Feasibility study on the use of carbonized cassava cortex as reinforcement in polymer-matrix composites

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Abstract: The feasibility of using carbonized cassava cortex (CCCtx) as reinforcement in polymer-matrix composites was studied by experimental investigation of the composites’ mechanical properties. The cortex was raised to a temperature of 550°C to get it carbonized and was subsequently milled to powder form. The powder was sieved into particle sizes of 150, 300, and 600 μm. Polymer-matrix composite materials were produced from them using thermosetting resin. Analyses of the energy dispersive spectroscope spectrum and X-ray diffraction of the CCCtx were carried out. The carbonized particles’ surface morphology was revealed by electron microscopy. The thermogravimetric analysis was also carried out. The component samples produced were tested for tensile strength, flexural strength, compressive strength, impact strength, elastic modulus, and hardness. For the evaluation of the composites, the particle sizes effect and wt% composition on the properties were studied and used as the criteria. The results showed that CCCtx can be used in reinforcing polyester resin.

Subjects: Materials Science; Composites; Materials Processing; Polymers & Plastics

ABOUT THE AUTHOR
The lead author, Dr Augustine Dinobi Omah, has investigated the dielectric properties of polymer-matrix composites developed from cassava cortex in his PhD research (2017). Prior to that, in 2009, his research group carried out the micro-structural and wettability studies of lead-free solders and determined the contact angle and the wetting time of the developed solders. In 2012, the team carried out a research on the study of clay-organic composites for the production of ceramic water filters. This present work explored the properties of the cassava cortex in order to complement the existing areas of its application and also to determine new areas of its application. Previous researches on the properties of cassava cortex do not seem to have fully presented the effect of carbonization on the mechanical properties of the cassava cortex. This work hopes to add to the existing knowledge on that.

PUBLIC INTEREST STATEMENT
Cassava cortex is part of the cassava peel and could be used to reinforce polymer composites. The use of this waste material helps save the environment and also provides raw materials for production. This study of the use of cassava cortex showed that lighter weight composites can be produced using carbonized cassava cortex as reinforcement. It also showed that the thermal properties of the cassava cortex composites produced are generally good and could be employed for low- and moderate-temperature applications. The properties of the produced composites which were measured are comparable to those of other polymer composites. The paper will appeal to people working in the area of development of new engineering materials. It is important because the results obtained from this research open new frontiers in the development and use of cost-effective agro-waste materials for mechanical applications, for both industrial designers and researchers.
Keywords: polymer-matrix composites; thermosetting resin; mechanical properties; electron microscopy; carbonized cassava cortex

1. Introduction

In the search for better engineering materials, intensive efforts have been made in the development of the composite materials as an alternative to metallic construction materials. Composite materials offer strength as well as lightweight when compared with metals and ceramic materials. They also provide some certain advantages over polymers alone. Composite materials can be classified as particle-reinforced, fiber-reinforced, and structural in nature. Their properties depend basically on the properties and relative amounts of the constituent phases and the shape, size, orientation, and distribution of the dispersed phase.

