
Bioscientist: Jurnal Ilmiah Biologi
https://e-journal.undikma.ac.id/index.php/bioscientist

June 2026 Vol. 14, No. 2
e-ISSN: 2654-4571
pp. 508-518

Evaluation of Rejected Soybean Milk-Based Liquid Organic Fertilizer with Garlic and Turmeric Additives in Hydroponic Cultivation

[1]Titik Suryani, [2]Lina Agustina, [3*]Santhyami, [4]Ima Aryani, [5]Sri Darnoto, [6]Siti Kartika Sari
[1,2,3,4,6]Biologi Education Program, Faculty of Teacher Training and Education, Universitas Muhammadiyah Surakarta, Sukoharjo, Indonesia
[5]Public Health Program, Faculty of Health Sciences, Universitas Muhammadiyah Surakarta, Sukoharjo, Indonesia
*Corresponding Author e-mail: san915@ums.ac.id

Received: September 2025; Revised: April 2026; Accepted: May 2026; Published: June 2026

Abstract: This study investigated the potential use of rejected soybean milk as a raw material for producing liquid organic fertilizer (LOF) for hydroponic cultivation. The research was designed as a laboratory-based experimental study. The LOF was formulated from soybean milk waste, spent mushroom baglog, turmeric, and garlic through anaerobic fermentation. It was then characterized based on sensory and chemical properties and applied to hydroponically cultivated water spinach (*Ipomoea aquatica*) over a 9-week growth period. Sensory evaluation showed that the resulting LOF was a brownish-orange, free-flowing, and odorless liquid, indicating the occurrence of humification processes during fermentation. Chemical analysis revealed low macronutrient concentrations, with nitrogen, phosphorus, and potassium contents of 0.18%, 0.003%, and 0.16%, respectively. These values were below the Indonesian National Standard for liquid organic fertilizer. The LOF also had an alkaline pH of 8.32. Plant growth trials demonstrated a progressive decline in growth performance as the proportion of soybean-milk-based LOF increased. The AB Mix treatment consistently produced superior results across all growth parameters, including plant height, leaf number, and leaf size. Plants treated with the LOF generally exhibited yellowish-green leaves and reduced vegetative vigor, although survival remained 100% across all treatments. These findings indicate that rejected soybean milk can be valorized into a physically stable LOF; however, the current formulation provides insufficient plant-available nutrients and may induce plant stress due to its high pH and the potential phytotoxic effects of turmeric and garlic extracts. Further optimization through nutrient enrichment, pH adjustment, and controlled additive concentrations is therefore required to develop soybean-milk-based LOF as a viable alternative to synthetic AB Mix for hydroponic cultivation.

Keywords: Hydroponic; liquid organic fertilizer; soybean milk

How to Cite: Suryani, T., Agustina, L., Santhyami, Aryani, I., Darnoto, S., & Sari, S. K. (2026). Evaluation of Rejected Soybean Milk-Based Liquid Organic Fertilizer with Garlic and Turmeric Additives in Hydroponic Cultivation. *Bioscientist: Jurnal Ilmiah Biologi*, *14*(2), 508–518. https://doi.org/10.33394/bioscientist.v14i2.17468

https://doi.org/10.33394/bioscientist.v14i2.17468

INTRODUCTION

Indonesia is predominantly an agrarian country, with agriculture serving as the main source of livelihood for a substantial proportion of its population. However, rapid urbanization and population growth have placed increasing pressure on agricultural land, particularly in densely populated urban areas, where farmland is frequently converted into residential and industrial zones (Gultom et al., 2021). This trend has reduced the availability of land for food production, while demand for food, especially vegetables, continues to increase alongside population growth. Addressing this challenge requires innovative cultivation techniques that can maximize production efficiency while reducing dependence on land availability. Hydroponic farming offers one promising solution because it can improve production efficiency, reduce dependence on arable land, and support crop cultivation in areas with limited or poor soil resources (Rajendran et al., 2024). Nevertheless, although hydroponic systems are efficient in land use, they remain highly dependent on synthetic nutrient solutions such as AB Mix, which are relatively costly and raise sustainability concerns related to resource use, nutrient sourcing, and environmental impact (Park & Williams, 2024; Wang et al., 2025). To date, limited studies have examined the use of agro-industrial waste as an alternative nutrient source in hydroponic systems, particularly using locally available materials in Indonesia. This gap underscores the need to develop sustainable and low-cost nutrient formulations that can reduce reliance on synthetic inputs while maintaining crop productivity.

