NPK Biofertilizer Production from Banana Peel, Feather, and Bone Ashes: Comparative Efficacy to 20:10:10 Inorganic Fertilizer

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Abstract

The possibility of formulating nitrogen, phosphorus and potassium (NPK) biofertilizer from ashes of waste organic materials such as chicken feathers, bone and banana peels is investigated in this study by first subjecting the agricultural waste to 80-250℃ heat in a muffle furnace to produce ash. Kjeldatherm block digestion unit, UV spectrophotometer, and flame photometers, respectively helped in measuring the concentrations of N, P and K inherent in the fertilizer precursors as well as in 5 formulated blends (i.e., A, B, C, D & E). It was discovered that NPK in the single substrate and blends favorably compared with standard NPK 20:10:10 chemical fertilizer to some extent. Among single material fertilizer sources, feather ash with 0.179:1:0.134 NPK and bone ash with 0.009:1:0.021 NPK had the closest nutrient content with the standard, showing potential promise. On the other hand, Blend E is the same as the standard, followed by Blend A, B, D and C, which are hierarchically close in elemental composition to the standard. The choice of these biofertilizers is dependent on their nutrient compositions, the type of crops to be grown, and the soil mineral requirements. Most importantly, different NPK ratio organic fertilizers produced in this study can competitively be produced in a large scale to address huge costs associated with the NPK 20:10:10 standard commercial fertilizer. Blend E (NPK 20:10:10) can be formulated locally by farmers in rural areas easily using this particular agricultural residue or a host of other confirmed farm wastes.

Keywords: *Bio-fertilizer, NPK 20:10:10, Inorganic fertilizer, Chicken bone, Feather ash, Kjeldahl method*

1. Introduction

NPK fertilizer is the combination of three macronutrients required by plants, i.e., nitrogen (N), phosphorus (P), and potassium (K) in the form of elemental N or ammonium (NH_4^+), phosphorus pentoxide (P_2O_5) and potassium oxide (K_2O), respectively, in certain ratios [1]. N supports plant growth, P supports the formation of sugar, oils and starch and K assists in photosynthesis, disease resistance, protein building and fruit quality. Elements that play a very crucial role in various physiological processes within plants, such as photosynthesis, cell division, enzyme activation, and the overall structure and function of plant cells are micronutrients (i.e., Fe, Mn, Zn, Cu, Mo, B, Cl and Ni) and macronutrients (viz., N, P, K, Ca, Mg, S, C, H and O), which also forms the constituents of various plants and animal residues [2, 3]. In soil, they enhance plants' growth and development. Kramer et al. [4] utilized legumes to check N loss from soil in which maize was planted, Nogalska et al. [5] used meat and bone meal as organic fertilizer leading to increased uptake of N, P, K, and Mg by the maize and Mulyono & Hidayat [6] showcased the enhanced yield of sweet corn by micro cattle bone ash. As

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such, farmers find this technique of replenishing nutrients in soils using waste residues of plants and animals easy and cost-effective compared to inorganic chemical fertilizers. Production of 2:1:1 NPK biofertilizer via anaerobic digestion experimented by Yunus et al. [7], as an example, utilizes banana peel, wastewater sludge, and chicken dung blends in varying proportions. Mixing of hoof and horn powder, castor bean cake, bone and blood meals was experimented on previously by de Almeida et al. [8] to formulate NPK biofertilizer.

There are different types of NPK fertilizers, namely, NPK 20:10:10, NPK 15:15:15, NPK 20:20:20, NPK 11:46:14, NPK 6:13:46, NPK 8:20:30 and NPK 30:10:10, etc. Maize and cassava can be grown using NPK 15:15:15, watermelon and vegetables, NPK 15:15:15 & 20:20:20 and cucumbers, NPK 6:13:46, 15:15:15 & 20:20:20 [9, 10]. These ratios indicate the nutrient composition of the fertilizer. Different plants may have varying nutrient requirements at different stages of growth. For example, a fertilizer with a higher P content (second number) is often used during the flowering or fruiting stage, as P promotes flower and fruit development. The first number (N) is associated with vegetative growth, and the third number (K) is linked to overall plant health and stress resistance [11]. NPK 20:10:10 is a versatile fertilizer that can be used for a wide range of plants and growth stages. It provides a balanced supply of nutrients that many plants need throughout their life cycle. This type of fertilizer is often considered a general-purpose or all-purpose fertilizer suitable for various types of plants, including vegetables, flowers, and ornamentals. The relatively higher N content makes NPK 20:10:10 suitable for promoting early vegetative growth. If the focus is to establish strong, green foliage in the initial stages of plant development, this ratio can be advantageous [12]. However, ammonia (NH_3) from natural gas is the industrial route followed to manufacture this type of fertilizer, with imminent air pollution problems [13]. Utilizing biomass waste from agricultural activities, perhaps is an alternative source of an environmentally beneficial approach, as exemplified using poultry feathers by Paul et al. [14].

In Nigeria, artificial fertilizers are made from nonrenewable petroleum fractions with excess heat and fuel requirements and the release of greenhouse gases. Since N, P and K elements are constituents of many organisms in varying proportions, this study aimed at utilizing both plant and animal waste to produce affordable organic fertilizer having a comparative advantage with chemical fertilizer. The present study is also triggered by the huge costs associated with inorganic fertilizer purchases by individuals and governments who invest a lot in subsidies to farmers. Thus, the specific objective of this study is to determine the NPK composition of chicken feather ash (FA), bone meal ash (BA) and banana peel ash (BPA), formulate organic fertilizer from the selected biomass blend and carryout comparative study between the produced organic fertilizer and an inorganic 20:10:10 NPK chemical fertilizer. Inorganic fertilizers derived from ground orange and banana peels by Nossier [15], notably enhance tomato quality due to improvements in NPK levels. Banana peels biofertilizer prepared by Sogani et al. [16] increases the germination rate of black gram crops. Nayaka & Vidyasagar [17] point to soil amendments and plant growth enhancement properties of biofertilizers produced from feather compost. Phosphorus content in mineral soils (0.009-0.15%) can be replenished using ash and bone phosphorus fertilizers [18, 19]. Similar selection of BA, FA, and BPA were not done in previous studies. According to Wazir et al. [20], ash chiefly consists of O, Ca, Fe, Ti, Si, Na, K, Al and Mg, making them suitable for biofertilizer production. Hence, the possibility of preparing different NPK blends from the selected biomass is investigated in this research, not only to create a value-added product but also to eliminate waste.

