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Characterization of Liquid Organic Fertilizer (LOF) Derived from Unmarketable Vegetables and Fruits

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ABSTRACT

The Malaysian government has been challenged with handling unmarketable vegetables and fruit waste that pollutes the environment and emits greenhouse gases, mainly methane and nitrous oxide. These greenhouse gases have been contributing to climate change. In contrast, these wastes consist of high moisture and readily biodegradable nutrients that can serve as the perfect substrate rate for fermentation. The valuable nutrients contained in these wastes can produce liquid organic fertilizers (LOF), which help improve the soil's physical, chemical, and biological characteristics and reduce the demand for inorganic fertilizers and costs to farmers. In this regard, a study was conducted to produce and characterize LOF derived from unmarketable vegetables and fruit waste. The waste was identified from the nearest wet market, collected, and incubated in containers with a ratio of 1: 2: 0.1 (10 kg unmarketable vegetable and food waste: 20 L water: 1 kg inducer) for 30, 45, and 60 days. The unmarketable vegetables and fruits were fermented using three different types of inducers: yeast (Y), brown sugar (BS), and shrimp paste (SP). Unmarketable vegetables and fruit waste with no inducer were also included as a control. Samples from the produced LOF were taken after 30, 45, and 60 days of fermentation, filtered, and subjected to analysis for pH, electrical conductivity (EC), macro-, and micronutrients. These experiments were laid out in a randomized

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complete block design (RCBD) with three replications. The highest nitrogen (0.95%), phosphorus (0.31%), potassium (1.68%), copper (0.23 ppm), and manganese (9.03 ppm) were obtained from LOF fermented for 60 days using yeast, indicating that it improved the nutrient availability of agricultural waste. Moreover, this treatment provided optimum pH and EC values for the growth and development of plants. Thus, LOF derived from unmarketable vegetable and fruit waste can be considered an attractive alternative for supplementing chemical fertilizers.

Keywords: Fermentation, food security, inducer, liquid fertilizer, sustainable farming, unmarketable

INTRODUCTION

The ever-increasing population causes a pressing need to increase food production. Food insecurity may quickly become a primary national concern within the context of insufficient production. In 2019, self-sufficiency rates in Malaysia for the five primary food commodities, such as rice, vegetables, fruits, beef, and milk, were 63%, 44%, 78.2%, 22.3%, and 64%, respectively (Hazri, 2022). As in many countries, the agricultural sector is Malaysia's main food supply source. Therefore, developing the agricultural sector is very important to balance the demand and supply of food products to sustain food security.

Among many other factors, the role of fertilizers in boosting agricultural productivity and food production is substantial. The application of fertilizers helps to replace the nutrients that crops uptake from the soil in food production. The agricultural productivity and crop yield would significantly decrease if the nutrients in the soil were low. The source of plant nutrients can be grouped into two general categories, which are inorganic and organic fertilizers. In contrast to organic, inorganic fertilizers typically have quick-release formulae that make nutrients readily available to plants only days after application. A plant can only use nutrients to the level of its extraction capacity and during its growth period. Thus, when fertilizers are applied untimely and excessively, the unused or unabsorbed remainders have the propensity to alter soil physicochemical characteristics, leach deep into groundwater under intensive rain or irrigation, and contaminate water sources, resulting in several human and animal health issues (Ibrahim et al., 2014; Mohd Zaini et al., 2022). Another crucial factor is the manufacturing of nitrogen (N), phosphorus (P), and potassium (K) chemical fertilizers, resulting in waste contaminating soil and water resources.

Additionally, intensive chemical usage for the long term in agricultural practices could significantly impact food safety issues and environmental health, such as acidifying or salinizing soils, which imposes huge costs of soil amendments (Mohd Zaini et al., 2022). Though chemical fertilizers are essential for enhancing crop productivity, they are among the most expensive agricultural supplies due to the high manufacturing costs associated with using imported inputs; thereby, they are unaffordable to poor farmers (da Silva et al., 2015). For that reason, the government of Malaysia has been requested to subsidize fertilizers for the sake of resource farmers, who are having difficulty coping with the ever-increasing prices, which have a very direct impact on increasing food production. Salahuddin Ayub, a former Minister of Agriculture and Agro-based Industries, claimed that subsidizing fertilizers is essential to enhance food production because the ongoing conflict between Russia and Ukraine is afraid to increase fertilizer costs globally (Bunyan, 2022).