Hydroponics is a soilless cultivation system in which plants are grown using water-based nutrient solutions as the primary growth medium (Rajendran et al., 2024). This system offers high productivity and efficient space utilization, making it particularly relevant for urban agriculture and other land-limited production contexts (Rajendran et al., 2024; Park & Williams, 2024). Conventional hydroponic systems commonly rely on AB Mix, a synthetic nutrient formulation widely used to supply essential elements required for plant growth. However, dependence on AB Mix raises sustainability concerns because it is inconsistent with the principles of organic farming, which emphasize natural inputs and the avoidance of synthetic chemicals (Subah et al., 2025). These concerns have encouraged increasing interest in the development of organic alternatives, particularly liquid organic fertilizers (LOFs), as potential substitutes for synthetic nutrient solutions in hydroponic cultivation (Park & Williams, 2024; Phibunwatthanawong & Riddech, 2019).

LOFs are nutrient solutions produced through the fermentation of organic materials, such as crop residues, household organic waste, agro-industrial residues, and animal manure. They offer several advantages, including rapid nutrient availability, ease of application, and the presence of beneficial microorganisms that may support nutrient transformation and plant health (Asngad et al., 2023; Febrianna et al., 2018; Phibunwatthanawong & Riddech, 2019). Compared with solid organic fertilizers, LOFs are more efficient in correcting nutrient deficiencies and are less susceptible to nutrient losses through leaching. Previous studies have successfully utilized vegetable waste (Ginandjar et al., 2019), livestock manure (Cintiyah et al., 2024), and agro-industrial residues (Lamba et al., 2025) as raw materials for LOF production, demonstrating positive effects on plant growth and nutrient recycling. However, most of these studies have focused on soil-based cultivation systems, while evidence regarding the effectiveness of LOFs in hydroponic systems remains limited and inconsistent. Recent reviews indicate that organic and food-waste-based hydroponic fertilizers still face challenges related to nutrient availability, salinity balance, microbial activity, and solution stability (Park & Williams, 2024; Wang et al., 2025). Moreover, the potential use of agro-industrial by-products, such as rejected soybean milk, as nutrient sources in hydroponic cultivation has not been adequately explored. This gap highlights the novelty of the present study, which evaluates the feasibility of soybean milk-based LOF as a sustainable alternative to synthetic AB Mix in hydroponic vegetable production.

Among various agro-industrial wastes, soybean milk processing generates considerable amounts of liquid and solid residues, including okara and spoiled or rejected soybean milk. Soybean processing by-products are increasingly recognized as valuable resources for circular and zero-waste processing systems because they contain proteins, carbohydrates, lipids, minerals, and bioactive compounds (Čech et al., 2022; Karim et al., 2025). If not properly managed, these wastes may cause environmental problems due to their high organic content, moisture level, and rapid decomposition (Čech et al., 2022). However, rejected soybean milk contains carbohydrates, proteins, fats, minerals, and vitamins, making it a promising raw material for fertilizer production (Lai et al., 2021). Soybean-based wastes are also known to contain essential macronutrients, including nitrogen (N), phosphorus (P), and potassium (K), which are critical for vegetative growth and productivity in hydroponic systems (Kurniawan et al., 2024).

Several studies have investigated soybean waste as a component of organic fertilizers, particularly soybean boiling water and okara (Čech et al., 2022). Nevertheless, limited attention has been given to the utilization of rejected soybean milk for LOF production, especially in hydroponic vegetable cultivation. This represents an important research gap. In addition, supplementing rejected soybean milk with mushroom baglog waste, which is characterized by high organic carbon content and a balanced C/N ratio (Satwhikawara et al., 2025), along with garlic and turmeric, introduces an innovative approach to formulating nutrient-rich LOF. The use of spent mushroom substrate or mushroom baglog waste is consistent with broader circular-economy strategies that convert organic residues into value-added agricultural inputs (Yang et al., 2024).

The novelty of this study lies in the development of an environmentally friendly LOF derived from rejected soybean milk combined with mushroom baglog waste and formulated specifically as an alternative nutrient source for hydroponic cultivation. Rejected soybean milk is an underutilized agro-industrial by-product rich in organic compounds; however, its application as a hydroponic nutrient source remains largely unexplored because of uncertainties regarding nutrient availability, microbial transformation, electrical conductivity, salinity, and potential phytotoxicity (Park & Williams, 2024; Wang et al., 2025). By integrating rejected soybean milk with mushroom baglog waste, this study proposes a novel strategy for converting locally abundant organic waste into value-added inputs for hydroponic systems. This approach not only promotes waste valorization and supports organic agriculture but also offers a potential pathway to reduce dependence on synthetic hydroponic nutrients while improving environmental sustainability.

Therefore, this study aims to: (1) analyze the nutrient composition of LOF produced from rejected soybean milk; (2) examine its effects on the growth and sensory characteristics of hydroponically grown vegetables; and (3) evaluate its potential as a sustainable alternative to conventional AB Mix.

