LAUTECH Journal of Engineering and Technology 19 (4) 2025: 13-24
10.36108/laujet/5202.91.0420

Production of Biofertiliser from Soybean Cake and Soypod

[1]Oladejo O. S., [2]Tiamiyu A. I. and [3]Olaniyan O. S.

[1,2,3]Department of Civil Engineering, Ladoke Akintola University of Technology, Ogbomoso, Nigeria.

Article Info

Article history:

Received: July 11, 2025
Revised: Aug. 6, 2025
Accepted: Aug. 8, 2025

Keywords:

Organic fertiliser, Solid State Fermentation (SSF), Soil fertility, Soybean cake, Soybean pod

Corresponding Author:
abdfatah2@gmail.com

ABSTRACT

Soil fertility can be improved by the use of fertiliser, from chemical or biological sources. Excessive use of chemical fertiliser has caused a large number of environmental pollutions in water, air and soil. This research aimed to produce organic fertiliser from soybean cake and pod using Solid State Fermentation (SSF). Soybean cake and pod samples from WASIL Oil Company, Sagamu, Nigeria, underwent NaOH pretreatment for delignification. Physico-chemical parameters, including temperature, Total Dissolved Solids (TDS), moisture content (MC), pH, phosphate, potassium, calcium, nitrate, and sulphate, were analyzed using standard methods. Microbial populations were determined through agar plate and broth culturing, while SEM, FTIR, and EDX analyses were conducted on raw and pretreated samples. Results showed that for soybean cake, temperature was 28.50 °C, TDS 34.9 mg/l, MC 58.4%, pH 7.56, phosphate 2.81 mg/l, potassium 2.50 mg/l, calcium 38 mg/l, nitrate 2.69 mg/l, and sulphate 32 mg/l. For soybean pod, values were 28.40 °C, 33.1 mg/l, 51.2%, 7.06, 2.90 mg/l, 2.8 mg/l, 41 mg/l, 2.84 mg/l, and 36 mg/l respectively. Microbial counts for soybean cake included Salmonella (2.4×10^4), E. coli (2.1×10^4), Bacillus (2.7×10^2), and Aspergillus (3.7×10^2), while the soybean pod showed Salmonella (1.9×10^4), E. coli (2.1×10^4), Bacillus (2.4×10^2), and Aspergillus (3.4×10^2). SEM revealed irregular morphological shapes at the surface layers. FTIR confirmed the presence of amine and carboxyl groups indicative of fertilisers, while EDX detected nitrogen, phosphorous, and other nutrients. The study concluded that SSF is suitable for the production of effective and economical organic fertiliser from soybean cake.

INTRODUCTION

In the past centuries, farmers were eager to the usage of chemical fertilisers as they yielded greater produce at harvest. But eventually, they realized that chemical fertilisers affect the soil fertility and kill beneficial microbes, which enhance the growth of the crops. The major issue they faced using chemical fertilisers is that the chemical fertilisers are not only affecting the soil but human beings as well (Devi and Sumathy, 2018).

Biofertilisers are low-cost, renewable sources of plant nutrients which replace chemical fertilisers. The use of Biofertiliser is of great importance because they are component of integrated nutrient management, and also a cost-effective and renewable source of energy for plants and helps in reducing the use of chemical fertilisers for sustainable agriculture (Rana *et al.*, 2013; Oladejo and Fasan, 2015).

Agro-wastes contain insoluble and soluble chemical constituents that can be utilized by microorganisms for fermentation processes (Subba, 1993; Caprara *et al*., 2011). The agro-wastes, such as decaying parts of plants, are the primary source of organic matter in soil (Subba, 1993). Therefore, agro-wastes are the cheapest source that can be used by farmers to improve the fertility of soil organic acids (Oladejo and Fasan, 2015).

Soybeans are one of the most widely grown leguminous crops globally, with over 260 million metric tons produced annually (FAO, 2019). Soybean pods contain high levels of nitrogen, phosphorus, and potassium, making them an ideal

candidate for conversion into biological fertilisers (Sharma and Singh, 2019; Patel *et al.*, 2020).

Agriculture is an essential sector that provides food, employment, and income for millions of people worldwide. However, it also generates significant amounts of waste, which can pose environmental challenges if not managed properly. These wastes can contaminate soil, water, and air, leading to negative impacts on human health and the environment (UNEP, 2018; Smith *et al*., 2019). The improper disposal of agricultural waste can lead to soil contamination, reduce soil fertility, affect plant growth, and potentially cause long-term health problems for humans and animals (USDA, 2020).

The overuse, mismanagement, and continuous application of chemical fertilisers have altered soil pH, increased pests, acidified soil crusts, which leads to loss of organic matter and humus, reduction of useful organisms, stunted plant growth, and even contributes to greenhouse gas emissions (Jones *et al*., 2020; Brown and Miller, 2019).

MATERIALS AND METHODS

Materials Collection

Three thousand grammes (3000g) each of soybean pods (Plate 1) and soybean cakes (Plate 2) were collected from WASIL Oil, Sagamu, Ogun state, Nigeria. They were kept in black polyethylene bags and transported to the Environmental Laboratory at Landmark University, where the pretreatment was carried out. The samples were nurtured in sodium hydroxide (NaOH) solution at a ratio of 40g of NaOH to 1000 cm^3 of distilled water, that is, 1 molar at room temperature for 24 hours, after which the samples were washed repeatedly with water and oven dried at 60 °C to a constant weight. This pretreatment is necessary to lessen the structure of lignocellulosic biomass (Zhang *et al*., 2018; Kumar and Sharma, 2017).

Plate 1: Soybean cake taken from WASIL Oil Sagamu.

