	0.075	0.042	0.231

There was no significant interaction between shallot varieties and liquid organic fertilizer (LOF) in terms of plant biomass. However, some varieties, i.e., 'Bima Brebes', 'Batu Ijo', 'Lansuna', and 'Lebana', produced the highest biomass (Fig. 1). In contrast, the variety 'Sumenep' had the lowest dry weight and plant biomass compared to the other varieties, with its biomass being only about one-third of that of 'Bima Brebes'. This indicates that 'Sumenep' was not well adapted to the Lembang highland environment.

The rate of LOF application significantly affected plant biomass (Fig. 2). Applying 10 mL L^{-1} and 20 mL L^{-1} of LOF increased plant biomass by 13% and 33%, respectively, compared to the control (without LOF). Other studies have reported varying results depending on the source of LOF. For example, LOF derived from coconut husk increased shallot bulb yield (Jayanti and Tanari, 2021), while frass-tea drench had little impact on lettuce growth (Tan et al., 2021). The interval and timing of LOF application also play a crucial role in its effectiveness. Applying LOF at three-day intervals enhanced leaf height, number, and weight in mustard plants (Santoso, 2022), and application between 6:00 and 7:00 AM had a positive effect on *Brassica chinensis* (Haryanto and Sabban, 2021). Therefore, the timing and frequency of LOF application are critical factors in optimizing crop production (Shaik et al., 2022).

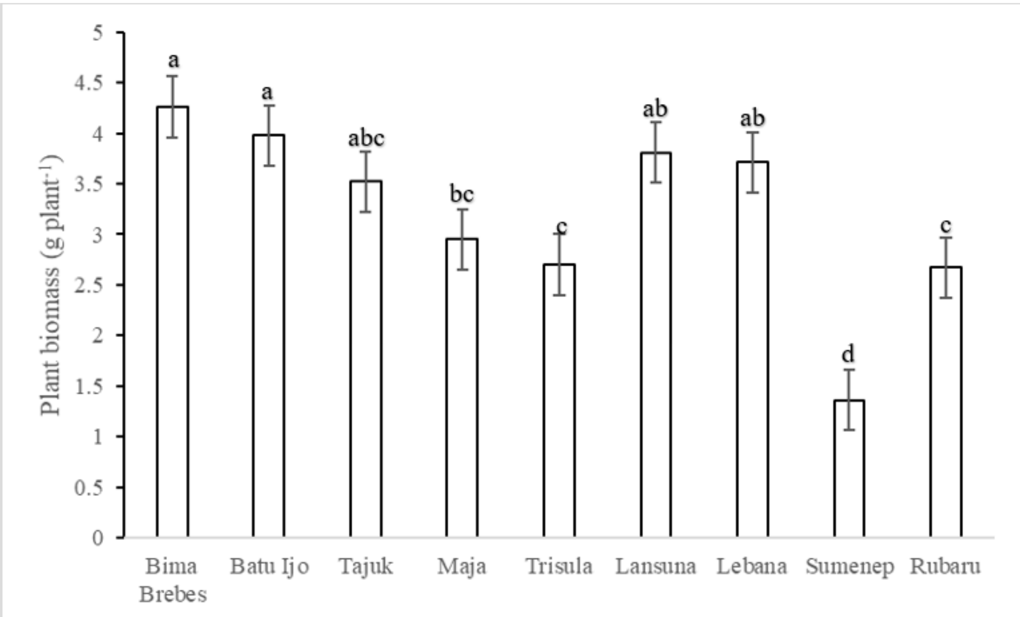

Fig. 1. Effect of varieties on shallot biomass at seven weeks after planting on plant biomass (g $plant^{-1}$) (n = 60) (P < 0.05).