METHOD

This study was designed as an experimental laboratory investigation conducted between December 2024 and March 2025, focusing on the production of liquid organic fertilizer (LOF) derived from rejected soybean milk obtained from SuleMu PCM Colomadu (Rahayu et al., 2025). The experimental workflow (Figure 1) comprised the formulation and fermentation of LOF, followed by nutrient characterization and its application to hydroponically grown vegetables, a methodological approach consistent with previous works on organic waste valorization for agriculture.

Materials and Equipment

All experimental work utilized standard laboratory tools such as measuring cylinders, fermentation vessels, pH and soil meters, waste crushers, cooking utensils, and sterile storage containers. The raw materials included 5 L of rejected soybean milk obtained from local tofu production units, soybean waste solids, sterilized mushroom baglog (spent substrate from mushroom cultivation), rice bran, fertile soil, green waste, fruit and banana peels, coconut water, soybean husks, molasses, as well as turmeric and garlic extracts. Rejected soybean milk was selected as the primary substrate due to its high organic content and protein residues, while mushroom baglog and rice bran were incorporated to enhance nutrient diversity and support microbial activity during fermentation. Molasses and coconut water served as carbon sources to stimulate microbial growth, whereas turmeric and garlic extracts were added for their antimicrobial properties. These ingredients were selected for their nutrient content and functional properties, reflecting established practices in organic fertilizer production.

Preparation of Liquid Organic Fertilizers (LOFs)

The preparation process began with the sterilization of mushroom baglog, which was crushed, combined with chopped ketapang leaves, coconut water, and soybean milk waste, and boiled for 5–10 minutes before cooling to approximately 50°C. Subsequently, homogenized organic wastes, rice bran, and the sterilized baglog were combined with the remaining soybean milk waste, to which molasses and fertile soil were added as microbial inoculants. The mixture was then transferred into airtight fermentation vessels and incubated under anaerobic conditions at ambient temperature (27–30°C) for 15 days, with periodic monitoring of pH, color, and odor changes as indicators of fermentation progress. The mixture was incubated anaerobically for 15 days, during which pH and physical properties were monitored. Upon completion, the fermented material was filtered into solid and liquid fractions: the solid residue was retained as compost, while the liquid fraction constituted the LOF. Turmeric extract, serving as a natural pH stabilizer, and garlic extract, providing phytohormones such as scordinin to stimulate root growth, were incorporated before bottling in sterile containers for storage under cool, shaded conditions. Supplementary turmeric and garlic extracts were prepared by diluting either powder or fresh material with water at a 1:1 ratio.

Sensory characterization of the LOF was conducted through direct observation of color, odor, and texture, using standardized descriptive criteria. Chemical analysis included measurement of pH using a digital pH meter, and determination of macronutrient content (total nitrogen, phosphorus, and potassium) using standard laboratory methods, including Kjeldahl digestion for nitrogen and spectrophotometric and flame photometric analyses for phosphorus and potassium, respectively.

Experimental Treatments

For application trials, water spinach (*Ipomoea aquatica*) was selected as test crops due to its prevalence in hydroponic cultivation. Plants were assigned to one control and three treatment groups using a completely randomized design with 3 replicates per treatment. Treatments were arranged as follows: 1) Control: Standard AB Mix nutrient solution; 2) Treatment 1: 1 part LOF (soybean milk) + 1 part LOF (coconut fiber) + turmeric water + ¼ garlic water, 3) Treatment 2: 2 parts LOF (soybean milk) + 1 part LOF (coconut fiber) + turmeric water + ¼ garlic water, 4) Treatment 3: 3 parts LOF (soybean milk) + 1 part LOF (coconut fiber) + turmeric water + ¼ garlic water. Each treatment was applied throughout the experimental period under similar environmental conditions. Growth parameters, including plant height, number of leaves, and leaf size, were measured at regular intervals, along with visual observations of leaf color and overall plant vigor.

Data collection

Data collection included three categories of measurement. First, the chemical composition of LOF was analyzed for nitrogen (N), phosphorus (P), and potassium (K) based on the quality standard (SNI 19-7030-2004). following based on quality standard (SNI 19-7030-2004). Second, plant growth parameters—height, number of leaves, and leaf color—were recorded at regular intervals. Finally, the sensory properties of the LOFs (color, texture, and odor) were evaluated to assess stability and user acceptability, in line with established approaches for organic fertilizer characterization.

To minimize variability, plant growth trials were conducted under controlled environmental conditions, with consistent temperature (approximately 27–30°C), relative humidity, and light exposure (natural or supplemented photoperiod), and all treatments were maintained under the same hydroponic system and nutrient delivery schedule.

