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Compositional and Structural Analysis of Selected Crop Residues and Potential Applications

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ABSTRACT: Population growth, increased food production and consumption, and industrialization have increased the number of crop residues generated in contemporary times. Inappropriate disposal of crop residues pollutes the atmosphere, contaminates water bodies, and exacerbates environmental degradation. Modification and conversion of crop residues to useful products are low-cost, eco-friendly, and contribute to achieving environmental sustainability. This study carries out experimental compositional analysis of plantain peel (PP), orange peel (OP), and corn cob (CC) to provide the necessary information in deciding their appropriate pretreatment techniques, conversion methods, and application options. The proximate analysis showed that carbohydrate constitutes 53.78 %, 62.75 %, and 67.58 % of PP, OP, and CC, respectively. Potassium has the highest concentration in PP with 657.50 ppm and CC with 381.50 ppm while magnesium is the most prominent element in OP with 254.30 ppm. Cellulose dominates the structural composition of PP, OP, and CC with 47.18 %, 65.56 %, and 56.48 %, respectively, followed by lignin, hemicellulose, and extractives. The outcomes of these analyses showed that with appropriate pretreatment, modifications, and conversion technologies, PP, OP, and CC can be converted to biogas, bioethanol, biomethane, and biohydrogen, and used as catalysts, biochar, and other value-added applications.

KEYWORDS: Crop residues, plantain peel, orange peel, corn cob, waste conversion

I. INTRODUCTION

Waste management is one of the major concerns of the current generation. Sustainable waste management which involves regulated waste generation, collection, transport, treatment, disposal, and conversion, entails a multidimensional approach that requires technology, sociocultural, economic, political, and legal interventions. Unfortunately, global waste generation has continued to increase due to population growth, increased food production and consumption, industrialization, and urbanization. For example, the global population which was 7.51 billion in 2016 has been predicted to become 8.55 billion in 2030 and 9.71 in 2050 [1]. The significant global population growth is expected to trigger the global waste generation that was 2 017 million metric tons (MMT) in 2016 to rise to 2 586 MMT in 2030 and advance to 3 401 MMT in 2050 (Figure 1) [2]. Nigeria, Ghana, and South Africa topped the solid waste generation chart in Africa in 2016 with 27.61 MMT, 21 MMT, and 18.46 MMT, respectively (Figure 2) [3]. The global waste management market which was worth USD 1.61 trillion in 2020 is expected to escalate to USD 2.5 trillion in 2030 [4]. Inappropriate waste management contributes to climate change, impacts sanitation, pollutes and contaminates the ecosystem, exacerbates environmental sustainability, and impairs human health.