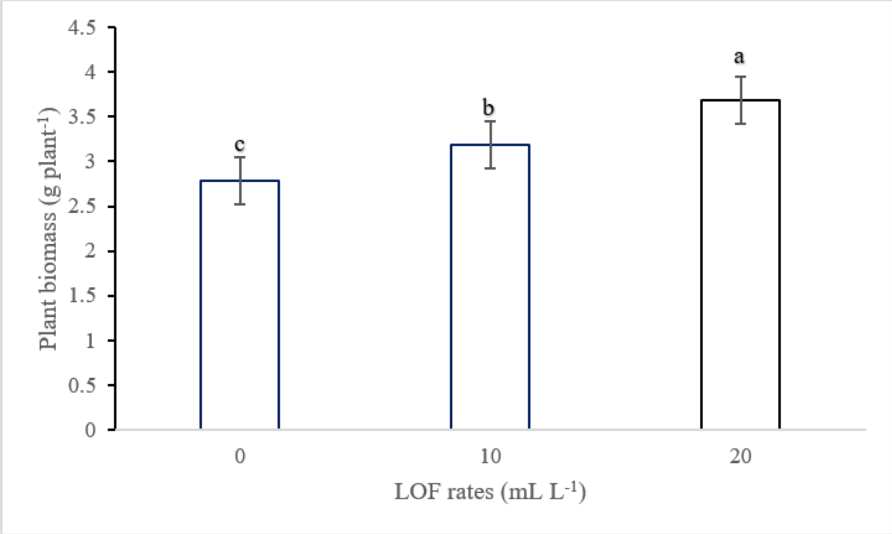

Fig. 2. Effect of liquid organic fertilizer rates (0, 10, 20 mL L^{-1}) on plant biomass (g $plant^{-1}$) (n =180) (P < 0.05).

Effect of varieties and liquid organic fertilizer rates on shallot yields and quality

Genotypes play a significant role in determining plant performance. The ANOVA results indicated that shallot varieties influenced bulb yield and quality, with an interaction observed between varieties and liquid organic fertilizer (LOF) rates affecting total soluble solids and vitamin C content (Table 3). In this study, most shallot varieties performed well in the upland region of Lembang, but 'Sumenep' showed poor growth, resulting in a low yield (Table 4). Similar genotype-specific responses to growth and yield in Lembang have been previously reported (Waluyo et al., 2021). For example, 'Bima Brebes' is well-adapted and produces good yields in both lowland (Azwir and Edi, 2016) and upland regions (Sopha, 2022). In contrast, 'Sumenep' tends to yield less compared to other varieties (Tan et al., 2021).

Table 3. ANOVA (mean square) of the bulb number (BN), bulb yield (PB), total soluble solids (TSS) and vitamin C (VC) of bulbs.

Source of Variances	DF	Mean square			
		BN	BY	TSS	VC
Varieties	8	44.548**	40336.111**	44.593**	1058.053**
LOF	2	0.652ns	5398.778ns	8.810**	19.639ns
Var. X LOF	16	0.611ns	1189.847ns	10.132**	71.154*
Error	52	0.952	2365.870	0.184	36.950
CV (%)		21	24	3	19
SD		4.01	16.86	0.61	94.15

**Significance ($P < 0.01$); ns = no significant difference ($P > 0.05$).

The shallot variety 'Bima Brebes' produced the highest bulb yield in this study, reaching approximately 8.18 t ha-1, based on a population of 250,000 plants per hectare. This superior performance is attributed to the higher number of leaves and greater biomass compared to other varieties, which likely enhances plant productivity through increased assimilation. Biomass accumulation in plant structures can indirectly boost productivity by improving the plant's capacity to store and use assimilates for metabolic processes (Elizani and Sulistyaningsih, 2019). The assimilates formed in the plant serve as food reserves or are stored in organs used during metabolic activities (Marpaung and Rosliani, 2019).

Vegetative growth is positively correlated with yield, as it enhances photosynthetic capacity, enabling the mobilization and translocation of photosynthates to storage organs. The higher number of tillers in 'Bima Brebes' leads to a greater number of bulbs per plant, which, in turn, boosts yield. As Firmansyah (2018) noted, a greater number of tillers results in more bulbs and increased production. The productivity of shallots is primarily determined by the number of bulbs, which is reflected in the tiller count and bulb weight (Purbiati and Timur, 2012).

Table 4. Number of bulbs and bulb yield in different varieties and liquid organic fertilizer concentrations.

Treatments	Number of bulbs per plant	Bulb yield per plant (g)
Varieties:		
Bima Brebes	9.67[a]	32.47[a]
Batu Ijo	3.79[ef]	29.64[ab]
Tajuk	8.84[ab]	30.72[ab]
Maja	3.23[f]	30.21[ab]
Trisula	4.91[de]	18.15[c]
Lansuna	4.56[ef]	31.44[a]
Lebana	7.37[bc]	29.59[ab]
Sumenep	6.72[c]	9.16[d]
Rubaru	6.06[cd]	23.17[bc]
P-value	0.000	0.000
LOF Rates:		
0 mL L^{-1}	6.18[ns]	25.72[ns]
10 mL L^{-1}	6.25	25.63
20 mL L^{-1}	5.95	26.83
P-value	0.508	0.112

Values marked by different letters in the same columns are significantly different ($P < 0.05$). ns = not significant at α = 5%.