Due to their importance, over 3 million useful and diverse studies having been carried out on them. These include strong reviews on the nature (Basumatary, 2013; Camargo, Satyanarayana, & Wyppych, 2009; Dányádi, 2009; Fuqua, Huo, & Ulven, 2012; Joshi, Drzal, Mohanty, & Arora, 2004; Müller, Bugnicourt, & Latorre et al., 2017; Saba, Tahir, & Jawaid, 2014), types (Basumatary, 2013; Dányádi, 2009; Fuqua et al., 2012; Gacitua, Ballerini, & Zhang, 2005; Joshi et al., 2004; Saba et al., 2014), processing (Camargo et al., 2009; Li, Tabil, & Panigrahi, 2007; Müller et al., 2017; Oksman et al., 2016), applications (Camargo et al., 2009; Chauhan, Chauhan, & Kaith, 2012; Dixit, Goei, & Dubey et al., 2017; Fuqua et al., 2012; Li et al., 2007; Mohammed, Ansari, Pua, Jawaid, & Islam, 2013; Müller et al., 2017; Verma, Gope, & Shandilya et al., 2013), and other developments of composites (Dányádi, 2009; Dixit et al., 2017; Li et al., 2007; Lionetto et al., 2018; Shivanku & Kumar, 2017). Of interest in this paper are particulate composites. They “consist of a matrix reinforced with a dispersed phase in form of particles” (Anon, 2018a). When compared to the fiber composites, which have had more prominence over time as shown by Chandramohan (2014), Chauhan et al. (2012), Dixit et al. (2017), Fuqua et al. (2012), Joshi et al. (2004), Li et al. (2007), Mohammed et al. (2015), Saba et al. (2014), Shivanku and Kumar (2017), Verma et al. (2013), Vijayakumar and Kalaiselvi (2014), and Visakh, Thomas, Oksman, and Mathew (2012a), particulate composites have gained acceptance in recent times due to their ease of production. As a result, many industries such as electronic, construction, aviation, and automobile have started using particulate composites (Aigbodion, 2007; Anon, 2018a, 2018b; Callister, 2007; Chandramohan, 2014; Omah, Okorie, & Omah et al., 2017; Saara, 2011; Sendeckyj, 1974; Sharma et al., 2018; Vijayakumar & Kalaiselvi, 2014; Visakh et al., 2012a; Yar, Montazerian, Abidzadeh, & Baharvandi, 2009). According to Ichazo, Albano, González, Perera, and Candal (2001) and Navaneethakrishnan and Athijayamani (2015), natural particulates offer advantages of environmental friendliness, renewability, and large quantity. Other advantages are lightweight, low cost, competitive specific mechanical properties, and reduced energy consumption during production. As a consequence, researchers have started to focus their attention on natural particulate filler composites sites (Ameh, Isa, & Sanusi, 2015; Fu, Feng, Lauke, & Mai, 2008; Oladele & Isola, 2016; Rothon & DeArmitt, 2003; Selvam, Ravi, & Raja, 2017; Shivanku & Kumar, 2017; Vaezi, Sardzehaad, & Nikzad, 2008; Vijayakumar & Kalaiselvi, 2014).

Filler materials are solid additives or particles added to a matrix material to improve its properties, to modify the processing characteristics, and to reduce cost (Donald, 1994). Fillers produced from powders are considered as particulate composites. The benefits offered by such fillers include enhanced strength, weight reduction, and a favorable coefficient of thermal expansion, as well as, increased stiffness, abrasion resistance, stability, and thermal resistance. Among the parameters on which natural filler-reinforced composite's mechanical properties depend, the filler-matrix interfacial bond strength affects it more than the others. Hence for composite materials to attain high mechanical properties, a strong filler-matrix interfacial bond is critical (Anon, 2018a; Dányádi, 2009).

Fillers are classified as either inorganic or organic. Owing to their low cost, the use of organic fillers in polymer-matrix composites has been receiving a greater attention in comparison with inorganic fillers. Agro-wastes, which have been veritable sources for fiber composite materials
(Askanian, Novello, & Coelho et al., 2015; Basumatary, 2013; Bendahou, Habibi, Kaddami, & Dufresne, 2009; Chandramohan, 2014; Getu & Sahu, 2014; Lancaster, Lung, & Sujan, 2013; Pandey, Ahmad, & Singh, 2003; Rafique & Zulfiqar, 2014; Visakh, Thomas, Oksman, & Mathew, 2012b), can also serve the same purpose for organic fillers. Organic fillers are biodegradable, non-abrasive, recyclable, and renewable. This makes them more preferable. Due to these advantages, the utilization of organic fillers derived from agricultural sources such as cassava peels, pineapple, jute, animal bones, wood, oil palm, rice husk, etc. in polymer-matrix composites has increased significantly. The use of organic fillers is beneficial to the environment because agro-waste materials, which otherwise may contribute to environmental pollution, form the raw materials for their production (Saira, 2011).

Several types of natural fillers have been studied to investigate their effect on composite materials’ mechanical properties. It has been largely found that natural filler materials could enhance the cement matrix’s ductility and toughness, and significantly increase its impact, flexural and tensile strengths (Anon, 2002; Bontempi, 2017; Dhawan, Singh, & Singh, 2013; Gacitua et al., 2005; Kroisová, Adach, & Fijalkowski, 2014; Schwarzova, Stevulova, Singovszka, & Terpakova, 2015; Tajvidi & Ebrahimi, 2003). According to Azam, Mohd, and Hameed et al. (2009), with respect to specific strength and modulus, the natural fillers have very good mechanical properties which may be good enough to compete with those of glass fillers. According to the author, a comparison of the mechanical properties, a pulp filler-reinforced thermoplastic composite with those of virgin polymer, showed an increase by a factor of 5.2 in a combination of stiffness and an increase by a factor of 2.3 in the strength over those of the virgin polymer. K. M. M. Rao and Rao (2007) aimed at enabling the production of economical and lightweight composites for mechanical applications by introducing new natural fillers in a polymeric matrix.

