

Proximate and Ultimate Analyses of Agricultural Byproducts: Sweet Potato Peel and Lemon Seed for Sustainable Water Treatment Applications

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ABSTRACT

Sweet potato peel (SPP) and lemon seed (LS) are agro-wastes commonly discarded in large quantities, particularly in Nigeria. With growing interest in sustainable waste management and eco-friendly water treatment solutions, these by-products offer potential as natural coagulants due to their unique chemical compositions. This study aims to investigate the feasibility of using surplus SPP and LS as natural coagulants for wastewater treatment, focusing on their proximate and ultimate characteristics to determine their effectiveness and potential applications. The proximate analysis revealed that both SPP and LS have low moisture content, beneficial for storage and reducing microbial growth risks. SPP showed higher ash, crude protein, and fibre content, which may enhance coagulation efficiency by improving floc formation and facilitating protein interactions. LS, on the other hand, exhibited significantly higher crude lipid content, indicating its potential in treating hydrophobic contaminants. The ultimate analysis highlighted LS's higher carbon content, suggesting better organic interactions, while SPP's higher oxygen and nitrogen content indicated greater reactivity and interaction potential with proteins. The sulfur content in SPP may offer unique advantages in forming sulfide bonds during coagulation. Based on the findings of this study, SPP and LS demonstrate significant potential as natural coagulants for wastewater treatment. Their distinct chemical properties suggest different applications, with SPP being particularly effective in protein-rich wastewater and LS in treating hydrophobic pollutants. The use of these agro-wastes not only provides an environmentally friendly alternative to chemical coagulants but also supports sustainable waste management practices, aligning with the principles of a circular economy.

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INTRODUCTION

Sweet potato (*Ipomoea batatas* Lam), a member of the Convolvulaceae family, originates from southern Mexico and Central America (Ahmad et al., 2021). While the plant is widely recognized for its nutritional value, different parts, including the leaves, stem, and tubers, are known to contain significant secondary metabolites such as triterpenes, coumarins, and batatins, which exhibit defined physiological activities (Batiga et

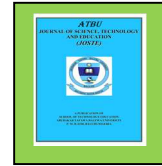
al., 2019). Typically, the tubers are peeled before consumption, and these peels are discarded, often in large quantities. The unique constituents of the sweet potato peel (SPP), distinct from those in the tuber, form the basis for investigating its potential for various applications. In light of the large volume of SPP generated as waste, especially in Nigeria, recent studies (Aboyeji et al., 2020; Olayinka, 2015) have identified valuable natural antifungal compounds within these peels

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making them of interest to various aspects of research.

In the same vein as the SPP, lemon seeds (LS), as a byproduct of the citrus processing industry, hold potential for sustainable applications, particularly in water treatment. Citrus fruits, including lemons, are highly valued both in the fresh market and as raw materials for food processing. The processing of citrus fruits generates significant amounts of byproducts such as peels, pulp, and seeds, which together account for about 50% of the total fruit processed (Medina-Herrera et al., 2024). With over 21 million tons of lemons produced globally in 2020, the volume of LS generated as waste is substantial (Panwar et al., 2021). LS which constitute about 1% of the solid waste produced during juice processing, are often overlooked despite their potential value. These seeds, alongside other parts of the lemon such as the peel, contain essential oils and other compounds that could be harnessed for various industrial applications (Nodola et al., 2024).

SPP and LS, as common agro-wastes, represent significant ecological burdens due to the large quantities produced during food processing. Despite this, their lignocellulosic content makes them valuable as low-cost, renewable, and sustainable materials for different applications including water and wastewater treatment. These materials, when subjected to appropriate treatments can be transformed into effective coagulants capable of removing aquatic pollutants. The chemical structure of these wastes enhances their potential to interact with and remove contaminants from water through coagulation mechanisms, making them promising candidates for sustainable water treatment solutions. This is in line with the concept of a circular economy that emphasizes the importance of reusing agricultural byproducts, such as fruits and vegetable waste, to mitigate environmental impacts and enhance ecosystem quality (Oyedeji et al., 2021; Shrivastava & Singh, 2022).