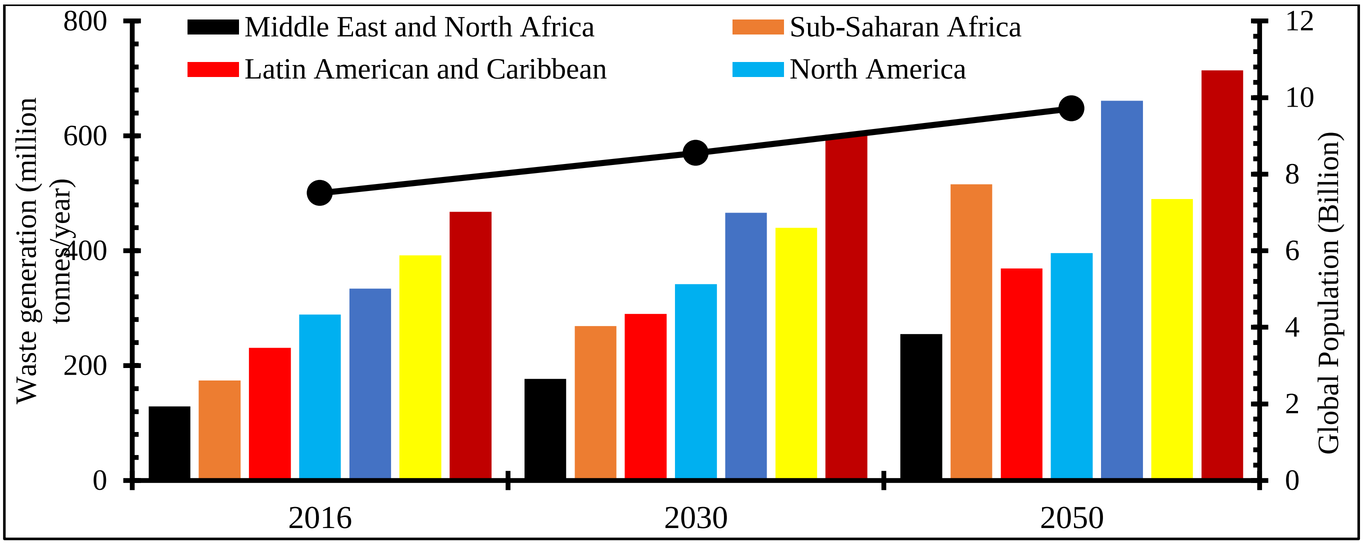

Figure. 1 Global waste generation and global population

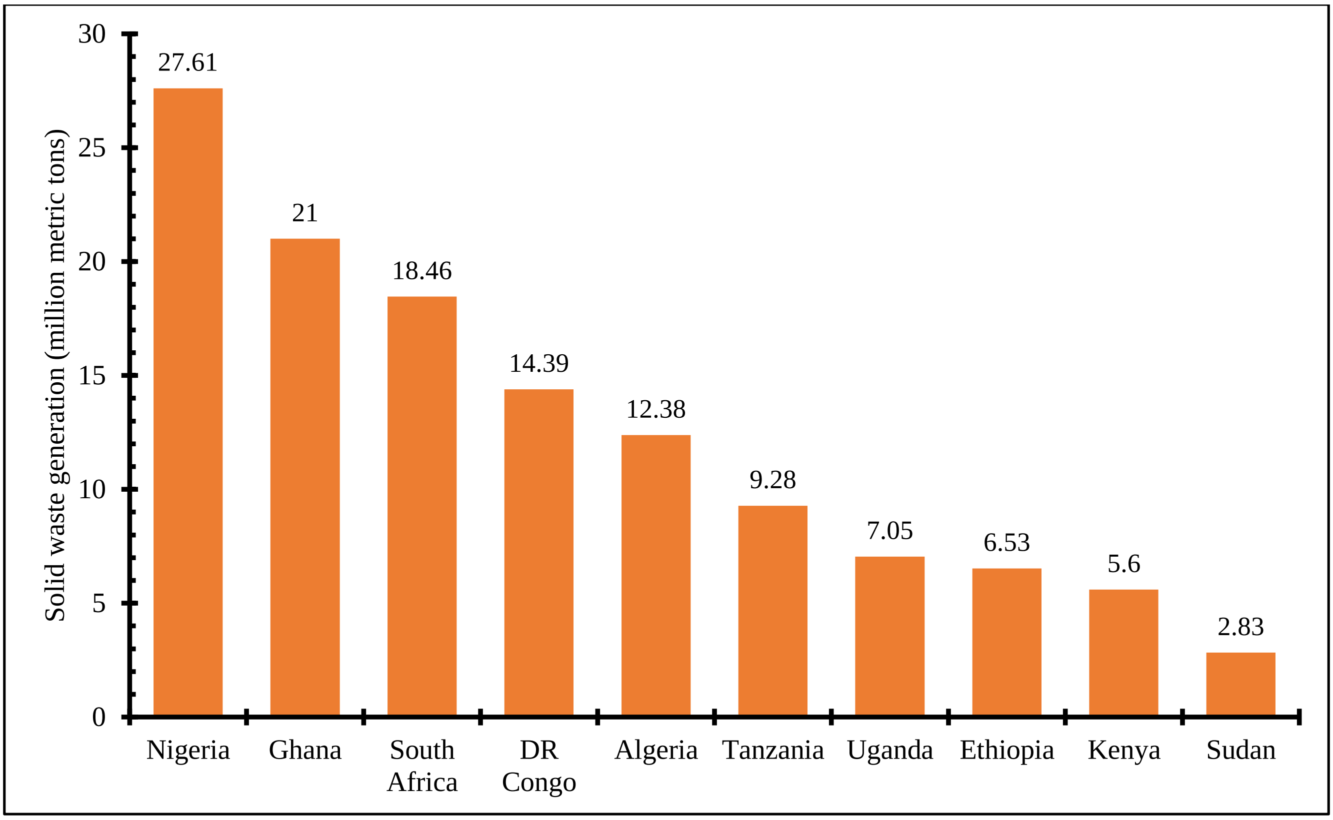

Figure 2. Solid waste generation in Africa in 2016

Wastes are materials that are produced and used during various activities with no intent for additional use and thus was discarded, rejected, or abandoned [5]. In a similar vein, when the costs of gathering, transporting, and processing the materials are more than the monetary or useful values of such materials, they can be categorized as waste [6, 7]. A substantial proportion of these solid wastes was generated in farms and other agricultural processing activities. Agricultural wastes are generated during land clearing and preparation, weeding, harvesting, and other agricultural activities as well as during domestic consumption and industrial conversion of agricultural products. They include woody and crop residues (leaves, wood chips, sawdust, wood offcuts, etc.), food and fruit residues (food wastes, peels, shells, etc.), animal and wastewater wastes (waste blood, livestock droppings, pig manure, feathers, etc.) fishing and aquaculture wastes (dead fish, fish fins, leftover feed, etc.), wastes generated from agricultural activities (farming, animal rearing, horticulture, gardening, hunting, etc.) and food preparation and processing wastes (wastewater, eggshells, rice husks, sugarcane bagasse, dairy wastewater, etc.) [6].

Crop residues are forms of waste generated during the post-harvesting or post-processing of crops. They are principally the leftovers from the harvesting, consumption, or utilization of crops. Crop residues may also include uneaten or discarded fruits. Notable examples of crop residues include leaves, egg shells, corn cob, corn hob, peels from plantain, banana, yam, cassava, lemon, orange, lemon, ginger, etc. Others are groundnut shells, coconut shells, wheat bran, soybean hulls, molasses, rice husks, sugarcane bagasse, pulps, and