Plate 2: Soybean Pod taken from WASIL Oil Sagamu.

Preparation of Fermented Powders

Fermented powders of soybean cake and pod were prepared via the solid-state fermentation (SSF) process. The SSF employed was modified after Asensio-Grau *et al*. (2020). Three thousand grammes (3000g) of soybean cake powder (SP) and 200 g of distilled water were added to fermentation bottles (300 mL) and then sterilised using an autoclave at 121 ℃ for 30 mins. 3mL of cultured suspension (3.2 mg/mL biomass, dry weight) was added to each sterilised bottle for SSF. The cultures were covered with tinfoil and incubated at 28 ℃ for 14 days in the dark. Upon completion of the incubation period, the fermented substrates were removed and transferred to a blast drying oven, where they were dried at 60 ℃ for 24 h. To achieve

a consistent particle size, the dried substrates were ground into powders and sifted through a 40-mesh sieve. Then, the fermented powders were stored in self-sealing polyethylene bags for further analysis and determination. SP without fermentation was sterilised under the same conditions as a control, corresponding to SSP (sterilised soybean meal powder).

Physical Parameters

The physical properties taken into consideration were determined through the following laboratory procedures;

a. Determination of Temperature

The temperature (℃) of each of the samples was measured using a digital thermometer (Model DT-3, accuracy ± 0.1 °C). The tip of the thermometer containing mercury was vertically immersed in the sample (of mixed ratio). The measurements were recorded only after a steady temperature was observed.

b. Determination of Total Solids

The total solid (TS) is made up of Dissolved solids (DS) and suspended solids (SS). Samples of different ratios were taken into a measuring cylinder and the electrode was inserted into it (probe). This was done using a multipara meter, which gives a reading in Mg/l.

$$\text{Total solids (m/l)} = \frac{mg.total\ solids \times 1000}{ml\ sample} \quad (1)$$

c. Determination of Moisture Content

Samples were placed in a pre-weighed sample container and taken into an oven at 105 ℃ for 24 h. Thereafter, samples were removed and rapidly transferred into a desiccator to prevent more moisture uptake from the atmosphere, and then reweighed. The amount of moisture removed was determined as

$$\% \text{ moisture content} = \frac{W_2 - W_3}{W_2 - W_1} \quad (2)$$

Weight of clean crucible, W_1

Weight of clean crucible + sample= W_2

Weight of clean crucible + dried sample= W_3

Total loss in weight= W_2 - W_3

Weight of sample= W_2 - W_1

Chemical Parameters

The chemical properties taken into consideration were determined through the following laboratory procedures;

a. Determination of pH

An electrometric method using a combination of a glass electrode with a reference potential provided by a standard calomel electrode was used for measuring pH, following APHA (2017) standard procedures. Immediately before sample measurement, the pH meter was standardised with two buffer solutions of different pH values to serve as a check for proper instrument response. Thereafter, measurements of the pH values of the samples were conducted. In the measurements of the pH values, the electrodes were thoroughly rinsed with buffer solutions between samples and after all measurements.

b. Determination of Phosphate

Phosphate was determined by Bray's method. 5 g of the sample was weighed in each sample bottle. 35 ml of extracting solution (containing IN of Ammonium Fluoride and 0.5 M of Hydrogen Chloride) was added to each sample, the mixtures were shaken for 5 minutes and filtered using (Whatman No 42) filter paper. The extracts were pipetted and 5 ml of the development solutions were added. These contents were then made up to mark 50 ml standard volumetric flask with distilled water and allowed to stand for 30 minutes. The absorbances were read at 660 nm wavelength using

a spectrophotometer (Spectronic 20, used in the determination of the intensity of colour). This same procedure was carried out for the blank, i.e., without a soil sample.

$$\text{Phosphate} = \frac{reading\ (in\ ppn) X\ volume\ of\ extracts}{Weight\ of\ sample\ \ (5\ g)} \quad (3)$$

c. Determination of Potassium

The flame photometer was placed in a location where there were no direct rays of sunlight or constant light emitted by an overhead fixture and free from dust and tobacco smoke. The sample and a blank and a potassium calibration standard in steps in any of the following application ranges: 0-1.0; 0-10 or 0-100 mg/l were prepared. Starting with the highest concentration and then working towards the most dilute solution, the emission on the photometer at 589 nm was measured. The calibration curve was constructed from the potassium standards. The sample was run on the photometer at 589 nm and the reading was noted.

$$\text{K(mg/l)} = \frac{Concentration\ reading\ on\ curve \times D}{Volume\ (ml) sample} \quad (4)$$

d. Determination of Calcium

A 100 ml sample was measured, and 2 ml of 2 M NaOH was added as a buffer solution. Using solochrome as an indicator, it will be pink, and titrate against EDTA. The colour changes from pink to light blue. Where A = ml titration for sample, B = ml titration for blank, M = molarity of $KMnO_4$

$$\text{Ca (mg/l)} = \frac{(A-B)\times M \times 40{,}080}{ml\ sample} \quad (5)$$

e. Determination of Nitrate

Nitrate was determined using the colorimetric method. A known volume of sample was mixed with sulfanilamide reagent in an acidic medium to form a diazonium salt. N-(1-naphthyl)-ethylenediamine dihydrochloride was then added to form a pink azo dye complex. The intensity of the pink color, which is proportional to the nitrate concentration, was measured spectrophotometrically at 543 nm wavelength against a reagent blank.