Agricultural by-products have shown significant potential as natural coagulants for water treatment, offering an environmentally friendly and sustainable alternative to chemical coagulants. These bio-coagulants can effectively

remove dyes and other contaminants from wastewater (Tsoutsas et al., 2024). For instance, *Moringa oleifera* (MO) seeds have been extensively studied for their coagulation properties (El Gaayda et al., 2022). In addition to MO seeds, other agricultural by-products have also been investigated for their coagulation efficiency. Chethana et al. (2016) studied several plant seeds, including *Acanthocereus tetragonus*, *Azadirachta indica*, *Cicer arietinum*, and *Moringa oleifera*, as bio-coagulants. These findings highlight the effectiveness of agricultural by-products as natural coagulants, which not only contribute to reducing the environmental burden of agro-waste but also provide a cost-effective solution for water treatment.

One of the major challenges in utilizing agro-waste like SPP and LS for water treatment is the lack of information on their feasibility. The means of establishing the feasibility of bio-coagulants is through proximate and ultimate analyses (Dadebo et al., 2022). These analyses provide information about the chemical composition and properties of bio-coagulants, which directly influence their coagulation efficiency. Proximate analysis involves determining moisture content, ash, volatile matter, and fixed carbon, which helps in understanding the thermal stability and reactivity of the material. Ultimate analysis, on the other hand, assesses the elemental composition, including carbon, hydrogen, nitrogen, and oxygen, which are crucial for evaluating the material's potential for adsorption and pollutant removal. Hence, this study aims to investigate the feasibility of the surplus SPP and LSS agro-waste for wastewater treatment purposes through the proximate and ultimate studies.

MATERIALS AND METHODS

Materials

The locally sourced raw materials, sweet potato and lemon were purchased from Samaru market, Zaria, Kaduna State. The sweet potato was peeled to obtain the SPP which was then dried overnight at 60 °C to increase polyelectrolyte concentration (Nirmala & Jadhav, 2012). LS from the lemon fruits were obtained

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from squeezing the fruits and the seed coat was removed using a mortar and pestle, and the coats and wings were manually separated. Both SPP and LS were ground using a domestic electronic blender and sieved through a 300-mesh sieve, as outlined by Hauwa et al. (2018). The resulting flours were further dried at 100 °C for 24 hours. For solution preparation, 10 grams of the dried sample were dissolved in 1 litre of distilled water, producing a concentration of 10 mg/mL.

Proximate Analysis

The proximate analysis was carried out to determine the moisture, ash, crude lipid, and crude fibre in the coagulants at the Nitrogen and Soil Science Department of the Institute of Agricultural Research, Ahmadu Bello University, Zaria. Moisture content was determined by drying two grams of the coagulant in a pre-weighed crucible at 105 °C until a constant weight was achieved. The percentage moisture content was then calculated using Equation (1).

$$\% \text{Moisture content} = \frac{W_3 - W_1}{W_2 - W_1} \times 100 \quad (1)$$

For ash content, two grams of the coagulant were ignited and ashed in a furnace at 550 °C for eight hours. The ash content was calculated using Equation (2).

$$\% \text{Ash content} = \frac{W_4 - W_1}{W_2 - W_1} \times 100 \quad (2)$$

The crude lipid content was determined using a Soxhlet extraction method, where twenty grams of the coagulant were extracted with petroleum ether. The percentage lipid content was calculated with Equation (3).

$$\text{Crude Lipid Content} = \frac{(W_5 - W_6)}{20g} \times 100 \quad (3)$$

Crude fibre content was determined by boiling the coagulant with sulfuric acid and sodium hydroxide solutions, followed by drying and incineration, and calculated using Equation (4).

$$\text{The loss of weight on incineration} = \frac{(C_1 - C_2)}{2g} \times 100 \quad (4)$$

