Review

Biochemical properties and biotechnological applications of cassava peels

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Received 6 March, 2023; Accepted 7 April, 2023

The peels of cassava (Manihot esculenta Crantz) for several decades had been highly underutilized until recent times when the potential applications of the peels in biotechnology and agricultural industries gained the attention of researchers. In this review, the biochemical/proximate composition of cassava peel alongside the effects of submerged or solid-state fermentation on its nutritional and anti-nutrient constituents was discussed. Furthermore, various industrial applications of cassava peels such as in the production of simple sugars and confectionaries, animal feeds, industrial enzymes, bioethanol, organic acids (including citric acid), and treatment of waste water were discussed. The use of cassava peels as good substrates for the production of tetracycline and other antibiotics was also highlighted. The present review advances the prospects of cassava peel as being more than just an agricultural waste but also an embodiment of future biotechnology products including bioethanol, biogas, citric acid and other biochemicals if properly and deliberately harnessed.

Key words: Agricultural waste, biotechnological applications, cassava (Manihot esculenta) peels, fermentation, proximate composition.

INTRODUCTION

Cassava is a highly widespread tropical crop produced in large quantities and mostly in arid, marginal soils (Tonukari, 2004; Tonukari et al., 2015; Egbune et al., 2022b). Nigeria is currently the world's largest producer of cassava, with an annual production of around 59.49 million metric tons (MMT). This accounts for

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approximately 20.4% of global cassava production, with Thailand coming in second place at 31.7 MMT. Furthermore, Nigeria’s production represents 59.5% of the total 139.6 MMT of cassava produced in Africa (Oghenejoboh et al., 2021; Egbune and Tonukari 2023).

In the processing of cassava, the roots are normally peeled to remove the two outer coverings; a thin brown outer covering and a thicker, leathery parenchymatous inner covering (Kongkiattikajorn and Sornvoraweat, 2011; Souto et al., 2016).

Large amounts of cassava peels are usually generated from cassava processing (Obadina et al., 2006; Amenaghawon et al., 2014; Adegbehingbe and Adeleke, 2021). The peels which are 1 to 4 mm thick account for 10 to 12% of the total dry matter of the root Maraphum et al. (2022), and are discarded when cassava is processed into various food products (Ozoegwu et al., 2017). Aro et al. (2010) reported that about 2.96 MMT of cassava peels are generated and discarded annually in Nigeria from about 10 MMT of cassava processed for garri alone. A more recent report indicates that Nigeria generates about 9 million tonnes of cassava peel annually (Ajala et al., 2018a, b).

A relatively small quantity of peels and unwanted tubers is fed directly to ruminants (Adelekan, 2012). However, a larger proportion of cassava solid wastes are indiscriminately discharged into the environment and amassed as waste dumps on sites where cassava is processed (Adelekan and Bamgboyé, 2009). Instead of allowing cassava peels to become solid municipal wastes, it is necessary to use them as cheap raw materials for some industries to manufacture useful products (Nwabueze and Otunwa, 2006) including animal feeds. This review highlights the chemical composition of cassava peels, effects of fermentation on its nutritional and anti-nutrient constituents, as well as several bioproducts obtainable from its biotransformation. The review posits cassava peel as being more than just an agricultural waste but as an embodiment of future biotechnology products including bioethanol, biogas, citric acid and other biochemicals if properly and deliberately harnessed.

### Table 1. Proximate composition of unfermented and Aspergillus niger fermented cassava peels.

<table>
<thead>
<tr>
<th>Composition (%)*</th>
<th>Unfermented cassava peels</th>
<th>Fermented cassava peels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture content</td>
<td>86.29</td>
<td>31.60</td>
</tr>
<tr>
<td>Ash</td>
<td>4.88</td>
<td>10.23</td>
</tr>
<tr>
<td>Protein</td>
<td>6.24</td>
<td>11.22</td>
</tr>
<tr>
<td>Fat</td>
<td>1.39</td>
<td>2.91</td>
</tr>
<tr>
<td>Crude fibre</td>
<td>10.88</td>
<td>8.87</td>
</tr>
<tr>
<td>Cyanide (ppm)</td>
<td>118.86</td>
<td>20.46</td>
</tr>
<tr>
<td>Starch</td>
<td>56.72</td>
<td>20.09</td>
</tr>
</tbody>
</table>

*Values are in percentage except for cyanide.