Data analyses

Data were analyzed using a descriptive-comparative approach, with treatment comparisons focusing on nutrient availability, plant performance, and the feasibility of LOF as an alternative to AB Mix for hydroponic systems. Quantitative data were summarized using mean values and presented to identify trends and relative differences among treatments, while qualitative observations were used to support the interpretation of plant responses. The analysis emphasized pattern consistency and performance gradients across treatments rather than statistical significance testing.

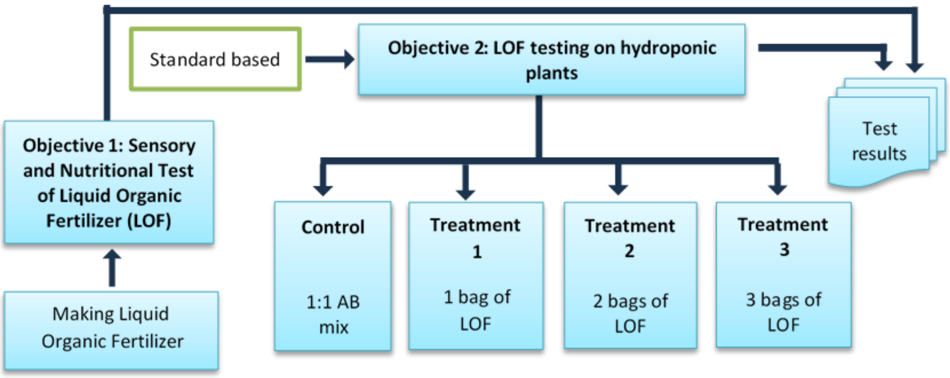

Figure 1. The experimental workflow

RESULTS AND DISCUSSION

Sensory Properties Rejected Soybean Milk Based LOFs

Sensory tests on organic liquid fertilizer based on rejected soy milk showed a brownish orange color, liquid texture and odorless aroma. The orange–brown coloration is commonly associated with advanced decomposition and formation of humic-like compounds (humification) and/or non-enzymatic in organic fermentation and waste-derived biofertilizers. Dark/brown hues often indicate a high content of soluble organic matter (humic and fulvic fractions), oxidized phenolic compounds, or pigments released during protein and carbohydrate breakdown. Such coloration can be a positive indicator of organic matter transformation toward stable, humified products (Zhu et al., 2024). In the context of hydroponic systems, this may indicate the presence of dissolved organic fractions that could contribute to nutrient buffering capacity and root-zone interactions, although their direct availability to plants remains dependent on further mineralization.

A free-flowing liquid texture suggests that a large proportion of the LOF constituents are solubilized (dissolved or colloidal organic molecules), which is desirable for ease of application (drip, foliar spray, fertigation). However, a truly liquid product can still vary widely in total suspended solids (TSS), viscosity, and nutrient concentration; therefore sensory “liquid” alone does not predict nutrient availability or phytotoxicity (Riddech et al., 2025). For hydroponic applications, a low-viscosity and well-solubilized formulation is particularly important to prevent clogging in irrigation systems and to ensure uniform nutrient distribution.

An odorless fermentation product often indicates that the process avoided generation or retention of strongly volatile malodorous compounds (e.g., ammonia, volatile fatty acids, sulfides, amines). This can occur when fermentation is carried out under controlled aerobic or well-managed anaerobic conditions with microbial communities that metabolize malodorous precursors, or when volatiles have been driven off and not retained. Odorless LOFs are generally preferable for handling and user acceptance; however, odor absence does not rule out microbiological hazards (pathogens) or the presence of non-volatile toxicants—so microbiological and chemical testing remains essential (Low et al., 2021). From an agronomic perspective, the absence of strong odors also suggests a more stable fermentation process, which is advantageous for storage, handling, and practical use in controlled hydroponic environments.

Macro Nutrient Content Rejected Soybean Milk Based LOFs

The analysis of nutrient content and pH in the liquid organic fertilizer (LOF) derived from reject soy milk revealed that the concentrations of nitrogen (0.18 %), phosphorus (0.003 %), and potassium (0.16 %) were all below the minimum requirements of the Indonesian National Standard (SNI), which stipulates 0.40 %, 0.10 %, and 0.20 % respectively. Such deficiencies in essential macronutrients are likely to limit plant growth, as nitrogen is critical for vegetative development, phosphorus for energy transfer and root formation, and potassium for physiological regulation, thereby contributing to the reduced growth performance observed in this study. In contrast, the pH value was 8.32, exceeding the standard range of 6.80–7.49. In hydroponic systems, an alkaline pH can significantly reduce the availability of key micronutrients, particularly iron (Fe) and manganese (Mn), which tend to precipitate or become less soluble under high pH conditions. This may lead to nutrient uptake constraints and physiological disorders such as chlorosis, consistent with the yellowish-green leaf symptoms observed in treated plants. This indicates that while the fertilizer exhibits alkaline characteristics, its macronutrient composition falls short of national quality benchmarks (Table 1), resulting in suboptimal nutrient availability and overall plant performance under hydroponic conditions.