2. Materials and Method

2.1. Materials, reagents and equipment

Chicken feathers and banana stems were obtained from chicken cottages and orchards respectively at Dangote Sugar Refinery, Numan, Adamawa State, Nigeria. Bone samples were collected from Jimeta Abattoir, Yola, Adamawa State, Nigeria. Required analysis was carried out in WAFT Laboratory FUT Minna and the Chemical Engineering Laboratory, MAU. Reagents used are sulphuric acid (H_2SO_4), hydrochloric acid (HCl), sodium hydroxide (NaOH), ascorbic acid ($C_6H_8O_6$), boric acid (H_3BO_3) and ammonium fluoride (NH_4F). Apparatus and equipment necessary for the production are B5700 Pyrex glass stirrer, HK-DC-320AS digital weighing balance, 1000 mL analogue heating mantle, digital flame-photometer 128, 100 mL borosilicate glass conical flask, 250 mL Pyrex glass measuring cylinder, PHS-25 digital pH meter, SX-2.5-12 muffle furnace (max. temperature = 1200°C, LGW-307 Markham borosilicate glass distillation apparatus, borosilicate glass titration apparatus and 6V-125 digital UV-spectrophotometer. During N content analysis, the Kyeldahl catalyst was employed.

2.2. Feedstock preparation

All waste samples were pretreated to comply with the standards by washing to remove dirt and traces of impurities such as sand in banana peel and meat in feathers before drying them. Specifically, banana peels were cut into 10-15 mm smaller pieces to hasten its drying. Both banana peels and the bone samples were sun-dried for 4 weeks. To reduce burning time and ensure an increased burning rate, manual size reduction by crushing the bone material was carried out. Following this was the burning of the chicken feather at 120°C at 1h intervals, the burning of bone specimen at 250°C at the same time interval, and the burning of banana peels at 80°C at 30 min intervals in a muffle furnace. A method similar to Anjum & Sundaram [21] was used to calculate the % ash content in the 3 samples. At 462.7°C, Adeniyi et al. [22] recovered 77.86% metal oxides from 200g of cow bone char using a muffle furnace, making animal bones an important nutrient source for plant growth. Gradual burning was ensured to prevent nutrient loss due to temperature effects. From the literature, broiler chicken feathers contain 0.8% ash [23], the ripe, unripe and overripe banana peel contains 8.16-9.88% ash [21] and pig bones, such as metacarpals, tibia, metatarsals and body bone contains 0.539-0.741% ash [24]. These amounts were compared with FA, BA and BPA percentages obtained in this study. Lastly, the 3 samples were manually ground and sieved into fine powder using a mortar and pestle.

2.3. Nitrogen content determination

The ground sample portion of 0.5g FA was weighed into a 50 mL Kjeldahl flask. Then, 10 mL of concentrated H_2SO_4 was added and swirled until the acid was thoroughly mixed with the sample. After the mixture was allowed to cool, ½ tablet of Kjeldahl catalyst was added to the mixture and heated in the Kjeldatherm digester till the digestion mixture became clear. The mixture was boiled gently for 5 h varying the temperature from lower to higher degrees before cooling until the H_2SO_4 condenses about 1/3 to the end of the tube. Sample residue was washed, filtered and made up to 100 mL (V_1) with distilled water, as carried out by Nordin et al. [25]. Care was taken not to lose the N content of the feedstock; as such, the temperature was maintained below 400°C during the digestion [26]. There is also evidence of crystallinity and color changes in bones during prolonged heating at 300°C according to Gallo et al. [27]. Plate 1 shows the digestion mechanism and the digested samples, respectively.

Plate 1. Samples (a) Undergoing digestion; (b) Filtered digested sample.

After digestion was completed, 5 mL of 2% H_3BO_3, comparatively less than the amount used in Nossier [15], was placed into a 100 mL conical flask (or receiving flask). Boric acid normally traps the NH_3 vapor from the digest. About 3 drops of mixed indicator (0.198 g bromocresol green & 0.132 g methyl red in 200 mL alcohol) were added. The receiving flask was placed in such a way that the tip of the condenser tube was below the surface of the boric acid. Next, 5 mL of the digested sample (Plate 1b) was pipetted into the Markham distiller and 10 mL 10% NaOH was added, joints were tightened and the sample was distilled until 100 mL distillate was collected in the receiving flask (V_2). Plate 2 (a & b) depicts the distillation setup and distilled samples, respectively.

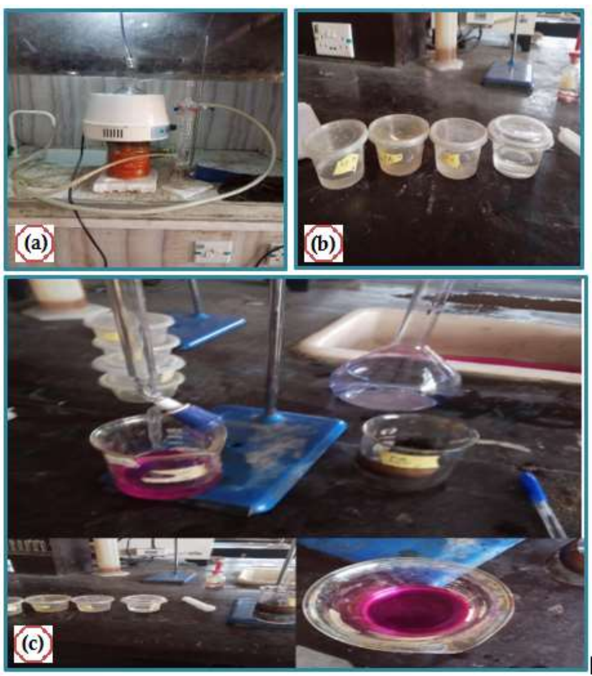

Plate 2. (a) Distillation set up; (b) Simple distillates; (c) Sample titration.

The distillate and a blank sample were titrated separately with 1% HCl. Plate 2c displays the titration process employed for determining N composition in this study. Percent N content was calculated as illustrated by Equation 1 [28] while N concentration was determined following methods described in Kjeldahl [29] and Saez-Plaza et al. [30].

$$\%N = \frac{M \times T \times 0.014}{W} \times \frac{V_2}{V_1} \times 100 \quad (1)$$

Where, T = $T_1 - T_2$ = control titer which varies with sample, T_1 = sample titer, T_2 = blank titer, M = molarity of acid (11.65), V_1 = volume of digest (100 mL), V_2 = volume of digest used (5 mL) and W = weight of sample at 0.2, 0.5 and 1.0g (i.e., Samples I-III, respectively – Table 1).