The use of organic fertilizers for food production can be considered one of the best alternatives to the challenges associated with chemical fertilizers and is a more sustainable and environmentally friendly agricultural practice (Mohd Zaini et al., 2022). Organic fertilizers are generally considered an effective way to sustain soil fertility and plant growth. Vegetables and fruits are usually available in excess in every household and around local markets. Food and Agriculture Organization of the United Nations (FAO) (2019) estimated that about one-third of the food production in the world is wasted. Agricultural wastes are a by-product of agriculture, such as unmarketable vegetables and fruits, rotten vegetables and fruits, fisheries, and household waste that are not utilized or thrown away so that they have no sale value but can directly cause environmental pollution and disease and interfere with environmental cleanliness. Unmarketable vegetables and fruits refer to produce that cannot be sold or marketed for various reasons, such as dehydrated, rotten, or overripe, which do not meet the quality standards required for commercial distribution (Duarte et al., 2009). These wastes that have been wasted and polluting the environment can be decomposed or processed into LOF, be used for food production, and be one of the viable solutions to overcome the problems linked to chemical fertilizers. Apart from contributing towards solving the challenges with chemical fertilizers, organic fertilizers are aligned with the Responsible Consumption and Production of the Sustainable Development Goals (SDG 12).

The use of organic fertilizers enhances soil properties such as improving nutrient mobilization from an organic and chemical source, promotes the colonization of mycorrhizae, improves phosphorous supply, promotes root growth due to better soil structure, increases soil organic matter content, enhances the exchange capacity of nutrients, increases soil water retention, and promotes soil aggregates and buffering capacity (Kala et al., 2011; Lal et al., 1997). Organic fertilizers can be available both in liquid and solid states. LOF is a soluble solution that supplies one or more nutrients that meet the plant's needs. Liquid fertilizer is being studied as a possible method to lengthen the shelf life of fertilizer. The liquid form allows the manufacturer to increase the number of nutrients and inducers; besides, it can tolerate a high temperature of 55°C (Nhu et al., 2018). In addition, when applying liquid fertilizers, the nutrients can be distributed more evenly, and their concentrations are set up to meet the needs of the plants (Ginandjar et al., 2019). Organic liquid fertilizer is produced after the anaerobic biological decomposition of organic materials, releasing some important plant nutrients in the form of complex and simple compounds. Research conducted by Martínez-Alcántara et al. (2016) demonstrated that applying LOF led to higher absorption of macro and micronutrients in citrus trees compared to utilizing mineral fertilizers. In addition, organic liquid fertilizer treatment yielded the highest measurements for plant height, number of branches per plant, leaf count, leaf area, fresh and dry weight, fruit quantity per plant, and overall chili yield (Deore et al., 2010). Pangaribuan et al. (2019) found consistent enhancement in sweet corn's growth, yield, and quality through LOF. The study concludes that LOF has the potential to serve as a supplementary addition to conventional inorganic fertilizers in tropical organic sweet corn cultivation.

The production of LOF can be enhanced by inducers such as brown sugar, yeast, and shrimp paste for the fermentation process. Brown sugar is added to waste to increase the fermentation rate of food waste because brown sugar contains glucose and can be used as a food resource by microorganisms (Zhang et al., 2013). Yeast assists in the process of degrading organic materials at the beginning of the fermentation process, *and Saccharomyces cerevisiae* also increases the amount of protein in liquid organic during the process (Hidayati et al., 2011). Shrimp paste constitutes a variety of fermented products derived from shrimp. Due to the effect of seafood and microbial protease on proteins, these fermented products are often higher in soluble amino acids and smaller peptide chains, which will help with plant nutrient availability (Mohd Zaini et al., 2022). Farmers can potentially mitigate environmental pollution's effects by transforming waste from dried shrimp paste into LOF. This fertilizer can be produced collaboratively within the community and utilized in a program promoting natural greening (Mohd Kamaruddin et al., 2021).