### BIOCHEMICAL PROPERTIES

The plant cell wall of agricultural wastes is formed by two carbohydrate fractions (cellulose and hemicellulose) embedded in a lignin matrix. Lignin is a phenolic macromolecule, resistant to enzyme attack and degradation, and thus its content and distribution are recognized as the most important factors determining cell wall recalcitrance to hydrolysis (Ezebuiro et al., 2015). Cassava peels are composed of hemicellulose, cellulose and lignin (Widiarto et al., 2019). Analysis of the chemical composition of cassava peels indicates the following chemical composition: dry matter 86.5-94.5%; organic matter 81.9-93.9%; crude protein 4.1-6.5%; neutral detergent fiber 34.4%; and lignin 8.4% (Kongkiattikajorn and Sornvoraweat, 2011). Ezebuiro et al. (2015) estimated the total carbohydrate in cassava peels to be 69.6 ± 1.2 (% dry weight). The proximate composition of cassava peels has been reported by several authors with differences in the values of the parameters measured. These variations can, however, be attributed to the availability of numerous variants of cassava and how the peels were processed prior to their analysis. Typical values of proximate composition of cassava peels and Aspergillus niger fermented cassava peels are listed in Table 1 (Olutosin and Kayode, 2021), while the chemical composition is depicted in Table 2 (Adelekan and Bamgboyé, 2009).

Cassava peels contain high cyanogenic glycosides and if not properly detoxified by soaking, drying, and scraping before being consumed, it can result in cyanide poisoning (Adegbahingbe and Adeleke, 2021). Cyanide poisoning occurs when an individual ingests, inhales, or absorbs high levels of cyanide. Cyanide is a potent toxin that interferes with the body’s ability to use oxygen, leading to cellular damage and ultimately death (McAllister et al., 2020). The effects of cyanide poisoning can vary depending on the dose and duration of exposure. Fermentation usually results in the reduction of cyanide to acceptable levels (Olutosin and Kayode, 2021; Egbune et al., 2023). During fermentation, microorganisms break down the cyanogenic glycosides into less toxic
Table 2. Chemical composition of cassava peels.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic carbon (%)</td>
<td>48.7</td>
</tr>
<tr>
<td>Total nitrogen (%)</td>
<td>1.0</td>
</tr>
<tr>
<td>C/N Ratio</td>
<td>48.7</td>
</tr>
<tr>
<td>K (%)</td>
<td>1.1</td>
</tr>
<tr>
<td>P (%)</td>
<td>1.6</td>
</tr>
<tr>
<td>NO₃ (%)</td>
<td>0.16</td>
</tr>
<tr>
<td>Zn (mg/kg)</td>
<td>125</td>
</tr>
<tr>
<td>Cu (mg/kg)</td>
<td>15</td>
</tr>
<tr>
<td>Mn (mg/kg)</td>
<td>180</td>
</tr>
<tr>
<td>pH</td>
<td>6.4</td>
</tr>
<tr>
<td>Na (%)</td>
<td>0.15</td>
</tr>
<tr>
<td>Ca (%)</td>
<td>0.9</td>
</tr>
<tr>
<td>Pb (mg/kg)</td>
<td>16.7</td>
</tr>
<tr>
<td>Ash (%)</td>
<td>52.6</td>
</tr>
</tbody>
</table>

Source: Adelekan and Bamgboye (2009) and Baenla et al. (2019).

Table 3. Compositions of the cassava peel hydrolysate obtained under the optimum conditions of 0.1 M sulfuric acid hydrolysis.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Concentration (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reducing sugars</td>
<td>60.74 ± 2.84</td>
</tr>
<tr>
<td>Glucose</td>
<td>37.09 ± 3.15</td>
</tr>
<tr>
<td>Xylose</td>
<td>4.79 ± 0.31</td>
</tr>
<tr>
<td>Rhamnose</td>
<td>4.05 ± 0.18</td>
</tr>
<tr>
<td>5-Hydroxymethyl-furfural</td>
<td>0.14 ± 0.06</td>
</tr>
</tbody>
</table>

Source: Yoonan et al. (2007).

