Liquid Organic Fertiliser from Palm Oil Mill Effluent, Siam Weed Leaves, and Avocado Seed Extracts: A Design Mixture Approach Formulation

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Abstract
The formation of a liquid organic fertiliser was carried out using palm oil mill effluent (POME), Siam weed, and avocado pear extract. POME was obtained from a local palm oil mill in Abak Local Government Area, Akwa Ibom State. The Siam weed plant used was harvested from an uncultivated farm land in Uyo, while the avocado pear seed was obtained from Abak. Avocado pear seed was cut, sundried, and then oven dried at 60 ° C, pulverised, and sieved. Thereafter, it was characterised. Also, the Siam weed was washed under running water, fermented in a digester for 2 weeks, and then the filtrate was collected in an airtight container for further use. The palm oil mill effluent was filtered and analysed for use. Liquid organic fertiliser (LOF) was produced using 500 g of POME, Siam Weed leaves, and avocado seed as substrates. The fourteen formulae of liquid organic fertiliser were produced with different ratios of substrates as generated by Design Mixture. The mixture was homogenised in a (Digester) and incubated at room temperature for 21 days. The mixture was stirred every 3 days during the fermentation process. The liquid organic fertiliser was sampled on days 7, 14, and 21 for chemical and microbiological analysis. Optimisation of the process was carried out following the Design of Experiments. Statistical analysis was performed according to the design mixture using Design Expert version 13. The result shows that the nitrogen, phosphorus, and potassium model yielded F values of 7.1, 8.37, and 197.53; and P values of 0.0104, 0.0158, and <0.0001, respectively, which implies that the models are statistically significant since their p values are less than 0.05. The result of the physiological

analysis shows that the pH of POME, Siam weed, and avocado pear seed extract are 6.4, 7.1, and 5.5, respectively. Furthermore, the nutrient composition of POME, Siam weed, and avocado pear seed extract shows the presence of nitrogen, phosphorus, and potassium, making it a suitable selection for the production of liquid organic fertilisers. The FTIR results showed that the main functional groups are hydroxyl with single bond bonds, as well as carbonyl and N–H groups. The results of the formulation showed that the material used for the formulation has some effect on the functional group of the liquid organic fertiliser produced. The optimal condition for the formulation of the LOF is a 0.6 desirability value. POME, Siam weed, and avocado pear seed extract were 5.19, 5.25, and 5.55 for nitrogen, phosphorus, and potassium content were 36.98%, 29.76%, and 31.77%, respectively.

Keywords: *Palm oil mill effluent, Siam weed, Avocado seed extract, Liquid organic fertilizer, Design mixture method*

1 Introduction

The Millennium Development Goals of the United Nations are initiatives aimed at achieving food security in the world. In its list of goals, the first Millennium Development Goal states that the United Nations is to eradicate extreme hunger and poverty by half of what it is by 2030 and that agricultural productivity is the key player if this is to be achieved. Of the eight MDGs, eradicating extreme hunger and poverty depends on agricultural productivity (WFP, 2024). With more than 220 million people, Nigeria is the most populated country in Africa and the sixth in the world. Rising inflation and the impact of the climate crisis continue to drive hunger in Nigeria (Okou *et al*., 2022). In Nigeria, there has been a high level of food insecurity over the past four decades as a result of neglect in food production (Mekonnen, 2021). The world population is projected to increase to more than 10 billion people over the next 30 years. Therefore, food supply will need to increase by 60% to meet predicted demand in 2050 (Pambuka *et al*., 2021, 2022; Kinge *et al*., 2022). Food distribution and manufacturing must be handled more effectively and sustainably to prevent supply shortages. The current increase in the world population to 7.8 billion has placed an increasing demand on crops, which poses great challenges in terms of how to feed such a large population (Worldometers, 2021). According to estimates from the United Nations Food and Agriculture Organisation, agricultural crop demand will increase by 60% by 2030 (Mitter *et al*., 2021). Improving food security requires strategies that can match future food demands with increasing population growth while conserving soil resources (Shahwar *et al*., 2023). High levels of hunger and food insecurity dominate most of Africa, and the situation continues to worsen due to increasing soil degradation (FAO, 2017).

To reach self-sufficiency, this will require increased and intensified agricultural production per land area, since the amount of available land is finite (Umesha *et al*., 2018). Fertiliser application is considered to play an important role in improving crop productivity. Chemical fertilisers have been widely used by countries to increase crop yield (Nabti *et al*., 2017). However, these chemical fertilisers cause serious environmental pollution by reducing the water retention capacity of the soil, and therefore its fertility, increasing soil acidity and reducing the number of microorganisms, resulting in nutritional imbalances in the soil (Nosheen *et al*., 2021).). Furthermore, these hazardous substances are not taken up by plants but accumulate in groundwater, negatively affecting the soil. Therefore, it is vital to shift the focus to the production of safe and environmentally friendly methods for sustainable crop production. Therefore, it is necessary to explore organic liquid fertilisation to obtain healthy food (Ammar, 2022).

Liquid organic fertilisers produced from agricultural residues and industrial waste are becoming increasingly popular (Rani *et al*., 2021). The application of liquid organic fertilisers through leaves is an effort to overcome the problems of plants depleted in nutrients originating from root penetration (Article and Access, 2012). The liquid fertiliser derived from palm sludge offers a sustainable solution for plant nutrition. Its organic composition promotes soil health and improves nutrient absorption. Organic fertilisers improve soil fertility and biodiversity while leaving no residues in plants, making them safe for the environment and human health (Lesik et al., 2019; Wongsaroj *et al*., 2021). Liquid organic fertiliser is a solution due to the decomposition of organic substances derived from plant residues, animal, and human waste that incorporates more than one detail of nutrient. In preference, liquid organic fertilisers do not harm soil and vegetation, although they are used as frequently as possible. Furthermore, liquid fertiliser can also be used as an activator to make compost (Bedair *et al*., 2022; Zafar *et al*., 2022). Today, many studies have demonstrated the possibility of producing organic fertilisers from organic waste, such as the organic fraction of municipal waste and municipal solid waste compost (MMWC) (Fernández-Delgado *et al*., 2020). These residues should not be applied directly to soils due to the possible presence of pathogens and potentially toxic elements. However, they have a considerably high content of organic carbon and nutrients, which can be recovered by extracting solid / liquid (S / L) within the circular economy framework (Bloem et al., 2017).

The Federal Government of Nigeria is focussing more on sustainable agriculture and economic development programmes, which, in turn, demand an inward-looking approach to agricultural inputs. Recycling waste for farm input is a viable option, as evident from earlier reported work (John *et al*., 1996; Egbewumi et al., 1997; Sridhar and Adeoye, 2004). The formulation of liquid fertilisers using palm oil mill effluent, avocado seed extract, and leaves of siam weed represents a novel approach to sustainable agricultural practices. With increasing concerns about the environmental impact of traditional chemical fertilisers and the need for more eco-friendly alternatives, there has been a growing interest in using agricultural by-products for fertiliser production (Ajaweed et al., 2022). In this context, the use of palm oil mill effluent, avocado seed extract, and Siam weed leaves presents a promising opportunity to reuse these abundant resources and address environmental and economic challenges in agriculture (Fertilizers Europe, 2024).).). The waste of the palm oil industry consists of solid waste, including palm mud, palm fruit, palm kernel shells, and liquid waste that is the end result of the palm oil processing process in the factory (FAO, 2019). The oil palm (Elaeis guineensis) is native to the humid tropics of West Africa. The tree blossoms when the annual rainfall is 2,000 mm or more.