In contrast, 'Sumenep' produced the lowest bulb yield, around 2.29 t ha^{-1}, significantly lower than its potential yield of approximately 6.34 t ha^{-1} on mineral soils. The low yield in this study is likely due to the harvest timing and environmental factors. While all varieties were harvested 65 days after planting, 'Sumenep' may require a longer growing period than other varieties. Additionally, shallots require high-intensity sunlight (Setiawati et al., 2014), and growing them in a greenhouse may have limited sunlight exposure, stressing plant growth and contributing to reduced performance.

LOF rates did not significantly influence the growth and bulb yields of shallots. This finding aligns with a previous study by Jayanti and Tanari (2021), which reported that frass-tea drench had a negligible impact on lettuce growth. Conversely, other research demonstrated varying results with different sources of LOF. For instance, LOF derived from coconut husks was found to increase shallot bulb yields (Santoso, 2022).

The lack of LOF effects on shallot growth and yield in this study may be attributed to the timing of its application. LOF was sprayed on the plants weekly from four to seven weeks after planting. With short growing periods of shallot, we can estimate that more frequent applications may be necessary. For example, Haryanto and Sabban (2021) reported that applying LOF at three-day intervals positively affected leaf height, number, and weight in mustard plants. Additionally, research on *Brassica chinensis* indicated that applying LOF between 6:00 and 7:00 WIT significantly improved crop height, leaf number, leaf area, and fresh weight compared to other application times (Shaik et al., 2022). Thus, the timing of LOF applications is critical, particularly for fast-growing crops like lettuce in soilless systems (Song et al., 2018).

Despite the limited impact on yield, shallot 'Sumenep' achieved the highest TSS across all LOF rates (Table 5). Furthermore, the application of LOF significantly increased the TSS in the 'Batu Ijo' and 'Tajuk' varieties (Table 5).

Shallots contain higher levels of vitamin C than common onions (*Allium cepa*) (Shahrajabian et al., 2020). Various factors, including weather conditions, significantly influence the chemical composition of shallot bulbs. For example, the weather during the growing season can affect key components such as L-ascorbic acid content, dry matter, total sugars, and nitrates. Plants can also enhance their vitamin C content through traditional agronomic practices, nutrient biofortification, or as a defense mechanism against stress conditions (Locato et al., 2013).

Fertilizers play a crucial role in shaping the nutrient content in plants. In this experiment, applying 10 mL L-1 of liquid organic fertilizer improved the vitamin C levels in two shallot varieties, 'Batu Ijo' and 'Maja' (Table 6). This suggests that the addition of liquid organic fertilizer can enhance vitamin C concentration. Similar findings have been reported in tomatoes, where liquid organic fertilizer increased vitamin C content (Sopha and Lukman, 2019; Sopha and Murtiningsih, 2021).

Table 5. Effect of varieties and liquid organic fertilizer rates on total soluble solids.

Variety	Liquid Organic Fertilizer Rates (mL L^{-1})		
	0	10	20
Bima Brebes	18.07^{b} A	17.73^{b} A	17.33^{bc} A
Batu Ijo	15.60^{d} B	16.20^{de} A	16.47^{cde} A
Tajuk	15.87^{d} B	16.80^{bcd} A	17.00^{cd} A
Maja	15.93^{d} A	16.07^{de} A	15.60^{e} A
Trisula	16.67^{cd} A	16.20^{de} B	16.47^{cde} AB
Lansuna	16.07^{d} A	15.53^{e} A	16.00^{de} A
Lebana	17.00^{bcd} A	16.53^{cde} A	17.33^{bc} A
Sumenep	22.47^{a} A	22.67^{a} A	23.40^{a} A
Rubaru	17.67^{bc} A	17.67^{bc} A	18.47^{b} A

Tukey's HSD method for mean comparisons shows that means with the same small letters in the same columns are not significantly different for varieties, and the same capital letters in the same row are not significantly different for liquid organic fertilizer rates at $\alpha = 5\%$.

Table 6. Effect of varieties and liquid organic fertilizer rates on bulb vitamin C content.

Variety	Liquid Organic Fertilizer Rates (mL L^{-1})		
	0	10	20
Bima Brebes	68.42^{cd} A	67.55^{d} A	68.70^{cd} A
Batu Ijo	75.32^{bcd} B	80.49^{b} A	80.20^{abcd} AB
Tajuk	85.67^{b} A	81.93^{b} B	80.78^{abcd} B
Maja	69.28^{cd} B	77.21^{bc} A	72.44^{bcd} A
Trisula	81.81^{bc} A	75.66^{bcd} A	96.59^{ab} A
Lansuna	77.04^{bcd} A	75.89^{bcd} A	70.49^{cd} A
Lebana	64.68^{d} AB	70.60^{cd} A	60.83^{d} B
Sumenep	100.04^{a} A	101.19^{a} A	102.91^{a} A
Rubaru	83.93^{b} A	82.22^{b} A	88.54^{abc} A

Tukey's HSD method for mean comparisons shows that means with the same small letters in the same columns are not significantly different for varieties, and the same capital letters in the same row are not significantly different for liquid organic fertilizer rates at $\alpha = 5\%$.