Bioethanol

Bioethanol is a renewable energy source produced mainly by fermentation of sugars. Although bioethanol production from fresh cassava peels is possible, it is not the most efficient method. The starch in cassava peels is not readily accessible for fermentation, so the starch must be extracted first. The extraction process involves hydrolysis, which breaks down the complex starch molecules into simple sugars that can be fermented into bioethanol (da Maia et al., 2020; Acheampong et al., 2022). Enzymes, acids, or heat can be used for hydrolysis. Therefore, it is more common to extract the starch from cassava peels before using them as a feedstock for bioethanol production. After the starch extraction, the remaining cassava peels can still be used for other purposes, such as animal feed, fertilizer, or biogas production. Cassava peels have an appeal as a source of bioethanol production because they are rich in cellulose (37.9%) and hemicellulose (37%), with considerably low lignin content (7.5%) (Daud et al., 2014). Therefore, cassava peels are good substrates for yeast fermentation for bioethanol production (Isah et al., 2019). Yoonan et al. (2007) showed that dilute sulfuric acid hydrolysis of cassava peels provided a hydrolysate with a high concentration of glucose and a low concentration of xylose, rhamnose and 5-Hydroxymethyl-furfural (Yoonan et al., 2007) (Table 3).

APPLICATION OF CASSAVA PEELS

Sugars and confectionaries

Cassava peels can undergo several methods of processing to yield sugar and confectionaries. Firstly, the peels are washed, peeled, and grated to obtain a pulp which is then mixed with water and heated to extract the juice (Mahato et al., 2019). After filtering to remove impurities, the juice is concentrated by boiling to produce a syrup that serves as a natural sweetener in food products (Castro-Muñoz et al., 2022). Alternatively, the dried and ground peels can be processed into a fine powder that acts as a natural sweetener for baking and other culinary applications. The roasted and ground peels can also be used as a flavoring agent to provide unique tastes in food products. Furthermore, the dried and ground peels can be processed into flour that serves as a gluten-free alternative to wheat flour in baking. Ultimately, the processing of cassava peels into sugar and confectionaries provides a sustainable approach to minimize waste and enhance the availability of alternative ingredients (Fernando et al., 2022). Usually, cassava peels contain starch, a relatively abundant renewable energy source, cheap, and easy to access for the production of fermentable glucose syrups and dextrins (Adeleke et al., 2017). The importance of reducing sugar cannot be overemphasized because it is an essential raw material for the production of ethanol and various biochemicals (Tonukari, 2004; Mohammed et al., 2014; Tonukari et al., 2015). Soaking and boiling of cassava peels for 120 min removed more cyanide and yielded high carbohydrate needed for reducing sugar production (Panghal et al., 2019).

Earlier studies by Yoonan and Kongkiattikajorn (2004) indicated that cassava peels produce lots of reducing sugars by dilute acid (sulfuric, hydrochloric and acetic acids) hydrolysis and digestion using enzymes (amylase, amyloglucosidase, cellulase, xylanase and pectinase). Their later research showed that sugar yields obtained from biomass hydrolysis provided a hydrolysate with a high concentration of glucose and a low concentration of xylose, rhamnose and 5-Hydroxymethyl-furfural (Yoonan et al., 2007) (Table 3).

Compounds such as cyanohydrins, which are then further degraded into ammonia and other harmless products (Mueed et al., 2022). This process is facilitated by the activity of lactic acid bacteria and other microorganisms present in the fermentation medium.

**Bioethanol**
acid hydrolysis of cassava peels can be used in ethanol production. The authors observed that the reducing sugars from the hydrolysates were consumed within 10 h of \textit{Saccharomyces cerevisiae} fermentation and ethanol yield obtained was 0.27 g/g. Abidin et al. (2014) observed that 0.5 M sulfuric acid solution was the optimum acid concentration for the hydrolysis process at a temperature of 100°C for 60 min and 4 days was the optimum time of the fermentation process for bioethanol production. They obtained 3.58% (v/v) bioethanol.