Traditional chemical fertilisers have played a crucial role in improving agricultural productivity by providing essential nutrients to crops (Kumar et al., 2022; Macik *et al*., 2020). However, its widespread use has raised significant environmental concerns, including soil degradation, water pollution, and the depletion of natural resources. In contrast, organic fertilisers derived from agricultural by-products offer a sustainable alternative that not only provides essential nutrients to plants but also helps improve soil health and reduce environmental impact (Asseffa *et al*., 2019). Palm oil effluent, generated as a byproduct of the palm oil industry, is rich in organic matter and nutrients, making it a valuable resource for the production of fertilisers. The palm oil mill effluent contains macronutrients such as N, P, and K that plants need to grow. Therefore, the application of POME to crops can save the cost of fertiliser (Muniswami *et al*., 2021). Avocado seed extract contains high levels of potassium, phosphorus and nitrogen, while Siam Weed leaves are rich in nitrogen and other essential micronutrients for plant growth (Kumar et al., 2022). When these ingredients are combined in a liquid fertiliser formulation, it is possible to create a nutrient-rich product that promotes healthy plant growth and improves soil fertility. The design mixture approach provides a systematic method for optimising the composition of liquid fertiliser to maximise nutrient content and effectiveness (Raffi and Charyula, 2021). By varying the proportions of palm oil mill effluent, avocado seed extract, and siam weed leaves, researchers can determine the ideal combination that meets the specific nutrient requirements of different crops and soil types. This approach allows greater flexibility and customisation in fertiliser production, ensuring optimal performance and yield results in diverse agricultural settings (Yulianingsih *et al*., 2021).

2 Materials and Methods

2.1 Sample Collection

The plant materials, Siam weed, used for the study were harvested from an uncultivated farmland on the main campus of the University of Uyo, Nwaniba Road, Akwa Ibom State, Nigeria. Additionally, avocado seed and palm oil mill effluent (POME) were obtained from localities in Abak Local Government Area, Akwa Ibom State. All chemicals and reagents used were analytical grade.

2.1.1 Materials and Reagents

The organic substrates that were used for the production of liquid organic fertiliser are;

i. Palm Oil Mill Effluent (POME)
ii. Fresh Siam weed
iii. Avocado Seed
iv. Deionised water
v. K_2SO_4, $CuSO_4$
vi. Sulphur acid (96-98%); hydrogen peroxide (~ 30%), NaOH (32 %), H_3BO_3 (4 % with indicators)

2.1.2 Equipment

Measuring cylinders (200 and 500 cm^3), Set of beakers (100, 250 and 500 cm^3), Aluminium foil, glass rod stirrer, Desiccators, Mesh sieve (250), Volumetric flasks (1000 cm^3), Electric oven, Weigh Balance, Laboratory Mill, digester, spatula, Petri dishes, test tubes, measuring cylinder, Whatman's no 2-filter paper, thermometer; spectrophotometers, flame photometer, Mannitol Ashby agar medium.

2.2 Sample Preparation

Figure 1 presents the flowchart of the steps taken to formulate the organic fertilizer from the samples.

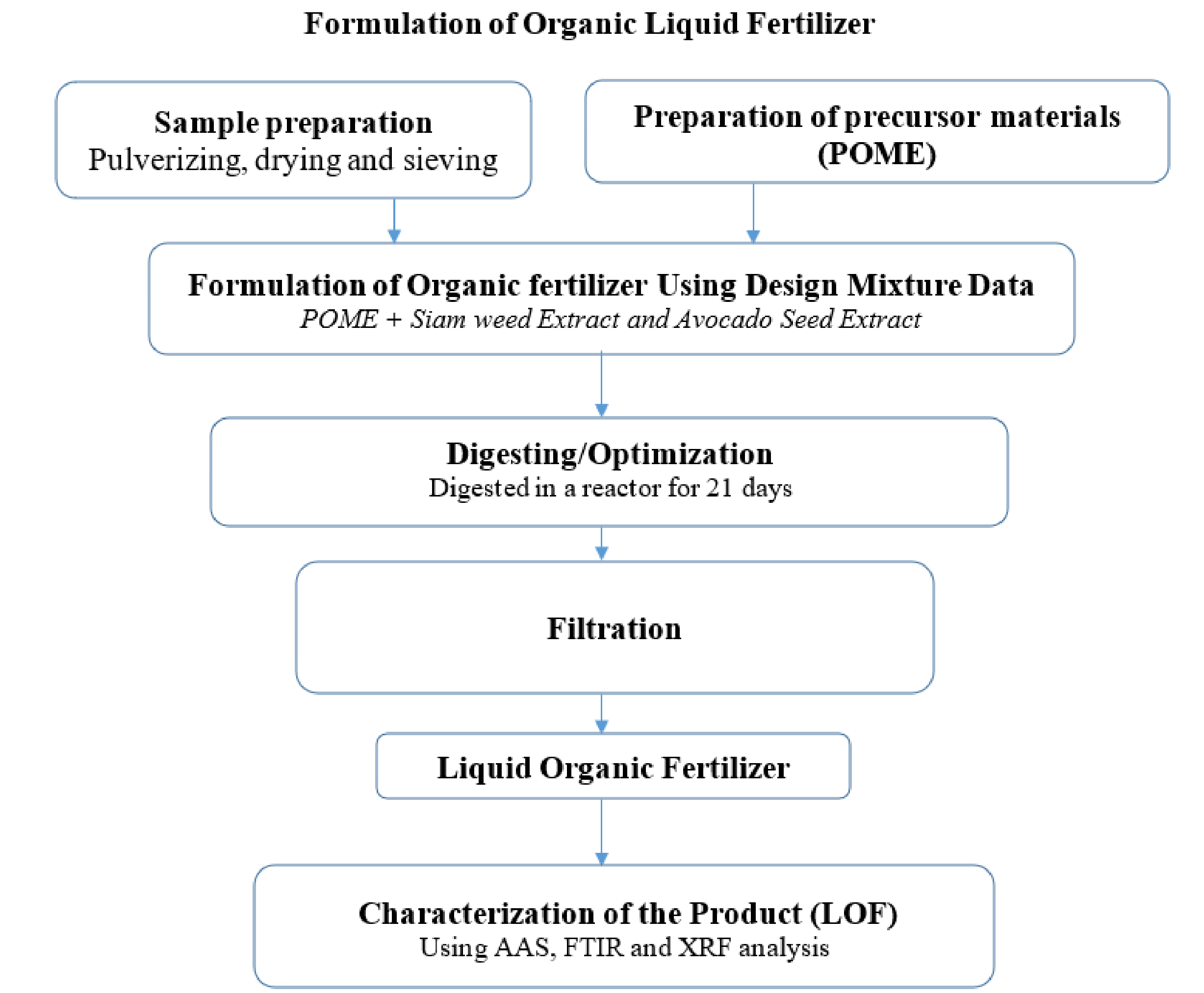

Figure 1: Flowchart for the formulation of organic liquid fertilisers

The avocado seed was cut into smaller pieces and sundried for 3 days to reduce the moisture content. The sample was then dried in an oven at 60 °C to a constant weight. After drying, the avocado seed sample was mixed into smaller particles using an electric blender, pulverized, and individually sieved using a 75 mm mesh size to remove foreign particles and obtain a uniform particle size. Thereafter, the sample was characterised for its physiochemical properties.

The method of Jamilah *et al*. (2017) was adopted here. The Siam weed was collected from the site mentioned above; then, the plant samples were placed under running tap water to remove any soil particles and finally rinsed twice with deionised water. The washed sample was placed in a fabricated digester, and a certain volume of water was added to the sample and left to ferment for two weeks. After two weeks of expiration, the sample was filtered out, and then the filtrate was collected and stored in an airtight container for determination of its physical and chemical properties.

The methods of Alias *et al*. (2020) were adopted in this study. POME was collected from the drain coming from the oil mill in Abak. POME was filtered through a muslin cloth strainer to separate solid particles of millimetre size. The POME filtrate was analysed for pH. The POME sample was then stored at room temperature before formulation of the LOF.