Table 1. Weight of various powdered materials taken for N-test.

S/No.	Materials	Weight Used (g)	Form
1.	Feather Ash	0.2, 0.5 & 1	Powder
2.	Bone Ash	0.2, 0.5 & 1	Powder
3.	Banana Ash	0.2, 0.5 & 1	Powder

A blank determination was later carried out in each series and the average blank value was used for subsequent calculations. Blank samples were obtained by adding all the reagents but not the sample in the subject.

2.4. Phosphorus and potassium analysis

P was extracted from the laboratory following some designed steps described in the literature. About 1 g of BA sample was weighed and shaken in 10 mL of 0.025 M HCl and 0.03 M NH_4F for 5 min, also described in Khan et al. [31]. P was determined on the filtrate by the molybdate-blue method using $C_6H_8O_6$ as a reluctant. Color development was measured at a wavelength of 880 nm on an atomic UV/visible spectrophotometer, previously used by Kshetri et al. (2017). Precisely, 2 mL of P standard solution and 4 mL of $C_6H_8O_6$ were placed in a sample bottle. The standard solution and the filtered samples prepared were analyzed using an Ultra-violent spectrophotometer. K was extracted from the BPA by mixing 10 mL of 1 N, ammonium acetate with 1g of BPA and shaken for 5 min. K content in the specimen was measured by analyzing the filtered extract using a flame-photometer set on emission mode at 776 µm, also employed by Tolubanwo et al. [33]. Consequently, the results were reported in mg/g of sample weight used for K determination in the BPA sample.

2.5. Liquid solution formulation and pelletization

About 5 g of samples of feather, bone, banana ash and the standard were weighed and diluted separately with 50 mL of water before allowing it to settle for 24 h. Each of the 4 samples was filtered with filter paper and topped with distilled water before measuring their pH using a PHS-25 digital pH meter. BA, FA, and BPA samples were weighed 80, 20 and 10g, respectively and mixed with

68.8g $CaCO_3$ as inert material [34] and then mixed with water at a ratio of 4:2:1. The resulting mixture of the 3 ash samples and the $CaCO_3$ were air dried to reduce moisture content, which then gives the targeted fertilizer shown in Plate 3.

Plate 3. Organic fertilizer produced.

Biofertilizer based on the above-specified weights of organic waste was named Blend A. Powder limestone in Blend A is capable of improving the yield and quality of plants and some soil properties [35].

2.6. Formulation of different biofertilizer NPK ratio

Blend B, which is a mixture of 50g, 25g and 25g FA, BA and BPA, Blend C consisting of 20g FA, 20g BA and 60g BPA, Blend D, a combination of 50g each of FA, BA and BPA and Blend E, which is a mixture of 20g FA, 10g BA and 10g BPA, were formed to give a varying ratio of NPK. NPK ratios from the respective blends were then determined based on known amounts of N, P and K in 1g of the respective samples.

3. Results and Discussion

3.1. N Percent of sample from N test experiment

Originally, all samples for the N test were digested using 10 mL concentrated H_2SO_4 (98%) and 1 tablet of the Kjeldahl catalyst in a 250 mL borosilicate beaker, then heated using the heating mantle maintained at 100°C for 1 h 30 min. Tables 2, 3, and 4 show N test results for varying sample weights of 0.2, 0.5 and 1.0g, tagged Samples, I, II and III, respectively.

In Table 2, N concentration in feather, bone, banana peel ashes and the standard NPK fertilizer sample (Notore 20:10:10) were found to be 0.07, 0.024, 0.01 and 0.114 mg/g, respectively per 0.2 g of biomass waste material taken. Taking 0.5 and 1g of materials also resulted in concentrations shown in Tables 3 and 4. Percent N content is a crucial indicator of the N concentration in organic materials, which is essential for assessing their potential as organic fertilizers.

Table 2. Sample I (Weight = 0.2g) N concentration.

S/No.	Materials	Weight (g)	Titer Value (mL)	N Conc. (mg/g)	%N
1.	Feather Ash	0.2	1.75	0.070	7.00
2.	Bone Ash	0.2	0.6	0.024	2.40
3.	Banana Peel Ash	0.2	0.1	0.001	0.10
4.	Standard	0.2	2.8	0.114	11.4

Table 3. Sample II (Weight = 0.5g) N concentration.

S/No.	Materials	Weight (g)	Titer Value (mL)	N Conc. (mg/g)	%N
1.	Feather Ash	0.5	7.60	0.124	12.4
2.	Bone Ash	0.5	1.81	0.029	2.90
3.	Banana Peel Ash	0.5	0.20	0.002	0.20
4.	Standard	0.5	11.70	0.191	19.10

Table 4. Sample III (Weight = 1.0g) N concentration.

S/No.	Materials	Weight (g)	Titer Value (mL)	N Conc. (mg/g)	%N
1.	Feather Ash	1.0	23.7	0.190	19.00
2.	Bone Ash	1.0	4.30	0.035	3.50
3.	Banana Peel Ash	1.0	0.20	0.002	0.20
4.	Standard	1.0	42.60	0.346	34.60

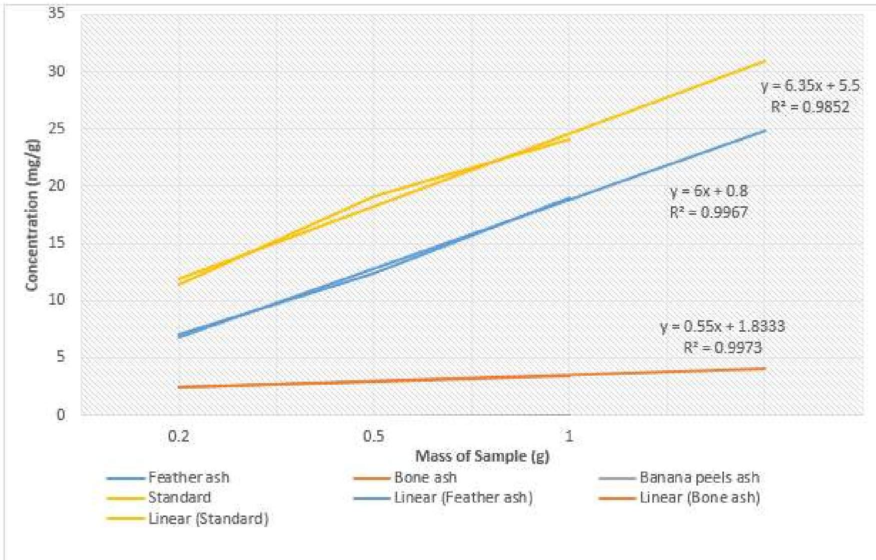

Figure 1. Nitrogen concentration curve.