The relatively low levels of nitrogen, phosphorus, and potassium are consistent with general characteristics of organic fertilizers derived from plant-based residues. Organic amendments typically contain nutrients in bound or complex organic forms, which are not immediately available for plant uptake (Chojnacka et al., 2020). In the case of soy milk waste, proteins, fibers, and phytates dominate its chemical composition, requiring microbial decomposition and mineralization before nutrients are released into soluble forms that plants can use (Hasan et al., 2023). Organic fertilizers generally have lower NPK concentrations than synthetic fertilizers, and nutrient availability depends heavily on microbial activity and soil conditions rather than being directly present in the material itself. The extremely low phosphorus concentration (0.003 %), far below the standard, may be explained by the fact that phosphorus in soybeans is predominantly stored as phytate, which is poorly soluble and often unavailable unless hydrolyzed by specific enzymes or microbial processes (Sutardi & Buckle, 2004). Similarly, the potassium content, though slightly closer to the threshold, remains lower than the standard due to natural variation in plant residues and the absence of supplementation with K-rich materials (Istiyova & Santosa, 2023).

Interestingly, the pH of the fertilizer was measured at 8.32, which is higher than the recommended neutral to slightly alkaline range. This elevated alkalinity can be linked to two main factors. First, the soy milk production process itself often involves the use of alkaline treatments or generates alkaline by-products during bean soaking and protein extraction, which may persist in the residual material (Li et al., 2019). Second, microbial decomposition during the preparation of the fertilizer can produce ammonia and other alkaline compounds, particularly when protein-rich substrates are involved (Kumar et al., 2022). Over time, the consumption of organic acids by microbes combined with the release of basic metabolites may further shift the pH upward. Elevated pH conditions, however, are not always desirable, as nutrient solubility, particularly of micronutrients such as iron and manganese, decreases in strongly alkaline environments, potentially reducing the agronomic effectiveness of the fertilizer.

Overall, the findings confirm that the fertilizer has the characteristic strengths and limitations of a plant-based liquid organic amendment. While the pH suggests a strongly alkaline formulation that may require adjustment, the deficiencies in N, P, and K point to the need for enrichment strategies if the product is intended to meet national standards. Blending with nutrient-rich organic materials such as composted animal manure, rock phosphate, or wood ash could improve the macronutrient content, while mild acidification using natural acids might help bring the pH closer to the optimal range for plant growth.

Table 1. Nutritional test of LOFs

No	Categories	Results	Quality standard
1	N (%)	0.18	0.4
2	P (%)	0.003	0.1
3	K (%)	0.16	0.2
4	pH	8.32	6.8 – 7.49

Growth Assay on Experimental Plant (water spinach)

A liquid organic fertilizer made from rejected soybean milk was tested on water spinach for 9 weeks. The growth results are shown in Table 2. Plants in the AB-mix control outperformed all LOF treatments by every growth indicator measured (height, leaf number, leaf size), with a monotonic decline in performance as the proportion of soybean-milk LOF increased (Control > T1 > T2 > T3). All LOF treatments produced a consistent yellowish-green leaf colour versus the green colour in the control. Survival remained 100% in all groups.

Table 2. The growth assay on experimental plant

No	Indicators	Treatment			
		Control	1	2	3
1	Height (cm)	70,83	48,5	31,27	18,6
2	Leaf colour	Green	Yellowish Green	Yellowish Green	Yellowish Green
3	Number of leaves	22	14,67	10,67	5,67
4	Leaf length (cm)	5,6-13,6	5,9-9,5	5,0 - 8,0	4,2-8,6
5	Leaf width (cm)	1,9-2,9	1,4-2,3	1,5-2,4	1,1-2,1
6	Survival rate (%)	100	100	100	100

The data show substantial reductions in above-ground vegetative parameters when AB-mix is replaced by LOF formulations, and the effect increases with greater proportion of soybean-milk LOF. This decline is closely associated with the low macronutrient content (N, P, and K) observed in the LOF, which limits the availability of essential nutrients required for optimal vegetative growth. As the proportion of soybean-milk LOF increased across treatments, nutrient dilution effects became more pronounced, leading to progressively reduced plant height, leaf number, and leaf size. This pattern (organic nutrient treatment < mineral control) is consistent with several studies comparing conventional mineral nutrient solutions to organic or compost-based nutrient sources in soilless culture: organic nutrient formulas often produce lower shoot growth and lower tissue macronutrient concentrations unless the organic formulation is specifically optimized and biologically managed (e.g., microbial inoculants, aeration) (Lau & Mattson, 2021).