2.3 Production of Liquid Organic Fertilisers/Process Optimisation

After the composter was prepared, the next step was to produce the liquid fertiliser using the mixed raw materials. Liquid organic fertiliser (LOF) was produced using 500 g of POME, leaves of siam weed, and avocado seeds as substrates. The fourteen formulas of liquid organic fertilisers were produced with different substrate ratios as generated by the Design Mixture (Table 1). The mixture was homogenised in a (Digester) and incubated at room temperature for 21 days. The mixture was stirred every 3 days during the fermentation process. Liquid organic fertiliser was sampled on days 7, 14, and 21 for chemical and microbiological analysis.

Optimisation of the process was carried out following the design of the experiment. Statistical analysis was performed according to the design mixture using Design Expert version 13. The simplex design was used for the optimisation of fertiliser production to examine the combined effect of the three different factors (independent variables), the pome, avocado seed, and *Chnornolaeua odorata* leaves on the responses (N, P, and K). A total of 14 runs were developed.

Table 1: Design Expert Table used for the experimental formulation

		Component 1	**Component 2**	**Component 3**	**Response 1**	**Response 2**	**Response 3**
Std.	Run	A: POME	B: Siam weed	C: Avocado	N	P	K
		%	%	%			
9	1	5.1	5.1	5.6			
11	2	6.0	5.0	5.0			
7	3	5.6	5.1	5.1			
4	4	5.5	5.5	5.0			
13	5	5.0	5.0	6.0			
1	6	6.0	5.0	5.0			
12	7	5.0	6.0	5.0			
8	8	5.1	5.6	5.1			
6	9	5.0	5.5	5.5			
10	10	5.3	5.3	5.3			
3	11	5.0	5.0	6.0			
5	12	5.5	50	5.5			
2	13	5.0	6.0	5.0			
14	14	5.5	5.5	5.0			

2.4 Characterisation of the Liquid Organic Fertiliser Produced

Chemical parameters such as pH in the liquid organic fertiliser were measured using a pH metre. Total nitrogen was determined using the Kjeldahl method. Total phosphorus was analysed using the wet digestion spectrophotometer method at a wavelength of 420 nm (Barton 1948). Total potassium analysis was performed using a flame photometer (Hesse and Hesse, 1971). Organic matter and organic carbon were determined using wet oxidation (Black, 1965). The content of macronutrients (total N (Kjeldahl method), P_2O_5 (Spectronic method), total Ca K_2O, Mg and S

(AAS method), organic C (Walkley and Black method) and micronutrients (total Fe, Mn, Cu, Zn, B, and Co) that were analysed by flame photometer.

2.4.1 Determination of pH

The pH of the liquid fertiliser produced was measured using Abdullahi *et al*. (2019). This was done using a digital pH metre; the pH metre was dipped in the organic fertiliser solution; the pH was determined by reading the result on the pH metre.

2.4.2 Total Nitrogen Content Determination

The nitrogen content of the fertiliser solution was determined by the Kjeldahl method, which consists of three steps: digestion, distillation, and titration. Sample digestion: The sample solution was stirred into a beaker using a magnetic stirrer for 5 min at 500 rpm, then 5 ml of the sample was added to a 250 ml test tube, using a pipette, 2 catalyst tablets CM (3.5g K_2 SO_4, 0.1 g $CuSO_4$, $5H_20$ Missouri); 20 ml of concentrated sulfuric acid (96-98%); 5 ml of hydrogen peroxide (~ 30%) was added to the test tube. The digestion unit was connected to a proper aspiration pump and a fume neutralisation system to neutralise the acid fumes created during the digestion phase. The samples were digested for 15 min. at 150 °C, plus 15 min. at 250 °C, and 40 min. at 420 °C. Distillation and Titration**:** The test tubes were cooled to 50-60 °C. The samples were distilled according to the following parameters (predefined method n°1): 50 ml of H_2O (dilution water); $0.1NH_2SO_4$ as titrant solution; 70 ml of NaOH (32 %); 6.38 protein factor; 30 ml of H_3BO_3 (4 % with indicators). The distillation and titration analysis time was 4 min for one test. The percentage of nitrogen was calculated according to Equation 1:

$$\%N = \frac{[(ml\ Standard\ acid \times N\ of\ acid) \times (ml\ blank \times N\ base)] \times (ml\ std\ base \times N\ of\ base) \times 1.4007}{Weight\ of\ sample\ in\ grams} \quad (1)$$

where 'N' is normality, "ml blank" denotes millilitres of base needed to back-titrate a reagent blank if standard acid is the receiving solution, or refers to the millilitres of standard acid needed to back-titrate a reagent blank if boric acid is the receiving solution, when standard acid is used as the receiving solution.

2.4.3 Phosphorus and Potassium Determination

Measurement of phosphorus concentration using UV/ViS spectroscopy: Analyse the liquid fertiliser produced using visible light and ultraviolet rays. The sample was suspended in deionised water with a clarifying agent. The P content was determined using a spectrophotometer after the addition of ammonium monovanadate reagent at a wavelength of 650 nm. The measurement of potassium concentration was carried out based on flame photometry (AOAC 2012).

3 Results and Discussion

3.1 Physicochemical Properties of Raw Materials and Characterisation

The properties of palm oil mill effluent, Siam weed, and avocado pear seed extract were analysed to determine their feasibility for the formulation of liquid organic fertilizer. The results of the analysis are presented in Table 2.

Table 2: Physiochemical properties of raw materials used

Property	POME	Siam weed	Avocado Pear Seed
pH	6.4	7.1	5.5
N	72.91 (mg/kg)	93.51 (mg/kg)	22.65 (mg/kg)
P	12.84 (mg/kg)	26.3 (mg/kg)	95.1 (mg/kg)
k	97.8 (mg/kg)	90.3 (mg/kg)	125 (mg/kg)

Soil pH and organic matter strongly affect soil functions and the availability of plant nutrients. Specifically, pH influences the solubility and availability of plant nutrients, the performance of pesticides (including herbicides), and the decomposition of organic matter (McCauley *et al*., 2017). Table 4.1 shows the pH and composition of N, P, and K of the component materials used for the formulation of liquid organic fertiliser. From the result, it is observed that the pH of POME is slightly acidic with a pH of 6.4. According to Prahesti and Dwipayanti (2011), the acidic pH close to neutral is formed by the activity of bacteria that convert organic acids into simpler compounds such as methane, ammonia, and carbon dioxide (CO_2). Since the pH of the POME is not too acidic, this makes it suitable for the formulation of the organic fertiliser. Furthermore, the nutritional composition of the POME shows that it is rich in nitrogen, phosphorus, and potassium, making it a suitable selection for the production of liquid organic fertilisers. This agrees with the findings of Habib et al., (1997), who stated that the nutrients in palm oil wastewater are nitrogen, phosphorus, potassium, magnesium, and calcium, all of which are essential nutrients for plant growth. Similarly, the properties of the Siam weed are shown in Table 1. From the result, it is observed that the pH of the Siam weed is 7.1, which is alkaline. This pH value range has been reported to support plant growth (Damayanti *et al*., 2018). Furthermore, Siam weed is observed to have a high nitrogen and potassium content, but is low in phosphorus; this could improve the potassium content of the organic fertiliser.