When comparing the N compositions in the organic materials and the standard sample, it is evident that the standard sample consistently exhibits higher N content compared to the organic materials. For example, in the 1g samples, the standard sample displayed an N content of 34.6%, while the highest N content among the organic materials was 19% in the FA. Generally, %N in 0.5-1.0g FA compares favorably with the 15% level obtained by Bharathi & Raj [23]. This indicates that the standard chemical fertilizer contains a higher concentration of N compared to the organic materials tested in this study. It also suggests that larger quantities of organic materials may be required to achieve N levels comparable to those found in typical chemical fertilizers. Figure 1 curve is a graphical representation of the N concentration in the organic materials tested in this study, specifically the FA, BA, and BPA. As the mass of the sample increases, the N concentration increases. This is evident in the curve's upward slope, which indicates a positive correlation between the mass of the sample and the N concentration. Evident in the curve's relative positions, FA has the highest N concentration among the organic materials tested, followed by the BA and the BPA.

3.2. Phosphorus and potassium concentrations

Table 5 shows P absorbance for standard samples prepared by varying the concentration from 2-10 ppm taking intervals of 2 ppm. This is the basis used for the test samples. On the other hand, Figure 2 depicts the P concentration (mg/g or ppm) versus absorbance of the standard sample solution prepared for both banana and feather ashes, while Figure 3 shows that of the BA sample.

A positive correlation between the P concentration and the absorbance of the standard samples occurs in Figure 2. The curve's upward slope indicates that the absorbance increases as the P concentration increases. Using the calibration curve, the absorbance value obtained from the Notore 20:10:10 fertilizer sample can be matched to the curve. By locating the absorbance value on the curve, the corresponding concentration of phosphorus can be determined.

Table 5. P fraction within standard sample solution.

S/No.	Standard Solution (ppm)	Absorbance (μm)	Bone Ash Sample Solution (ppm)	Absorbance (μm)
1.	2	0.112	2	0.7716
2.	4	0.175	4	1.4870
3.	6	0.194	6	2.2843
4.	8	0.204	8	3.1221
5.	10	0.265	10	3.8872

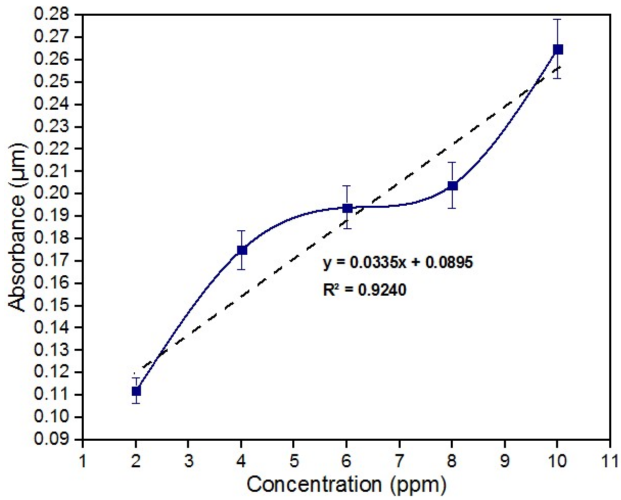

Figure 2. Phosphorus standard curve.

Same way, the K absorbance curve (Figure 3), gave the concentration of P in the samples through a process known as calibration. Calibration involves establishing a relationship between the absorbance of a substance at a specific wavelength and its known concentration. This relationship can then be used to determine the concentration of an unknown sample based on its absorbance. It is observed that absorbance increases as the concentration of standards increases from 2-10 mg/g.

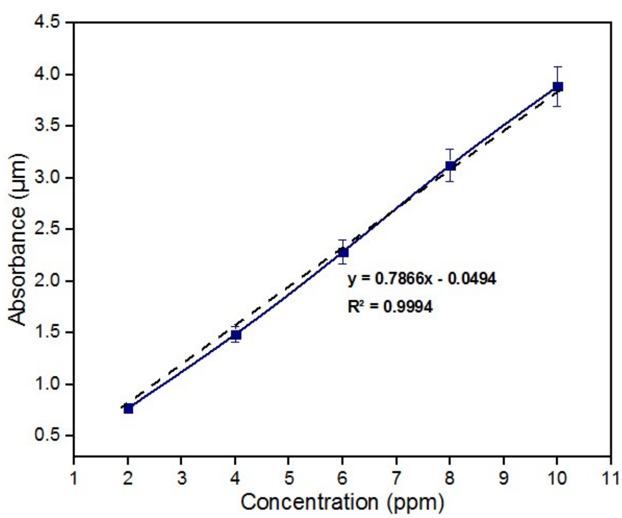

Figure 3. Curve for P concentration in bone ash sample.

Respective P and K concentrations obtained from calibration curves in Figures 2 and 3 for the organic samples and standard solution are showcased in Tables 6-8. It presents the results obtained using a methodology based on the Kjeldahl method, which involves incinerating the samples at a specified temperature to avoid denaturing the organic compounds in each sample.

3.3. NPK ratios formed by organic materials

Tables 6, 7, and 8 provide valuable insights into the NPK ratios for different organic materials and a standard NPK fertilizer sample. N, P & K amounts in FA range from 0.07-0.19, 0.0447 and 0.0334 mg/g in this study, which is less comparable to 6.94%, 0.063% and 6 ppm, respectively in Nayaka & Vidyasagar [17]. NPK ratios are crucial for understanding the nutrient composition of organic materials and their potential as organic fertilizers.

In Table 6, the NPK ratio for FA is approximately 1.57:1:1, indicating a balanced nutrient composition suitable for plant growth; the NPK ratio for BA is approximately 0.006:1:0.044, suggesting a very low N content compared to P and K and; the NPK ratio for BPA is approximately 0.0003:1:0.236, indicating a very low N content and a high K content.