$$\text{Nitrate (mg/l)} = \frac{A \times F \times 1000}{V} \quad (6)$$

f. Determination of Sulphate

Sulphate is precipitated hydrochloric acid medium as barium sulphate by the addition of a chloride solution. Take 100 to 400 ml of the sample, filter if necessary. Add 1:1 HCl in drops until then, add three drops in excess and evaporate to 50 ml. Boil the solution and add boiling sodium chloride solution until all the sulphate is precipitated. Digest in a water bath until the precipitate has settled. Dry the sintered-glass crucible to constant weight. Connect the filtering equipment to the vacuum pump and filter the precipitate through a sintered-glass crucible. Wash many times with hot water until the filtrate is chloride-free ($AgNO_3$ test). Dry the crucible precipitate in an oven at 103-105 ˚C to constant weight. Know the weight of the precipitate alone by difference.

$$SO_4^{2-}\ (\text{mg/l}) = \frac{mg\ BaSO_4 \times 411.5}{ml.\ sample} \quad (7)$$

Microbial Parameters

Microbiological analysis was carried out on samples to show the presence of microorganisms, and the procedures used to determine the samples are given below;

a. Determination of Salmonella

One hundred milliliter (100 ml) of buffered peptone water was added to the sample. The mixture was shaken in an up-and-down motion at least 10 times in a 30 cm (1 ft) arc in approximately 30 seconds. The sample was incubated for 24 ± 2 h at 35 °C. 1 ml of the incubated pre-enrichment was moved into 10 ml of tetrathionate (TT) broth. 0.1 ml of the incubated pre-enrichment was transferred to 10 ml

of medium. The TT broth and the Bpw medium were incubated for 24 ± 2 h at 42.0 ± 0.2 °C (water bath). After incubation, a loopful of TT broth was streaked onto brilliant green agar plates. All plates were incubated for 24 ± 2 h at 35 °C. Plates were checked for the presence of colonies that may be Salmonella. Any 5 typical colonies from each plate were selected and hatched on TSI and LIA inclines at 24 ± 2 h at 35 °C.

b. Determination of *Escherichia coli*

A 1ml sample of soybean cake and pod was taken into one of the 100 ml volumetric flasks and made to the mark with distilled water. Three petri dishes were obtained and an adsorbent pad was put in each of them. Two milliliters (2 ml) of M-coliform broth solution were dispensed in three different petri dishes with an adsorbent pad. Sterilised pipettes were used to withdraw volumes, ranging from 0.1 ml to 2 ml, as found convenient, from the diluted samples made. Each was made up to 100 ml and then filtered through a membrane filter with the aid of a vacuum pump. The filter membrane was placed in the adsorbent pad containing the broth solution. The broth served as a nutrient for the coliforms. Then it was placed in an incubator pre-set to 35.0 ± 5 ℃. It was incubated for 24 hours. Greenish-metallic shining colonies on the filter membrane were observed.

c. Determination of *Bacillus spp*

Since a petri dish was provided with bacterial colonies or a prepared slide of mixed bacteria, a part of the colony on the end of a wire loop was picked up, and the sample was smeared on a microscope slide with a drop of water. With a dropping pipette, a drop of methylene blue was put on the smear. It was left there for a minute. The stain was washed off the sample with a gentle stream of water. The slide was dried by blotting it very gently with filter paper. The sample was examined under the microscope.

d. Determination of *Aspergillus spp*

A small sample of each of the cultured samples was placed on a clean glass slide and Gram staining was carried out for better visibility. The slide was placed under a microscope to determine the presence of Aspergillus species by looking for conidiophores (a type of spore-producing structure) and conidia (the asexual spores).

Analytical Characterization

a. Fourier Transform Infrared Spectrometer (FTIR)

FTIR spectroscopic analysis was performed on both raw and chemically treated samples of soybean cake and pod to determine characteristic functional groups present in the samples.

b. Scanning Electron Microscopy (SEM)

Particle dimensions and morphology were examined using SEM (Hitachi SU 3500 scanning microscope, Tokyo, Japan) to observe physical surface characteristics of the samples.

c. Energy Dispersive X-ray Spectroscopy (EDX)

SEM-EDX analysis was employed to observe the physical morphology of sample surfaces and analyze elemental compositions, including light elements such as carbon, nitrogen, and oxygen. The EDX detector was equipped with ultra-thin element light windows capable of detecting elements with atomic numbers greater than 4. TESCAN Scanning Electron Microscope analysis was performed on both raw and chemically treated soybean cake and pod samples.

RESULTS AND DISCUSSION

Physical analysis of the Soybean cake and pod

Table 1 shows the temperature, Total Dissolved Solids (TDS), and moisture content (MC) for soybean cake and soybean pod, respectively. The soybean cake sample showed a reduced temperature of 7.744% and 4.04% after pretreatment and aerobic

digestion, respectively. The raw soybean cake had a temperature of 29.7 ℃ and was reduced to 28.5 ℃ after aerobic digestion. Similarly, the soybean pod sample showed a 5.76% and 1.44% percentage reduction in temperature after pretreatment and aerobic digestion, respectively. Total dissolved solids (TDS) is a function of how solids are present with or without digestion. The TDS for soybean cake showed a percentage increase of 15.74% and 7.72% after pretreatment and aerobic digestion, respectively. The soybean cake with a TDS of 32.4 mg/l increased to 37.5 mg/l and 34.9 mg/l after pretreatment and aerobic digestion, respectively. It was observed that for the soybean cake with an MC of 11.2%, it increased to 41.6% and 58.4% after pretreatment and aerobic digestion, respectively. Also, the soybean pod with an MC of 9.4% increased to 39.8% and 51.2% after pretreatment and aerobic digestion. This increase in MC is expected because when the soybean cake and pod were chemically treated, they underwent a process, thereby absorbing water and the MC further increased during the aerobic digestion. Similar trends have been reported by Mouhamad *et al.* (2020) and Okareh *et al.* (2014) in their studies on organic waste treatment, where chemical pretreatment led to increased water absorption capacity due to structural modifications of the lignocellulosic matrix.