In addition, the alkaline pH (8.32) of the LOF likely exacerbated nutrient limitations by reducing the solubility and uptake of key micronutrients such as iron and manganese, which are critical for chlorophyll synthesis. This is reflected in the consistent yellowish-green leaf coloration observed in all LOF treatments, indicating chlorosis associated with impaired micronutrient availability. Mineral AB-mix solutions supply nutrients in readily plant-available inorganic forms with an engineered macronutrient balance; this supports rapid vegetative growth. Organic extracts and waste-derived LOFs deliver nutrients largely in complex and/or organic forms that require microbial mineralization to become available. In poorly optimized or closed hydroponic/soilless settings, this can produce transient nutrient deficits, resulting in reduced growth and chlorosis (yellowish leaves) (Alkaabi et al., 2025). Therefore, the combined effects of insufficient nutrient concentration and unfavorable pH conditions provide a coherent explanation for the inferior growth performance of LOF-treated plants compared to the AB-mix control.

Further analysis is both garlic (*Allium sativum*) and turmeric (*Curcuma longa*) contain bioactive secondary metabolites (e.g., sulfur compounds in garlic, curcuminoids and other phenolics in turmeric) that have documented allelopathic or phytotoxic effects on other plants depending on concentration and exposure method. Several studies show that aqueous extracts or root exudates of garlic and turmeric can inhibit germination or early growth and can induce oxidative stress at higher concentrations; conversely, some low-dose formulations can act as bio stimulants. This indicates a clear dose-dependent response, in which suboptimal or excessive concentrations may shift their role from growth-promoting to growth-inhibiting agents. The consistent yellowing and reduced leaf number in T1–T3 could therefore reflect dose-dependent phytotoxic effects or stress responses caused by these botanicals within the LOF (Anjani et al., 2024; Ding et al., 2020). This finding is in line with previous studies reporting that plant-based extracts in hydroponic or soilless systems often require precise dosage control to avoid inhibitory effects on plant growth, particularly when combined with nutrient-limited formulations. From an application perspective, these results suggest that the inclusion of garlic and turmeric in LOF formulations must be carefully optimized, as their bioactive compounds may exacerbate nutrient stress under suboptimal nutrient conditions. Future research should therefore focus on determining optimal concentration thresholds of these additives, evaluating their interactions with nutrient availability and pH, and assessing their effects under controlled hydroponic conditions. Additionally, formulation improvements may include reducing or fractionating these extracts, integrating microbial inoculants to enhance nutrient mineralization, and adjusting pH to improve nutrient uptake efficiency. Such targeted optimization is essential to enhance the agronomic performance and practical feasibility of soybean milk-based LOF as a sustainable alternative in hydroponic systems.

CONCLUSION

In this 9-week trial, the rejected soy milk-based liquid organic fertilizer (LOF), in its current formulation, resulted in a marked decline in the vegetative performance of *Ipomoea aquatica* compared with the standard AB-mix mineral nutrient solution. Sensory and chemical characterization indicated low macronutrient availability and an alkaline pH, which were associated with reduced growth and chlorotic symptoms across all LOF treatments. Despite these limitations, this study highlights the novel potential of rejected soy milk as an underutilized raw material for liquid organic fertilizer production, thereby contributing to waste valorization and supporting the development of more sustainable nutrient sources for hydroponic systems. However, the current formulation remains suboptimal, most likely due to insufficient nutrient availability, unfavorable pH conditions, and possible dose-dependent phytotoxic effects from garlic and turmeric additives. A key limitation of this study is the use of a single formulation without prior optimization of additive concentrations or nutrient balance. Future research should therefore focus on nutrient enrichment, pH adjustment, systematic optimization of botanical additives, and the exploration of microbial enhancement strategies to improve nutrient availability and plant performance.

RECOMMENDATION

To develop the LOF into an agronomically effective and standards-compliant product, reformulation and targeted testing are required. Priority actions should include: (1) enriching or blending the LOF to increase plant-available N, P, and K concentrations in accordance with SNI standards, for example through supplementation with composted manure, potassium-rich materials, phosphate sources, concentrated nutrients, or mineral adjuncts, while also standardizing total dissolved solids and electrical conductivity; (2) adjusting the pH toward neutral conditions, for instance through mild acidification using safe organic acids, and monitoring pH stability over time; and (3) reducing potential phytotoxicity by conducting dose–response tests for turmeric and garlic extracts and applying controlled fermentation or enzymatic treatments, such as the use of phytase-producing microbes, to mineralize phytate and other bound nutrients. Implementing these steps will help clarify the causal constraints observed in this study and determine whether the LOF can be safely optimized for practical horticultural application.