In Table 7, NPK ratio for FA is approximately 0.248:1:0.187, showing a lower N content and a balanced P and K content; NPK ratio for BA is approximately 0.014:1:0.032, indicating a low N content and a relatively higher P content compared to K and; the NPK ratio for BPA is approximately 0.001:1:0.472, suggesting an extremely low N content and a high K content similar to NPK 8:20:30 [36]. Haraldsen et al. [37] discovered that meat and bone meal are good P and N fertilizers.

In Table 8, the NPK ratio for FA is approximately 0.179:1:0.134, indicating a lower N content and a balanced P and K content; the NPK ratio for BA is approximately 0.009:1:0.021, suggesting a low nitrogen content and a relatively higher P content compared to K and; the NPK ratio for BPA is approximately 0.0002:1:0.374, indicating an extremely low N content and a high K content. These NPK ratios provide valuable information for formulating organic fertilizers with specific nutrient compositions tailored to the needs of different crops and soil conditions.

Table 6. N, P and K concentrations in all organic materials used (at 0.2g N and 1g P & 1g K).

S/No.	Materials	N (mg/g)	P (mg/g)	K (mg/g)	Ratio
1.	Feather Ash	0.070	0.0447	0.0334	1.57:1:1
2.	Bone Ash	0.024	3.856	0.0886	0.006:1:0.044
3.	Banana Peels Ash	0.001	1.339	2.36	0.0003:1:0.236
4.	Standard	0.114	4.731	3.121	2.55:1:1.68

Table 7. N, P and K concentrations in all organic materials used (at 0.5g N and 1g P & 1g K).

S/No.	Materials	N (mg/g)	P (mg/g)	K (mg/g)	Ratio
1.	Feather Ash	0.124	0.0447	0.0334	0.248:1:0.187
2.	Bone Ash	0.029	3.856	0.0886	0.014:1:0.032
3.	Banana Peels Ash	0.002	1.339	2.36	0.001:1:0.472
4.	Standard	0.191	4.731	3.121	3.12:1:2.06

Table 8. N, P and K concentrations in all organic materials used (at 1g each of N, P & K).

S/No.	Materials	N (mg/g)	P (mg/g)	K (mg/g)	Ratio
1.	Feather Ash	0.190	0.0447	0.0334	0.179:1:0.134
2.	Bone Ash	0.035	3.856	0.0886	0.009:1:0.021
3.	Banana Peels Ash	0.002	1.339	2.36	0.0002:1:0.374
4.	Standard	0.346	4.731	3.121	3.12:1:2.06

In the context of organic fertilizer production, the NPK ratio of FA that is closest to the standard NPK ratio of 20:10:10 is the most desirable. This is because it indicates a balanced nutrient composition that aligns with the standard NPK fertilizer, which is commonly used in agricultural practices. Comparing the NPK ratios of FA to the standard NPK ratio of 20:10:10, the NPK ratio for FA in Table 8 (0.179:1:0.134) is the best approximation, as its ratio is closer to the standard and suggests a balanced nutrient composition similar to the standard NPK fertilizer. Also based on these comparisons, the NPK ratio for BA (i.e., 0.009:1:0.021) is the best approximation to the standard while none of the NPK ratios for BPA in Table 6-8 closely approximate the standard NPK ratio of 20:10:10 – but the closest is 0.0002:1:0.374. Hence, ranking the best NPK ratios for the organic materials based on the proximity of the NPK ratios to the standard fertilizer, shows that 0.179:1:0.134 for FA, 0.009:1:0.021 for BA and 0.0002:1:0.374 for BPA are number 1, 2 and 3 respectively. In terms of nutrient content, the ranking may differ depending on the specific nutrient requirements of the plants being grown. For example, if a plant requires a higher P content, then the NPK ratio of BA may be more desirable than that of FA. Similarly, in terms of plant growth potential, the ranking may also differ depending on the specific plant species and growing conditions. Some plants may require higher N content for vegetative growth, while others may require higher P and K content for flowering and fruiting [38].

3.4. Organic NPK biofertilizer produced

Blend A, B, C, D and E biofertilizer shown in Table 9 contains FA, BA and BPA in the ratio of 8:2:1, in which the compositions of N, P and K in the combined mixture are 16.15, 16.17 and 16.52 mg, respectively. Blend A (1:6:2) has a higher P content compared to N and K, implying that the blend may be more suitable for promoting root development and overall plant growth. Blend B (1:13:6) with a high P and K content and low N, may be beneficial for enhancing disease resistance, improving fruit quality, and promoting overall plant vigor. Blend C (1:34:31) has a significantly higher K content compared to N but proportionate to P, suggesting that this blend may be particularly useful for promoting flowering, fruiting, and overall stress tolerance in plants. Blend D (1:29:11) has a higher P content compared to N and K, signifying its high suitability for promoting root development and overall plant growth, similar to Blend A. Lastly, Blend E (20:10:10) closely approximates the standard NPK ratio of 20:10:10, which is commonly used in agricultural practices. It suggests a balanced nutrient composition suitable for a wide range of plants and growth stages, namely, in watermelon, cucumber and okra production [39–41]. These implications highlight the versatility of the different blends in addressing specific plant needs, such as root development, flowering, fruiting, and overall plant vigor, based on their respective NPK ratios. In order of proximity to the standard, the best NPK fertilizer is ranked from Blend E, A, B, D and C, in this study.

Table 9. Produced organic fertilizer compositions.

S/No.	Organic Waste	Weight Specified (g)	Concentration and %Composition	NPK Ratio
Blend A				
1.	Feather Ash	80	15.92mg N, 94.086mg P & 28.044mg K (11.53% N, 68.15% P & 20.32% K)	1:6:2
2.	Bone Ash	20		
3.	Banana Peel Ash	10		
Blend B				
1.	Feather Ash	50	10.425mg N, 132.11mg P & 62.81mg K (5.08% N, 64.34% P & 30.58% K)	1:13:6
2.	Bone Ash	25		
3.	Banana Peel Ash	25		
Blend C				
1.	Feather Ash	20	4.62mg N, 158.354mg P & 144.708mg K (1.5% N, 51.47% P & 47.03% K)	1:34:31
2.	Bone Ash	20		
3.	Banana Peel Ash	60		
Blend D				
1.	Feather Ash	50	11.35mg N, 328.935mg P & 124.1mg K (2.44% N, 70.83% P & 26.73% K)	1:29:11
2.	Bone Ash	50		
3.	Banana Peel Ash	50		
Blend E				
1.	Feather Ash	20	105.26mg N, 2.6mg P & 17.8mg K (83.77% N, 2.07% P & 14.16% K)	20:10:10
2.	Bone Ash	10		
3.	Banana Peel Ash	10		

It's important to consider the specific nutrient requirements of the plants being grown and the intended growth outcomes when selecting the most suitable blend for optimal growth and yield. For example, Ayeni [42] realized an upsurge in soil nutrient levels above the optimal requirement for arable crop yield when cocoa pod ash, NPK 20:10:10 and poultry manure were combined.