Table 1: Physical Analysis of Soybean Cake and Soybean Pod Samples

	Soybean Cake			**Soybean Pod**		
Parameters	Raw	Pretreated	Aerobic	Raw	Pretreated	Aerobic
Temperature (℃)	29.7	27.4	28.5	27.8	26.2	28.4
TDS (mg/l)	32.4	37.5	34.9	29.7	38.6	33.1
MC (%)	11.2	41.6	58.4	9.4	39.8	51.2

Chemical Analysis of the Soybean cake and pod.

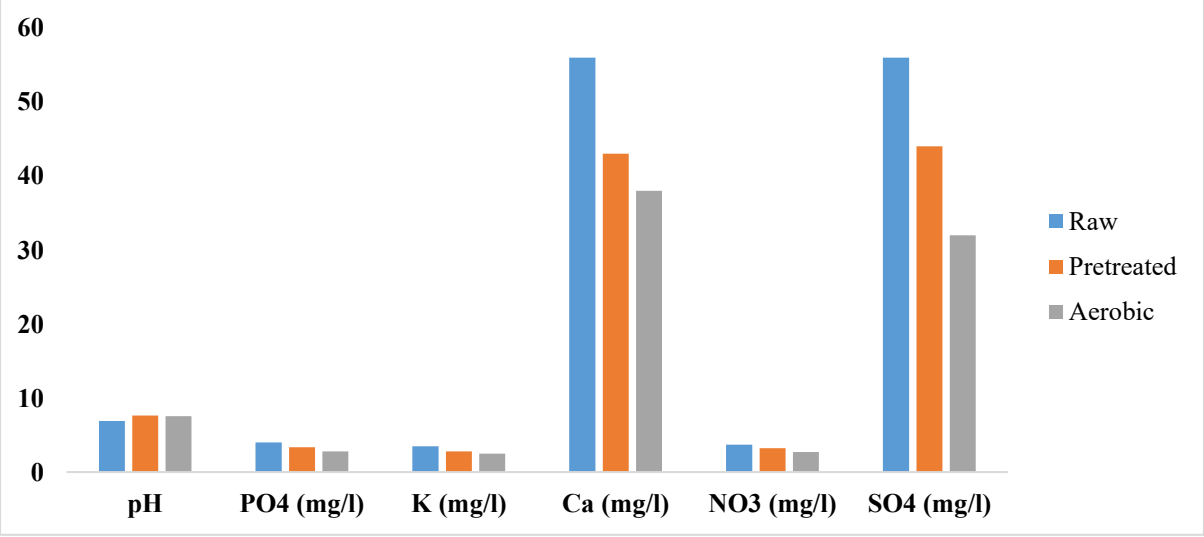

Figure 1: Variation of Chemical Analysis of **Soybean** Cake

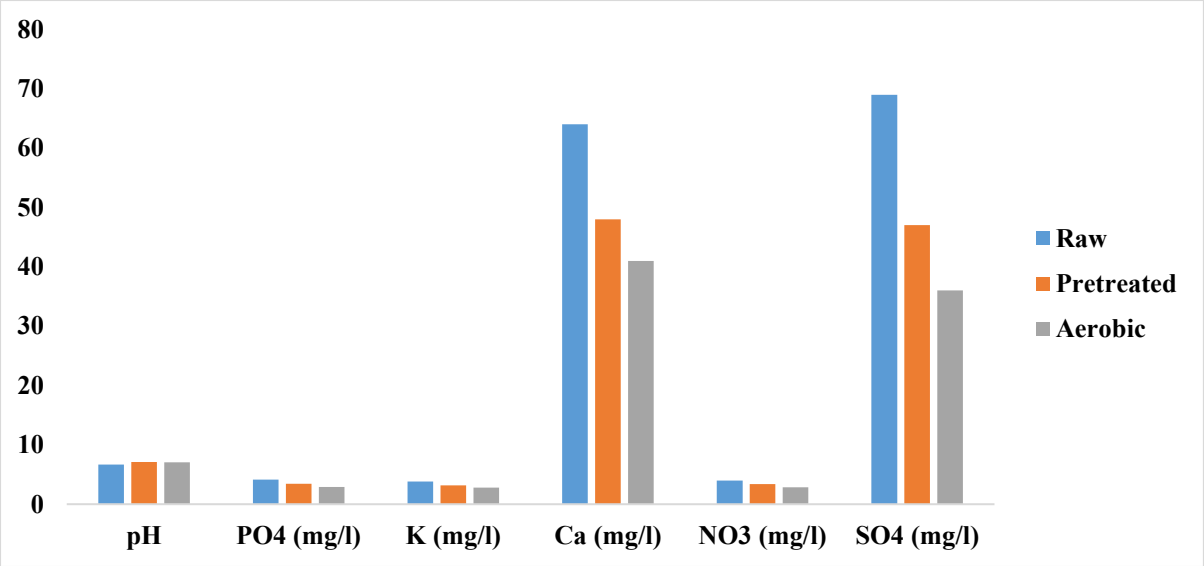

Figure 2: Variation of Chemical Analysis of Soybean Pod

The pH, phosphate, potassium, calcium, nitrate, and sulphate for soybean cake and soybean pod are presented in Figures 1 and 2. The pH of soybean cake increased from 6.91 to 7.64 and 7.56 after pretreatment and aerobic digestion, respectively. Also, for the soybean pod, the pH increased from 6.67 to 7.10 and 7.06 after pretreatment and aerobic digestion, respectively. The pH values obtained after aerobic digestion for the samples are within the recommended 7-8 pH range, and hence, the organic fertilizer produced is suitable for plant growth and nourishment. The pH values indicate near-neutral to slightly alkaline conditions, which are optimal for most crops as they enhance nutrient availability and microbial activity in soil (Brady and Weil, 2017). Moreover, the change in pH is a good indicator, as microbial activity has changed (Mouhamad *et al.,* 2020). The PO_4^{3-} (mg/l) for soybean cake significantly reduced by 16.71% and 29.93% after pretreatment and aerobic digestion, respectively. Notably, the PO_4^{3-} (mg/l) reduced from 4.01 mg/l to 3.34 mg/l and 2.81 mg/l after pretreatment and aerobic digestion, respectively. Also, the PO_4^{3-} (mg/l) for soybean pod significantly reduced by 17.55% and 30.29% after pretreatment and aerobic digestion, respectively. This reduction could be attributed to the formation of complex organic phosphorus compounds during the fermentation process, which are more stable and slowly released forms of phosphorus that are beneficial for sustained plant nutrition (Singh *et al.*, 2018). Potassium (K^+) (mg/l) for soybean cake significantly reduced by 20.00% and 28.57% after pretreatment and aerobic digestion, respectively.

Mainly, the K^+ (mg/l) reduced from 3.5 mg/l to 2.80 mg/l and 2.50 mg/l after pretreatment and aerobic digestion, respectively. The reduction in potassium levels could be due to the complexation of K^+ ions with organic matter during fermentation, creating slowly available forms that provide sustained nutrient release when applied to soil (Kumar *et al*., 2019). Also, the K^+ (mg/l) for soybean pod significantly reduced by 15.79% and 26.32% after pretreatment and aerobic digestion, respectively. The Ca^{2+} (mg/l) for soybean cake significantly reduced by 23.21% and 32.14% after pretreatment and aerobic digestion, respectively. Mainly, the Ca^{2+} (mg/l) reduced from 56 mg/l to 43 mg/l and 38 mg/l after pretreatment and aerobic digestion, respectively. Also, the Ca^{2+} (mg/l) for soybean pod significantly reduced by 25.00% and 35.94% after pretreatment and aerobic digestion, respectively.