1.1. Cassava cortex (CCtx)

One of the agricultural materials that could be used as a natural filler is the CCtx obtained from the cassava. The cassava (*manihot esculenta crantz*) is mainly cultivated for its starchy roots (Figure 1 (a)). It is a perennial shrub woody in nature. Mainly, it is consumed in the humid tropics (Hillocks, 2002; Lin et al., 2011; Ozoegwu, Eze, Mgbemene, Mgbemene, & Ozor, 2017; Phillip, Taylor, & Sanni et al., 2005) as a cheap carbohydrates source. Nigeria produces the largest quantity of cassava in the world. Other large producers include Brazil, Thailand, and Indonesia (Ozoegwu et al., 2017; Phillip et al., 2005). In the sub-Saharan Africa, cassava is consumed by over 500 million people as their staple food with an average consumption of approximately 500 cal/day (FAO, 2018). This leads to the generation of a huge quantity of waste of cassava peel annually.

The cassava peel is made up of the periderm and the cortex (Figure 1(b)). Annually, cassava peels production in Nigeria is about 450,000 tons with a tendency to increase (Ajao, Abdullahi, & Atere et al., 2009). Thesepeels are usually discarded and allowed to rot as waste. Both chemical and biological reactions occur in the rotting peels resulting in the devastation of the vegetation and soil around those heaps. It has been shown by Ajao et al. (2009), Ozoegwu et
al. (2017) and Phillip et al. (2005) that the peels could be recycled into higher value products or could be used as raw material in some other industries. They also presented that the peels could serve as food or be used as feed after biological treatment. CCtx, being a solid carbonaceous material, may contain some volatile matter that may hinder a good interfacial bonding between the matrix and the particulate filler; thus, there is the need for carbonization of the cortex before its usage. Details about carbonization could be found in Richard, 2008 and Tetsuro, Michio, and Shuji et al., 2018.

This work is aimed at investigating the feasibility of producing polyester matrix composites using the CCtx waste as reinforcement. The objectives of the work include studying the effects of different particle sizes of carbonized cassava cortex (CCCtx) on the physical, thermal, and mechanical properties of the produced composites in order to determine where the produced composite could be applied. It also includes studying the nature of the microstructure of the resulting composites to find out how the properties compare with those of other polymer composites.

2. Materials and method

2.1. Materials
In this research, the materials used include the CCtx which was procured from local dealers in Nsukka town, Enugu State, Nigeria. Cobalt naphthalate was used as the accelerator, while methyl-ethyl-ketone peroxide served as the catalyst. The polyester resin used was the thermosetting type in paste form; brand name: HY NEW MATERIAL, model number: BB103#, place of origin: China, with the following technical details:

- Mix ratio: 100:0.4:2
- Appearance: liquid
- Color: bluish and transparent
- Acid number = 15–21
- Viscosity at 25°C = 350–600 mPa⋅s
- Thixo index = 2–3
- Water absorption (24 h) = 0.05%
- Specific gravity at 25°C = 1.10–1.18
- Gel-time at 25°C = 9–15 min
- Peak exotherm = 140–170°C.

Petroleum jelly was used as the releasing agent.

2.2. Method
Figure 1(b) shows the photograph of the raw CCtx. The CCtx was washed in clean water and dried in the sun for 2 weeks. It was then carbonized in a heat treatment furnace at a temperature of 550°C for 1 h in the absence of oxygen. The 1-h soaking time at 550°C was to ensure complete removal of all the water and other volatile substances which could negatively affect the properties of the formed composites. The CCtx was milled after carbonization using a Techno Agencies Techno-1A burr mill. The resulting powder was sieved using Digital Plus T Dry siever (Haver & Boecker) to particle sizes of 150, 300, and 600 μm.
Figure 2. Photographs of cassava a cortex (a) sieved uncarbonized (b) sieved carbonized.