seeds [8, 9]. Though they are generated in large quantity and constitutes sanitary eyesore, they are largely biodegradable and non-hazardous. When disposed of inappropriately, they emit unpleasant odours, attract flies, rodents, and other pathogens, and contaminate surface and underground water bodies. Burning of crop residues emits smoke and particulate matter, and impacts the physical, biological, chemical, and biotechnological properties of the soil ecosystem [9, 10]. To ameliorate the challenges emanating from the uncontrolled generation and inappropriate disposal of crop residues, it is imperative to develop and implement cost-effective, environmentally friendly, and innovative techniques for the sustainable management of crop residues. The conversion of crop residues to biofuel, biochar, activated carbon, charcoal, catalysts, catalyst support, and other useful industrial raw materials is part of the sustainable utilization pathways.

A. Review of Literature

The subject of conversion of crop residues to useful products and for diverse applications has been conducted and reported. Over the years, scientists have devoted time and other resources to conducting investigation conversion pathways and developing valuable products from crop residues. In a recent study, Reddy and Chhabra [11] and Lin and Begho [12] reported that burning crop residues to causes air pollution reduces soil fertility, endangers soil microbes, and triggers detrimental effects on human health. They advised the conversion of crop residues to useful products. In line with this advice, Wang et al. [13], Jha et al. [14], and Hoang et al. [15] described the processes and technologies for the utilization of crop residues as viable raw materials and catalysts for biofuel generation. They described crop residues as inexpensive, readily available, and ecologically friendly raw materials for the synthesis of biogas, biodiesel, bioethanol, and other forms of biofuels.

