Vol. 14(1), pp. 1-8, January-June 2023
DOI: 10.5897/BMBR2023.0292
Article Number: EC62B8570611
ISSN 1538-2273

http://www.academicjournals.org/BMBR

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**Biotechnology and Molecular Biology Reviews**

*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, biogas, 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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**Table 1.** Proximate composition of unfermented and *Aspergillus niger* fermented cassava peels.

| Composition (%)* | Unfermented cassava peels | Fermented cassava peels |
|---|---|---|
| Moisture content | 86.29 | 31.60 |
| Ash | 4.88 | 10.23 |
| Protein | 6.24 | 11.22 |
| Fat | 1.39 | 2.91 |
| Crude fibre | 10.88 | 8.87 |
| Cyanide (ppm) | 118.86 | 20.46 |
| Starch | 56.72 | 20.09 |

*Values are in percentage except for cyanide.
Source: Olutosin and Kayode (2021).

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 Bamgboye, 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 bio-products 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.

## 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 Bamgboye, 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 (Adegbehingbe 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.

| Parameter | Amount |
|---|---|
| Organic carbon (%) | 48.7 |
| Total nitrogen (%) | 1.0 |
| C/N Ratio | 48.7 |
| K (%) | 1.1 |
| P (%) | 1.6 |
| $NO_3$ (%) | 0.16 |
| Zn (mg/kg) | 125 |
| Cu (mg/kg) | 15 |
| Mn (mg/kg) | 180 |
| pH | 6.4 |
| Na (%) | 0.15 |
| Ca (%) | 0.9 |
| Pb (mg/kg) | 16.7 |
| Ash (%) | 52.6 |

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.

| Parameter | Concentration (%) |
|---|---|
| Reducing sugars | 60.74 ± 2.84 |
| Glucose | 37.09 ± 3.15 |
| Xylose | 4.79 ± 0.31 |
| Rhamnose | 4.05 ± 0.18 |
| 5-Hydroxymethyl-furfural | 0.14 ± 0.06 |

Source: Yoonan et al. (2007).

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.

## 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).

### 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 has 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 can be used in ethanol production. The authors observed that the reducing sugars from the hydrolysates were consumed within 10 h of *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 *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 *Trichoderma reesei* for 5 days using yeasts isolated from palm wine. The reducing sugar yield of 1.78 g/mL of the hydroxylate was fermented for bioethanol production using *S. cerevisiae* and *Candida tropicalis* to produce 40.72 and 29.90 g/L of ethanol, respectively after 96 h. Furthermore, Akinruli et al. (2022) isolated bacteria (*Sporosarcina terrae*, *Bacillus cereus*, *Proteus mirabilis* and *Pseudomonas taiwanensis*) and fungi (*Wickerhamomyces rabaulensis*, *Rhizopus nigrican*, and *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). Hydroxylates of cassava peels can be converted into organic acids such as glycolic, levulinic, ferulic, 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 *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 *A. niger* and *Aspergillus tereus* 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 *Rhizopus oligosporus* and *Lactobacillus plantarum* after acidic and alkaline hydrolysis of cassava peels. In another study, unhydrolyzed cassava peels inoculated with a mixed culture of *R. oligosporus* and *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 *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 *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 bet aglucosidase from the white rot fungus, *Trametespolyzona*, 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

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

| Sample | Cumulative gas yield (L/total mass of slurry, kg) | Lag period (days) | Mean volume of gas production (L/total mass of slurry, kg) |
|---|---|---|---|
| Untreated cassava peels | 68.7 | 58 | 2.39 |
| Cassava peels treated with KOH | 111.3 | 10 | 4.45 |
| Cassava peels treated with potash | 124.1 | 7 | 4.97 |

Source: Ofoefule et al. (2010).

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 high 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 Bamgboye (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 digestion 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 severally reported (Oghenejoboh et al., 2016; Adeolu and Adewoye, 2019). Oghenejoboh et al. (2016) reported 100% removal efficiency of $Pb^{2+}$ 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 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* M609RQY 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 Niayale 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, Avwioroko 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 tetracycline (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


Abidin Z, Saraswati E, Naid T (2014). Bioethanol production from waste of the cassava peel (*Manihot esculenta*) by acid hydrolysis and fermentation process. International Journal of PharmTech Research 6(4):1209-1212.