Table 9 provides the NPK ratios for the different blends, offering a comprehensive view of the nutrient composition in each blend. On the other hand, Tables 6, 7, and 8 offer detailed information on the P and K concentrations in the individual samples. Ultimately, the "best" choice would be the blend or individual sample that most effectively addresses the specific needs of the plants and the soil, leading to optimal growth and yield [43]. In this study, only the pH of Blend A (pH = 7.09) was determined, while others are mere theoretical formulations (suggested) whose pH was not measured. The optimal pH for soil application can vary depending on the specific plants being grown, but in general, a slightly acidic to neutral pH is often considered best for most plants. A pH range of 6.0 to 7.5 is typically suitable for a wide variety of plants, as it allows for the availability of essential nutrients in the soil. Therefore, a pH of 7.09 (Blend A) or 7.49 (Standard) would both fall within the acceptable range for most plants. However, it's important to note that different plants have specific pH preferences, and some may thrive in slightly more acidic or alkaline conditions [44–46].

Hence, setting up a laboratory scale which would ultimately lead to a large industrial-scale plant with the selection of the right construction materials described in the literature [47, 48], would go a long way in advancing this study's findings. The use of natural gas to produce NH_3 and in turn generate inorganic fertilizer is a route that releases an enormous amount of greenhouse gases. Challenges of global warming witnessed all around the world could be addressed using biofertilizers produced from these blends, thereby safeguarding the environment [49], [50].

4. Conclusion

Formulations of 1:6:2, 1:13:6, 1:34:31, 1:29:11 and 20:10:10 NPK biofertilizer blends (i.e., A, B, C, D & E, respectively) from FA, BPA and BA was theoretically achieved. However, NPK in a single organic waste ash sample is a maximum of either one element (N, P, or K) or combinations of two (N&P, P&K and N&K) which may be suitable if the soil and plant growth requirements are not the entire NPK elements. Because different plant's vegetative growth, flowering, root development and fruiting demand specific amounts of micronutrients in the soil. As mentioned, the respective blends ranked from Blend E, A, B, D to C based on comparative property with standard 20:10:10 NPK, are beneficial in various aspects of plant vitality mentioned above; and may be preferable to NPK quality in single ash samples. A discovery specific to this study was the formation of NPK 20:10:10 similar to one of the most common commercial NPK, demonstrating the ability to convert banana peel, chicken bone, and feather wastes into useful agricultural supplements. Favored by a suitable biofertilizer pH, the developed organic fertilizer (Blends A-E) can be used to amend soil texture and structure, also considering its production simplicity, precursor availability and environmental friendliness compared to the standard 20:10:10 inorganic fertilizer. Field trials for comparative study of their ability to grow certain types of crops should be carried out. Additionally, large-scale development of this alternative way of manufacturing NPK 20:10:10 should be established.

Abbreviation:

NPK	Nitrogen, Phosphorus and Potassium
FA	Feather Ash
BPA	Banana Peel Ash
BA	Bone Ash
P	Phosphorus
N	Nitrogen
K	Potassium

Nomenclature

P_2O_5	Phosphorus pentoxide
K_2O	Potassium oxide
H_2SO_4	Sulphuric acid
NaOH	Sodium hydroxide
HCl	Hydrochloric acid
$C_6H_8O_6$	Ascorbic acid
H_3BO_3	Boric acid
NH_4F	Ammonium fluoride
Ammonium	NH_4^+
Ammonia	NH_3

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Conflicts of Interests/Competing Interests

No potential conflict of interest concerning this research, authorship and publication exist.

Data Availability

No additional dataset is concealed in this study. All findings were showcased in the discussion section.

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References

[1] J. B. Jones, "Inorganic chemical fertilizers and their properties," in *Plant Nutrition and Soil Fertility Manual*, 2nd ed., CRC Press: Taylor and Francis Group, 2012, pp. 1–12.

[2] J. U. Itelima, W. J. Bang, I. A. Onyimba, M. D. Sila, and O. J. Egbere, "Bio-fertilizers as key player in enhancing soil fertility and crop productivity: A review," *Direct Res. J. Agric. Food Sci.*, vol. 6, no. 3, pp. 73–83, 2018, doi: 10.26765/DRJAFS.2018.4815.

[3] E. T. Jaja and L. I. Barber, "Organic and inorganic fertilizers in food production system in Nigeria," *J. Biol. Agric. Healthc.*, vol. 7, no. 18, pp. 51–55, 2017.

[4] A. W. Kramer, T. A. Doane, W. R. Horwath, and C. van Kessel, "Combining fertilizer and organic inputs to synchronize N supply in alternative cropping systems in California," *Agric. Ecosyst. Environ.*, vol. 91, no. 1–3, pp. 233–243, 2002, doi: 10.1016/S0167-8809(01)00226-2.

[5] A. Nogalska, J. Czapla, Z. Nogalski, M. Skwierawska, and M. Kaszuba, "The effect of increasing doses of meat and bone meal (MBM) on maize (Zea mays L.) grown for grain," *Agric. Food Sci.*, vol. 21, no. 4, pp. 325–331, 2012, doi: 10.23986/afsci.6423.

[6] Mulyono and T. Hidayat, "Foliar application of micro cattle bone ash in increasing growth and yield of sweet corn (Zea mays saccharata Sturt.)," in *Second International Conference on Sustainable Agriculture [30-31 July 2019, Yogyakarta, Indonesia]- IOP*

Conference Series: Earth and Environmental Science, 2020, vol. 458, no. 012024, pp. 1–4, doi: 10.1088/1755-1315/458/1/012024.

[7] M. U. Yunus, K. Silas, A. L. Yaumi, and B. H. Kwaji, "Development of biofertilizer from locally sourced materials," *Indones. J. Innov. Appl. Sci.*, vol. 3, no. 1, pp. 51–60, 2023, doi: 10.47540/ijias.v3i1.671.