Biochar derived from crop residues has also been used for soil conditioning [16], removal of toxic gases [17], crop nutrient recycling [18], wastewater treatment [19], material for supercapacitors [20], microbial fuel cells [21], adsorbents and dye removal [22], aggregates and cement additives [23], and other innovative applications. Similar works on the pretreatment, technologies for conversion, and avenues of the utilization of crop residues are testimonies to the multifaceted applications of crop residues [24-26]. More specifically, there have been investigations on the evaluation, conversion, and application of plantain peel (PP), orange peel (OP), and corn cob (CC) by different researchers in various jurisdictions. The recent literature survey on the conversion, potential application, and avenues for utilization of PP [27-29], OP [30-32], and CC [33-35] revealed the areas of possible applications.

B. Motivation, Aim, and Objective

Arising from the above, it is doubtful whether enough foundational studies have nee carried out to form the basis for detailed works on the application of PP, OP, and CC as a resource. This forms the motivation for the current study. This study aims to carry out proximate, elemental, and structural compositional analyses on PP, OP, and CC. The objective of the research is to determine the content and composition of the selected crop residues to provide the necessary information in deciding the appropriate pretreatment techniques, conversion methods, and application options for the selected wastes. The outcome of the current study will enrich the literature by providing information on the transformation of waste into useful products. Updated information on the requisite data on the composition of the selected waste that will aid their pretreatment and application potentials. The scope of this work is limited to laboratory determination of the proximate, elemental, and structural compositions of PP, OP, and CC. The thermal characterization, conversion, and utilization of the selected waste materials for various applications are outside the scope of this work.

II. MATERIALS AND METHODS

A. Materials description and collection

PP is the fleshy outer covering of a plantain fruit. It is bright green when unripe but turns yellow when ripe. Plantain is a major group of banana varieties and a staple food across the world. The global production of plantain is about 39.5 million tons with Uganda, the Democratic Republic of Congo, and Ghana topping the global production chart with 7.4 million tons, 4.9 million tons, and 4.7 million tons, respectively, in 2020. Nigeria produced about 3.1 million tons of plantain in 2020 [9, 36, 37]. It can be consumed alone in raw, boiled, roasted, fried, soup preparation, or in combination with other foods. Plantain peels are used for body lotions and other care products. It can be used to treat skin disorders, facilitate wound healing, speed up cell regeneration, and used to treat wrinkles, allergies, and other skin disorders [38].

OP is the fleshy outer covering of the pericarp of orange. It is usually removed to access the juice and the seed in the orange fruit. Orange is fleshy, nutritious, and nearly round citrus fruit of the family Rutaceae. Oranges account for over 50 % of the global production of all citrus fruits and are preferred to lemon, grapefruit, and mandarin. In the year 2022, the global production of oranges was put at 49.01 million metric tons (MMT) with Brazil, China, and European Union leading the producer countries with 16.9 MMT and 7.8 MMT, and 6.1 MMT, respectively [39]. Orange is a popular raw material for beverages, food, and pharmaceutical industries, and a major source of citric acid. The OP contains hesperidin, a form of flavonoid, which is effective in lowering blood cholesterol and triglyceride levels as well as regulating blood pressure [40]. It possesses anti-inflammatory and anti-aging properties and is effective in dead skin exfoliation, reversing aging, correcting blackheads, and rejuvenating dead cells, acne, and blemishes [41].

CC is the hardcore portion of the corn upon which the seeds are attached. Corn, also called maize is the third leading cereal crop in the world. The global production of corn in 2022 was put at 1 147 MMT with the United States, China, and Brazil supplying 348 MMT, 277 MMT, and 125 MMT to the global market [42]. Corn is consumed in various forms by humans, livestock, and animals and serves as a major raw material for the production of bakery products, beverages, brewed, and citric acid. Corns are fermented for the production of bioethanol and other biofuels and used as raw materials in pharmaceutical industries. CC serves as livestock beddings, abrasive for cleaning and pot scrubbers, converted to charcoal, and used as fuel for cooking. They are effective as oil sorbents, polishing agents, eco-friendly rodenticide, and a potent remedy for bladder infections [43].

