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Conversion of Oil Palm Empty Fruit Bunch Fiber Waste into Green Liquid Organic Fertilizer

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ABSTRACT

Solid wastes generated from the oil palm industry contain valuable nutrients like nitrogen, phosphorus, and potassium that can significantly enhance plant growth and potentially elevate fertilizer production. This study aims to identify the optimal formulation of liquid organic fertilizer (LOF) derived from oil palm empty fruit bunch (OPEFB) fiber waste. Three formulations of LOF were prepared, comprising OPEFB waste, molasses, noni fruit, and cattle urine, designated as Formulation A, B, and C. These formulations underwent a 14-day anaerobic incubation period. The formulated OPEFB LOF was then analyzed for nutrient content, electrical conductivity, and total dissolved solids. This study also examines the soil properties and plant growth outcomes following the application of the formulated OPEFB LOF. The results indicated that Formulation A exhibited the highest nutrient concentrations, specifically 485 ppm nitrogen, 95 ppm phosphorus, and 1007 ppm potassium. In comparison to the other two OPEFB LOF formulations, Formulation A showed the lowest values for total dissolved solids (502 ppm) and electrical conductivity (8.14 dS/m). The findings demonstrated that Formulation A displayed the most favorable growth characteristics in terms of leaf count, plant height, leaf length, and leaf width. This is attributed to the nitrogen-boosting properties of cattle urine, along with the complementary effects of molasses and noni fruit as soil improver and bio-activator. This study confirms the viability of utilizing green organic fertilizer derived from OPEFB substrate in agriculture, replacing conventional inorganic fertilizers.

1. Introduction

The palm oil industry in Malaysia stands as a pivotal resource, driving significant agricultural and economic advancements within the country. As of 2020, Malaysia accounted for 25.8% of global palm oil production and 34.3% of global palm oil exports, according to the Malaysian Palm Oil Council [1]. However, the rapid expansion of oil palm plantations has generated substantial agricultural waste, posing challenges during replanting and raising significant environmental concerns. Throughout

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various stages such as replanting, pruning, and milling, the oil palm industry produces a variety of biomass, including empty fruit bunches, fiber, shells, wet shells, palm kernels, fronds, and trunks. Among these, empty fruit bunches represent the largest solid waste from palm oil processing. OPEFBs are rich in cellulose, hemicellulose, lignin, nitrogen, phosphorus, as well as various micronutrients and organic matter, which not only enhance soil fertility but also meet nutritional requirements [2]. This makes OPEFB particularly suitable for conversion into fertilizer.

Current agricultural practices often criticize the use of inorganic fertilizers due to their associated health and environmental risks. Prolonged and consistent application of these fertilizers leads to the accumulation of heavy metals in plant tissues, which in turn diminishes crop nutrition and grain quality. Furthermore, long-term use of inorganic fertilizers can adversely affect soil texture, microbial communities, and pH levels, ultimately reducing productivity. The adverse effects linked with inorganic fertilizers have spurred researchers and practitioners to explore alternative fertilizers, particularly organic options, which are expected to enhance plant yields while mitigating the detrimental impacts associated with inorganic fertilizers [3].

Organic fertilizers are predominantly derived from natural sources rather than synthetic materials. Previous studies have demonstrated the efficacy of utilizing OPEFB as fertilizer due to its high nutrient content. Windiastuti *et al.,* reported that OPEFB compost contains 1.91-3.62% nitrogen, 0.62-1.51% potassium, 0.83% calcium, 0.54-0.94% phosphorus, 0.09% magnesium, and 51.23% organic carbon, with a carbon: nitrogen (C/N) ratio of 26.82% and a pH ranging from 7.13 to 9.59 [2]. The application of OPEFB fertilizer, composed of 50 g OPEFB compost and 50 g coconut/plant, has been shown to increase the height of oil palm seedlings and enhance soil fertility [4]. In addition to utilizing OPEFB, studies have explored the use of palm oil mill effluent combined with a starter culture comprising molasses, yeast, and effective microorganisms to produce liquid organic fertilizers (LOF). As a result, the LOF contains nutrient levels comparable to traditional organic fertilizers: 0.14% nitrogen, 0.05% phosphorus pentoxide, 0.07% potassium oxide, 0.01% magnesium oxide, 0.001 mg/l calcium oxide, 0.12% organic carbon, and a C/N ratio of 0.86 [5].

Microorganisms play a crucial role during fermentation of LOF by breaking down substrates that facilitate the decomposition and recycling of organic matter [6]. LOF includes a binding agent that facilitates rapid absorption of the fertilizer solutions sprayed to the soil surface [7]. The application of LOF, containing nitrogen, potassium, and phosphorus (NPK), is expected to enhance the soil's physicochemical properties and promote plant growth. To the best of our knowledge, there is no study reported on the production of LOF utilizing OPEFB as the primary material, supplemented with molasses, natural bio-activator, and nutrient booster. This paper aims to assess the efficacy of this LOF formulation derived from OPEFB fiber waste and other compositions. The study includes evaluating the nutrient composition, electrical conductivity (EC), and total dissolved solids (TDS) of the prepared LOF, along with examining soil characteristics and plant growth outcomes in the experimental plants.