[8] L. G. de Almeida, J. S. Candian, A. I. I. Cardoso, and H. G. Filho, "Nitrogen, phosphorus, and potassium content of six biofertilizers used for fertigation in organic production system," *Comun. Sci. Hortic. J.*, vol. 12, no. e3275, pp. 1–6, 2021, doi: 10.14295/CS.v12.3275.

[9] A. S. Akinbani and L. S. Ayeni, "Effect of fertilizer types on nutrient uptake and yield of cassava in Ondo Southwestern Nigeria using farmers' simulation method," *Greener J. Agric. Sci.*, vol. 9, no. 1, pp. 095–101, 2019, doi: 10.15580/GJAS.2019.1.022819040.

[10] Farmsquare, "The best NPK fertilizer for your crops," *Farmsquare Nigeria*, 2022. https:/fertilizer.com.ng/en/npk-fertilizers-and-its-uses (accessed Dec. 23, 2023).

[11] A. Khalofah, H. A. Ghramh, R. N. Al-Qthanin, and B. L'taief, "The impact of NPK fertilizer on growth and nutrient accumulation in juniper (Juniperus procera) trees grown on fire-damaged and intact soils," *PLoS One*, vol. 17, no. 1, pp. 1–14, 2022, doi: 10.1371/journal.pone.0262685.

[12] I. A. Ewetola, V. O. A. Ojo, A. A. Amisu, P. A. Dele, and J. A. Olanite, "Comparative performance of fertilizer types on growth, yield of Panicum maximum var. Ntchisi (JAC) and Andropogon tectorum during early rainy season in Abeokuta South West, Nigeria," *Niger. J. Anim. Sci.*, vol. 20, no. 4, pp. 504–512, 2018.

[13] R. Pajura, A. Maslon, and J. Czarnota, "The use of waste to produce liquid fertilizers in terms of sustainable development and energy consumption in the fertilizer industry-A case study from Poland," *Energies*, vol. 16, no. 4, pp. 1–24, 2023, doi: 10.3390/en16041747.

[14] T. Paul, A. Mandal, and K. C. Mondal, "Waste to value aided fertilizer: An alternative cleaning technique for poultry feathers waste disposal," *Ann. Microbiol. Immunol.*, vol. 1, no. 2, pp. 1–10, 2018.

[15] M. I. Nossier, "Impact of organic fertilizers derived from banana and orange peels on tomato plant quality," *Arab Univ. J. Agric. Sci. Ain Shams Univ. Cairo, Egypt*, vol. 29, no. 1, pp. 459–469, 2021, doi: 10.21608/ajs.2021.46495.1278.

[16] M. Sogani, K. Sonu, Z. Syed, and J. Rajvanshi, "Preparation of biofertilizer blend from banana peels along with its application in agriculture and plant microbial fuel cell," in *IOP Conference Series: Earth and Environmental Science*, 2023, vol. 1151, no. 1, doi: 10.1088/1755-1315/1151/1/012034.

[17] S. Nayaka and G. M. Vidyasagar, "Development of eco-friendly bio-fertilizer using feather compost," *Ann. Plant Sci.*, vol. 2, no. 7, pp. 238–244, 2013.

[18] M. Wyciszkiewicz, A. Saeid, K. Chojnacka, and H. Gorecki, "Production of phosphate biofertilizers from bones by phosphate-solubilizing bacteria Bacillus megaterium," *Open Chem*, vol. 13, pp. 1063–1070, 2015, doi: 10.1515/chem-2015-0123.

[19] M. Jastrzebska, M. K. Kostrzewska, K. Treder, W. P. Jastrzebski, and P. Makowski, "Phosphorus biofertilizers from ash and bones-Agronomic evaluation of functional properties," *J. Agric. Sci.*, vol. 8, no. 6, pp. 58–70, 2016, doi: 10.5539/jas.v8n6p58.

[20] A. Wazir, Z. Gul, and M. Hussain, "Comparative study of various organic fertilizers effect on growth and yield of two economically important crops, potato and pea," *Agric. Sci.*, vol. 9, no. 6, pp. 703–717, 2018, doi: 10.4236/as/2018.96049.

[21] S. Anjum and S. Sundaram, "Comparative study on nutrient composition and functional characteristics of tropical fruits with emphasis on banana fruit peel," *Int. J. Pharm. Pharm. Sci.*, vol. 14, pp. 25–35, 2022.

[22] A. G. Adeniyi *et al.*, "Metal oxide rich char from muffle furnace and retort heated reactor treated cow bone," *Clean. Eng. Technol.*, vol. 8, no. 100485, pp. 1–8, 2022, doi: 10.1016/j.clet.2022.100485.

[23] S. V Bharathi and I. V Raj, "Studies on the chemical properties of broiler chicken feathers," *Pharma Innov. J.*, vol. 10, no. 7, pp. 202–204, 2021.

[24] S. A. Lee, L. V. Lagos, M. R. Bedford, and H. H. Stein, "Quantities of ash, Ca, and P in metacarpals, metatarsals, and tibia are better correlated with total body bone ash in growing pigs than ash, Ca, and P in other bones," *J. Anim. Sci.*, vol. 99, no. 6, pp. 1–6, 2021, doi: 10.1093/jas/skab149.

[25] N. A. Nordin, N. A. Najwa, N. Fatihah, and N. Syazwani, "Development of organic fertilizer from banana peel, egg shell and yeast for the effective growth of chili plant," *Multidiscip. Appl. Res. Innov.*, vol. 3, no. 2, pp. 302–311, 2022, doi: 10.30880/mari.2022.03.02.034.

[26] C. M. F. dos Santos, C. M. Narciso, and I. R. Soares, "Analysis of heat treatment of chicken bones for the obtaining of phosphate biofertilizer," *Brazilian J. Dev.*, vol. 6, no. 3, pp. 14288–14296, 2020, doi: 10.34117/bjdv6n3-337.

[27] G. Gallo, S. V Ushakov, A. Navrotsky, and M. C. Stahlschmidt, "Impact of prolonged heating on the color and crystallinity of bone," *Archaeol. Anthropol. Sci.*, vol. 15, no. 143, pp. 1–25, 2023, doi: 10.1007/s12520-023-01842-0.

[28] M. Ibrahim, Y. R. Tasi'u, M. Umma, and I. I. Dangora, "The effects of inorganic fertilizer on soil characteristics and production of Egg Plant (Solanum melongena) in Warawa area of Kano State," *Stand. Res. J. Agric. Sci.*, vol. 2, no. 8, pp. 129–135, 2014.