From the analysis, the avocado pear seed extract shows a pH value of 5.5, which is also slightly acidic. Furthermore, the result of the nutrient analysis of avocado pear seed revealed that it is very rich in potassium (Table 1). This is also demonstrated by the result presented by Nwaokobia *et al*. (2018). Damayanti *et al*. (2018) reported that the microbes of liquid organic fertilisers with the highest and best growth were at pH 6.5. The combination of the three components of the liquid organic fertiliser gives a pH that supports plant growth. From the result in Table 1, it was visible that the three samples (POME, Siam weed, and avocado pear seed extract) are all rich in the main nutritional elements, including magnesium, calcium, potassium, nitrogen, and phosphorus. The palm oil mill effluent is observed to contain more potassium and nitrogen (97.8mg/kg and 72.91 mg/kg). But it has low phosphorus content, while the presence of other macronutrients where also observed, which agrees with the findings of Wun *et al*. (2017). The Siam weed also shows a higher nitrogen and potassium content (93.51mg/kg and 90.3mg/kg) with a small amount of phosphorus and the presence of macronutrients (Ogundare *et al*., 2019; Akinrinola, 2018; Suryanto *et al*., 2020). Avocado pear seed extract is found to contain potassium in its highest amount but a lower nitrogen content (Nwaokobia *et al*., 2018; Bangar *et al*., 2022).

3.2 Liquid Organic Fertiliser Formulated with Design Mixture

The mixture design presented 14 unique run parameters for the formulation of organic fertiliser. These were carried out meticulously in the laboratory, and the results for the nitrogen, phosphorus, and potassium content were calculated and presented in percentages as shown in Table 3.

Table 3: Design mixture table showing the three responses obtained.

Std.	Run	Component 1 A: POME %	Component 2 B: Siam weed %	Component 3 C: Avocado %	Response 1 N %	Response 2 P %	Response 3 K %
9	1	5.1	5.1	5.6	25.5	34.2	39.3
11	2	6.0	5.0	5.0	14.5	35.2	45.0
7	3	5.6	5.1	5.1	19.5	35.4	40.3
4	4	5.5	5.5	5.0	17.0	32.5	46.7
13	5	5.0	5.0	6.0	16.9	41.5	33.0
1	6	6.0	5.0	5.0	16.5	34.8	43.7
12	7	5.0	6.0	5.0	15.5	33.8	33.7
8	8	5.1	5.6	5.1	20.0	35.9	36.0
6	9	5.0	5.5	5.5	24.5	36.2	35.1
10	10	5.3	5.3	5.3	22.7	35.1	37.8
3	11	5.0	5.0	6.0	21.3	37.3	34.4
5	12	5.5	50	5.5	16.2	48.7	34.4
2	13	5.0	6.0	5.0	20.0	26.7	32.9
14	14	5.5	5.5	5.0	18.5	31.6	47.5

3.3 Statistical Analysis of the Formulation of Liquid Organic Fertilisers

The result of the formulation of the liquid organic fertiliser was modelled using the mixture design in the Design Expert version 13. The model considered three responses, which were nitrogen content, phosphate content, and potassium content. The responses were used to measure the nutritional quality of the organic fertiliser formulated using palm oil mill effluent, avocado seed extract, and Siam weed. The results were analysed using the statistical tools in Designer 13. The nitrogen, phosphorus, and potassium content of the different formulated samples was tested and subjected to ANOVA analysis. Tables 4 to 6 show the ANOVA results for nitrogen, phosphorus, and potassium content, respectively.

Table 4: ANOVA for a special cubic model for the nitrogen content of the LOF

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	576.70	6	96.12	7.10	0.0104	significant
(1)Linear Mixture	267.52	2	133.76	9.88	0.0091	
AB	6.71	1	6.71	0.4958	0.5041	
AC	5.93	1	5.93	0.4383	0.5291	
BC	76.60	1	76.60	5.66	0.0489	
ABC	49.90	1	49.90	3.69	0.0963	
Residual	94.73	7	13.53			
Lack of Fit	9.73	3	3.24	0.1526	0.9228	not significant
Pure Error	85.00	4	21.25			
Cor Total	671.43	13				

Table 5: ANOVA for a special cubic model for phosphorus

Source	Sum of Squares	df	Mean square	F-value	p-value	
Model	2895.31	8	361.91	8.37	0.0158	significant
(1) Linear mix	1334.24	2	667.12	15.43	0.0073	
AB	2.25	1	2.25	0.0520	0.8286	
AC	1104.92	1	1104.92	25.56	0.0039	
BC	6.04	1	6.04	0.1398	0.7238	
A^2BC	15.59	1	15.59	0.3606	0.5744	
AB^2C	287.12	1	287.12	6.64	0.0496	
ABC^2	558.38	1	558.38	12.92	0.0156	
Residual	216.15	5	43.23			
Lack of fit	24.64	1	24.64	0.5146	0.5128	not significant.
Pure error	191.52	4	47.88			
Cor total	3111.47	13				

(1) Inference for linear mixtures uses Type I sums of squares.

Table 6: ANOVA for a quadratic model for the potassium content of LOF

Source	Sum of squares	df	Mean square	F-value	p-value	
Model	1127.66	5	225.53	197.53	< 0.0001	significant.
(1) Linear mix	730.73	2	365.37	320.01	< 0.0001	
AB	396.11	1	396.11	346.94	< 0.0001	
AC	0.0038	1	0.0038	0.0033	0.9555	
BC	0.8760	1	0.8760	0.7673	0.4066	
Residual	9.13	8	1.14			
Lack of fit	3.19	4	0.7969	0.5360	0.7196	not significant.
Pure error	5.95	4	1.49			
Total cor	1136.79	13				

It is observed that the model for the nitrogen, phosphorus, and potassium model yielded an F value of 7.1, 8.37, and 197.53, respectively, as seen in Tables 4 to 6, which implies that the models are significant. Similarly, the model P-values are another statistical tool to measure the significance of a model. A model with a P-value less than 0.05 shows that the model is significant; therefore, the nitrogen, phosphorus, and potassium models show a P-value of 0.0104, 0.0158, and <0.0001, respectively. This implies that all three models are statistically significant, since their p-values are less than 0.05.

3.4 FTIR result of the materials and the organic liquid fertiliser produced

The Fourier transform infrared has become very important in the characterisation processes of organic compounds as a result of its ability to determine their functional groups. Figures 2 to 5 show the spectra of POME, Siam weed, and avocado pear seed extract samples and the liquid organic fertiliser sample formulated. Table 6 sums up the different broadband networks and their functional groups extracted from the FTIR result in Figure 2. In the IR spectra of the POME, the absorption bands at 2925 and 2855 cm-1 were attributed to aliphatic methylene groups and said to be fat and lipid (Grube *et al.*, 2006). Furthermore, the shoulder peak of 2855 cm-1 almost disappeared in the POME. It could be suggested that the components of fat and lipid were consumed by microorganisms in the anaerobic digestion process, catalysing a complex series of biochemical reactions that mineralise organic matter to produce methane and carbon dioxide. The results were also supported by the reduction in the oil and grease content in fresh POME from 2861 to 150 mg L-1 after the nitrification process (Table 7). The band attributed to the hydroxyl group and water (3400 cm-1) was also detected in the fresh raw POME.