2. Methodology

2.1 Preparation of Liquid Organic Fertilizer

The materials used for preparing the LOF were OPEFB, fiber waste, molasses, noni (*Morinda citrifolia L.*) fruit, and cattle urine. OPEFB fiber waste is primarily produced from the hollow fruit bunches of oil palm trees after factory oil extraction. OPEFB fiber waste was chosen as the main component of the LOF formulation due to the high NPK contents compared to oil palm frond and oil palm trunk fibers [8]. Molasses was employed as a fertilizer and soil improver, particularly on soils with poor structure. Molasses contributes carbohydrates and alter the C/N ratio in the soil, affecting soil microbial ecology and reducing parasitic nematodes on plants. Molasses sterilizes the soil to a certain degree and encourage nitrogen fixation [9]. Noni fruit served as a natural bio-activator for the LOF [10]. Bio-activators are chemicals that help bacteria break down hydrocarbons. Cattle urine was used in this study to boost nutrient content in the soil. According to reports, cattle urine deposition is a significant source of nitrogen input to the soil [11,12].

The OPEFB fiber waste was collected from FGV Palm Industries Sdn. Bhd., Gambang, Pahang (Coordinate: 3.3830°N, 103.0036°E). Cattle urine was provided by a local cattle farm owner in Kuantan, Pahang. Noni fruit solution and molasses were procured from a local supplier. For comparative purposes, a commercial liquid organic fertilizer was purchased locally. Brazilian spinach (*Alternanthera sissoo sp.*) was chosen as the plant sample for this study. Before preparing the LOF, the OPEFB fiber waste sample was dried under direct sunlight for 2 days to reduce its moisture content to 10%. The dried OPEFB fiber waste was then used in three different formulations: Formulation A, Formulation B, and Formulation C, each labeled based on their unique compositions. Further details about the LOF formulations can be found in Table 1. Each formulation was mixed with 1 L of water and fermented anaerobically for 14 days in sealed containers. Subsequently, the three formulations were compared with a commercial fertilizer and a control sample (soil without fertilizer). The experiments were conducted in Gambang, Pahang (Coordinates: 3.7070° N, 103.1025° E) from December 2021 to January 2022.

Table 1
Experimental sample pots for Brazilian spinach

Sample Pot	Description	Formulation
1	Formulation A	OPEFB waste (1 kg) + molasses (50 g) + noni fruit (0.04 L) + cattle urine (2 g)
2	Formulation B	OPEFB waste (1 kg) + molasses (50 g) + noni fruit (0.04 L)
3	Formulation C	OPEFB waste (1 kg) + molasses (50 g)
4	Commercial Fertilizer	Natural ingredient + active enzyme + bacteria + organic acid
5	Control	No fertilizer was applied

2.2 Stem Cuttings Method

In this study, Brazilian spinach was used and planted using a method known as stem cutting. The method was employed to fully propagate Brazilian spinach into 15 cuttings. Each cutting was planted in a pot to grow and labeled according to the sample pot in Table 1. The cuttings were manually sown at a depth of 1/2 to 1 inch, to cover the soil and maintain moisture. Watering Brazilian spinach twice a day has been done since it requires more water and sunlight. After 21 days of growth, the plant was ready to be harvested for data collection.

2.3 Monitoring Analysis

The readings of pH, temperature, and moisture content of all samples were taken daily using a soil analyzer and digital moisture meter. The reading was taken in the morning between 7 am to 9 am and in the evening between 5 pm to 7 pm. To obtain an accurate reading, the soil analyzer and digital moisture meter were immersed in 2/3 of the soil depth. The readings were averaged after being taken three times. After two weeks of fermentation of all formulated LOF, the Brazilian spinach began fertilizing. Then, both plants were examined for number of leaves, plant height, length of leaf, and width of leaf every week for three weeks. The three LOF formulations and commercial LOF were analyzed for NPK content using Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) for soil analysis. The initial LOF referred to LOF that had been fermented for 2 weeks, while the final

LOF referred to LOF that had been fermented for 4 weeks. The readings of TDS and EC were taken by using a digital TDS and EC meter. The meter was immersed in the LOF without exceeding the immersion line. The reading was taken three times, and the average value was recorded.

3. Results

3.1 Analysis of Nutrients Content in the Liquid Organic Fertilizer

NPK and the availability of water are often considered as the primary factors in crop growth, development, and economic production. The supply of adequate mineral nutrition can result in a higher yield and quality of crops. Mineral nutrition involves providing, absorbing, and utilising essential minerals that agricultural plants need to grow and produce properly. Figure 1 shows initial and final nitrogen concentration in different OPEFB LOF formulations. The highest nitrogen content (485 ppm) was obtained by Formulation A, followed by Formulation C and B, which had data recorded at 465 ppm and 445 ppm, respectively. High content of nitrogen helps plants to grow faster, and this allows the soil to be used more efficiently. Formulation A is composed of OPEFB fiber waste, molasses, noni fruit, and cattle urine. The nitrogen content is improved through the combination of all components. It has been reported in literature that cattle urine patches can contain extremely high amounts of soluble nitrogen (approximately 500-1000 kg nitrogen/ha), which is more than 2-3 times the nitrogen uptake capacity of pastures [12].