Figure 2(a) shows the sieved uncarbonized CCTx, while Figure 2(b) shows the sieved CCCtx. The prepared CCTx, Figure 2(b), and polyester resin were properly mixed and poured into a mold. The mixture was allowed to cure in the mold and was removed for test analysis. The composites were produced by varying the CCTx content from 10 to 60 wt% in steps of 10 wt %. Digital weighing machine 310g/0.001g NAPCO Electronic Weigh Scale JA-310 was used. The fabrication of polyester–CCCtx composites was done by simple hand lay-up technique (Figure 3).

2.3. Characterization

The characterization of the CCCtx particles was done using the scanning electron microscope (SEM)/energy dispersive spectroscopy (EDS), X-ray diffraction (XRD), and thermogravimetric analysis. The characterization tests of the produced composites were done with the abovementioned equipment at the University of Witwatersrand, Johannesburg, South Africa.

2.3.1. The XRD analysis

The various elements and phases distribution within the CCCTX particles were determined through XRD analysis. The analysis was carried out on a Philips PW1720 X-ray diffractometer set at scan speed of 3°/min using Cu Ka radiation, (Ka = 1.79026 Å).
2.3.2. Microstructural analysis
The surface morphology of the CCCtx particles was identified using the SEM JEOL JSM-6480LV complemented by EDS. The thoroughly washed sample was cleaned and thereafter, air-dried. It was then observed at 20 kV after having 100 Å thick platinum coat applied on it in JEOL sputter-ion coater.

2.3.3. Thermal decomposition of the CCCtx particles
A TGA Q50 thermogravimetric analyzer was used to observe the thermal decomposition in global mass loss terms. A sample of the CCCtx was tested at varied temperatures from 29°C (room temperature) to 900°C. The controlled temperature change was done by varying the heating at the rate of 10°C/min with the segment sampling being set at 0.5 s per point.

2.3.4. Density determination
Archimedes principle was used to determine the sample's density from the simple Equation (1) (George, Sreekala, & Thomas, 2001)

\[
\text{Density} = \frac{\text{Mass}}{\text{Volume}}
\]  

(1)

2.3.5. Hardness value determination
An ACCUSIZE Industrial Tools HR150A 3R Rockwell Hardness Tester set on F scale was used to determine the hardness value of the test samples. A minor load of 3 kg was initially applied to a sample of 7 mm thickness and later by a major load of 60 kg. The digital gauge recording was then taken as the hardness value.

2.3.6. Impact energy determination
The composite samples' impact strengths were tested on a Charpy impact testing machine (Liangong JB-300 Manual Impact Testing Machine) to determine the energy absorbed by the material. A v-notch 2 mm deep was made in sample materials to provide stress concentration on it. Each sample was fractured using the pendulum of the machine. The impact energy was then read directly from the machine scale.

2.3.7. Tensile strength determination
Tensile test of the samples was carried out on a Hounsfield tensometer (TecQuipment TQ SM 1002 Bench Top tensile testing machine). The samples were cut to dimension 60 mm × 20 mm × 10 mm and a length of 30 mm was marked. The samples were each tested and the maximum stress (ultimate tensile strength) and maximum strain were recorded. The tensile strength was calculated using Equation (2).

\[
\text{UTS} = \frac{P_{\text{max}}}{A_o}
\]  

(2)

where \( P_{\text{max}} \) = maximum load

\( A_o \) = the test sample's original cross-sectional area.

2.3.8. Bend/flexural strength determination
This was also carried out on the Hounsfield tensometer tensile testing machine. Samples of dimension 60 mm × 20 mm × 10 mm were cut and bent using a support and a center point load to breaking point. The flexure strength was then calculated and recorded.

2.3.9. Compressive strength determination
Samples were cut to dimensions of 50 mm × 50 mm × 50 mm and tested on the universal compressive testing machine (TESTRESOURCES 100 Series Modular Compression Test Machine maximum load 10 kN). Compressive load was gradually applied until a maximum load was reached. The compressive strength was calculated from the load read directly from the digital meter.
2.3.10. Thermogravimetric analysis
The composites’ thermal stability was evaluated by the change in weight of the composite with increase in temperature. Each sample was kept in a mild steel crucible in a furnace and heated to a temperature of about 200°C. A soaking time of 20 min was allowed. The change in the sample weight was measured and recorded.