Table 7: FTIR result for the materials and formulated fertiliser

Constituent	Broadband (cm^{-1})	Functional Group
Palm Oil Mill Effluent	2925	CH
	2861	CH
	2855	CC
Siam weed	3312	O-H
	2894	C-H
	1725	CO
	1642	HOH
	1253	CC
Avocado seed	3164–3308	O-H
	2831–2962	CW
	1598	N-H
	1400	O-H
		C-N
	1033	C-O
Formulated liquid organic fertiliser	3300	OH
	3345	NH
	1658	C=O
	1450	CH

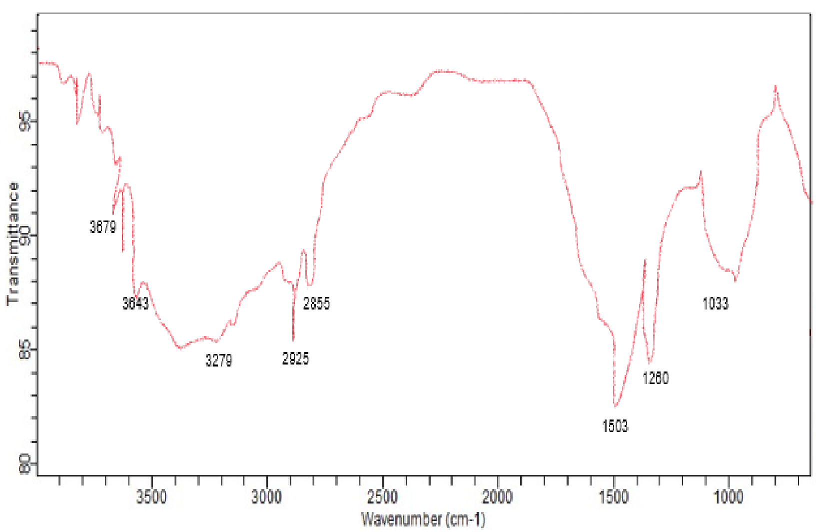

Figure 2: FTIR result of the palm oil mill effluent

In the spectrum of Siam weed (Figure 3), there is a peak at 3312 cm-1 assigned to the O–H stretching vibration of the hydrogen-bonded hydroxyl group in the cellulose molecule. The cellulose C-H stretching groups appeared at 2894 cm-1, while the C-O stretching frequency of the ester group and the stretching vibration of the aromatic ring in lignin, hemicellulose, and other components appeared at 1723 cm-1 and 1253 cm-1. The peak at 1515 cm-1 is assigned to the C-C of the aromatic lignin ring, and the bending vibration of H-OH of the absorbed water at 1642 cm-1 is due to the hydroxyl groups in the cellulose, as shown in Table 7. Therefore, it reveals the presence of cellulose, hemicellulose, and lignin, with characteristic peaks that indicate these components.

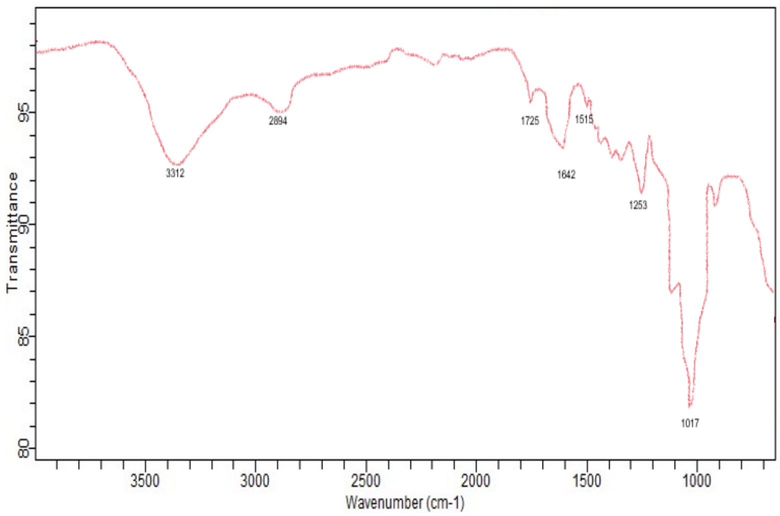

Figure 3: FTIR result of the Siam weed sample

The FTIR spectrum of the avocado seed extract in Figure 4 generates the main peak positions, such as 3164-3330 cm-1, 2831-2962 cm-1, 1598 cm-1, 1400 cm-1, 1033 cm-1, and 509 cm-1. A wide peak at 3164-3308 cm-1 indicates the presence of the functional group OH of the alcohol compound (Ramesh *et al*., 2015; Jae *et al*., 2009). The bands 2831–2962 cm-1 are associated with the stretching of DH in the alkane chain. The existence of the NH group is evidenced by the absorption of the 1598 cm-1 wave number contained in the amine compound. A peak of 1400 cm-1 corresponds to the bending O-H group found in alcohol compounds (Rodiah and Nanda, 2017). Vibrations of the O group in alcohol compounds and a stretching of the C-N in aliphatic amine compounds appear at 1033 cm-1 (Niraimathi *et al*., 2013). The hydroxy group is important in the synthesis of ZnO nanoparticles as a reducing agent and stabiliser (Rodiah and Nanda, 2017). The free amine group in avocado seed extract acts as a stabiliser in the synthesis of nanoparticles.

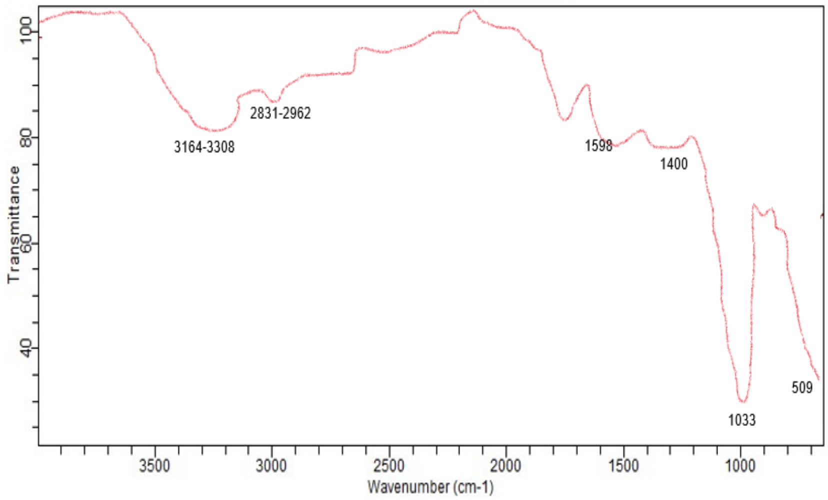

Figure 4: FTIR result of avocado pear seed

The FTIR spectrum of the organic fertiliser formulated is reported in Figure 5. The peak at 3300 cm-1 exposes a wide and strong absorption band, which can be related to the hydroxyl (OH) and amine (NH) group (Domínguez *et al*., 2006). The small peak with a low intensity band at 2345 cm-1 corresponds to the NH stretching of an amine group (Sulaiman *et al*., 2010). Signal at 1658 cm -1 concerning the C = O bond of the carboxylic group (Gerzabek *et al*., 2006; Oliveira *et al*., 2012) and the band at 1450 cm-1 revealing the deep and long peak which corresponds to CH and NH (amide II) groups, are related to the presence of proteins in the peak, which organic fertiliser (Bailey *et al*., 1998). The medium intensity peak that appeared at 1050 cm-1 is associated with antisymmetric stretching of PO4 3- v3, confirming the existence of phosphate molecules (probably from bone meal) in the developed NPK fertiliser (Farmer, 1974). A sharp and intense peak at 870 cm-1 relating to the carbonate group (CO_3^{-2}) (Smidt *et al*., 2002). The short peak at 586 cm-1 associated with the alkyl halide group signifies the presence of chlorine in the WBL waste (Rajeshkumar *et al*., 2013).