Abomohra A, Faisal S, Ebaid R, Huang J, Wang Q, Elsayed M (2022). Recent advances in anaerobic digestion of lipid-rich waste: challenges and potential of seaweeds to mitigate the inhibitory effect. Chemical Engineering Journal 499:137829.

Acheampong NA, Akanwariwiak WG, Mensah M, Fei-Baffoe B, Offei F, Bentil JA, Borquaye LS (2021). Optimization of hydrolases production from cassava peels by Trametes polyzona BKW001. Scientific African 12:e00835.

Acheampong NA, Akanwariwiak WG, Mensah M, Fei-Baffoe B, Offei F, Bentil JA, Borquaye LS (2022). Conversion of cassava peels into bioethanol using the OSTEP approach. Biomass Conversion and Biorefinery pp. 1-14.

Adegbehingbe T, Adeleke B (2021). Bioethanol Production from Cassava Peels Inoculated with Saccharomyces cerevisiae and *Zymomonas mobilis*. Journal of Advances in Microbiology 21(9):58-67.

Adekeye AB, Amole TA, Oladimeji SO, Raji AA, Odekunle TE, Olasusi O, Adebayo AA (2021). Growth performance, carcass characteristics and cost benefit of feeding broilers with diets containing high quality cassava peel (HQCP). African Journal of Agricultural Research 17(3):448-455.

Adelekan BA (2012). Cassava as a potent energy crop for the production of ethanol and methane in tropical countries. International Journal of Thermal and Environmental Engineering 4(1):25-32.

Adelekan BA, Bamgboye AI (2009). Comparison of biogas productivity of cassava peels mixed in selected ratios with major livestock waste types. African Journal of Agricultural Research 4(7):571-577.

Adeleke B, Akinyele B, Olaniyi O, Jeff-Agboola Y (2017). Effect of fermentation on chemical composition of cassava peels. Asian Journal of Plant Science and Research 7:31-38.

Adeolu AT, Adewoye SO (2018). Comparative Production of Citric and Itaconic Acids from Cassava Peels by Aspergillus spp. and the Indigenous Microflora. Journal of Advances in Biology and Biotechnology 18(2):1-10.

Adeolu AT, Adewoye SO (2019). Efficacy of cassava peel extracts for the removal of heavy metals from hospital sewage sludge in Nigeria. Journal of Health and Pollution 9(23):190908.

Afolabi FT, Ayodele EO (2020). Comparative Study of Bioethanol Production and Reducing Sugar Yields from Cassava Peels Using Fungi. Acta Microbiologica Bulgarica 36:153.

Ahou YS, Bautista Angeli JR, Awad S, Baba-Moussa L, Andres Y (2021). Assessment of Inoculum to Substrate Ratio to Recover Energy from Cassava Wastes Through Anaerobic Digestion. Waste and Biomass Valorization 12:1891-1900.

Ajala AS, Adeoye AO, Olaniyan SA (2018a). Drying kinetics of fermented cassava peels for citric acid production, International Journal of Management Technology and Engineering 8(8):1190-1197.

Ajala AS, Adeoye AO, Olaniyan SA, Fasonyin OT (2020). A study on effect of fermentation conditions on citric acid production from cassava peels. Scientific African 8:e00396.

Ajala AS, Olaniyan SA, Adeoye AO, Fasonyin OT, Olatunde SJ, Adebayo GA (2018b). Analysis of costs of energy in cassava peels hydrolysis. World Journal of Engineering Research and Technology 4(6):267-278.

Akinruli FT, Ibiyemi MF, Oluwasusi VO, Ajayi FA (2022). Isolation of microorganisms from cassava peels for the production of bioethanol. GSC Biological and Pharmaceutical Sciences 19(1):278-287.

Amenaghawon NA, Ogbeide SE, Okieimen CO (2014). Application of Statistical Experimental Design for the Optimisation of Dilute Sulphuric Acid Hydrolysis of Cassava peels. Acta Polytechnica Hungarica 11(9):1-12.

Amole TA, Adekeye AB, Adebayo AB, Okike I, Duncan AJ, Jones CS (2022). High-Quality Cassava Peel®(HQCP®) mash as a feed ingredient for livestock–a review of feeding trials. ILRI Project Report.