Despite the huge quantities of unmarketable vegetables and fruit in the farmers' fields and around markets in Malaysia, these wastes have not yet been exploited in organic fertilizer. As far as the author knows, only limited information is available in the literature regarding the usage of these unmarketable vegetable and fruit wastes in the form of LOF. To date, raw food wastes have been utilized in the agricultural system to boost plant growth; however, the nutritional compositions of fermented wastes have not yet been known. Thus, this study was carried out to produce and characterize LOF derived from vegetables and fruits under various inducer and fermentation times.

MATERIALS AND METHODS

Treatments and Experimental Design

This research was conducted in Ladang 10, Universiti Putra Malaysia, Serdang, Selangor, Malaysia. The unmarketable vegetables and fruits were collected from the local market and cut into small pieces (±2 cm) before being filled into a 45-L container. The unmarketable vegetables and fruits consisted of 1.5 kg cabbage, 1.5 kg lettuce, 1.5 kg green spinach, 1.5 kg bok choy, 1.5 kg Chinese broccoli, 1.5 kg water spinach, 0.5 kg bananas, and 0.5 kg papayas. The unmarketable vegetables and fruits were mixed with a ratio of 9:1, weight by weight. The containers were filled with unmarketable vegetables and fruits, water, and inducer with a ratio of 1:2:0.1 (weight: volume: weight). All the ingredients were mixed well in a gallon container and covered with a lid for anaerobic fermentation. The gallon container was placed in the shade and stirred for three days once to accelerate microbial activities. The treatments of this study comprised factorial combinations of 3 inducers and three fermentation periods. Unmarketable vegetables and fruit waste with no inducer were also included as a control. The four inducers were no inducer (NO), yeast (Y), brown sugar (BS), and shrimp paste (SP). The unmarketable vegetables and fruits were allowed to ferment for three different periods. The three different fermentation periods were: 30 days (30D), 45 days (45D), and 60 days (60D). The two factors (4 inducers and three fermentation periods) were combined factorially and laid out in a randomized complete block design (RCBD) with three replications.

Analysis of LOF

At the end of each of the fermentation periods of 30, 45, and 60 days, liquid samples (leachate) were taken from the containers, filtered, and subjected to analyses for pH, EC, total nitrogen (N), phosphorous (P), potassium (K), magnesium (Mg), calcium (Ca), iron (Fe), manganese (Mn), copper (Cu), and zinc (Zn). The methods of devices employed to determine pH were pH meter, electrical conductivity (EC) with EC meter; total N was the Kjeldahl method (Campbell & Hanna, 1937); P was the spectrophotometric method (J. Murphy & Riley, 1962), K, Ca, Mg, Fe, Mn, Cu, and Zn were inductively coupled plasma atomic emission spectrometry (ICP) method (Hamalová et al., 1997).

Statistical Analysis

Two-way analysis of variance (ANOVA) was employed by using *R*-studio. When significant differences among treatments existed $p < 0.05$ and $p < 0.01$, means separations were performed using Tukey's test.

RESULTS AND DISCUSSION

Inducers and Fermentation Period Effects on Chemical Properties of LOF

Results showed that applying various inducers to produce LOF from unmarketable vegetables and the fermentation period significantly affected the N, P, K, Mg, Ca, Cu, Mn, Fe, and Zn contents, pH, and EC (Table 1). The interaction effects between inducers and the fermentation period were also significant for all the measured variables (Table 1).

The pH of the produced LOF ranged

from 3.1 to 7.0 with brown sugar and shrimp paste, respectively (Table 1). The highest pH of the LOF was obtained from the decomposition of unmarketable vegetables using shrimp paste for 60D (7.54) followed by 45D (7.27), which were not statistically different from the fermentation of organic materials for 60D without inducer (7.41). The lowest pH (2.9–3.3) was recorded from the fermentation of unmarketable vegetables using brown sugar regardless of the fermentation period (Table 1). The pH of LOF without inducer, using yeast and shrimp paste at different fermentation periods, was moderately acidic to neutral, while brown sugar was strongly acidic (H. F. Murphy, 1968). These acidic pH values with brown sugar were caused by the substrate's high sugar content, which microbes used to produce lactic or acetic acids (Phibunwatthanawong & Riddech, 2019). It showed that the higher the sugar concentration in the substrate, the higher the organic acids and the lower the pH. There were also significant differences in pH among all the inducers and fermentation periods. Generally, the tested inducers varied significantly among each other in their pH values, and pH increased as the fermentation period progressed from 30 to 60 days, indicating that all treatments had higher pH values at 60D of fermentation (Table 1). Similar results were also reported by Tan (2015), who documented that the pH trend of fermenting samples increased from the early period to the 90th day.