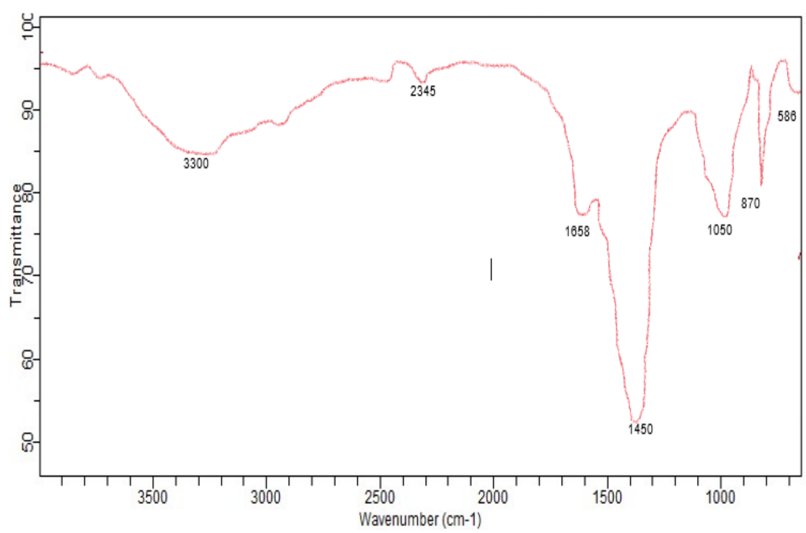

Figure 5: FTIR result of one of the formulated liquid organic fertiliser samples

Generally, the FTIR results show that the main functional groups are hydroxyl with single-bond bonds, as well as carbonyl and N–H groups. The results of the formulation showed that the material used for the formulation has some effect on the functional group of the organic liquid fertiliser produced, as reported in the spectra of the fertiliser samples in Figures 3 to 5. This also agrees with the findings of (Oliveira *et al*., 2012) and (Matheri *et al*., 2020).

3.5 Model Equation

The equations for the nitrogen, phosphorus, and potassium models were generated by Design Expert software after analysis of the laboratory results/responses. The multiple regression analysis of the experimental data results in a second-order polynomial model. The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default, the high levels of the mixture components are coded as +1 and the low levels are coded as 0. The coded equation is useful to identify the relative impact of factors by comparing the coefficients of the factors. This model can be used to navigate the design space. where N, P, and K are the response, and A, B, and C are the coded values of the variables, including Palm oil mill effluent (POME) (A), Siam weed (B), and avocado pear extract (C), respectively. The model equation is presented as Equations 2 to 4.

Final Equation in terms of L_Pseudo Components:

i. $$N = 31.26A + 35.21B + 43.19C + 8.94AB + 10.69AC + 38.40BC + 214.72ABC \quad (2)$$

ii. $$P = 69.93A + 60.35B + 88.67C - 5.19AB + 147.99\,AC + -10.94\,BC + 390.05\,A^2BC + 1674.01\,AB^2C - 2367.87\,ABC^2 \quad (3)$$

iii. $$K = 88.63A + 66.82B + 75.94 + 65.35AB - 0.2423AC - 3.68BC \quad (4)$$

3.6 Diagnostic Plot and Response Surface

The precision of the model can be assessed by comparing the actual NPK determined experimentally with the predicted results generated by the model. Figures 6 to 8 demonstrate the linear relationship between the predicted and actual NPK. For a model to be properly fitted, the point has to be distributed along the diagonal line or very close to it. A plot with the points scattered far away from the model indicates that the experimental model is not closely related to the experimental model. From the results obtained, it is observed that the points are well distributed along the diagonal line for the N, P, and K models, as shown in Figures 6, 7, and 8. The difference between actual and predicted results may have been attributed to the common experimental errors that took place during the conduct of the experiments, such as parallax error when reading the measurement graduations on instruments like the weighing scale (Park et al., 2010). It can be observed that the actual values lie near the predicted line, and thus these results are reliable.

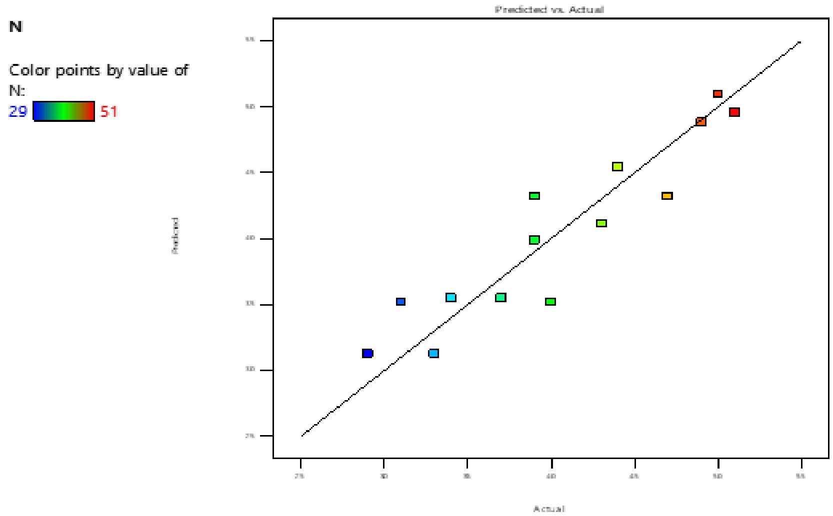

Figure 6: A plot of predicted vs. actual for the nitrogen model

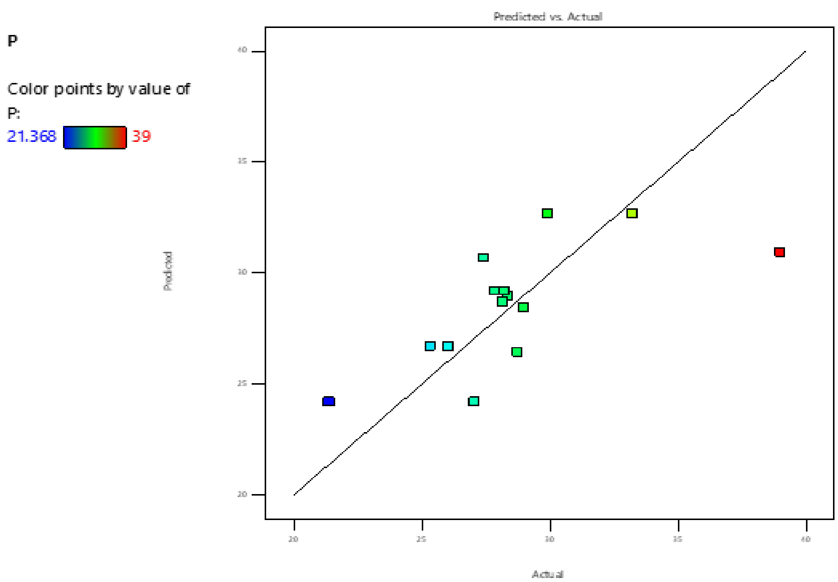

Figure 7: A plot of predicted vs. actual for the phosphorus model

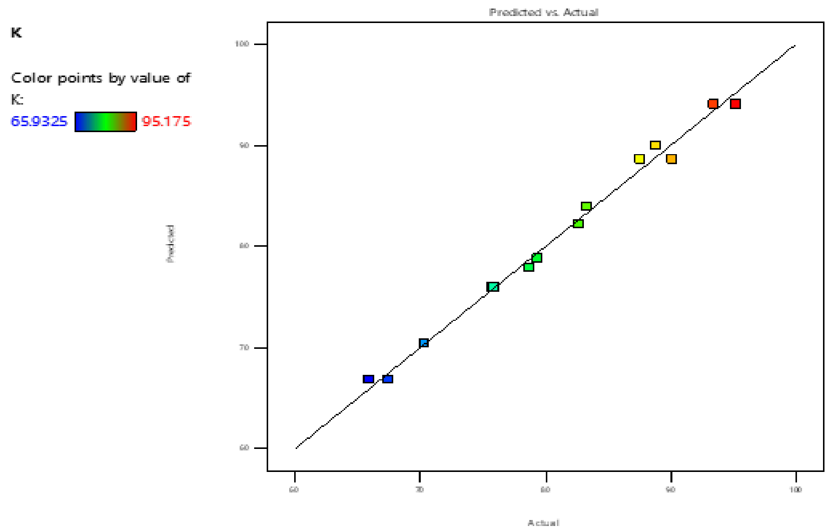

Figure 8: A plot of predicted vs. actual for the potassium model

The contour plot is used to study the impact of the independent variables on the response. Therefore, the contour plot shows the combined effect of the three factors on the NPK content of the organic liquid fertiliser produced, and the vertex shows a region of severe condition. The 3D surface plot depicted in the respective figures helps to effectively describe and comprehend the impact of these process components. The area of intense blue colour shows a lesser effect on the response, while the region with intense red colouration shows a stronger effect on the response; this is better illustrated with the 3D ternary plot. Figure 9 shows the contour plot for nitrogen content; from the graph it is observed that avocado pear extract and Siam weed show a higher effect on the nitrogen content of the fertiliser, this is represented by the red region between the avocado and the Siam wee region, while POME show a lesser effect as that region is depicted by a blue colouration.