Aro SO, Aletor OO, Tewe JO (2010). Nutritional potentials of cassava tuber wastes: A case study of a cassava starch processing factory in South-Western Nigeria. Livestock Research for Rural Development 22(11):42-47.

Asagbra AE, Sanni AI, Oyewole OB (2005). Solid-state fermentation production of tetracycline by Streptomyces strains using some agricultural wastes as substrate. World Journal of Microbiology and Biotechnology 21(2):107-114.

Avwioroko OJ, Anigboro AA, Tonukari NJ (2016). Biotechnological application of cassava-degrading fungal (CDF) amylase in broiler feed formulation. Biotechnology Journal 10(1):1-12.

Baenla J, Mbah JB, Ndjock IDL, Elimbi A (2019). Partial replacement of low reactive volcanic ash by cassava peel ash in the synthesis of volcanic ash based geopolymer. Construction and Building Materials 227:116689.

Castro-Muñoz R, Correa-Delgado M, Córdova-Almeida R, Lara-Nava D, Chávez-Muñoz M, Velásquez-Chávez VF, Ahmad MZ (2022). Natural sweeteners: Sources, extraction and current uses in foods and food industries. Food Chemistry 370:130991.

Crini G, Lichtfouse E, Chanet G, Morin-Crini N (2020). Applications of hemp in textiles, paper industry, insulation and building materials, horticulture, animal nutrition, food and beverages, nutraceuticals, cosmetics and hygiene, medicine, agrochemistry, energy production and environment: A review. Environmental Chemistry Letters 18(5):1451-1476.

da Maia JL, Cardoso JS, da Silveira Mastrantonio DJ, Bierhals CK, Moreira JB, Costa JAV, de Morais MG (2020). Microalgae starch: A promising raw material for the bioethanol production. International Journal of Biological Macromolecules 165:2739-2749.

Daud Z, Awang H, Kassim ASM, Hatta MZM, Aripin AM (2014). "Comparison of pineapple leaf and cassava peel by chemical properties and morphology characterization. Advanced Materials Research pp. 384-388 doi: 10.4028/www.scientific.net/AMR.974.384.

Daud Z, Kassim ASM, Aripin AM, Awang H, Hatta MZM (2013). Chemical composition and morphological of cocoa pod husk and cassava peels for pulp and paper production. Australian Journal of Basic and Applied Sciences 7(9):406-411.

Dorleku WP, Bayitse R, Hansen ACH, Saalia FK, Bjerre AB (2022). Response surface optimisation of enzymatic hydrolysis of cassava peels without chemical and hydrothermal pretreatment. Biomass Conversion and Biorefinery pp. 1-14.

Egbune EO, Aganbi E, Anigboro AA, Ezedom T, Onojakpor O, Amata AI, Tonukari NJ (2023). Biochemical characterization of solid-state fermented cassava roots (*Manihot esculenta* Crantz) and its application in broiler feed formulation. World Journal of Microbiology and Biotechnology 39(2):1-12.

Egbune EO, Avwioroko OJ, Anigboro AA, Aganbi E, Amata AI, Tonukari NJ (2022a). Characterization of a surfactant-stable α-amylase produced by solid-state fermentation of cassava (*Manihot esculenta* Crantz) tubers using *Rhizopus oligosporus*: Kinetics, thermal inactivation thermodynamics and potential application in laundry industries. Biocatalysis and Agricultural Biotechnology 39:102290.

Egbune EO, Ezedom T, Anigboro AA, Aganbi E, Amata AI, Tonukari NJ (2022b). Antioxidants and antigenotoxic properties of Rhizopus oligosporus fermented cassava (Manihot esculenta Crantz). African Journal of Biochemistry Research 16(3):39-46.

Egbune EO, Tonukari NJ (2023). Fermented mixture of cassava roots and palm kernel cake can substitute for maize in poultry feed formulation. African Journal of Biochemistry Research 17(1):1-8.

Ezebuiro V, Ogugbue CJ, Oruwari B, Ire FS (2015). Bioethanol production by an ethanol-tolerant Bacillus cereus strain GBPS9 using sugarcane bagasse and cassava peels as feedstocks. Journal of Biotechnology and Biomaterials 5(4):1-9.