Results presented that the highest EC of the LOF (32.33 dS/m) was recorded from the fermentation of unmarketable vegetables using shrimp paste for 60D. In contrast, the lowest EC (3.35–3.85 dS/m) was attained from brown sugar, irrespective of the fermentation period (Table 1). The shrimp paste (29.26 dS/m) and brown sugar (3.11 dS/m) inducers had the maximum and minimum EC values, respectively, compared to LOF produced from yeast (16.86 dS/m) and no inducer (6.71 dS/m) at all fermentation periods (Table 1). Similar to the pH values, the EC values also varied greatly among inducers and increased consistently as the fermentation period advanced (Table 1).

Results exhibited that the highest N content in the LOF was recorded from the fermentation of food waste for 60D using yeast (0.95%), followed by 45D (0.91%). Whereas the lowest N contents of LOF (0.23–0.24%) were obtained from brown sugar inducer regardless of fermentation period (Table 1). LOF without inducer at any fermentation periods (0.23–0.25%) and shrimp pest at 30D of the fermentation period (0.24%) also resulted in lower N contents. Results generally showed a significant increase in N contents of LOF fermented with yeast and with progress in the fermentation period (Table 1). The N contents of LOF increased from 0.26% at 30D to 0.32% at 60D of fermentation, indicating that the more days of fermentation, the higher the N contents. The significantly higher N content of LOF fermented with yeast could be ascribed to the transformation of ammonia to nitrate due to the involvement of nitrifying bacteria.

As microorganisms, yeasts can successfully metabolize and ferment organic materials in this natural setting because they can access essential nutrients and substrates (Walker & Stewart, 2016). In terms of nutrition, yeasts are less demanding compared to other microorganisms, such as lactic acid bacteria. The growths of microorganisms are highly enabled in the presence of fundamental substances like fermentable carbohydrates, amino acids, vitamins, minerals, and oxygen. Microorganisms can improve nutrient release from organic materials and enhance nutrient absorption from carbohydrates and other elements (Maicas, 2020).

The significantly lower N content of LOF fermented with brown sugar (0.23%) occurred due to the limited availability of nutrients and oxygen (Aisyah et al., 2011). Because of the very strongly acidic medium, it could be difficult for the bacteria to ferment the organic materials in brown sugar inducer to rebuild N. Moreover, oxygen is not distributed uniformly on the pile when organic matter is decomposed, and N is released in the form of ammonia to the air. Fermentation is faster in airtight environments (anaerobic) that do not require oxygen (Aisyah et al., 2011). It prevents the ammonia from being converted to nitrate, which further downstream the release of N in the form of ammonia gas. The ammonia gas is released into the air when temperature and pH are high (Ayuningtias, 2014).

N is one of the essential plant nutrients because it plays the most important role in various physiological processes. N has a crucial role in plants' growth and development, including the production of chlorophyll (dark-green color), which promotes plants' leaves, stems, and roots. Rapid early growth and enhanced development of leafy vegetables improved fruit quality and enhanced protein content of fodder crops, among a few of the vital roles that N plays in plants (Leghari et al., 2016). A deficiency of N in soils or plants negatively affects metabolism and results in abnormal plant growth and development, ultimately leading to reduced yield. In the absence of adequate N, plants exhibit deficiency symptoms such as yellowish leaves, a warranting indicator that enough N needs to be applied to correct the problem.