2.3.11. Swell growth analysis
Dimensional stability of the composite when subjected to change in temperature and humidity was quantified by measuring its percentage swell growth. The thickness of the sample before being introduced into an oven, \( T_{bo} \), was measured. The temperature in the oven was stabilized at 200°C and the samples which had been placed on a steel tray were kept inside the furnace for 1 h. The samples were withdrawn from the oven and kept to cool down. The samples’ thicknesses, \( T_c \), were noted. The percentage of the swell were computed as

\[
S_p = \frac{(T_c - T_{bo})}{T_{bo}} \times 100
\]

where \( S_p \) = percentage swell growth.

\( T_{bo} \) = thickness of the samples before being introduced into the oven.

\( T_c \) = thickness of the samples after being withdrawn from the oven.

3. Results and discussion

3.1. X-ray diffractometer of the CCCtx
The XRD pattern of the CCCtx obtained had many diffractions as shown in Figure 4. The major diffraction peaks are 24.4°, 31.0°, 32.54°, and 12.25° and their inter-planar distances are 4.23, 4.00, 3.19, and 8.3Å. The phases corresponding to these peaks are Quartz low (SiO\(_2\)), Albite, C-rich, ordered (Na, Ca), Al (Si, Al)\(_3\)O\(_8\), calcium carbide (CaC\(_2\)), and sodium silicon (Na\(_{10}\)Si\(_{136}\)), while each of these phases has a score of 74, 47, 30, and 26, respectively. The presence of these phases implies that CCCtx can be a feasible reinforcement material in a polymer matrix because they contain common elements found in polymer-reinforced composites. This is in agreement with the studies

![XRD pattern of the carbonized cassava cortex.](image)
carried out by other researchers (Kroisová et al., 2014; Olumuyiwa, Isaac, & Adewunmi et al., 2012). The analysis confirmed that no harmful element is contained in the CCCtx but rather contained therein are C, O, Si, Ca, Al, and Na.

3.2. SEM/EDS of the CCCtx

Figures 5–9 show the SEM images of the CCCtx particles' surface morphology. The shape and size of the particles vary as revealed by the microstructure of the CCCtx. The shapes can be sorted into mainly prismatic, spherical, and fibrous geometry. The SEM micrographs show that there was great dispersal of particles, high homogeneity, and high stable distribution in all directions.

The particles were solid in nature as observed. The EDS spectrum of the CCCtx particulates revealed the elemental compositions. The major constituents were carbon, oxygen, silicon, nitrogen, and calcium but due to the effect of carbonization, there was more wt% of carbon in the CCCtx (Figure 6).

3.3. Thermal properties (DTA/TGA) of the CCCtx

The DTA curves were used in determining the temperatures of destruction, \( T_{des} \), of the CCCtx samples. The “Derivatograph OD 102” at a heating rate of 10°C/min in argon recorded the DTA data. The results of the DTA/TGA scan are shown in Figure 10. Endothermic effects which are pronounced are observed at temperatures between 300°C and 400°C in the DTA curves and they correspond to the process of oxidative degradation. This also corresponds to volatile matters being released.

The samples started decomposing and forming byproducts when they were heated close to 300°C. This could be seen from Figure 10. The byproducts formed included carbon and silica. The silica ash possibly delayed the decomposition process resulting in a more thermally stable CCCtx. The maximum thermal decomposition occurred around the temperatures of 770°C which is higher than the decomposition temperature of polymer. This shows that the thermal stability of a polymer composite can be increased using the CCCtx. From Figure 10 it can be seen that the CCCtx composite shows the greatest percentage decomposition of nearly 30% around 700–800°C. At temperatures above 800°C, the residual weight stabilized toward the weight of the silica and carbon content in CCCtx. This agrees with an earlier work reported in Hassan, Oghenevweta, and Nyior et al. (2013).

Figure 5. Photomicrograph of CCCtx composites as revealed by SEM.
3.4. Density of the CCCtx particulate composites
The calculated density of the CCCtx was 1.02 g/cm$^3$, which puts it in the category to be considered as a light material. This calculated value falls in the same range of the density of other biomass materials which is 1.0 and 2.2 g/cm$^3$ (Anon, 2002).