[29] J. Kjeldahl, "A new method for the determination of

nitrogen in organic matter," *Zeitschrift fur Anal. Chemie*, vol. 22, pp. 366–382, 1883, doi: 10.1007/BF01338151.

[30] P. Saez-Plaza, T. Michalowski, M. J. Navas, A. G. Asuero, and S. Wybraniec, "An overview of the Kjeldahl method of nitrogen determination. Part I. Early history, chemistry of the procedure, and titrimetric finish," *Crit. Rev. Anal. Chem.*, vol. 43, no. 4, pp. 178–223, 2013, doi: 10.1080/10408347.2012.751786.

[31] A. M. Khan *et al.*, "Conversion of waste animal bones to biofertilizer and adsorbent for wastewater treatment: An innovative approach to develop zero-waste technology," *Res. Sq.*, pp. 1–28, 2023, doi: 10.21203/rs.3.rs-3134479/v1.

[32] P. Kshetri *et al.*, "Transforming chicken feather waste into feather protein hydrolysate using a newly isolated multifaceted keratinolytic bacterium Chryseobacterium sediminis RCM-SSR-7," *Waste Biomass Valoris.*, pp. 1–13, 2017, doi: 10.1007/s12649-017-0037-4.

[33] S. E. Tolubanwo, N. A. A. Okereke, C. N. Madubuike, G. I. Nwandikom, and N. N. Oti, "The effect of fertilizer type-mucuna and NPK, on the proximate values of orange flesh sweet potato," *Int. J. Res. Stud. Agric. Sci.*, vol. 5, no. 11, pp. 52–57, 2019, doi: 10.20431/2454-6224.0511007.

[34] P. Matkowski, A. Lisowski, and A. Swietochowski, "Pelletising pure wheat straw and blends of straw with calcium carbonate or cassava starch at different moisture, temperature, and die height values; Modelling and optimisation," *J. Clean. Prod.*, vol. 272, no. 122955, 2020, doi: 10.1016/j.jclepro.2020.122955.

[35] P. Intanon, A. Keteku, and R. Intanon, "Effect of different materials on soil pH improvement, soil properties, growth, yield and quality of sugarcane," in *13th International Conference of the East and Southeast Asia Federation of Soil Science Societies [13th ESAFS, 12-15 December 2017 at Pattaya-Thailand]*, 2017, p. 243.

[36] S. O. Jadoski, M. F. Maggi, A. dos S. Lima, D. J. Vieira, and R. Wazne, "NPK formula review 8-30-20 with the addition of gypsum agricultural compared to conventional fertilizer for potato (Solanum tuberosum L.) production," *Pesqui. Apl. Agrotechnologia*, vol. 3, no. 1, pp. 111–115, 2010.

[37] T. K. Haraldsen, P. A. Pederson, and A. Gronlund, "Mixtures of bottom wood ash and meat and bone meal as NPK fertilizer," in *Recycling of Biomass Ashes*, 2011, pp. 33–44.

[38] A. S. Jeng, T. K. Haraldsen, A. Gronlund, and P. A. Pedersen, "Meat and bone meal as nitrogen and phosphorus fertilizer to cereals and rye grass," *Nutr. Cycl. Agroecosystems*, vol. 76, no. 2, pp. 183–191, 2006, doi: 10.1007/s10705-005-5170-y.

[39] G. M. Ubi and W. Ubi, "Growth and yield response of cucumber (Cucumis sativa L) to N.P.K 20:10:10 fertilizer application in Southern Nigeria," *Int. J. Avian Wildl. Biol.*, vol. 3, no. 6, pp. 443–445, 2018, doi: 10.15406/ijawb.2018.03.00138.

[40] O. A. Agba, B. E. Ubi, S. C. Chukwu, and S. C. Eze, "Effects of spacing and NPK 20:10:10 fertilizer on the growth and yield of okra (Abelmoschus esculentus L. (Moench))," *Vegetos An Int. J. Plant Res.*, vol. 31, no. 2, pp. 1–7, 2018, doi: 10.4172/2229-4473.1000415.

[41] S. U. Awere and D. A. Onyeacholem, "Effect of spacing and NPK 20:10:10 fertilizer on the growth and yield of watermelon (Citrullus lanatus) in Enugu, South Eastern Nigeria," *J. Exp. Res.*, vol. 2, no. 2, pp. 93–99, 2014.

[42] L. S. Ayeni, "Effect of sole and combined cocoa pod ash, poultry manure and NPK 20:10:10 fertilizer on soil organic carbon, available P and forms of nitrogen on alfisols in Southwestern Nigeria," *Int. Res. J. Agric. Sci. Soil Sci.*, vol. 1, no. 3, pp. 77–82, 2011.

[43] Syafruddin, Herawati, A. Abdullah, M. Azrai, I. Meida, and Sulastri, "Effectiveness and recommendation of NPK-compound fertilization on maize," in *2nd ICFST IOP Conference Series: Eart and Environmental Science 2021*, 2021, vol. 911, no. 012031, pp. 1–11, doi: 10.1088/1755-1315/911/1/012031.

[44] D. Neina, "The role of soil pH in plant nutrition and soil remediation," *Appl. Environ. Soil Sci.*, vol. 2019, no. 5794869, pp. 1–9, 2019, doi: 10.1155/2019/5794869.

[45] S. O. Oshunsanya, "Introductory chapter: Relevance of soil pH on agriculture," in *Soil pH for Nutrient Availability and Crop Performance*, S. Oshunsanya, Ed. IntechOPen, 2019, p. 82.

[46] S. H. Prabhudev *et al.*, "Effect of soil pH on plants growth, phytochemical contents and their antioxidant activity," *J. Adv. Appl. Sci. Res.*, vol. 5, no. 5, pp. 15–39, 2023.

[47] P. Baboo, "Experience of material in fertilizers industries," *Glob. Sci. Journals J. Glob. Mark.*, vol. 9, no. 1, pp. 1668–1681, 2021.

[48] P. Baboo, "Material technology for fertilizers industries." pp. 1–95, 2021, doi: 10.13140/RG.2.2.20549.99044.

[49] P. Baboo, "Biofertilizers and ecofriendly approach," *Indian J. Environ. Prot.*, vol. 29, no. 12, pp. 1046–1054, 2009.

[50] P. Baboo, "Environment management and advanced waste treatment system in nitrogeneous fertilizers plant." pp. 1–20, 2016.