Second study: effect of liquid organic fertilizer on red-chili pepper

Effect of liquid organic fertilizer rates and method of application on soil chemical properties

The method of application significantly impacted the concentration of base cations and phosphate availability (Table 7). Foliar application resulted in higher concentrations of base cations, such as Ca^{2+}, K^{+}, and Na^{+} compared to soil drenching, whereas phosphate availability was greater in the drenching method. This difference may be attributed to microbial activity. LOF is rich in beneficial microorganisms, including phosphate-solubilizing bacteria, with concentrations reaching 30 x 106 CFU mL^{-1}. Despite the presence of beneficial microorganisms, LOF also contains decomposer organisms that require nutrient sources to sustain their activity. This could explain the lower concentrations of base cations in the drenching method, as these microorganisms likely competed for nutrients, thereby reducing the availability of cations in the soil.

Table 7. Effect of application method and liquid organic fertilizer rates on soil chemical properties.

Treatments	pH	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	P-Bray	C-org
		(cmol (+) kg^{-1})				(mg kg^{-1} soil)	%
Application method							
Leafy application	4.98^{ns}	0.44^{a}	0.13^{ns}	0.10^{a}	0.06^{a}	7.84^{b}	3.25^{ns}
Drench to soil	4.85	0.31^{b}	0.08	0.07^{b}	0.02^{b}	11.56^{a}	3.30
P-value	>0.05	<0.05	>0.05	<0.05	<0.01	<0.05	>0.05
LOF rates (mL L^{-1})							
0	4.90^{ns}	0.44^{ns}	0.15^{ns}	0.08^{ns}	0.02^{b}	10.02^{ns}	3.22^{ns}
5	4.96	0.39	0.11	0.09	0.02^{b}	10.54	2.75
10	4.84	0.35	0.08	0.09	0.06^{a}	8.40	3.62
15	4.95	0.35	0.08	0.10	0.06^{a}	9.84	3.52
P-value	>0.05	>0.05	>0.05	>0.05	<0.01	>0.05	>0.05
CV (%)	7	19	37	22	41	3	19

Effect of liquid organic fertilizer rates on red chili pepper yield and quality

The application method did not significantly impact chili pepper fruit yield. Nevertheless, the application of 5 to 10 mL L^{-1} liquid organic fertilizer led to an increase in the marketable yield of red chili peppers, while the application of 15 mL L^{-1} liquid organic fertilizer resulted in a reduction of unmarketable yield (Fig. 3). The improvement in marketable yield and reduction in unmarketable yield could be attributed to enhanced plant resistance to pest and disease attacks. During the growth period, pesticides were employed to manage pest and disease pressures. Despite this, a high pest population, particularly of *Helicoverpa armigera*, still inflicted damage on the plants, ultimately reducing the marketable yields.

Plant resistance is regulated by both genetic and environmental factors, with biotic and abiotic influences playing key roles. Abiotic factors, such as temperature, humidity, nutritional status, wind, rainfall, and fertilization, are particularly relevant in influencing plant resistance (Pinto and Ongaratto, 2019). The application of higher rates of liquid organic fertilizer may enhance the nutritional status of plants, potentially strengthening their resistance to biotic stress. However, further research is needed to fully elucidate the mechanisms behind these observed effects.