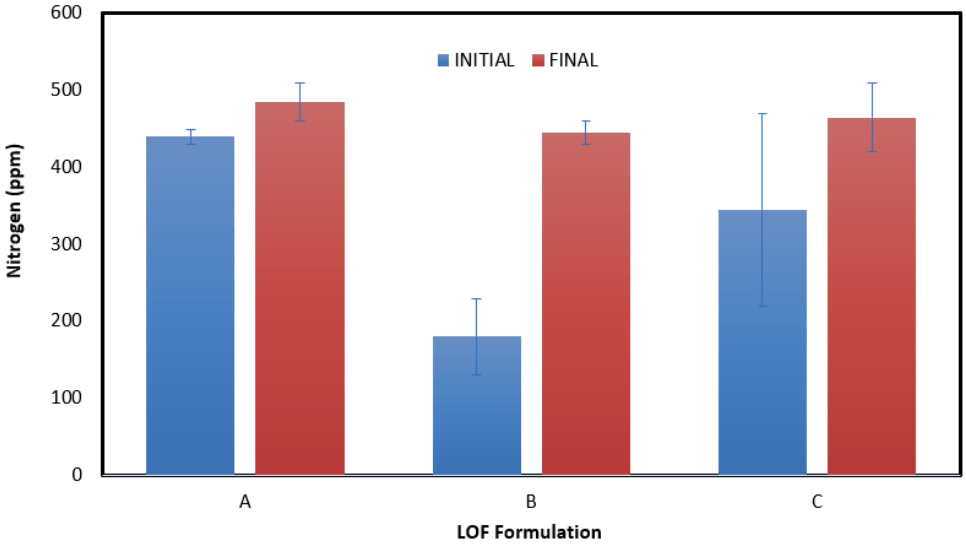

Fig. 1. Nitrogen concentration in different OPEFB LOF Formulation

Plant growth can be improved by nitrogen, a component of the plant cell, which is formed from ammonia (NH_3). Nitrogen is a crucial element in the synthesis of amino acids and proteins. It stimulates vegetative growth (green) in the same way that a leaf does. If plants lack nitrogen, they will exhibit signs such as slow/stunted growth, yellowish green leaves, narrow leaves, short and straight leaves, and old leaves that quickly turn yellow and die [13]. Beneficial microorganisms in LOF can help improve soil nutrient availability by nitrogen fixation and the production of plant hormones such as indole-3-acetic acid (IAA), gibberellic acid (GA), abscisic acid (ABA), 1-minocyclopropane-1-carboxylate (ACC) deaminase, salicylic acid, and siderophore. For benchmarking purpose, the nitrogen concentration of the commercial fertilizer was measured and recorded at 545 ppm. It is noteworthy that the difference is minimal (approximately 60 ppm), demonstrating the potential suitability of Formulation A as a commercial green biofertilizer. In terms of sustainability, the use of green biofertilizer has many advantages compared to chemical nitrogen fertilizers. It is a well-known fact that inorganic fertilizer requires a substantial amount of fossil fuels to produce chemical nitrogen fertilizer, which leads to harmful gaseous emissions [14].

Figure 2 displays the concentration of initial and final phosphorus in various OPEFB LOF formulations. Formulation A performed the best with 95 ppm of phosphorus, followed by Formulation C (89 ppm) and Formulation B (74 ppm). The high content of phosphorus in the OPEFB LOF has assisted in the growth of roots for plants. Phosphorus, produced from phosphorus pentoxide, has several functions in the plant, including transporting energy metabolism, stimulating flowering and fruiting, stimulating root growth, increasing seed formation, and stimulating cell division and tissue expansion. Elemental phosphorus-deficient plants will show signs of fruit/seed formation and stunted, decreased, or reddish-purple leaves [13]. Phosphorus is required for proper root formation and aids in the plant's drought resistance [15]. The presence of phosphorus is necessary for plant growth and development, including seed and fruit ripening [16]. In this finding, Formulation A recorded only a 5% difference compared to commercial fertilizers with a value of 100 ppm phosphorus.