The results of nutrient analyses showed that the highest P contents were found in LOF fermented using yeast for 60D (0.31%) followed by 45D (0.26%). In contrast, the lowest P contents, which were negligible, were found using shrimp paste inducer regardless of fermentation period (Table 1). The decomposition of organic materials using brown sugar also resulted in low P contents (0.01–0.05%), which were statistically not different from shrimp paste. The highest P content in the LOF fermented for 60D using yeast could be attributed to the rise in total P due to the microbial activities in the inducer. The current result is in line with the findings of Lesik et al. (2019), who stated that the activities of decomposing fungi such as *Lactobacillus* sp., *Streptoyces* sp., cellulose, and yeast could remodel P and enhance its content. The fermentation process contributes to accelerating the breakdown and reorganization of organic materials. The higher P content in the LOF fermented for 60D using yeast could also be ascribed to the availability of N, which are directly correlated; the higher the N content, the higher the P content (Table 2). The availability of more N in the LOF decomposed for 60D by yeast could have enhanced the rapid multiplication of microorganisms that ultimately increased the P content (Hidayati et al., 2011).

The lowest P contents in the LOF fermented using shrimp paste and brown sugar could be linked to the limited availability of N, which inhibited microbial activities that consequently resulted in the formation of the reduced amount of P. The reduction in P levels could also be related to the limited availability of other nutrients required by bacteria for the fermentation process, which could have contributed to the slow rate of organic matter decomposition. The limited availability, in turn, resulted from organic matter not being fully converted to nutrients that are used for metabolism (Santi, 2008). Generally, the highest P contents in LOF were recorded from organic matter decomposition with yeast, and more P was produced as the fermentation period increased (Table 1).

P is an essential plant nutrient that plays vital roles in plant processes, including photosynthesis, respiration, energy production, and nucleic acid biosynthesis. It is also crucial to various plant structures, including phospholipids (Balemi & Negisho, 2012). In the absence of sufficient P in soils or plants, the older leaves change to yellowish or reddish color due to the formation of anthocyanin pigment, which is one of the symptoms of deficiency of P.

Like the analytical results for P, the highest K content (1.68%) was found in the LOF fermented for 60D using yeast, whereas the lowest K in the LOF (0.53%) was obtained from the decomposition of organic matter for 30D using brown sugar (Table 1). The highest K with a longer fermentation period could be due to the fact that yeast has a large amount of K, and it increases during active metabolism (aerobic or anaerobic respiration of certain other substrates) (Armstrong, 1961). This fact is consistent with the (United States Department of Agriculture [USDA], 2019), which stated that 100 g of yeast contains 955 mg of K. In the presence of bacteria, microorganisms use K as a biocatalyst, and their activity significantly impacts the rise in K levels (Lesik et al., 2019). Similar to N and P nutrients, the highest K content in the produced LOF was obtained from the decomposition of organic matter using yeast, and it increased with an advanced period of fermentation (Table 1). Similar results were also reported by Hastuti et al. (2022), who stated that the levels of N, P, and K in organic fertilizers enhanced as the fermentation period increased from 7 to 21 days: the longer the fermentation time, the higher the N, P, and K contents in the fertilizer.

K is one of the most important minerals because many biochemical and physiological processes that affect plant growth, development, and metabolism depend on it. It plays a crucial function as a biocatalyst in synthesizing and breaking down carbohydrates and converting proteins and amino acids. Additionally, it helps plants to withstand various biotic and abiotic stresses, including diseases, pest attacks, drought, salinity, cold, and waterlogging (Wang et al., 2013).

The highest Mg (0.19%) and Ca (0.09%) contents in the LOF were recorded from the decomposition of organic matter for 60D using shrimp paste and brown sugar, respectively. At the same time, the lowest Mg and Ca were obtained from the fermentation of vegetable leachates without any inducer (Table 1). The richness in Mg sources is ascribed to the enhanced amount of Mg in the LOF fermented with shrimp (Team Phactual, 2019). Similarly, brown sugar contains high Ca due to its molasses content (O'Connor, 2007), resulting in the maximum amount of Ca in the LOF when the organic matter is fermented. Like other macronutrients, the contents of Mg and Ca in the LOF enhanced with an increasing fermentation period (Table 1).