NO_3^- (mg/l) for soybean cake significantly reduced by 12.90% and 27.69% after pretreatment and aerobic digestion, respectively. Particularly, the NO_3^- (mg/l) reduced from 3.72 mg/l to 3.24 mg/l and 2.69 mg/l after pretreatment and aerobic digestion, respectively. The reduction in nitrate levels is consistent with findings of Mahalakshmi and Naveena (2016), with similar trends in organic fertiliser production from agricultural wastes. This reduction indicates conversion of nitrate to organic nitrogen forms, which are more stable and provide gradual nutrient release. Also, the NO_3^- (mg/l) for soybean pod significantly reduced by 15.33% and 28.64% after pretreatment and aerobic digestion, respectively. Notably, the NO_3^- (mg/l) reduced from 3.98 mg/l to 3.37 mg/l and 2.84 mg/l after pretreatment and aerobic digestion, respectively. The SO_4^{2-} (mg/l) for raw soybean cake was 56 mg/l and it reduced significantly to 44 mg/l after pretreatment and 32 mg/l after aerobic digestion. Similarly, the SO_4^{2-} (mg/l) for the soybean pod reduced from 69 mg/l to 47 mg/l and 36 mg/l after pretreatment and aerobic digestion, respectively. The reduction in SO_4^{2-} after aerobic digestion is an indication that digestion has taken place. These values are comparable to those reported by Okareh *et al*. (2014) in their study on organic fertiliser production from food wastes.

Microbial Analysis

The microbial parameters for soybean cake and pod samples are shown in Table 2. The soybean cake showed the presence of microbes with Salmonella at 2.4×10^4, Escherichia coliform at 2.1×10^4, Bacillus at 2.7×10^2 and Aspergillus count at 3.7×10^2.

These microbes in the digested soybean cake will provide nutrients since organic fertiliser incorporates living micro-organisms, which are not present in chemical fertilisers. This result is similar to Mahalakshmi and Naveena (2016) and Okareh *et al*. (2014). In Mahalakshmi In Mahalakshmi and Naveena (2016), the organic fertiliser produced from banana waste showed the presence of microbes of Salmonella, Escherichia coliform, Bacillus and Aspergillus. The soybean pod showed the presence of microbes: Salmonella at 1.9×10^4, Escherichia coliform at 2.1×10^4, Bacillus at 2.4×10^2 and Aspergillus count at 3.4×10^2. These microbes in the digested soybean pod will provide nutrients since organic fertiliser incorporates living micro-organisms, which are not present in chemical fertilisers.

Analytical Characterization

The results of the FTIR, SEM and EDX for the chemical structure analysis are presented in the following sections.

Fourier Transform Infrared Spectrometer (FTIR)

a. FTIR of Raw Soybean Cake

The FTIR analysis of soybean cake and pod is shown in Figures 3 and 4. The wavelength of raw soybean cake at 1500 cm^3 is 1550 in Figure 3, and for treated soybean cake in Figure 4, the wavelength at 1500 cm^3 is 1598.6. The wavelength value is an indication that chemical pre-treatment has successfully eliminated the lignin and hemicellulose content, which inhibits the production of organic fertilisers (Zhang *et al*., 2018; Kumar and Sharma, 2017).

b. FTIR of Raw Soybean pod

The functional groups and transformation of the soybean pod before and after pretreatment are shown in Figures 5 and 6. For the raw soybean pod at wavelength 1500 cm^3 is 1554.9 in Figure 5 and the wavelength for the treated soybean pod at 1500 cm^3 is 1569.5 in Figure 6, indicating that the chemical treatment utilized has successfully removed the lignin and hemicellulose content that are present in the soybean pod (Zhang *et al*., 2018; Kumar and Sharma, 2017).