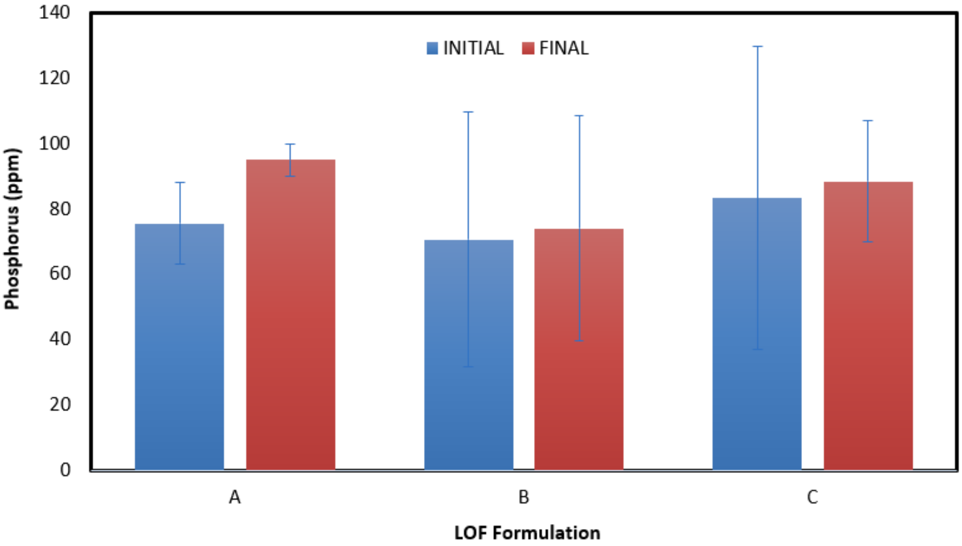

Fig. 2. Phosphorus concentration in different OPEFB LOF Formulation

The initial and final concentration of potassium in various OPEFB LOF formulations is compared in Figure 3. As expected, Formulation A is the most prominent among the other formulations. The order of the LOF formulations in terms of phosphorus content is as follows: Formulation A (1007 ppm) > Formulation C (990 ppm) > Formulation B (928 ppm). The phosphorus content in the commercial fertilizer is 1012 ppm, which is not much different from Formulation A. High potassium content has led to the strengthening of plant stems and the fight against disease. Potassium is generated from potassium oxide and plays a role in photosynthesis, assimilation transport, enzymes, and minerals, including water [17]. When plants lack potassium, their stems and leaves become limp or fall, their dark green leaves turn bluish green, their tips yellow and dry, and brown patches emerge on the leaves [13]. Potassium is a crucial biocatalyst for synthesis and disassembly of carbohydrates, particularly for the conversion of proteins and amino acids. In the presence of bacteria, microorganisms use potassium as a biocatalyst, and their activity has a significant effect on the increase in potassium [18].

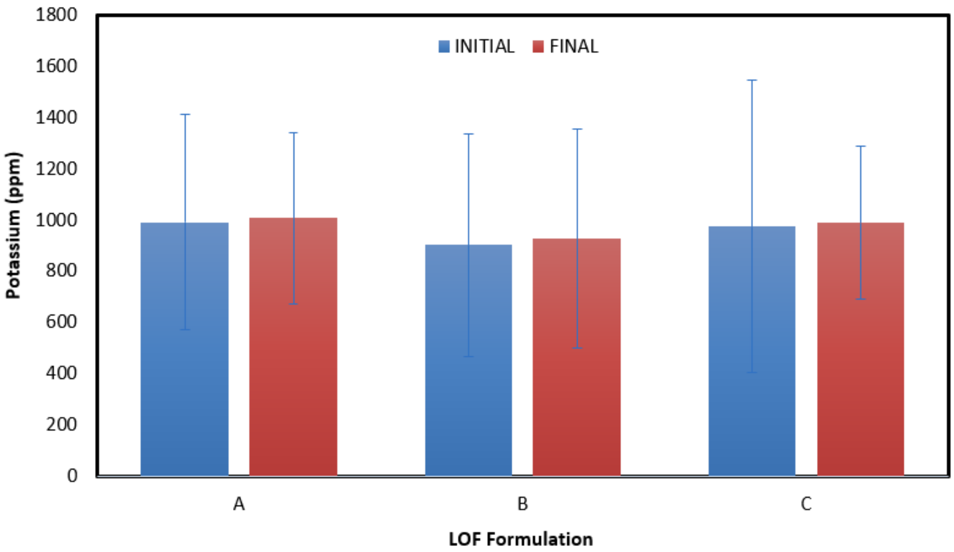

Fig. 3. Potassium concentration in different OPEFB LOF Formulation

Figure 4 shows the TDS content in the various OPEFB LOF Formulations samples. The data represents the total concentration of dissolved substances in the fertilizers. The graph showed that Formulation B had the highest value, which was 862 ppm. On the other hand, the commercial LOF recorded TDS of 400 ppm. In LOF, the TDS is an effective predictor of salinity because it describes the inorganic salts and small amounts of organic materials that are present in the solution [19]. TDS levels in the range of 500 ppm to 1,000 ppm are considered good for health reasons. There are four types of TDS: type I is freshwater with TDS less than 1,000 ppm; type II is brackish water with TDS between 1,000 and 10,000 ppm; type III is saline water with TDS between 10,000 and 100,000 ppm; and type IV is brine water with TDS greater than 100,000 ppm [20]. High in TDS affecting the plant by the root systems of the plants will eventually have trouble taking up many of the nutrients.