The results of micronutrient analyses in LOF showed that organic matter decomposition for 60D using yeast gave the highest Mn (9.03 mg/kg) and Cu (0.233 mg/kg) contents (Table 1). These results showed that the synthesis of LOF derived from unmarketable vegetables using yeast as an inducer for 60D was the best source for most micronutrients. LOF produced using brown sugar as an inducer for 60D had the highest Fe (11.70 mg/kg) content. As the fermentation period increased from 30 to 60 days, the contents of Zn, Fe, Mn, and Cu in the LOF also consistently enhanced regardless of inducers, indicating the need to allocate sufficient time for organic matter to be fully decomposed by various microorganisms. Similar results were also reported by Ullah et al. (2019), who stated that fermentation with yeast proved more productive than molasses.

The status of the nutrient contents of the produced LOF was evaluated according to the available regulations in Malaysia and other Asian countries. According to the Decree of the Indonesian Minister of Agriculture (DIMA) number 70/Permentan/SR.140/10/2011, the normal range of pH in LOF needs to be 4-9. Thus, the pH of the produced LOF, except those made of brown sugar, met the quality standard for minimal technical requirements (Refilda et al., 2018). According to the standards set for LOF in Thailand (National Bureau of Agricultural Commodity and Food Standards [ACFS], 2005), good quality LOF should normally have an EC value of less than 20 dS/m (Phibunwatthanawong & Riddech, 2019). Accordingly, the LOF produced using shrimp paste, irrespective of the fermentation period, was found to be more than the optimum range; thereby, it could aggravate soil salinity due to its high level of EC.

Although the availability of the highest N, P, and K contents in yeast decomposed LOF for 60D of fermentation (0.95, 0.31, and 1.68%, respectively), results could not meet the quality standard of LOF set in the Agriculture Regulation No.28/Regulation of

Table 1

Effect of various inducers and fermentation period on pH, electrical conductivity (EC), macronutrients (nitrogen [N], phosphorus [P], potassium [K], magnesium [Mg], and calcium [Ca]) and micronutrients (zinc [Zn], iron [Fe], manganese [Mn], and copper [Cu]) in a liquid organic fertilizer

Inducer	Fermentation period (Day)	pH	EC (dS/m)	N (%)	P (%)	K (%)	Mg (%)	Ca (%)	Zn (mg/kg)	Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)
None	30	5.33^{cd}	6.17^{f}	0.26^{de}	0.10^{c}	0.96^{ef}	0.01^{h}	0.01^{h}	0.23^{ef}	2.37^{f}	0.13^{e}	0.00^{c}
	45	5.25^{d}	6.49^{f}	0.28^{de}	0.10^{cd}	0.92^{fg}	0.02^{gh}	0.04^{de}	0.67^{cde}	2.67^{f}	0.30^{e}	0.00^{c}
	60	7.41^{a}	7.47^{f}	0.32^{cde}	0.03^{de}	1.00^{e}	0.05^{f}	0.07^{b}	0.80^{bcde}	4.07^{e}	3.37^{c}	0.00^{c}
Yeast	30	5.67^{bcd}	15.32^{e}	0.83^{b}	0.23^{b}	1.24^{c}	0.07^{e}	0.03^{g}	0.07^{f}	4.27^{e}	0.10^{e}	0.13^{abc}
	45	5.66^{bcd}	16.86^{de}	0.91^{ab}	0.26^{ab}	1.35^{b}	0.08^{d}	0.04^{d}	0.40^{def}	6.57^{d}	5.83^{b}	0.07^{bc}
	60	5.78^{bc}	18.40^{d}	0.95^{a}	0.31^{a}	1.68^{a}	0.08^{d}	0.06^{c}	0.43^{def}	7.57^{c}	9.03^{a}	0.23^{a}
Brown sugar	30	2.90^{e}	3.35^{g}	0.23^{e}	0.04^{cde}	0.53^{i}	0.02^{gh}	0.01^{h}	0.70^{cde}	0.57^{h}	0.20^{e}	0.07^{bc}
	45	3.12^{e}	3.49^{g}	0.23^{e}	0.05^{cde}	0.62^{h}	0.03^{g}	0.04^{ef}	1.20^{bc}	10.83^{b}	0.40^{e}	0.17^{ab}
	60	3.30^{e}	3.85^{g}	0.25^{de}	0.01^{e}	0.64^{h}	0.03^{gh}	0.09^{a}	2.40^{a}	11.70^{a}	2.00^{d}	0.13^{abc}
Shrimp paste	30	6.10^{b}	26.30^{c}	0.24^{e}	0.00^{e}	0.88^{g}	0.11^{c}	0.01^{h}	0.97^{bcd}	0.47^{h}	0.17^{e}	0.13^{abc}
	45	7.27^{a}	29.16^{b}	0.35^{cd}	0.01^{e}	1.14^{d}	0.12^{b}	0.03^{g}	1.17^{bc}	2.73^{f}	0.13^{e}	0.13^{abc}
	60	7.54^{a}	32.33^{a}	0.40^{c}	0.00^{e}	1.17^{cd}	0.19^{a}	0.04^{f}	1.33^{b}	1.23^{g}	0.20^{e}	0.13^{abc}
Fermentation period	*p*-value	***	***	***	ns	***	***	***	***	***	***	ns
inducer	*p*-value	***	***	***	***	***	***	***	***	***	***	***
Fermentation period × Inducer	*p*-value	***	***	*	**	***	***	***	***	***	***	*