The PP and OP were collected at the fruit market while the CC was gathered from various consumer households near the Ekiti State University, Ado Ekiti campus, and transported in separate sealed plastic to the laboratory. Figure 3 shows the picture of the PP, OP, and CC, as collected.

Figure 3. The samples as collected (a) PP, (b) OP, (c) CC

B. Samples Preparation

The collected waste materials were washed in running water to eliminate dirt and other unwanted substances from the body. The washed materials were first sundried in the open air for a few days to remove the moisture content and prevent decay and fungal growth. Thereafter, the sundried materials were further dried in the oven and maintained at 60 for 10 mins to total dehydration. The over-dried PP, OP, and CC materials were pulverized with a laboratory grinder and labeled as a, b, and c, respectively, as shown in Figure 4. The samples were separately kept in airtight laboratory glass vials to prevent contamination for further tests.

Figure 4 the samples in powder form (a) PP, (b) OP, (c) CC

C. Experimental Methods

The three samples were subjected to various laboratory tests to determine the proximate, mineral, and structural compositions. The laboratory analyses were carried out at Sustainable laboratory service Ltd., Akure, Nigeria. All the chemicals and reagents used in the study were of analytical grade.

Proximate analysis: The proximate analysis involves the determination of the carbohydrate, crude fat, crude fiber, ash Content, and protein content of the three samples. The proximate analysis was carried out according to AOAC standard procedures [44].

Percentage Moisture content (MC): The moisture content is the estimation of the amount of water in the samples. The percentage MC % is estimated by subtracting the dry weight from the wet weight (loss in weight), dividing the result by the wet weight, then multiplying by 100, as shown in Equations 1 and 2.

$$MC\ \% = \frac{Wet\ weight - Dry\ weight}{Wet\ weight} \times 100 \quad (1)$$

$$MC\ \% = \frac{W_1 - W_2}{W_1} \times 100 \quad (2)$$

Fat Content: Fat content is the amount of fats contained in a sample. The extraction of fat from the samples is carried out with Soxhlet apparatus with ether or petroleum ether by continuously extracting the fat content with 40 / 60°C petroleum ether in a convenient extractor (Soxhlet extractor). The ether extraction method operates on the principle of easy extraction of non-polar components into natural solvents including carbohydrates. The fat content is estimated using Equation 3.

$$\% \, Fat = \frac{(W_1+W_2)W_3}{(W_1+W_2)} \times 100 \quad (3)$$

Where W_1= weight of the empty dish, W_2= weight of dish + sample, and W_3= weight of dish + dried sample.

Ash Content: The ash content is the incombustible residue after a sample is completely burned. The sample was heated to 600 °C to ensure the removal of all moisture and volatiles (as vapour) and organics (as carbon dioxide and oxides of nitrogen). The residues are thereafter analyzed. Since the sample is dry, we calculate the percentage ash content on a dry basis, using Equation 4. The percentage of organic matter is calculated using Equation 5.

$$\% \, Ash \; content \; (dry \; basis) = \frac{Weigh \; of \; ash}{Weight \; of \; dry \; sample} \times 100 \quad (4)$$

$$\% \, Organic \; matter = 100 - \% \, Ash \; content \quad (5)$$

Crude fiber Content: Crude fibre is that portion of the plant material that is not ash or dissolves in a boiling solution of 1.25% H2SO4 or 1.25% NaOH. The crude fiber content is determined using a reflux condenser and according to AOAC [44]. The governing formula is shown in Equation 6.

$$\% \, \text{Crude fibre content} = \frac{W_2 - W_3}{W_1} \times 100 \quad (6)$$

Where W_1 = weight of the sample (g), W_2 = weight of crucible with dry residue (g), W_3 = weight of crucible with ash (g).

Protein Content: The protein content was calculated as the sum of individual amino acid residues in the sample after subtraction of the molecular weight of water. The Kjeldahl method was performed according to method 981.10 of the AOAC International [44, 45].