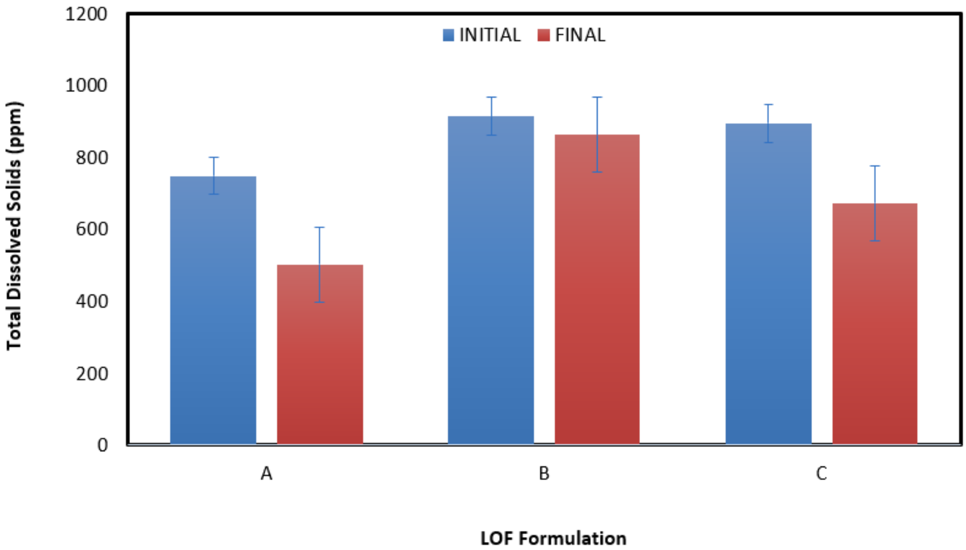

Fig. 4. TDS concentration in different OPEFB LOF Formulation

EC of a liquid is a measure of its ability to conduct an electric charge. Its capability is dependent on the amounts of dissolved ions, the ionic strength, and the temperature at which measurements are taken [21]. Materials in EC can be derived from nature, such as geological conditions and seawater, or from human activities, such as home and industrial waste, as well as agriculture [22]. As can be seen, EC data of the OPEFB LOF formulations are presented in Figure 5. The results presented the total amount of fertilizer ions in the OPEFB LOFs. The graph showed that formulation C had the highest value with 9.17 dS/m followed by formulation B, formulation A, and commercial LOF with data measured at 8.57 dS/m, 8.14 dS/m, and 5.25 dS/m, respectively. In this analysis, a lower EC is more beneficial for the plant. Generally, plant growth can be hindered by excess salts as they impact the soil-water balance. Hence, EC is divided into 6 types: type I is non-saline, if EC less than 700 dS/m; type II is slightly saline, if EC rely between 700 and 2,000 dS/m; type III is moderately saline, if EC higher than 2,000 and less than 10,000 dS/m; type IV is highly saline with EC value from 10,000 till 25,000 dS/m; type V is very highly saline, if EC value between 25,000 and 45,000 dS/m; and type IV is brine water with EC more than 45,000 dS/m [20].

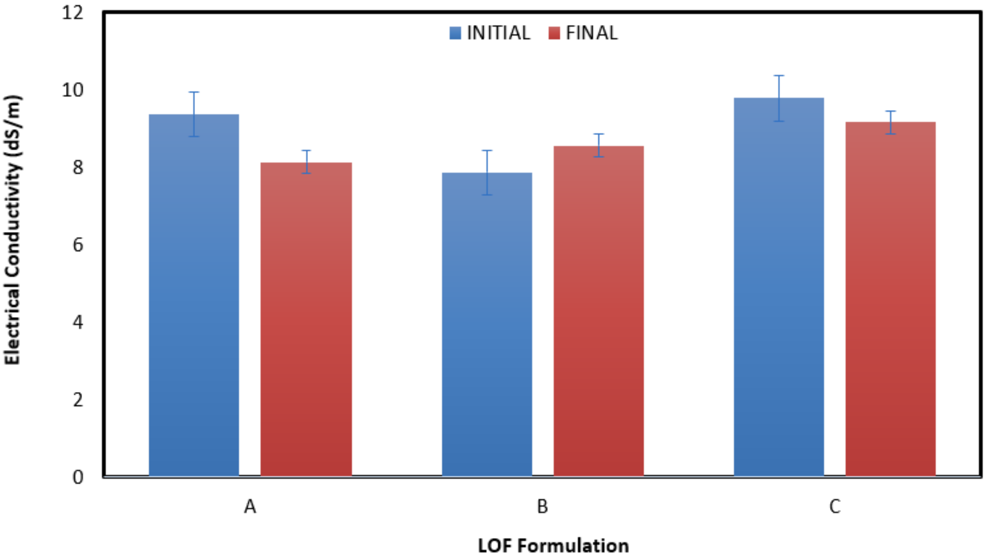

Fig. 5. EC value in different OPEFB LOF Formulation

3.2 Results from the Monitoring Analysis of the Soil Condition

3.2.1 Soil moisture analysis

Figure 6 displays the soil moisture content of Brazilian spinach samples over a 4-week period. The graph indicates that all samples able to maintain moisture levels ranging from 70% to 80%. In week 4, the commercial fertilizer exhibited the highest moisture content among the samples, measuring 79%, followed by Formulation A at 78%. According to Shahrudin and Mokhtar, the best microbial activity occurs when the moisture content is between 70% and 80% [23]. Meanwhile, the minimum requirement for microbial activity is 50% of the moisture content. The capability of the OPEFB LOF formulations to hold water is determined by the moisture content of the soil samples. The moisture content for all samples shows that the results are influence by the addition of water to the soil to ensure the moisture content in a suitable range throughout the day. In terms of plant nutrient, potassium is a vital mineral nutrient that helps plants retain water. Plants absorb potassium from the soil, enhancing their water use efficiency and bolstering their tolerance and resistance to withstand drought stress [17]. The results align with the data presented in Figure 3, indicating that Formulation A exhibits a potassium concentration most similar to that of the commercial fertilizer.