Table 2: Microbial Analysis of Soybean Cake and Soybean Pod Samples

	Soybean Cake			**Soybean Pod**		
Parameters	Raw	Pretreated	Aerobic	Raw	Pretreated	Aerobic
Salmonella Count	3.0×10^4	1.0×10^2	2.4×10^4	2.6×10^4	0	1.9×10^4
E. Coli	3.6×10^5	1.3×10^2	2.1×10^4	2.9×10^5	1.1×10^2	2.1×10^4
Bacillus Count	4.0×10^2	1.6×10^2	2.7×10^2	3.2×10^2	1.4×10^2	2.4×10^2
Total viable count	4.6×10^5	1.4×10^4	3.7×10^2	3.8×10^5	1.2×10^4	3.4×10^2

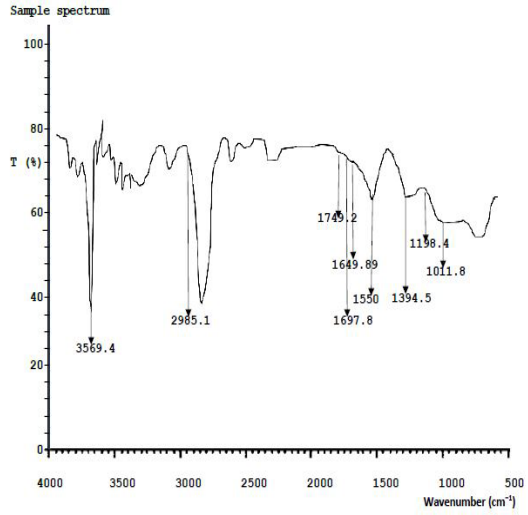

Figure 3: FTIR image of Raw Soybean Cake

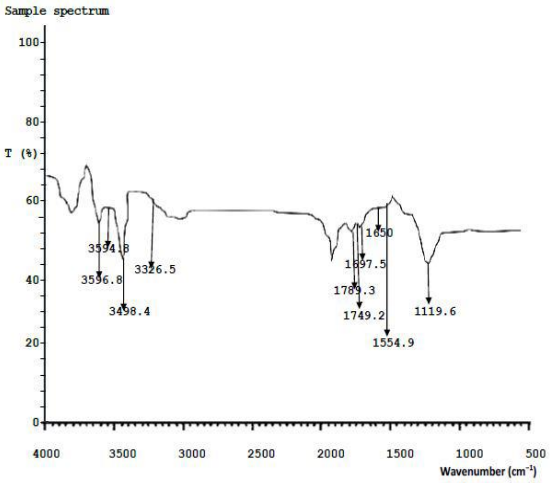

Figure 5: FTIR image of Raw Soybean Pod

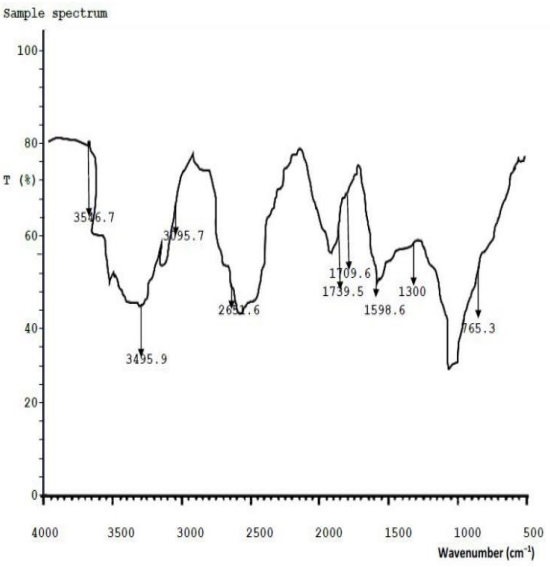

Figure 4: FTIR image of Treated Soybean Cake

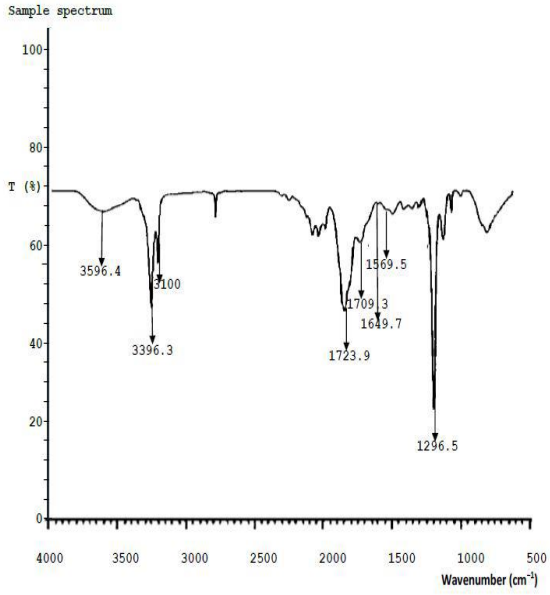

Figure 6: FTIR image of Treated Soybean Pod

Scanning Electron Microscopy

a. SEM of Raw Soybean Cake

The morphological characteristics of the soybean cake samples before and after pre-treatment were observed using SEM analysis. The SEM analysis of soybean cake is shown in Figures 7 and 8. It can be seen from the Figures that the raw soybean cake shows irregular morphological shape with lumps of particles and deep porous overlap at its surface layer and the treated soybean cake shows a network of fibre particles with many hollow spaces in between its surface, which are connected. This structural modification indicates successful delignification and increased surface area for microbial accessibility, which enhances the fermentation process and nutrient release characteristics (Liu *et al*., 2019).

b. SEM of raw Soybean pod

The morphological characteristics of the soybean pod samples before and after pre-treatment were observed using SEM analysis. The SEM analysis of the soybean pod is shown in Figures 9 and 10. It can be seen from the Figures that the raw soybean pod shows the agglomeration of the rough particles with irregular shapes and the treated soybean pod shows rough cluster particles with pores in its structural layer.