Figure 11 shows the density of the CCCtx–polyester composites. The results obtained showed that the composites' density decreased slightly with increase in the weight fraction of the CCCtx in the polyester matrix. This is because the polyester matrix has a density which is higher than that of the CCCtx. The density of the composites also slightly decreased as the particles size of the CCCtx increased from 150 to 600 µm as shown in Figure 11. The density values obtained here in this study fall within the levels acceptable for bio-composites production (Kandachar & Brouwer, 2001).

3.5. Water absorption capacity of the composites
Figure 12 shows the test results of the capacity of the composites for water absorption. It shows that the composite material of 600 µm particles size absorbed more water than the 300 and 150 µm. It is also shown that the absorbed water amount increased, as the filler loading increased. This is because water absorption is a measure of material porosity (Sreekala, Kumaran, & Joseph et al., 2000). As the particle size gets bigger and the filler loading gets higher, the tendency of imperfections in form of pores to form in the composite gets higher, and the more the water that can be absorbed.

3.6. Tensile properties
The tensile strengths and modulus tests results are respectively shown in Figures 13 and 14. Figure 13 shows that as the particle size gets smaller the tensile strength gets higher. This may be due to the uniformity of filler distribution, which efficiently hinders the particle chains movement during deformation.

As shown in Figure 14, the composites' tensile modulus as well as their stiffness will increase at lower particle sizes due to this mechanism (Khalid, Sahari, & Khalid, 1998). Optimum tensile strength of 6.3, 5.8, and 5.53 N/mm$^2$ at 40 wt% CCCtx at 150, 300, and 600 µm CCCtx, respectively, were obtained. At these optimum points, the tensile strength
obtained was as a result of the filler’s stability in supporting transferred stresses from the polymer matrix. A previous paper reported similar results for composite material produced with rice straw/polypropylene (Khalid et al., 1998). The slight decrease in the tensile strength beyond these optimum points may be attributed to the increase in the interfacial area as the particle content increased. This interfacial area increase resulted in weak interfacial bonding between the particles and matrix polymer.

3.7. Flexural strength
With increase in the filler loading in the polyester matrix, the flexural strength of the composites increased (Figure 15). Flexural strengths of 23.00, 18.00, and 16.7 N/mm² at 50 wt% CCCtx were recorded for 150, 300, and 600 µm of CCCtx, respectively, showing a decrease in flexural strength as the particle size increased. A combination of the compressive and tensile components acting on the material contributes the flexural strength of the composite.
As the particulate wt% is increased, the composite's flexural strength records an improvement. This is ascribed to the compressive component. This component depends less on the interface as compared with the tensile component. The particles' random arrangement most likely led to better compressive forces absorption and the rigidity. These led to the overall flexural strength increase (Pothan, Oommen, & Thomas, 2003).

3.8. Compressive strength
As the percentage of the CCCtx in the matrix increased, the composites' compressive strength increased. This may be as a result of the matrix being hardened by the CCCtx particles. Figure 16 shows compressive strength as it varies with wt% CCCtx.

3.9. Hardness values
Figure 17 shows the composites' hardness values. From the figure, the composite samples' hardness values increased as the filler loading of CCCtx increased in the polyester matrix. This was due to the distribution of the particles' hard and brittle phases in the ductile polyester matrix. This is in line with Kandachar and Brouwer (2001).
3.10. Impact energy

Figure 18 shows the values of different composites' impact energy recorded during the impact tests. The impact energy of the composites lightly decreased with increase in CCCtx particles as shown in the result of the impact energy test. The decrease could be as a result of the presence of second phase particles' weight fraction and clusters. These results agree with the works of Khalid et al. (1998) and Mishra, Misra, Tripathy, Nayak, and Mohanty (2002). At smaller filler loading, the composites with 150 µm CCCtx absorb higher impact energy than those of 600 µm CCCtx. This is because smaller particles enhance good interfacial bonding between the matrix and the filler and are able to distribute the energy within the particles.

When compared with the impact and hardness strength analyses, the tensile properties agree with the obtained results. The increasing amount of hard CCCtx in the polyester matrix and the high tensile modulus relate with the increase in the hardness. The matrix's elastic behavior, on the other hand, varies proportionally with the addition of the CCCtx. This could be deduced from the impact test. The ability of the composites to absorb impact energy decreases as the CCCtx fillers
Figure 10. DTA/TGA analysis of CCCtx.