Carbohydrate Content: The carbohydrate content of the sample was determined by estimating the percent remaining after all the other components have been measured as shown in Equation 7.

$$\% \, \text{Carbohydrates} = 100 - \% \, \text{Moisture} - \% \, \text{Protein} - \% \, \text{Lipid} - \% \, \text{Mineral} \quad (7)$$

D. Elemental Analysis

The powdered samples were first digested by dissolving 1.0 g of them into 12 ml of HNO3 at room temperature and left for about 12 h. About 4.0 ml perchloric acid (HClO4) was added to the mixture and heated gradually to 300 ºC. After 90 min, white fumes were noticed and the mixture was allowed to cool down. The cooled sample was transferred to 100 ml volumetric flasks and the volumes of the contents were made to 100 ml of distilled water. The digested samples were stored in a clean airtight vial, labelled accordingly, and ready for analysis. The elemental composition analysis was determined using atomic absorption spectrophotometer (AAS), flame photometry, and spectrophotometry according to standard methods [46]. zinc, magnesium, calcium, cadmium, manganese, and sulphur were determined by AAS, sodium, potassium, by flame spectrophotometry, phosphorus, and chromium, by spectrophotometry [47]. Nitrogen is determined using Kjeldahl method [44, 45].

E. Structural Characterization

The hemicellulose, cellulose, and lignin contents of the samples were determined using wet chemistry methods. During the process, 0.5 g of powdered sample per entry was analyzed. All of the reagents used in this study were of analytical grade. The experiments were performed three times to reduce error and ensure replicability [48].

F. Statistical Analysis

All determinations were carried out in triplicates. The mean, standard deviation (SD), coefficient of variation (CV), and chi-square were applied to interpret the results obtained. The significance level was set at $P<0.05$. The mean, SD, CV, and chi-square were estimated using Equations 8 – 10.

$$\text{Standard Deviation}, \sigma = \sqrt{\frac{\sum (x_i - \mu)^2}{N}} \quad (8)$$

σ = Standard deviation, N = Population size, x_i = Each value from the population, μ = Mean

$$\text{CV} \, (\%) = \frac{\text{Standard Deviation}}{\text{Mean}} \times 100 \quad (9)$$

$$\text{Chi square}, x^2 = \sum \frac{(O_i - E_i)^2}{E_i} \quad (10)$$

O_i = Observed value, E_i = Expected value

III. RESULTS AND DISCUSSIONS

A. Proximate composition

The results of the proximate analysis of the powdered PP, OP, and CC samples are presented in Table 1. Carbohydrates constitute the major constituent of the samples. This may be due to the high carbohydrate content of the fruit. The high carbohydrate content of the samples allows them to provide the needed protective covering for the fruit. CC, which is the hardest of the three samples contains the highest carbohydrate content. There is no significant difference between the fiber composition of PP and OP but CC presented the highest value of 12.04 %. the CC presented the lowest fat when compared with PP ad OP. The PP has the highest ash content of 9.89 % followed by OP at 7.64 % and CC at 3.67 %. These results are in agreement with earlier studies by Abubakar et al. [49], Naqvi et al. [50], and Gotmare and Gade [51].

Table 1. Proximate composition of plantain peel orange peel and maize cub

Parameters	PP	OP	CC	Mean	SD	CV (%)	x^2
Moisture (%)	7.27	6.11	5.56	6.31	0.873	723.222	0.241

Fat (%)	15.03	10.52	5.52	10.36	4.757	217.710	4.370
Ash (%)	9.89	7.64	3.67	7.07	3.149	224.382	2.807
Protein (%)	6.57	5.96	5.63	6.05	0.477	1269.310	0.075
Fiber (%)	7.46	7.02	12.04	8.84	2.780	317.986	1.749
Carbohydrate (%)	53.78	62.75	67.58	61.37	7.003	876.372	1.598