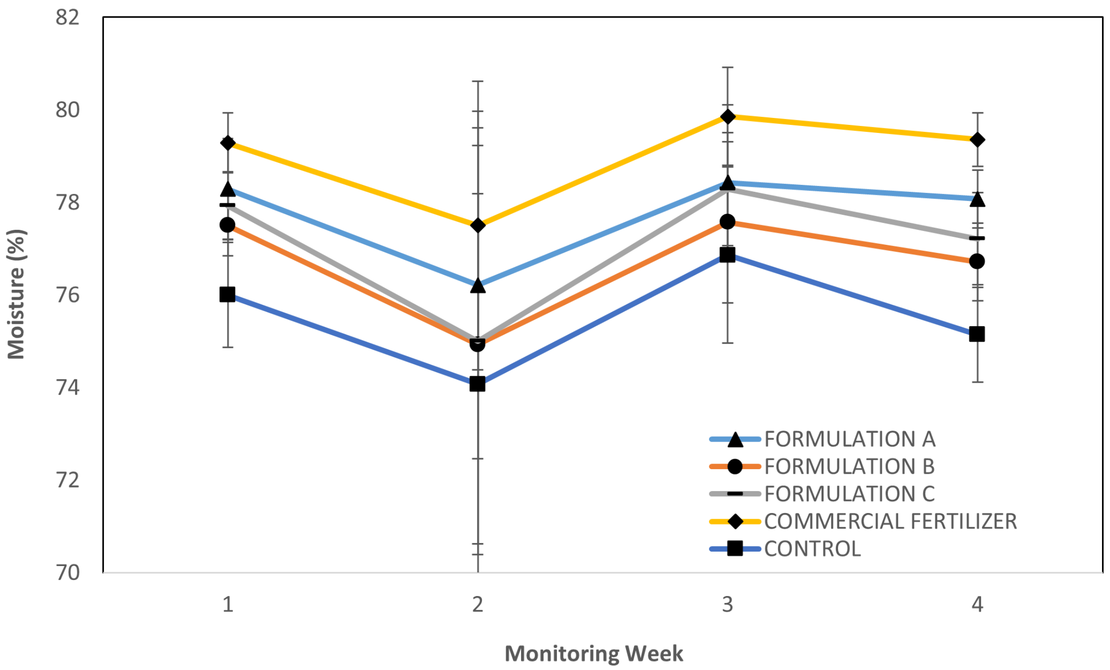

Fig. 6. Soil moisture of the sample pot versus monitoring week for Brazilian spinach

3.2.2 pH of the soil

Figure 7 illustrates the pH levels of soil samples over a four-week period for Brazilian spinach. The trend continued to increase, with pH levels recorded between 6.8 and 7. pH level of Formulation A was found to be the closest to that of the commercial fertilizer and control sample during the last week of observation. Organic fertilizers stimulate microbial activity in the soil, where microbes generate organic acids as they decompose organic matter [24]. Over time, this process may lead to a gradual decrease in pH levels. This phenomenon likely contributed to the slightly acidic condition observed in the soil samples treated with OPEFB LOF formulations. On one hand, the results show that the commercial fertilizer maintained a pH range most preferable to plant development, ranging from neutral to slightly alkaline. Meanwhile, the pH of the control treatment started slightly acidic but steadily approached neutral levels over the course of the week. Based on observations, the Brazilian spinach plants in all sample pots were able to grow and survive. Further details regarding the plant growth will be addressed later. The findings indicate that Brazilian spinach can germinate and grow in soils that have varying pH levels. Previous study mentioned that excessive usage of chemical fertilizer could lead to the infertility of the soil as the long-term usage of chemical fertilizer changes the pH of the soil [23]. Therefore, this underscores the importance of opting for green LOF instead of chemical fertilizers.