Crude protein content was assessed through the Kjeldahl method, with nitrogen content calculated using Equation (5), and crude protein content obtained using Equation (6). Lastly, total carbohydrate content was determined by difference, using Equation (7).

$$\%N = \frac{14 \times M \times V_t \times T_V \times 100}{1.5g \times V_a} \quad (5)$$

$$\% \text{Crude Protein} = \%N \times 6.25 \quad (6)$$

$$\% \text{Total Carbo} = 100 - (\% \text{Moisture} + \% \text{Ash} + \% \text{Fat} + \% \text{Protein} + \% \text{Fibre}) \quad (7)$$

Where W_1 , W_2 , W_3 , W_4 , W_5 , and W_6 are the weights of the empty crucible (before adding the sample), crucible plus the coagulant sample before drying, crucible plus the coagulant sample after drying to constant weight, crucible plus the ash after ashing in the furnace, empty round bottom flask (before extraction), and round bottom flask plus the extracted oil after drying. C_1 and C_2 are the weight of the insoluble residue after drying and insoluble residue after incineration. M is the molarity of the hydrochloric acid (HCl) used in titration, V_t is the total volume of the diluted digest (after digestion), T_V is the titre volume, V_a is the Aliquot volume of the digest used for distillation and $\%N$ is the percentage of nitrogen in the coagulant.

Ultimate Analysis

The ultimate analysis was carried out in line with the ASTM D3176-15 (ASTM, 2015) in which the dried and grounded SPP and LS samples were sieved to ensure uniform particle size. For carbon analysis, the powdered sample was combusted in a high-temperature oxygen-rich environment. The gas was collected and quantified using infrared gas analyzers. Nitrogen analysis was performed using the Dumas method, where the sample was combusted at high temperatures in the presence of a catalyst, converting nitrogen to nitrogen gas (N_2). The volume of nitrogen gas produced is measured



using a thermal conductivity detector. The sulfur content was determined by combusting the sample in an oxygen-rich environment, converting sulfur to sulfur dioxide (SO₂). The volume or concentration of SO₂ was measured using an infrared absorption. Oxygen content was measured using an oxygen analyzer.

RESULTS AND DISCUSSION

Proximate Characteristics of the Natural Coagulants

In analyzing the proximate characteristics of coagulants derived from SPP and LS, the results obtained in Table 1 show notable differences and similarities in their composition, which can significantly influence their applicability and effectiveness in water treatment processes. The moisture content of SPP and LS are relatively low, at 2.01% and 1.76% respectively. These values suggest good storage stability, as lower moisture content in coagulants

reduces the risk of microbial growth and degradation (Zaidi et al., 2019). Low moisture content is advantageous for the shelf-life and transport of coagulants in dry form. Ash content for SPP and LS are 2.40% and 1.83%, respectively. Ash content represents the inorganic residue left after combustion and can indicate the presence of minerals in the coagulants (Abo-El-Enein et al., 2011). Lower ash content, as seen in LS, suggests purer organic material which might translate to fewer impurities affecting coagulation efficiency. LS shows a significantly higher crude lipid content at 13.31% compared to 2.89% for SPP. High lipid content can affect the hydrophobicity of coagulants, potentially enhancing the aggregation of non-polar substances during coagulation (Xia et al., 2017). This property could make LS particularly effective in settings with oil or other hydrophobic contaminants.

Table 1: Proximate characteristics of SPP and LS coagulates

Properties	Coagulants	
	SPP	LS
Moisture (%)	2.01	1.76
Ash (%)	2.40	1.83
Crude Lipid (%)	2.89	13.31
Crude Protein (%)	17.88	13.31
Crude Fibre (%)	18.36	15.12
Carbohydrates (%)	52.44	48.82
Carbon Monoxides (%)	116	108
Methane (%)	3.52	5.23
Carbon Dioxide (%)	2.17	2.75
Nitrogen Dioxide (%)	0.84	0.82