B. Elemental composition

Table 2 shows the elemental composition of the samples. For the PP, potassium, sodium, calcium, and magnesium dominated the elements with 657.5 ppm, 452 ppm, 436 ppm, and 311 ppm, respectively. For the OP, the dominating elements are magnesium, potassium, and sodium with 254.3 ppm, 248.25 ppm, and 173 ppm, respectively. Similarly, potassium, sodium, magnesium, and calcium were more prominent than other elements with 381.5 ppm, 325.25 ppm, 277.25 ppm, and 118.2 ppm, respectively. The nitrogen, Sulphur, chromium, manganese, copper, and zinc content of the three samples was negligible. The trend of these results substantially agrees with earlier studies conducted by Shariff et al. [52], Naqvi et al. [50], and Gotmare and Gade [51].

Table 2. Elemental composition of plantain peel, orange peel, and corn cub

Element	PP	OP	CC	Mean	SD	CV (%)	x^2
Sodium (ppm)	452.00	173.40	325.25	316.88	139.488	227.176	122.802
Potassium (ppm)	657.50	248.25	381.50	429.08	208.733	205.566	203.082
Calcium (ppm)	436.25	72.55	118.20	209.00	198.123	105.490	375.626
Magnesium (ppm)	311.25	254.30	277.25	280.93	28.653	980.464	5.845
Copper (ppm)	3.05	0.48	0.39	1.31	1.510	86.509	3.492
Chromium(ppm)	0.11	0.12	0.19	0.14	0.044	321.182	0.027
Manganese(ppm)	2.03	0.12	0.32	0.82	1.050	78.429	2.677
Sulphur(ppm)	0.04	0.02	<0.01	0.02	0.015	152.753	0.020
Phosphorus(ppm)	56.30	40.55	26.30	41.05	15.006	273.553	10.971
Zinc	9.11	3.96	2.66	5.24	3.411	153.712	4.438
Chlorine	64.85	54.25	41.50	316.88	139.488	227.176	122.802
Nitrogen	0.13	0.08	0.09	429.08	208.733	205.566	203.082

C. Structural characterization

The results of the structural analysis of PP, OP, and CC showed that cellulose dominated the structure of the samples with 65.56 %, 56.48 %, and 47.18 % for OP, CC, and PP, respectively, as shown in Table 3. These results are confirmation of the high carbohydrate content of the samples as shown in Table 1. The composition of lignin is more than that of hemicellulose for the three samples. The compositions of the extractives are less than 10 % for the three samples. Previous studies including Ayala et al. [53], Shariff et al. [52], and Thangavelu et al. [54] were in agreement with these results.

Table 3. Structural composition of plantain peel, orange peel, and corn cub

Parameters	PP	OP	CC	Mean	SD	CV (%)	x^2
Cellulose (%)	47.18	65.56	56.48	56.41	9.190	613.768	2.995
Hemicellulose (%)	17.08	9.47	10.95	12.50	4.035	309.802	2.605
Lignin (%)	25.97	21.08	27.29	24.78	3.272	757.437	0.864
Extractives (%)	9.77	3.89	5.28	6.31	3.073	205.433	2.992

IV. DISCUSSIONS

From the results of the compositional tests, it is clear that PP is made up of mainly carbohydrates (53.78 %) and fat (15.03 %). The proximate composition of PP shows a high concentration of sodium, calcium, potassium, and magnesium as well as phosphorus and chlorine in mild quantity. The high concentration of dietary carbohydrates and other essential minerals make it a good antioxidant and a good replacement for wheat flour in cookie production. PP is used as food fortification and medication in the treatment of heart diseases, hormonal imbalances, penile dysfunction, and nerve malfunction. The high calcium content helps in ensuring healthy bones and teeth [55, 56]. The low percentage of lignin makes PP easy to be degraded and digested without much pretreatment. The high cellulose content makes PP a feedstock for biomethane, bioethanol, and biobutanol production [26, 57, 58].