Recently, Osemwengie et al. (2020) obtained maximum bioethanol yield of 1.911% from \textit{S. cerevisiae} fermentation of cassava peels at the optimum hydrolysis time, enzyme (α-amylase) loading, and incubation period of 2.5 h, 1 mg/L and 3 days, respectively. In other research, Afolabi and Ayodele (2020) compared the yields of ethanol from the fermentation of pretreated cassava peels with methanol plus acid followed by solid-state fermentation using \textit{Trichoderma reesei} for 5 days using yeasts isolated from palm wine. The reducing sugar yield of 1.78 g/mL of the hydrolysate was fermented for bioethanol production using \textit{S. cerevisiae} and \textit{Candida tropicalis} to produce 40.72 and 29.90 g/L of ethanol, respectively after 96 h. Furthermore, Akinruli et al. (2022) isolated bacteria (\textit{Sporosarcina terrae}, \textit{Bacillus cereus}, \textit{Proteus mirabilis} and \textit{Pseudomonas taiwanensis}) and fungi (\textit{Wickerhamomyces rhabautilis}, \textit{Rhizopus nigerican}, and \textit{A. niger}) from cassava peels and were able to produce bioethanol using these inherently isolated microorganisms.

Organic acids

Cassava peels can be used as a substrate for the production of organic acids through a process called fermentation (Zakariyah et al., 2021). Fermentation is a metabolic process that involves the conversion of sugars or carbohydrates into other compounds such as organic acids, gases, or alcohol, by microorganisms like bacteria or fungi (Egbune et al., 2023). During fermentation, microorganisms utilize the sugars present in cassava peels as a source of energy and convert them into organic acids such as lactic, acetic, and citric acids (Sánchez et al., 2021). These organic acids can be recovered and purified for various industrial applications.

Cassava peels are high cellulosic material which makes it a potential substrate for the production of value-added products such as organic acids (Prado et al., 2005). Hydrolysates of cassava peels can be converted into organic acids such as glycolic, levulinic, fufural, and formic acids through biorefineries processes (Daud et al., 2014). Ajala et al. (2020) hydrolysed cassava peels using hydrochloric acid to obtain reducing sugar, which was then inoculated with \textit{A. niger} for the production of citric acid. Using inoculum concentration of 7 to 11%, fermentation time of 1 to 4 days, temperature between 23 and 39°C and ethanol concentration of 0 to 4%, they obtained the lowest and highest citric acid values of 2.6 and 4.9 g/L, respectively in solid state fermentation, and 0.68 and 1.68 g/L, respectively in submerged fermentation. Adeolu and Adewoye (2018) have also employed \textit{A. niger} and \textit{Aspergillus terreus} in the production of citric and itaconic acids from cassava peels.

The lignocellulosic nature of cassava peels (Xu et al., 2020) makes lactic acid fermentation from it attractive. Ogbonnaya et al. (2013) reported the production of lactic acid from cassava peels using cultures of \textit{Rhizopus oligosporus} and \textit{Lactobacillus plantarum} after acidic and alkaline hydrolysis of cassava peels. In another study, unhydrolyzed cassava peels inoculated with a mixed culture of \textit{R. oligosporus} and \textit{L. plantarum} produced only 4.6 g/100 g substrate, the mixed culture fermentation of alkali hydrolyzed peels produced a maximum lactic acid concentration of 36.4 g/100 g substrate (Nwokoro, 2014). Using \textit{L. plantarum} as the fermentative organism, Zakariyah et al. (2021) reported that unhydrolyzed cassava peels yielded 4.80% of lactic acid, while the acidic and alkali hydrolysates of the substrate yielded 10.53 and 4.75%, respectively.

Industrial enzymes

Industrial enzymes play a crucial role in various industries, including food and beverage, textile, pulp and paper, detergent, biofuel, and pharmaceutical (Crini et al., 2020). They act as catalysts, speeding up chemical reactions and increasing product yields, which leads to increased efficiency, reduced production costs, and improved product quality.