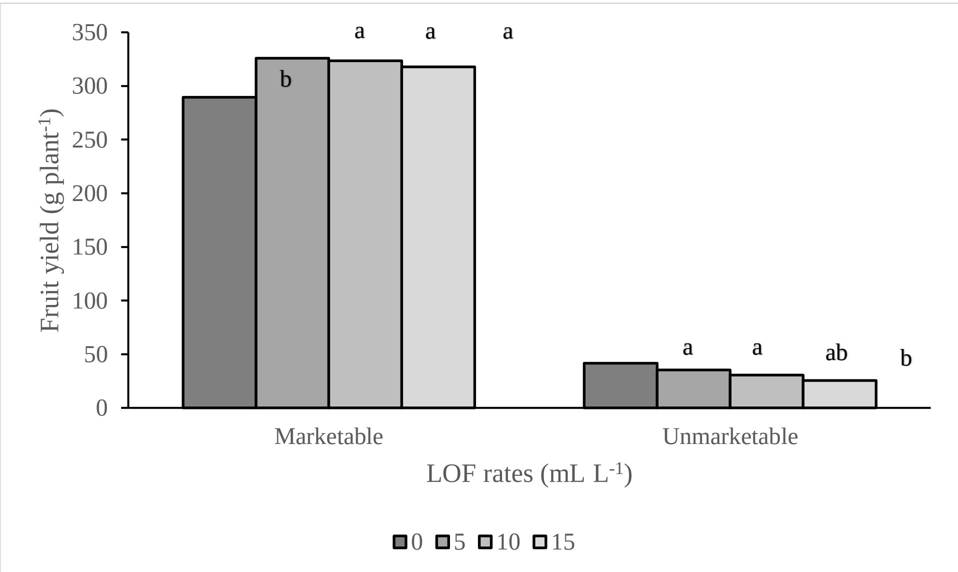

Fig. 3. Effect of liquid organic fertilizer rates on marketable and unmarketable fruit yield per plant (g $plant^{-1}$) (n = 40) ($P \leq 0.05$).

The application method had various effects on the plant's hydrogen and sulfur concentrations. Additionally, the rate of LOF influenced both plant nutrient content and fruit quality (Table 8). Specifically, the application of 10 mL L^{-1} LOF increased the concentrations of nitrogen, hydrogen, sulfur, and protein in the chili plants, while also enhancing the total soluble solids in chili fruits. The observed increase in plant protein content is likely due to improved nutrient uptake, particularly nitrogen. This increase in protein content is significant, as it correlates with an improvement in product quality, which is increasingly demanded by consumers. Higher protein intake contributes to important health benefits, such as increased muscle mass, enhanced leg strength, and improved bone density (Hertzler et al., 2020).

Table 8. Effect of application method and liquid organic fertilizer rates on plant content and fruit quality.

Treatments	Plant concentration (%)					Fruit quality	
	N	C	H	S	Protein	TSS (%)	Vit. C (mg 100^{-1})
Application method							
Foliar application	3.40^{ns}	34.67^{ns}	4. 89^{b}	0.01^{b}	21.24^{ns}	10.91^{ns}	193.60^{ns}
Drench to soil	3.58	36.87	5.16^{a}	0.17^{a}	22.39	10.78	256.02
P-value	> 0.05	> 0.05	< 0.01	< 0.01	> 0.05	> 0.05	> 0.05
LOF Rates (mL L^{-1})							
0	3.18^{b}	33.23^{b}	4.78^{b}	0.09^{ab}	19.86^{b}	10.56^{ab}	230.45^{ns}
5	3.32^{ab}	34.75^{ab}	5.02^{ab}	0.05^{b}	20.75^{ab}	10.45^{b}	202.95
10	3.86^{a}	37.31^{a}	5.12^{a}	0.14^{a}	24.10^{a}	11.08^{ab}	270.60
15	3.61^{ab}	37.79^{a}	5.17^{a}	0.08^{ab}	22.55^{ab}	11.28^{a}	195.25
P-values	< 0.05	< 0.05	< 0.05	< 0.01	< 0.05	< 0.05	> 0.05
CV (%)	15	12	6	9	15	6	19

Conclusion

The application of liquid organic fertilizer derived from black soldier fly frass significantly influenced shallot biomass, increased the total soluble solids in 'Batu Ijo' and 'Tajuk', and enhanced the vitamin C content in 'Batu Ijo' and 'Maja'. There was no significant difference observed between the application methods, whether drenching the soil or spraying the leaves. Additionally, the application of liquid organic fertilizer improved the marketable yields of red chili peppers while simultaneously reducing the yield of unmarketable fruit. Furthermore, the liquid organic fertilizer enhanced nutrient uptake and increased the protein content of red chili peppers. Therefore, black soldier fly frass demonstrates significant potential as a liquid organic fertilizer that can effectively promote vegetable growth and yield when applied at rates of 5 to 10 mL L^{-1}.

Acknowledgements

We would like to express our gratitude to the Research Organization for Agriculture and Food (BRIN) for providing funding for this research. We also extend our appreciation to Prof. Dr. Julian Heyes for his valuable suggestions throughout the study. Additionally, we thank Laboratorium Kawasan Yogyakarta for facilitating the plant analysis and Laboratorium Kawasan Bandung for their assistance with the soil analysis.

Conflict of Interest

The authors indicate no conflict of interest in this work.

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