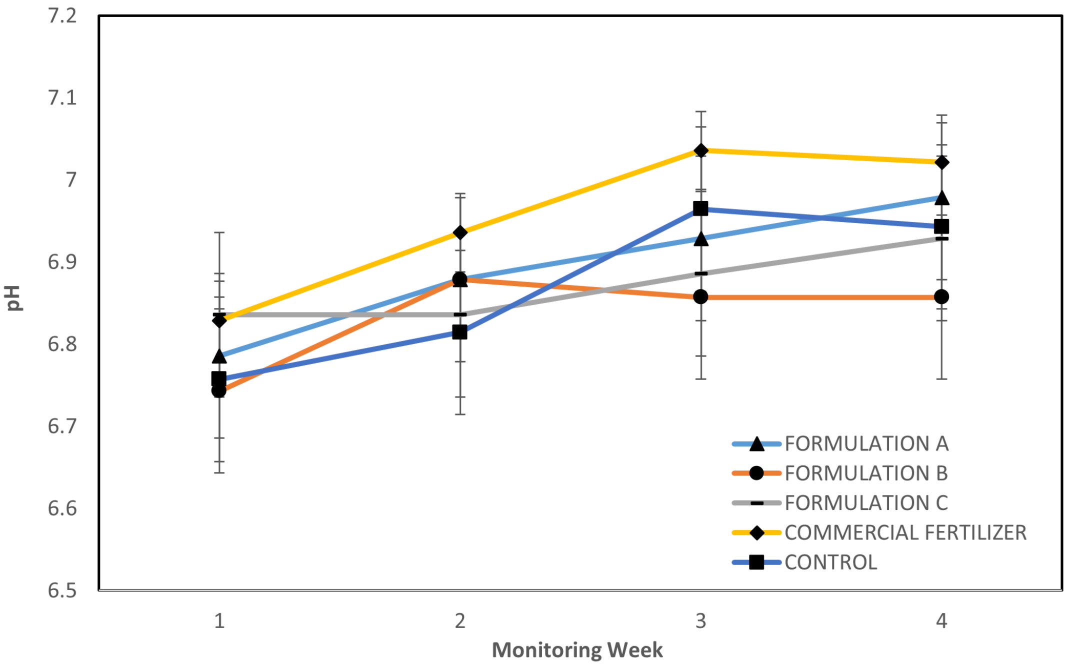

Fig. 7. Soil pH of the sample pot versus monitoring week for Brazilian spinach

3.2.3 Soil Temperature analysis

Figure 8 illustrates the weekly soil temperatures of various pot samples of Brazilian spinach. Soil temperature is critical for plant growth as it directly impacts the optimal functioning of soil organisms. Moreover, it influences the plant processes, soil moisture levels, aeration, and the availability of plant nutrients [25]. As depicted in the graph, all samples experienced temperatures ranging between 28.0°C and 29.5°C. Notably, in week 3, there was a slight decrease in soil temperature across all samples due to the onset of the rainy season, followed by a gradual increase in week 4. Among the formulations observed, Formulation A consistently exhibited the lowest temperature throughout the four-week period. Typically, low soil temperatures are more favourable for the plant growth. Due to its preference for wet soil, Brazilian spinach can thrive at temperatures that range from chilly to cold.

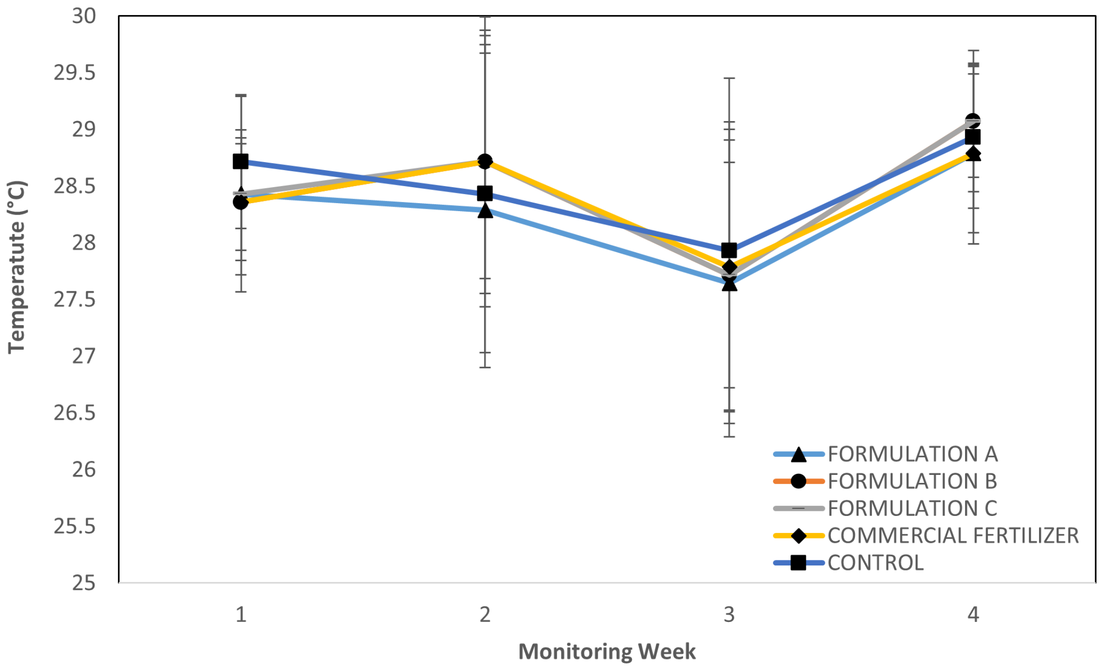

Fig. 8. Soil temperature of the sample pot versus monitoring week for Brazilian spinach