ACKNOWLEDGMENT

We would like to express our gratitude to the University of Muhammadiyah Surakarta for funding this research under the *Riset Kompetitif* scheme with contract number 95.6/A.3-III/LRI/IV/2025. We would also like to thank the Biology Education Laboratory of the Faculty of Teacher Training and Education, UMS, for providing the greenhouse facilities and infrastructure that support this research.

REFERENCES

Alkaabi, A., Almansoori, E., Hebsi, M. A. L., Aldhaheri, S., Hassan, F. E., Ali, N. A. A., Al Shurafa, K. A., Tzortzakis, N., Di Gioia, F., & Ahmed, Z. F. R. (2025). Vertical hydroponic lettuce: Impact of organic nutrients on antioxidant phytochemicals. *Annals of Agricultural Sciences, 70*(1), 100386. https://doi.org/10.1016/j.aoas.2025.100386

Anjani, N., Rahayu, T., & Sidiq, Y. (2024). Rhizosphere bacteria increased the height and root number of chili plants (*Capsicum annuum* L.). *Scientiae Educatia, 13*(1), 39. https://doi.org/10.24235/sc.educatia.v13i1.15158

Asngad, A., Agustina, L., Irawan, D. L., & Konitah, Z. (2023). Kandungan NPK dan uji sensoris pada pupuk organik cair kombinasi *Azolla microphylla* degan daun kersen dan ampas teh. *Bioeksperimen: Jurnal Penelitian Biologi, 9*(1), 80–87.

Čech, M., Herc, P., Ivanišová, E., Kolesárová, A., Urminská, D., & Grygorieva, O. (2022). Okara—by-product from soy processing: Characteristic, properties, benefits, and potential perspectives for industry. *International Journal of Experimental Research and Review, 28*, 66–83.

https://doi.org/10.52756/ijerr.2022.v28.009

Chojnacka, K., Moustakas, K., & Witek-Krowiak, A. (2020). Bio-based fertilizers: A practical approach towards circular economy. *Bioresource Technology, 295*, 122223. https://doi.org/10.1016/j.biortech.2019.122223

Cintiyah, F., Salundik, S., PDMH, K., & Komala, I. (2024). Optimization of liquid organic fertilizer from livestock manure with *Indigofera* for hydroponic lettuce growth. *Agro Bali: Agricultural Journal,* 7(3), 676–690. https://doi.org/10.37637/ab.v7i3.1875

Ding, H., Ali, A., & Cheng, Z. (2020). An allelopathic role for garlic root exudates in the regulation of carbohydrate metabolism in cucumber in a hydroponic co-culture system. *Plants, 9*(1). https://doi.org/10.3390/plants9010045

Febrianna, M., Prijono, S., & Kusumarini, N. (2018). The use of liquid organic fertilizer to increase nitrogen uptake and growth and yield of mustard (*Brassica juncea* L.) on sandy soil. *Jurnal Tanah dan Sumberdaya Lahan, 5*(2), 2549–9793. http://jtsl.ub.ac.id

Ginandjar, S., Frasetya, B., Nugraha, W., & Subandi, M. (2019). The effect of liquid organic fertilizer of vegetable waste and planting media on growth and yield of strawberry (*Fragaria* spp.) Earlibrite cultivar. *IOP Conference Series: Earth and Environmental Science, 334*(1). https://doi.org/10.1088/1755-1315/334/1/012033

Gultom, O. B., Ginting, B., Lubis, M. Y., Azwar, T. K. D., & Pasaribu, M. P. J. (2021). Repercussions of agricultural land conversion policy on food security in Indonesia. *IOP Conference Series: Earth and Environmental Science, 782*(3). https://doi.org/10.1088/1755-1315/782/3/032054

Hasan, M., Arpitha, S. R., Das, C., Laishram, R., Sasi, M., Kumar, S., Maheshwari, C., Krishnan, V., Kumari, S., Lorenzo, J. M., Kumar, M., Sachdev, A., & Dahuja, A. (2023). Research trends and approaches for the nutritional and bio-functionality enhancement of fermented soymilk. *Journal of Functional Foods, 107*, 105698. https://doi.org/10.1016/j.jff.2023.105698

Istiyova, L. R., & Santosa, S. (2023). Isolasi bakteri pelarut kalium rhizosfer padi di Sragen sebagai ketahanan dan pertumbuhan tanaman. *Bioeksperimen: Jurnal Penelitian Biologi, 9*(1), 50–56.

Karim, A., Osse, E. F., & Khalloufi, S. (2025). Innovative strategies for valorization of byproducts from soybean industry: A review on status, challenges, and sustainable approaches towards zero-waste processing systems. *Heliyon, 11*(3), e42118.