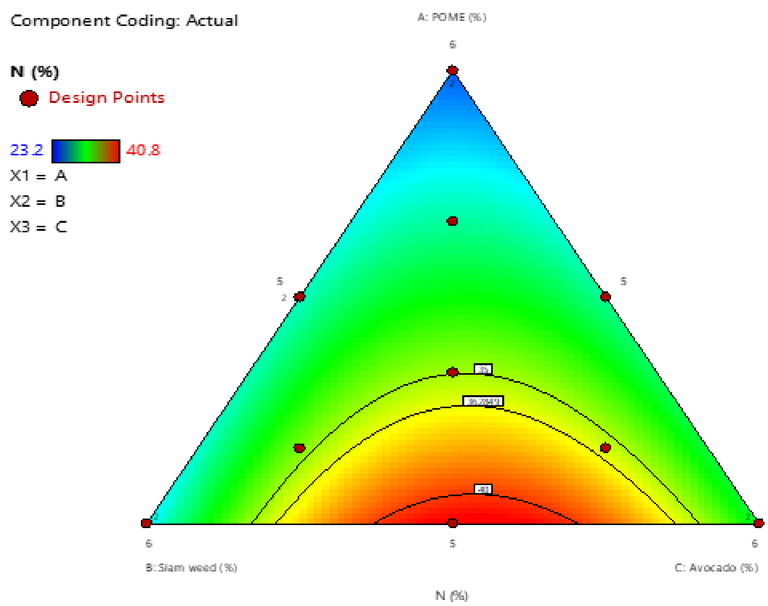

Figure 9: Contour plot of the nitrogen model

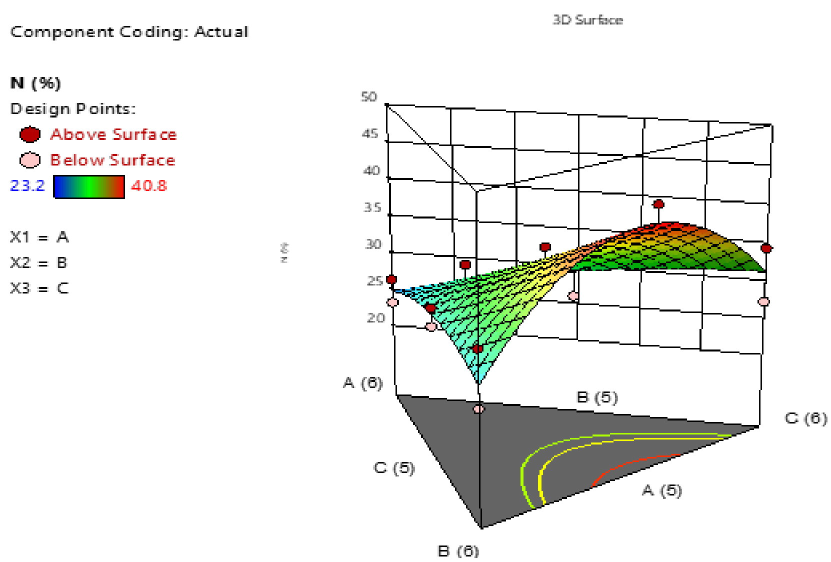

Figure 10: 3D surface plot for the nitrogen model

Similarly, the effects of POME, Siam Weed, and avocado pear extract on phosphorus were shown in the 3D plot, and the contour plots are shown in Figures 11 and 12, respectively. From the graph, it is observed that Siam weed has the lowest effect on the yield of phosphorus in the fertiliser, while the highest effect is observed from the avocado pear seed extract, as depicted in the shape of the graph in the 3D plot. This may be attributed to the fact that avocado pear seed extract was reported to show a high phosphorus composition. For the potassium model, the 3D plot shows a more complex pattern than the previous plots. From the graph in Figure 13, it is observed that the combination of Siam weed and POME has shown the highest effect on potassium yield in the fertiliser, while the lowest effect is felt around the avocado pear seed region, as shown in the 3D graph in Figure 14.