Energy Dispersive X-ray Spectroscopy (EDX)

The EDX analysis revealed the elemental composition of both raw and treated soybean cake and pod samples. The analysis confirmed the presence of essential nutrients, including nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and sulfur (S) in both samples. The presence of these macronutrients and micronutrients confirms the potential of the processed materials as effective organic fertilisers (Chen *et al*., 2020).

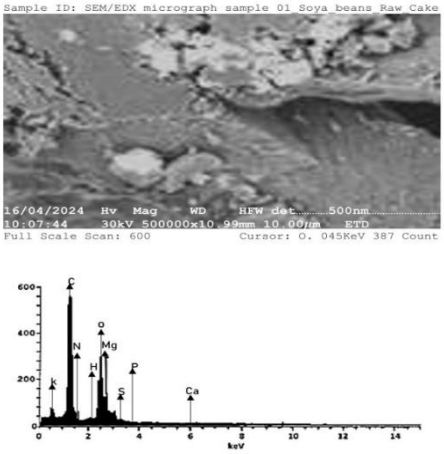

Figure 7: SEM/EDX image of Raw Soybean Cake

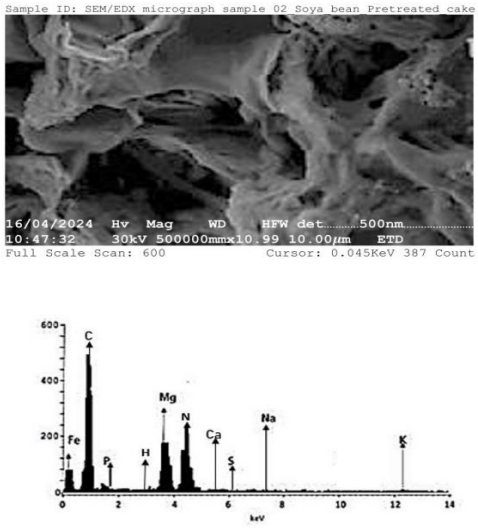

Figure 8: SEM/EDX image of Treated Soybean Cake.

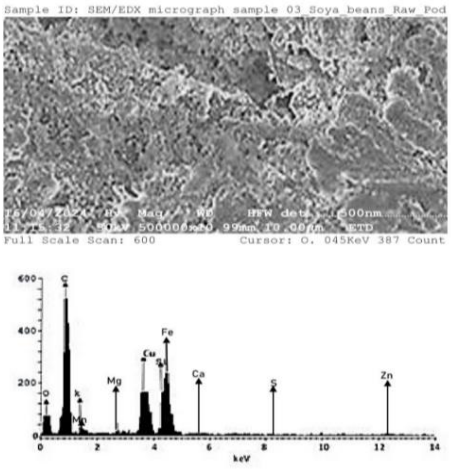

Figure 9: SEM/EDX image of Raw Soybean Pod

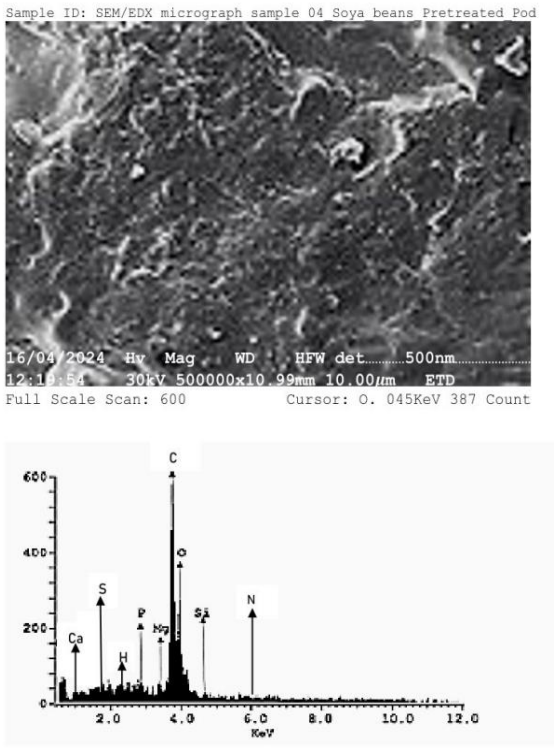

Figure 10: SEM/EDX image of Treated Soybean Pod

CONCLUSION AND RECOMMENDATIONS

This study successfully demonstrated the production of bio-fertiliser from soybean cake and pod using solid-state fermentation (SSF). The physical properties showed significant changes after pretreatment and aerobic digestion. Chemical analysis revealed optimal pH values of 7.56 and 7.06 for soybean cake and pod, respectively, after aerobic digestion, which fall within the recommended range for plant growth. Microbial analysis confirmed the presence of beneficial microorganisms, which contribute to soil health and nutrient cycling. FTIR analysis confirmed successful removal of lignin and hemicellulose content through chemical pretreatment and SEM analysis revealed structural modifications with increased porosity and surface area in treated samples, facilitating better microbial accessibility and nutrient release. The technique of SSF for the production of organic fertiliser from soybean cake and pod is effective and it should also be extended to other agricultural waste materials for the production of organic fertiliser. The comparative analysis of the performance of the organic fertiliser from soybean cake and pod with chemical fertiliser should be investigated.