Figure 11. Variation of density with wt% of CCCtx.

Figure 12. Water absorption against wt% of CCCtx.
Figure 13. Variation of tensile strength against wt% of CCCtx.

Figure 14. Variation of elastic modulus against wt% of CCCtx.

Figure 15. Variation of flexural strength against wt% of CCCtx.
Figure 16. The compressive strength as it varies with wt% of CCCtx.

Figure 17. Variation of hardness values against wt% of CCCtx.

Figure 18. The impact energy as it varies with wt% of CCCtx.
loading increases because the ratio of the polyester matrix to fillers lessens. The results obtained here are still within the standard level for bio-composites (Mishra et al., 2002).

Generally, for a given wt% loading, the total surface energy of the smaller particles is higher. The strength increases with increasing filler particles’ surface area by way of a more efficient mechanism of stress transfer. The smaller particles gave a better reinforcement in agreement with the presentation of Buggy, Bradley, and Sullivan (2005). The authors had studied the mechanical properties of nylon composites filled with kaolin and presented that the strength of the composite increased with decreasing mean particle size.

3.11. Thermal gravimetric values
The percentage mass loss values are shown in Figure 19. The composites' mass loss decreased as the particle sizes of the CCCtx increased. The moisture and volatile content in the particles of same composition is directly proportional to the volume occupied by the particles. The smaller particles are more closely packed and contain more moisture and volatiles than the larger-sized particles for the same given volume. Consequently, they will lose more of the moisture and volatiles on decomposition and hence lose more mass. The overall mass loss of the samples is within the range of acceptable mass loss of carbonized particulate composite as experimented by Mohanty and Misra (2000).

3.12. Percentage swell growth values
The percentage swell growth values of different composites recorded during the swell growth analysis are given in Figure 20. The swell growth of the composites gradually increased as the particle sizes of the CCCtx composites increased. Thus it can be inferred that the CCCtx particulate-based composite can be used for applications where smaller particulates are required.

It was observed that bigger particle size composites suffer from weakness in particle dispersal and homogeneity and it is most likely to be because of the large mass and size. Due to weak interaction between the particles and the matrix, particles tend to pull out and form agglomerates which reduce the composites' strength properties. It was also observed that the smaller the particle size, the better the properties. This could be due to the fact that there is more interfacial contact between the smaller particle reinforcement and the polyester resin than there is between the larger particles and the polyester resin. Compressive strength, tensile strength, flexural strength, and hardness values of the produced composites increased as the percentage of CCCtx increased in the polymer matrix but decreased after exceeding 40 wt% (and or 50 wt%) filler loading for tensile strength and hardness.

![Figure 19. Percentage mass loss of CCCtx.](image)
3.13. Cost analysis

Apart from the CCtx which was locally sourced, all the other materials have standard costs which are globally fixed. Hence only the cost of the cassava peel processing is presented here. The cassava peels cost N300.00 for 50 kg quantity. When dried and carbonized, approximately 11.6 kg of materials were obtained from the 50 kg waste. When the energy cost of running the furnace for the carbonization and the mill are included, the cost of producing the 11.6 kg of the CCCTX stood at N345.00 (N1.00 = $0.0028). For the properties which the CCCTX imparts on the polymer matrix, this is relatively insignificant when compared to the cost of the other materials for the production of the composite. This implies that CCCTX is a cost-effective polymer reinforcement material.

4. Conclusions

Development and characterization of polymer matrix (polyester) containing different wt% of filler loading and particle sizes of CCCTX have been carried out following the investigation into the properties.

The following conclusions are deduced from the results and discussion:

(1) CCCTX can be used in reinforcing polyester resin.
(2) Lightweight composites can be produced using CCCTX as reinforcement.
(3) For a given wt% fraction, the composite mechanical properties can be increased with decreasing particle size.
(4) The thermal properties of the CCtx composites are generally good. Hence it can be employed for low- and moderate-temperature applications.
(5) The properties of the materials which were measured are comparable to those of other polymer composites.
(6) The results obtained from this research open new frontiers in the development and use of cost-effective agro-waste materials for mechanical applications, for both industrial designers and researchers.

From the foregoing, it can be concluded that producing polyester matrix composites using CCtx waste as reinforcement is feasible and worthwhile.

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Competing Interest
The authors declare no competing interests.
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