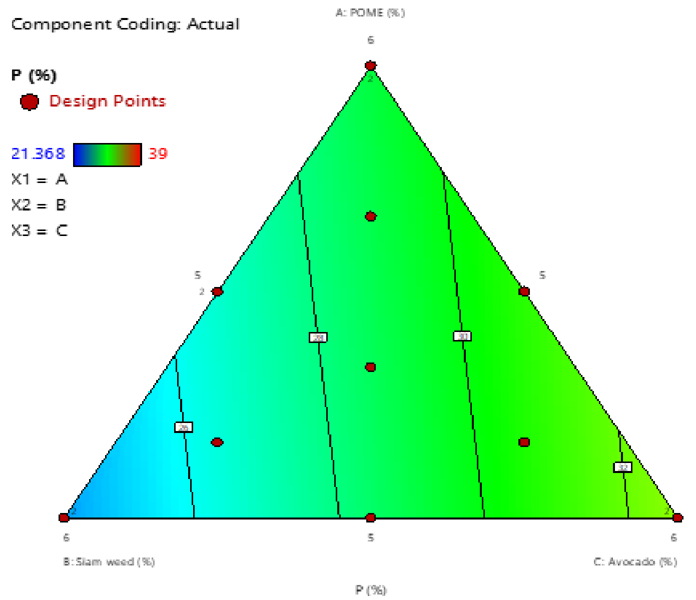

Figure 11: Contour plot of the phosphorus model

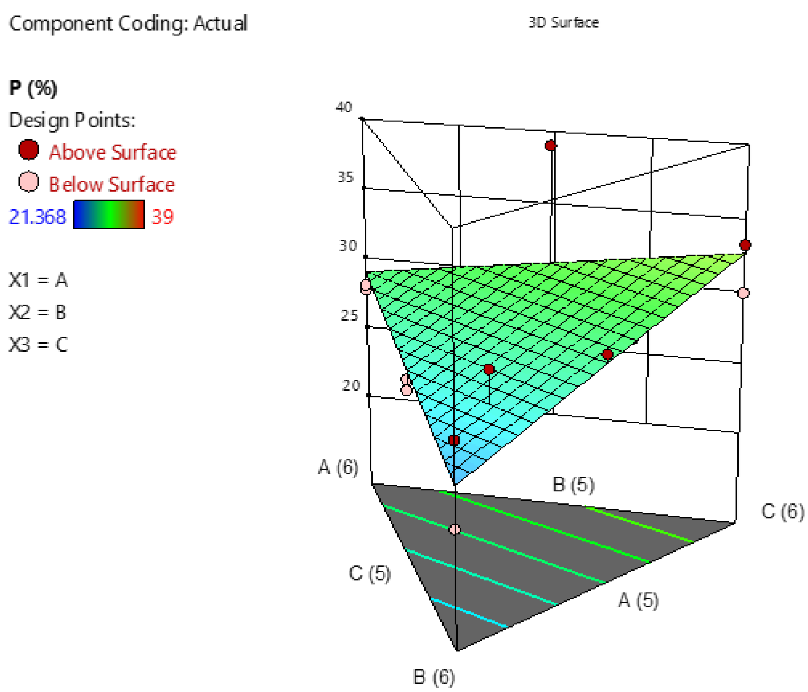

Figure 12: 3D surface plot for the phosphate model

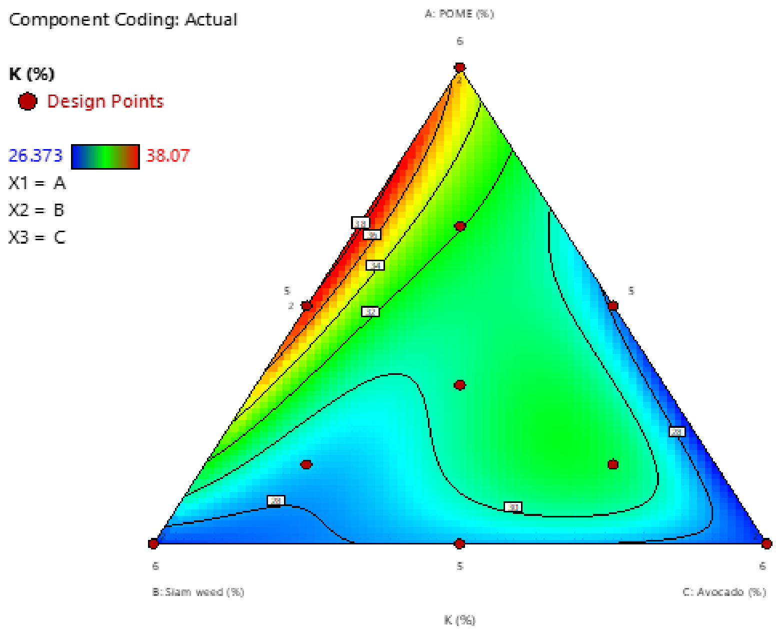

Figure 13: Contour plot of the potassium model

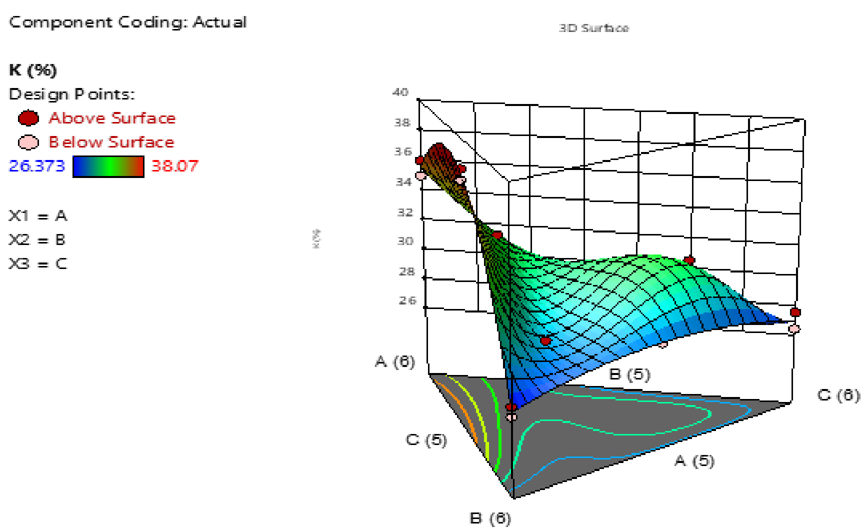

Figure 14: 3D surface plot for the potassium model

3.7 Optimisation and Comparison with Organic Fertiliser

The optimisation of the process was carried out using the numerical optimisation tool in Design Expert 13, which generated the optimisation table in Table 8. The numerical optimisation technique was used to optimise the independent variables, i.e., palm oil mill effluent, Siam weed, and avocado pear extract. The response variables selected for optimisation were the nitrogen, phosphorus, and potassium content. The optimal condition was found by minimising the palm oil mill effluent (POME), Siam weed, and avocado pear extract, while maximising the nitrogen, phosphorus, and potassium content of the liquid organic fertiliser. Using this condition, three solutions were obtained. The optimal condition for the formulation of the liquid organic fertiliser is shown in Table 8. The optimal conditions for POME, Siam weed, and avocado pear extract were 5.19, 5.25, and 5.55 with a desirability value of 0.60. At this optimal condition, the nitrogen, phosphorus, and potassium content were 36.98%, 29.76%, and 31.77%.

Table 8: Optimisation result for the LOP model

Number	POME	Siam weed	Avocado	N	P	K	Desirability	
1	**5.19**	**5.26**	**5.54**	**36.98**	**29.76**	**31.77**	**0.60**	**Selected**
2	5.56	5.43	5.00	28.68	27.03	38.07	0.53	
3	5.54	5.46	5.00	28.74	26.89	38.07	0.53	

The result of the optimised liquid organic fertiliser shows a very high percentage of N, P, K of 36.98%, 29.76%, and 31.77%. This shows a great improvement and a more balanced level of NPK of organic fertiliser. This is very close to the composition of an inorganic fertiliser 2: 2: 2 NPK (Yerizam *et al*., 2021). Therefore, it can be concluded that the formulation and optimisation of liquid organic fertilisers are very close to those of inorganic fertilisers.

3.8 Plant Testing

The formulated liquid organic fertiliser was applied to a water leaf plant to study the effect of the formulated fertiliser on plants. A piece of land was cleared, tilled, and divided into 3 equal portions; the same sample of waterleaf plant was planted in the three portions. There, after planting a portion without any fertiliser applied, a conventional NPK fertiliser, acquired from a fertiliser store, was applied to the next piece of land while the last piece of land was tested using the produced LOF. After 4 to 6 weeks of planting, the effect of the fertiliser produced was observed by the size of the leaves and colour of the leaves. Figure 15 shows the result of the waterleaf planted without any fertiliser; Figure 16 shows the waterleaf plant with NPK fertiliser, while Figure 17 shows the waterleaf plant with LOF. From the picture, it is observed that the plant without fertiliser produced leaves with a yellowish colour, which shows a deficiency in nitrogen, and the ears of the leaves are observed to be smaller than those with fertiliser. Also, by looking at Figure 15, it is observed that the leaves are much greener and the leaves are broader. The waterleaf treated with LOF was also found to be greener than the NPK fertiliser, as observed in Figures 16 and 17. Although that of NPK shows a broader leaf than that of the LOF. This confirms that the properties of the organic liquid fertiliser produced are close to those of a conventional fertiliser in terms of nutrient release.

Figure 15: Water leaf plant planted without fertiliser application

Figure 16: Water leaf plant planted with NPK fertiliser

Figure 17: Water leaf plant planted with LOF fertiliser

4 Conclusions

In conclusion, the formulation of liquid organic fertilizer using palm oil mill effluent, Siam weed, and avocado seed extract demonstrates a sustainable approach to enhancing agricultural productivity while addressing environmental concerns associated with chemical fertilizers.

i. The physicochemical properties of the raw materials indicated their suitability for fertilizer production. POME exhibited slight acidity and a rich nutrient profile, especially in nitrogen, phosphorus, and potassium. Siam weed was notably high in nitrogen and potassium, whereas avocado pear seed extract contributed significantly to potassium levels.
ii. The effective mixture design led to reliable formulations, with significant statistical analyses affirming the models for nitrogen, phosphorus, and potassium contents.
iii. FTIR analyses revealed the presence of necessary functional groups in the components and the formulated fertilizer, confirming the biochemical interactions that occurred during formulation.
iv. The optimization process yielded a liquid organic fertilizer with high levels of N, P, and K, comparable to conventional inorganic fertilizers, as reflected in the plant testing results.
v. Using the liquid organic fertilizer (LOF) on waterleaf produced comparable traits to those treated with conventional NPK fertilizers, showcasing its potential as a sustainable alternative. Thus, the findings suggest that the liquid organic fertilizer not only meets the nutrient needs of plants but also aligns closely with the efficiency of traditional fertilizers, thereby contributing to more sustainable agricultural practices.

Conflict of Interest

The authors declare that there are no conflicts of interest between the authors.

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