3.3 Results from the Phytomorphology Analysis of Brazilian Spinach

3.3.1 Number of leaf

Table 2 displays the average leaf count across all plant samples over a three-week period. Initially, plants treated with OPEFB LOF showed poorer performance compared to those treated with commercial fertilizer and the control sample. However, there was a noticeable increase in leaf numbers after that. Specifically, plants treated with Formulation B exhibited a higher leaf count than the control samples in Week 2 and 3. Due to the short duration of the study, it is quite difficult to relate the data with the effectiveness of the OPEFB LOF in terms of number of leaves. Supposedly, high content of NPK in the OPEFB LOF will contribute to the plant growth and photosynthesis. However, it is worth noting that noni fruit does significantly impact plant growth. Formulation C (without noni fruit as a bio-activator) showed no increase in leaf count. It is hypothesized that naturally occurring microorganisms in the noni fruit solution aid in the decomposition of organic matter and enhance the photosynthesis process of Brazilian spinach. This is because the bio-activator contains bacteria such as photosynthetic bacteria, lactic acid bacteria, yeast, actinomycetes, and fermented fungi [26].

Table 2
Average number of leaves of Brazilian spinach

Sample Pot/ Duration	Week 1	Week 2	Week 3
Formulation A	9±1	10±1	12±2
Formulation B	9±1	13±1	14±1
Formulation C	9±1	9±1	9±1
Commercial Fertilizer	12±1	15±1	15±1
Control	10±1	11±1	13±1

3.3.2 Plant height

The average plant height for Brazilian spinach in all plant samples is shown in Table 3. As expected, the highest plant height was obtained by sample pot with commercial fertilizer. Average plant height in sample pots of Formulation A and B was found consistently increased from Week 1 to Week 3. The findings align with earlier analyses regarding leaf count, demonstrating that LOF supplemented with bio-activator media enhances plant growth more effectively.

Table 3
Average plant height of Brazilian spinach

Sample Pot/ Duration	Week 1 (cm)	Week 2 (cm)	Week 3 (cm)
Formulation A	4.40±0.34	4.55±0.54	5.48±0.59
Formulation B	5.05±0.38	5.55±0.54	5.73±0.75
Formulation C	3.18±0.68	3.18±0.68	3.18±0.68
Commercial Fertilizer	5.20±0.30	5.95±0.05	6.95±0.45
Control	3.50±0.30	4.10±0.10	4.60±0.30

3.3.3 Length and width of leaf

Table 4 provides information on the average leaf length and width of Brazilian spinach for each sample pots. It was observed that sample pot with commercial fertilizer obtained the best plant growth. Among the three OPEFB LOF formulations, Formulation A had the highest mean leaf length and leaf width. This trend is expected as Formulation A obtained the highest nutrient contents. The soil conditions for the Formulation A also are the most suitable for the plant growth. In addition, if microorganisms can develop in an environment that is conducive to their growth, they could be extremely effective in dissolving nutrients and making them available for plant growth. As a consequence, the microbes in the combination had a positive influence on the plant's capacity to absorb nutrients. The use of OPEFB waste in conjunction with a bio-activator, urea, and molasses may prove to be a beneficial technique for increasing growth and yield while simultaneously lowering environmental pollution levels. Cattle urine was one of the materials utilized in the production of Formulation A, and it also helped to improve the plant's growth. The application of cattle urine at different levels to the soil may have resulted in improvements in soil fertility and structure, increased soil organic matter, and increased microbial activity. The nutrients released from the urine may have contributed to rapid root development and increased leaf growth.

Table 4
Average length and width of leaf of Brazilian spinach

Treatment	Week 1		Week 2		Week 3	
Leaf Growth (cm)	Length	Width	Length	Width	Length	Width
Formulation A	0.75±0.05	0.83±0.05	1.42±0.27	1.27±0.22	1.58±0.24	1.31±0.13
Formulation B	0.57±0.09	0.69±0.11	0.88±0.23	1.04±0.15	1.08±0.37	1.05±0.16
Formulation C	0.68±0.05	0.66±0.05	1.28±0.05	1.06±0.05	1.43±0.05	1.13±0.05
Commercial Fertilizer	0.98±0.05	1.20±0.07	1.78±0.17	1.52±0.08	1.93±0.12	1.62±0.12
Control	0.70±0.05	0.76±0.05	1.34±0.03	0.83±0.17	1.40±0.03	1.02±0.15

4. Conclusions

The utilization of agricultural waste, specifically oil palm OPEFB fiber, as the primary component of LOF, was successfully achieved. Three formulations of OPEFB LOF were developed, each employing distinct organic substrates. Formulation A demonstrated the highest nutrient content, containing 485 ppm nitrogen, 95 ppm phosphorus, and 1007 ppm potassium. It was observed that plants grown with Formulation A exhibited the most favourable growth characteristics when evaluating the impact of LOF on Brazilian spinach development. The soil properties, including moisture, pH, and temperature, in samples treated with Formulation A closely resembled those of commercial fertilizer. This study underscores the potential of utilizing LOF derived from oil palm OPEFB fiber waste as a substitute for inorganic fertilizers in nursery.

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