For example, enzymes such as α-amylase, cellulase, and xylanase are used in the food industry to modify starches, improve texture, and enhance flavor (Egbune et al., 2022a). Enzymes like lipase and protease are used in the detergent industry to remove stains and improve cleaning efficiency. In the textile industry, enzymes like cellulase are used to create a "stone-washed" effect on denim, while in the paper and pulp industry, enzymes are used to reduce energy consumption during the bleaching process (Liu and Kokare, 2023). Olanbiwoninu and Odunfa (2016) isolated \textit{A. terreus} KJ829487 from cassava peels with the ability to produce high concentration of xylanases and cellulases. The fungus effectively hydrolyzed the cassava peels lignocellulosic biomass to fermentable sugars (glucose, xylose, rhamnose, etc). The investigation of Acheampong et al. (2021) obtained maximum production of amylase, xylanase, endo glucanase, exo glucanase, and β-agarosidase from the white rot fungus, \textit{Trametespolypsona}, after 14 days fermentation with cassava peels at 30°C, 60% moisture and pH 6, with higher activities produced by solid-state fermentation compared to submerged fermentation. Recent studies
have shown that cassava peels can be a suitable substrate for the production of various industrial enzymes, including cellulase, xylanase, α-amylase, glucoamylase, and pectinase (Sujithra et al., 2019; Laothanachareon et al., 2022; Gou et al., 2023). The production of these enzymes was achieved through solid-state fermentation or submerged fermentation using microorganisms such as A. niger and Bacillus licheniformis (Steudler et al., 2019; Moran-Aguilar et al., 2021). Cassava peels are rich in carbohydrates, including starch, cellulose, hemicellulose, and pectin, which can serve as a carbon source for microbial growth and enzyme production (Laothanachareon et al., 2022). Moreover, cassava peels are an inexpensive and readily available feedstock, making them an attractive substrate for enzyme production (Dorleku et al., 2022).

### Biogas

Initial digestion studies carried out on cassava peels showed that the peels are poor producers of biogas, probably as a result of their content of toxic cyanogenic glycosides (Okafor, 1998). As a result, they require treatment to enhance their yield of biogas and onset of gas flammability. Blending cassava peels with animal wastes can be an effective treatment method to enhance the biogas yield and improve the onset of gas flammability during anaerobic digestion. Ofoefule and Uzodinma (2009) reported that blending cassava peels with pig dung and poultry droppings resulted in higher biogas yield and faster onset of gas flammability compared to using cassava peels alone. The addition of animal wastes can provide a more diverse microbial population and a balanced nutrient composition, which are necessary for efficient anaerobic digestion (Abomohra et al., 2022). Animal wastes are rich in nitrogen and other essential nutrients, which can promote microbial growth and activity, leading to higher biogas production. Moreover, the addition of animal wastes can also improve the carbon-to-nitrogen ratio (C/N) of the feedstock. Cassava peels are often high in carbon and low in nitrogen, while animal wastes are rich in nitrogen and low in carbon. Blending these two feedstocks can balance the C/N ratio, which is critical for optimal microbial activity and biogas production. Investigations of Adelekan and Bamgbuye (2009) indicated that mixing cassava peels with livestock waste (poultry and piggery) in a ratio 1:1 by mass generated high amounts of biogas. In another study, Ofoefule et al. (2010) observed that the low biogas yield and slow onset of gas production/flammability of cassava peels under anaerobic fermentation can be enhanced by chemical treatment with KOH and potash (Table 4). Chemical treatment with KOH and potash can enhance the anaerobic digestion process of cassava peels (Ahou et al., 2021). KOH (potassium hydroxide) and potash (potassium carbonate) are alkali chemicals that can improve the solubility and accessibility of organic matter in cassava peels by breaking down the lignocellulosic structure (Figueroa et al., 2020). This treatment increases the availability of the carbon source for microorganisms, leading to a higher biogas yield and faster onset of gas production (Gunes et al., 2019). In addition to enhancing biogas yield and production rate, chemical treatment with KOH and potash can also improve the digestate quality by increasing the nutrient content and reducing the lignocellulosic content, which can be used as a fertilizer for crops (Kim et al., 2022).

### Treatment of wastewater

The use of cassava peels for the treatment of wastewater as well as bioleaching of heavy metals has been severely reported (Oghenejoboh et al., 2016; Adeolu and Adewoye, 2019). Oghenejoboh et al. (2016) reported 100% removal efficiency of Pb²⁺ with fermented cassava peels as compared to 95% by unfermented cassava peels, while 96% of phenol was removed by fermented cassava peels against 93% by unfermented cassava peels. These authors postulated that the better performance of fermented cassava peels over unfermented cassava peels may be as a result of its higher pH arising from the lowering of cyanide from the cassava peels due to the process of fermentation. They recommended a two-stage fermented cassava peels adsorption column arranged in series to treat refinery wastewater efficiently to reduce the concentration of phenol to 0.005 mg/L allowed by the Federal Environmental Protection Agency (FEPA) of Nigeria or to totally remove phenol from the effluent. The study of Adeolu and Adewoye (2019) also