Sodium, potassium, magnesium, and calcium are important nutrients for both humans and animals. The high composition of these nutrients in the samples enhances their utilization as food supplements and fortification. Also, calcium derived from crop residues and other forms of waste is an important element required as a catalyst for biodiesel production [59]. Potassium derived from crop residue is a cost-effective raw material for fertilizer production and to enhance food security [60]. The elemental composition of the three samples makes the identified crop residue a source for the recovery of precious elements and a circular economy. The low sulphur contents of the samples point to the safe, non-toxic, and eco-friendly nature.

The high composition of cellulose in the samples confirms their high carbohydrate contents. Biomass with high cellulose content is rich in fermentable sugars and is easily converted to biofuels, chemicals, and other products. The high cellulose content of PP, OP, and CC makes them feasible and cost-effective feedstock for biofuels, biochemicals, and other products. Hemicellulose is a vital element of plant cell walls and an important ingredient for biomass conversion and utilization. The samples contain enough hemicellulose to support their conversion to biofuels and other bioproducts [61]. Lignin is the leading non-carbohydrate constituent of lignocellulosic biomass and represents the degree of recalcitrance of biomass to digestion during conversion and utilization. It provides strength, stability, and hydrophobicity to the plant. It also protects the polysaccharides from microbial or external attacks, particularly during degradation. For most biomass, lignin content ranges from 15 % to 40 % [62]. Biomass with a high percentage of lignin is difficult to convert and would necessarily need to be pretreated to ease its conversion. The percentage of lignin for the PP (25.97 %), OP (21.08 %), and CC (27.29 %) show that the biomass can be digested and fermented without any form of pretreatment. Crop residues such as PP, OP, and CC due to their physical, structural, and compositional properties are viable and low-cost materials for biochar, activated charcoal, adsorbents, carbon nanotubes, supercapacitors, and other useful products. The choice of crop residues for conversion to value-added products contributes to sanitation, environmental sustainability, and material recovery.

V. CONCLUSION

Huge wastes are generated from the harvesting, conversion, utilization, and consumption of various crops, fruits, and other agricultural products. The inappropriate disposal of these wastes constitutes a sanitary and environmental nuisance that pollutes the environment, contaminates aquatic ecosystems, and impacts human health. Crop residues can be applied as raw materials for the industry, applied as manures, and converted into biofuels, biochemicals, and other bioproducts for various applications. The conversion and utilization of crop residues are cost-effective, eco-friendly, and support the recovery of precious minerals.

The current effort characterizes PP, OP, and CC to determine their proximate, elemental, and structural compositions. The work also includes statistical analysis of the results of the characterization and suggestions on the areas of possible applications of the selected crop residues. The outcome of the study shows that the samples are dominated by carbohydrates in the proportion of 53.78 %, 62.75 %, and 67.58 % for PP, OP, and CC, respectively. The major elemental composition for the samples is calcium, sodium, potassium, and magnesium while sulphur, nitrogen, and chromium are in negligible percentages. This supports the application of crop residues as fertilizers, food supplements, food fortification, and a good avenue for the recovery of some precious minerals. The high cellulose composition makes the samples viable raw materials for biofuel and other bioproducts. The lignin content of the samples is less than 30 % and within the acceptable level to allow their conversion without serious pretreatment procedures.

The study reinforces the valuable usefulness of crop residues in biofuel production, material recovery, fertilizer, food fortification, and valuable raw materials for the industry. Important products such as heterogeneous catalysts, biochar, activated charcoal, carbon nanotubes, supercapacitors, adsorbents, etc. can be fabricated from crop residues for household and industrial applications. However, more characterization is needed to determine the thermal stability and other features of the crop residues. Collaborative and innovative research such as the use of statistical, optimization, and modeling tools for the characterization, properties determination, modification, and utilization options available for crop residues are needed. Government should encourage and motivate small-scale entrepreneurs, scientists, environmentalists, and other stakeholders to invest more in the conversion and utilization of waste. Government should incentivize waste collection and conversion by the provision of tax holidays, low-interest loans, etc to encourage investment in waste conversion endeavors.

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