Note. Means ± standard error with different letters is significantly different at $p < 0.05$ using Tukey, ns = No significant, *$p \leq .05$, **$p \leq .01$, ***$p \leq .001$

the Minister of Agriculture/OT.140/2/200. The regulation stated that LOF's total N, P, and K contents should be greater than 2% (Wahida & Suryaningsih, 2016). Thus, the quality of the LOF fermented with and without inducers could not fulfill the requirements to be considered as LOF in terms of its N, P, and K contents. However, the K content in the LOF decomposed by yeast for 60D (1.68%) was closer to the standard.

Similarly, the micronutrient analytical results showed insufficient contents to meet plant requirements. The normal concentration range of Mn needed in plants is typically from 20 to 300 mg/kg (Brouder et al., 2003), Fe (50 to 250 mg/kg) (Goos & Johnson, 2000), Zn (20 to 100 mg/kg) (Slaton et al., 2005), and Cu (8 to 20 mg/kg (Tilley, 2021).

CONCLUSION

Results of the current study presented that fermentation of unmarketable vegetable leachates for a longer period significantly improved the pH, EC, macro-, and micro-nutrient contents of the produced LOF. Results of the macro- and micro-nutrient analyses for the LOF derived from unmarketable vegetables through fermentation for 60D using yeast as an inducer showed the highest nitrogen (0.95%), phosphorus (0.31%), potassium (1.68%), copper (0.23 ppm), and manganese (9.03 ppm). Moreover, this treatment resulted in optimum pH and EC values for the growth and development of plants. Results also showed that the concentrations

Table 2
Correlation coefficients (r) between nitrogen (N), phosphorus (P), and potassium (K) in different fermentation days

Variables measured	30 days N (%)	30 days P (%)	30 days K (%)	45 days N (%)	45 days P (%)	45 days K (%)	60 days N (%)	60 days P (%)
30 days P (%)	0.84***							
30 days K (%)	0.79**	0.73**						
45 days N (%)	0.98***	0.79***	0.82***					
45 days P (%)	0.94***	0.95***	0.78**	0.89***				
45 days K (%)	0.73**	0.52ns	0.91***	0.82***	0.60*			
60 days N (%)	0.97***	0.79**	0.84***	0.99**	0.88***	0.84***		
60 days P (%)	0.99***	0.89***	0.78**	0.97***	0.95***	0.71**	0.97***	
60 days K (%)	0.86***	0.68*	0.95***	0.91***	0.76**	0.97***	0.93***	0.85***

Note. ns = No significant, $^*p \leq .05$, $^{**}p \leq .01$, $^{***}p \leq .001$

of the nutrients in the LOF increased with the advancement in the fermentation period; as the fermentation period increased, the concentrations of macro- and micro-nutrients consistently enhanced. Despite the significant improvements in quality with the addition of inducers and increased fermentation period, the contents of nutrients in the produced LOF did not meet the quality standards set for LOF by Agriculture Regulation No.28/Regulation of the Minister of Agriculture/OT.140/2/200. Considering the benefits of environmental management, soil health, reduction in chemical fertilizers, and costs incurred by smallholder farmers, further study with an increased ratio of inducers to unmarketable vegetable leachates and fermentation period are recommended to enhance the quality of LOF.

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