REFERENCES

APHA (American Public Health Association). (2017). *Standard Methods for the Examination of Water and Wastewater* (23rd ed.). American Public Health Association, American Water Works Association, Water Environment Federation.

Asensio-Grau, A., Calvo-Lerma, J., Heredia, A., and Andrés, A. (2020). Enhancing the nutritional profile and digestibility of lentil flour by solid-state fermentation with Pleurotus ostreatus. *Food & Function*, 11, 7905-7912.

Brady, N. C., and Weil, R. R. (2017). *The Nature and Properties of Soils* (15th ed.). Pearson Education.

Brown, L. K., and Miller, S. J. (2019). Environmental impacts of chemical fertilisers on soil health and ecosystem services. *Environmental Science & Policy*, 94, 145-152.

Caprara, C., Gioacchini, P., Marzadori, C., and Ciavatta, C. (2011). Evaluation of compost and digestate effects on soil quality: A chemical and biochemical approach. *Waste Management*, 31(5).

Chen, Y., Wang, H., Liu, J., and Zhang, M. (2020). Elemental analysis of organic fertilisers using energy dispersive X-ray spectroscopy: Implications for nutrient management. *Journal of Environmental Management*, 265, 110515.

Devi, R., and Sumathy, R. (2018). Production and characterization of biofertiliser using soybean cake and soypod waste. *International Journal of Scientific Research and Reviews*, 7(4), 120-127.

FAO (Food and Agriculture Organization). (2019). *Global soybean production statistics*. Food and Agriculture Organization of the United Nations. Retrieved from https://www.fao.org/faostat/en/#data/QCL

Jones, A., Panagos, P., Barcelo, S., Bouraoui, F., Bosco, C., Dewitte, O., Gardi, C., Erhard, M., and Yigini, Y. (2020). *The State of Soil in Europe: A contribution of the JRC to the European Environment Agency's Environment State and Outlook Report – SOER 2020* (EUR 29123 EN). Publications Office of the European Union.

Kumar, A., and Sharma, S. (2017). Recent updates on different methods of pretreatment of lignocellulosic feedstocks: A review. *Bioresources and Bioprocessing*, 4(1), 7.

Kumar, V., Singh, P., and Jordon, J. (2019). Utilization of agricultural waste for sustainable biofertiliser production. *Journal of Cleaner Production*, 229, 1284-1292.

Liu, X., Wang, Y., Chen, L., and Zhou, H. (2019). Surface morphology changes in lignocellulosic biomass during pretreatment and their impact on enzymatic hydrolysis. *Biotechnology for Biofuels*, 12, 45.

Mahalakshmi, R., and Naveena, M. L. (2016). Usage of banana pseudostem waste for the production of potassic biofertiliser using cellulolytic bacteria. *International Journal of Current Microbiology and Applied Sciences*, 5(8), 336-349.

Mouhamad, R. S., Mohammed, Z. J., Abdulhadi, A. A., Abbas, M., Iqbal, M., and Nazir, A. (2020). Production and characterization of organic manure from liquorice residues. *Information Processing in Agriculture*, 7(2), 233-241.

Okareh, O. T., Oyewole, S. A., and Taiwo, L. B. (2014). Conversion of food wastes to organic fertiliser: A strategy for promoting food security and institutional waste management in Nigeria. *Journal of Research in Environmental Science and Toxicology*, 3(4), 68-73.

Oladejo, O. S., and Fasan, A. B. (2015). Production of biofertiliser from rice waste, cow dung and timber sawdust (*Daniela Oliveira*). *International Journal of Chemical, Environmental and Biological Sciences (IJCEBS)*, 3(2), 96-102.

Patel, R., Kumar, M., and Singh, D. (2020). Nutrient composition and fertiliser potential of soybean pod waste. *Waste and Biomass Valorization*, 11(8), 4321-4330.

Rana, A., Saharan, B., Nain, L., Prasanna, R., and Shivay, Y. S. (2013). Improving soil fertility and productivity through bio-fertiliser application in soybean-wheat cropping system. *Soil Biology and Biochemistry*, 58, 136-142. https://doi.org/10.1016/j.soilbio.2012.11.016

Sharma, K., and Singh, R. (2019). Valorization of soybean processing waste for sustainable agriculture. *Journal of Environmental Management*, 235, 518-526.

Singh, B., Kunhikrishnan, A., Singh, B. P., and Naidu, R. (2018). Organic phosphorus in soil: Chemistry and bioavailability. *In Phosphorus in Agriculture: 100% Zero Waste* (pp. 125-145). Springer.

Smith, P., House, J. I., Bustamante, M., Sobocká, J., Harper, R., Pan, G., West, P. C., Clark, J. M., Adhya, T., Rumpel, C., Paustian, K., Kuikman, P., and Pugh, T. A. M. (2019). Global change pressures on soils from land use and management. *Global Change Biology*, 25(8), 2685-2700.

Subba Rao, N. S. (1993). *Biofertilisers in agriculture and Forestry* (3rd ed.). Oxford & IBH Publishing Co. Pvt. Ltd.

UNEP (United Nations Environment Programme). (2018). *Agricultural waste management: A global perspective*. United Nations Environment Programme. Retrieved from https://www.unep.org/resources/report/agricultural-waste-management

USDA (United States Department of Agriculture). (2020). *Sustainable Agriculture Research and Education*. Retrieved from https://www.usda.gov/topics/sustainable-agriculture

Zhang, Q., Tang, L., Zhang, J., Mao, Z., and Jiang, L. (2018). Optimization of thermal-dilute sulfuric acid pretreatment for enhancement of methane production from cassava residues. *Bioresource Technology*, 267, 494-502.