Proteins can influence coagulation through their ability to form complex compounds with contaminants. SPP, with a crude protein content of 17.88%, surpasses LS, which has 13.31%. Higher protein content in SPP might enhance its ability to coagulate proteins and other nitrogenous compounds in wastewater, as indicated Zhou et al. (2023). The fibre content of SPP and LS is 18.36% and 15.12% respectively. Fibre could contribute to the formation of a more robust floc structure during coagulation,

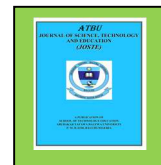
enhancing the removal efficiency of suspended solids. This was seen also in the study of Kurusu et al. (2022) when iron-grafted cellulose fibre was used for water treatment. Carbohydrates in SPP and LS are 52.44% and 48.82%, respectively. Carbohydrates may aid in the coagulation process by providing sites for the adsorption of colloidal particles. Higher carbohydrate content could correlate with improved coagulation capabilities, particularly in turbid waters, as observed also by Zhou et al. (2023). Gaseous components like CO,

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CH₄, O₂, CO₂, and NO₂ are present in trace amounts but vary between the two coagulants. The presence of these gases, especially CO could influence the behaviour of coagulants during oxidation-reduction reactions involved in water treatment processes and influence the efficiency of these coagulants (Czarnota et al., 2023).

Ultimate Characteristics of the Natural Coagulants

The ultimate analysis of SPP and LS given in Table 2 shows that the carbon content in SPP is relatively low at 37.21%, compared to 55.89% in LS. This higher carbon percentage in LS suggests a greater potential for organic interactions, which may enhance its coagulant

properties. Higher carbon content often correlates with increased surface activity and adsorption capabilities (Demiral et al., 2021), potentially making LS more effective in certain applications where organic interactions are crucial. In contrast, the oxygen content is higher in SPP (31.84%) than in LS (20.26%). Oxygen is associated with various functional groups like hydroxyl and carbonyl, which could influence the material's reactivity and its interaction with other substances (Czarnota et al., 2023). The greater oxygen content in SPP might suggest more potential for interactions due to these functional groups, potentially affecting its coagulation performance.

Table 2: Ultimate characteristics of SPP and LS coagulates

Properties	Coagulants	
	SPP	LS
Carbon (%)	37.21	55.89
Oxygen (%)	31.84	20.26
Nitrogen (%)	4.55	3.67
Sulphur (%)	13.75	3.375

Furthermore, Table 2 shows that SPP contains 4.55% nitrogen, which is higher than the 3.67% found in LS. Nitrogen is essential for proteins and amino acids, contributing to the coagulant's ability to interact with other substances, such as proteins in wastewater treatment. Therefore, the higher nitrogen content in SPP might make it more effective in applications where protein-related interactions are significant, as discussed in the proximate characteristics (Zhou et al., 2023). SPP has a notable sulphur content of 13.75%, while LS contains only 3.375%. Sulphur can influence the material's reactive properties and its interaction with other molecules. The high sulphur content in SPP may offer unique reactive properties, such as enhanced formation of sulphide bonds, which could be advantageous in specific coagulation processes (Mohamad et al., 2023).

CONCLUSIONS

This study evaluated the potential of SPP and LS as natural coagulants for wastewater

treatment by analyzing their proximate and ultimate characteristics. Both SPP and LS were found to be viable candidates for sustainable water treatment, with distinct properties influencing their specific uses. SPP's higher ash, protein, fibre, oxygen, nitrogen, and sulfur content suggests enhanced coagulation efficiency and reactivity, while LS's higher lipid and carbon content indicates its effectiveness in treating hydrophobic contaminants. These findings support the use of SPP and LS as eco-friendly alternatives to chemical coagulants, promoting sustainable waste management and a circular economy.

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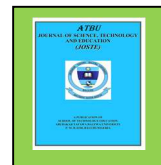
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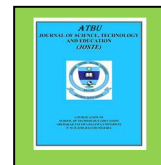
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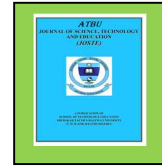
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