Kumar, S., Diksha, Sindhu, S. S., & Kumar, R. (2022). Biofertilizers: An ecofriendly technology for nutrient recycling and environmental sustainability. *Current Research in Microbial Sciences,* 3, 100094. https://doi.org/10.1016/j.crmicr.2021.100094

Kurniawan, L., Maryudi, M., & Astuti, E. (2024). Utilization of tofu liquid waste as liquid organic fertilizer using the fermentation method with activator effective microorganisms 4 (EM-4): A review. *Equilibrium Journal of Chemical Engineering, 8*(1), 100. https://doi.org/10.20961/equilibrium.v8i1.84056

Lai, J. C. H., Masrun, K. H., Madin, N., Baini, R. H., & Samat, N. A. S. (2021). Production and performance of okara/sago and okara/banana peel organic fertilizers in plantation. *Journal of Engineering Science and Technology, 16*(6), 4423–4437.

Lamba, R., Sangwan, S., Sehrawat, N., Singh, A., Singh, S., & Kumari, A. (2025). Development of liquid organic fertilizers using agro-industrial wastes for the hydroponic cultivation of lettuce. *International Journal of Environmental*

Research, 19, 124.

Lau, V., & Mattson, N. (2021). Effects of hydrogen peroxide on organically fertilized hydroponic lettuce (*Lactuca sativa* L.). *Horticulturae, 7*(5). https://doi.org/10.3390/horticulturae7050106

Li, X., Liu, X., Hua, Y., Chen, Y., Kong, X., & Zhang, C. (2019). Effects of water absorption of soybean seed on the quality of soymilk and the release of flavor compounds. *RSC Advances, 9*(6), 2906–2918. https://doi.org/10.1039/c8ra08029a

Low, C. W., Ling, R. L. Z., & Teo, S.-S. (2021). Effective microorganisms in producing eco-enzyme from food waste for wastewater treatment. *Applied Microbiology: Theory & Technology*, 28–36. https://doi.org/10.37256/amtt.212021726

Park, Y., & Williams, K. A. (2024). Organic hydroponics: A review. *Scientia Horticulturae, 324*, 112604.

Phibunwatthanawong, T., & Riddech, N. (2019). Liquid organic fertilizer production for growing vegetables under hydroponic condition. *International Journal of Recycling of Organic Waste in Agriculture, 8*, 369–380.

Rahayu, T., Nurcahyanto, G., Aryani, I., Suryani, T., Musbita, E., Sari, S. K., Maimun, M. H., Ripdianti, A. D., & Hardianto, A. G. M. P. (2025). Improving marketability and quality of Sulemu soy milk: A community engagement approach to product diversification. *Community Empowermentment, 10*(6), 1395–1406.

Rajendran, S., Domalachenpa, T., Arora, H., Li, P., Sharma, A., & Rajauria, G. (2024). Hydroponics: Exploring innovative sustainable technologies and applications across crop production, with emphasis on potato mini-tuber cultivation. *Heliyon, 10*(5), e26823. https://doi.org/10.1016/j.heliyon.2024.e26823

Riddech, N., Ngo, M. N., Boonlue, S., Dongsansuk, A., Santanoo, S., & Theerakulpisut, P. (2025). Physical and chemical properties evaluation of liquid organic fertilizers (LOFs) and their effects on promoting rice growth. *Sustainability, 17*(7). https://doi.org/10.3390/su17073087

Satwhikawara, R., Fernando, A., & Tusa'adah, F. (2025). Utilising oyster-mushroom baglog waste via vermiculture: A circular-economy business potential study in small-scale oyster mushroom businesses in Cikarang. *International Journal of Family Business Practices, 8*(1), 63–79.

Subah, Z., Ryu, J. H., & Mirkouei, A. (2025). Comparative study on aquaponic and hydroponic systems for sustainable hemp production in a controlled environment. *Horticulturae, 11*(6), 1–16. https://doi.org/10.3390/horticulturae11060588

Sutardi, & Buckle, K. A. (2004). Characteristic of phytases from soybeans and microorganisms involved in the tempe production. *Jurnal Teknologi dan Industri Pangan, XV*(3), 232–238. https://journal.ipb.ac.id/index.php/jtip/article/view/596

Wang, O., Deaker, R., & Van Ogtrop, F. (2025). A systematic review of food-waste based hydroponic fertilisers. *Agricultural Systems, 223*, 104179.

Zhu, Y., Cao, Y., Fu, B., Wang, C., Shu, S., Zhu, P., Wang, D., Xu, H., Zhong, N., & Cai, D. (2024). Waste milk humification product can be used as a slow release nano-fertilizer. *Nature Communications, 15*(1), 1–13. https://doi.org/10.1038/s41467-023-44422-5