### Table 4. Generation of biogas from cassava peels.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Cumulative gas yield (L/total mass of slurry, kg)</th>
<th>Lag period (days)</th>
<th>Mean volume of gas production (L/total mass of slurry, kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated cassava peels</td>
<td>68.7</td>
<td>58</td>
<td>2.39</td>
</tr>
<tr>
<td>Cassava peels treated with KOH</td>
<td>111.3</td>
<td>10</td>
<td>4.45</td>
</tr>
<tr>
<td>Cassava peels treated with potash</td>
<td>124.1</td>
<td>7</td>
<td>4.97</td>
</tr>
</tbody>
</table>

Source: Ofoefule et al. (2010).
assessed the bioleaching of heavy metals from hospital sewage sludge using cassava peels fermentation extracts. They observed optimum heavy metals removal using A. tereus fermentation extract for Ni (78.4%) and Zn (72.3%), and recommended that the adoption of fermented cassava peels for removal of heavy metals will ensure safe disposal of the treated sewage sludge.

Animal feed production
Cassava peels have been evaluated as a feedstuff for animals (Osei et al., 1990; Orororo et al., 2014). The pioneering work of Oboh (2006) showed that cassava peels fermented with S. cerevisiae, Lactobacillus delbruckii and Lactobacillus coryneformis have increased protein contents (from 8.2 to 21.5%), and reduced cyanide (from 44.6 to 6.2 mg/kg) and phytate (from 1043.6 to 789.7 mg/100 g) contents. Using Trichoderma viride ATCC 36316 and submerged fermentation, Ezekiel et al. (2010) reported a massive increase in crude proteins in cassava peels from 4.21 to 36.52%, with 29.03% as true proteins. They also observed that the essential amino acids were all present in the fermented cassava peels. Fermentation of the cassava peels into enriched animal feed by the white rot fungus Panustigrinus M609PQY was also investigated by Ruqayyah et al. (2011). The authors obtained 71.31% protein increase and 61.66% lignin degradation. Ezekiel and Aworh (2013) also observed increase in crude proteins from 4.21% in unfermented cassava peels to 10.43% in the fermented samples. Other studies revealed that the nutrient value of cassava peels improves when augmented with animal wastes and fermented with rumen liquor microorganisms (Oloruntola et al., 2015).

The increase in crude proteins and mineral contents, as well as reduction of anti-nutritional factors (phytate and cyanide) and fibre contents of the fermented cassava peels makes it a highly digestible component for livestock feed production. According to Niyale et al. (2020), average daily weight gain was higher for sheep offered the ensiled cassava peels diet which has improved crude protein contents than the dried or control diet. Other investigations showed that pig feeds formulated with cassava peels pretreated with A. niger enhanced its metabolisable energy and other nutritive values such as increased serum calcium and albumin levels as well as increase in the body weight of the pigs (Tonukari et al., 2016). Also, Awvioroko et al. (2016) concluded that the maize content in broiler feed can be replaced with cassava peels improved with fungal amylase up to a maximum of 60%. Several studies have investigated the impact of cassava peel meal as an animal feed ingredient on animal growth and weight. For example, Adekeye et al. (2021) found that broiler chickens fed diets containing up to 30% cassava peel meal had similar growth performance and haematological indices to those fed a control diet. Similarly, Amole et al. (2022) found that cassava peel meal could replace up to 30% of maize in pig diets without any adverse effect on growth performance or nutrient digestibility. Overall, these studies suggest that cassava peel meal can be safely used as a substitute feed ingredient for animals without any negative effects on growth performance or nutrient digestibility.

PERSPECTIVES
The applications of cassava peels are far from exhaustive and new products from the peels are still being discovered. Cassava peels are also good substrates for the production of tetracyclines (Asagbra et al., 2005) and possibly other antibiotics. The peels are also excellent substrates for the cultivation of fungal biomass including A. niger on a large-scale (Olutosin and Kayode, 2021). The chemical and morphological properties of cassava peels indicate that it is a promising alternative fiber sources for pulp and paper making (Daud et al., 2013). Therefore, cassava peels which are often discarded during processing constitute an important potential resource if properly harnessed biotechnologically.

CONFLICT OF INTERESTS
The authors have not declared any conflict of interests.

REFERENCES