Ezekiel OO, Aworh OC (2013). Solid state fermentation of cassava peel with *Trichoderma viride* (ATCC 36316) for protein enrichment. International Journal of Nutrition and Food Engineering 7(3):202-209.

Ezekiel OO, Aworh OC, Blaschek HP, Ezeji TC (2010). Protein enrichment of cassava peel by submerged fermentation with *Trichoderma viride* (ATCC 36316). African Journal of Biotechnology 9(2):187-194.

Fernando NML, Amaraweera APSM, Gunawardane OHP, Wanninayaka WMDB, Manipura A, Manamperi WAR, Kulathunga KMAK (2022). Sustainable Biorefinery Approach for Cassava: Engineer 55(2):71-88.

Figueroa KHN, García NVM, Vega RC (2020). Cocoa By-products. Food Wastes and By-products: Nutraceutical and Health Potential 373-411.

Gou C, Wang X, Yu Y, Huang J, Wang X, Hui M (2023). One-step enzymatic hydrolysis of sweet potato residue after gelatinization for bioethanol production by *Saccharomyces cerevisiae*. Biomass Conversion and Biorefinery pp. 1-10.

Gunes B, Stokes J, Davis P, Connolly C, Lawler J (2019). Pre-treatments to enhance biogas yield and quality from anaerobic digestion of whiskey distillery and brewery wastes: A review. Renewable and Sustainable Energy Reviews 113:109281.

Isah Y, Kabiru HD, Danlami MA, Kolapo SF (2019). Comparative analysis of bioethanol produced from cassava peels and sugarcane bagasse by hydrolysis using *Saccharomyces cerevisiae*. Journal of Chemical Society of Nigeria 44(1):233-238.

Kim JY, Jung JM, Jung S, Park YK, Tsang YF, Lin KYA, Kwon EE (2022). Biodiesel from microalgae: Recent progress and key challenges. Progress in Energy and Combustion Science 93:101020.

Kongkiattikajorn J, Sornvoraweat B (2011). Comparative study of bioethanol production from cassava peels by monoculture and co-culture of yeast. Agriculture and Natural Resources 45(2):268-274.

Laothanachareon T, Bunterngsook B, Champreda V (2022). Profiling multi-enzyme activities of *Aspergillus niger* strains growing on various agro-industrial residues. 3 Biotech 12(1):17 doi: 10.1007/s13205-021-03086-y.

Liu X, Kokare C (2023). Microbial enzymes of use in industry. In Biotechnology of microbial enzymes (pp. 405-444). Academic Press.

Mahato N, Sinha M, Sharma K, Koteswararao R, Cho MH (2019). Modern extraction and purification techniques for obtaining high purity food-grade bioactive compounds and value-added co-products from citrus wastes. Foods 8(11):523.

Maraphum K, Saengprachatanarug K, Wongpichet S, Phuphuphud A, Posom J (2022). Achieving robustness across different ages and cultivars for an NIRS-PLSR model of fresh cassava root starch and dry matter content. Computers and Electronics in Agriculture 196:106872.

McAllister J, Kunsman GW, Levine BS (2020). Carbon monoxide/ cyanide. Principles of Forensic Toxicology, pp. 545-560.

Mohammed A, Oyeleke SB, Egwim EC (2014). Pretreatment and hydrolysis of cassava peels for fermentable sugar production. Asian Journal of Biochemistry 9(1):65-70.

Moran-Aguilar MG, Costa-Trigo I, Calderón-Santoyo M, Domínguez JM, Aguilar-Uscanga MG (2021). Production of cellulases and xylanases in solid-state fermentation by different strains of *Aspergillus niger* using sugarcane bagasse and brewery spent grain. Biochemical Engineering Journal 172:108060.

Mueed A, Shibli S, Jahangir M, Jabbar S, Deng Z (2022). A comprehensive review of flaxseed (*Linum usitatissimum* L.): health-affecting compounds, mechanism of toxicity, detoxification, anticancer and potential risk. Critical Reviews in Food Science and Nutrition pp. 1-24.

Niayale R, Addah W, Ayantunde AA (2020). Effects of ensiling cassava peels on some fermentation characteristics and growth performance of sheep on-farm. Ghana Journal of Agricultural Science 55(2):107-121.

Nwabueze TU, Otunwa U (2006). Effect of supplementation of African breadfruit (*Treculia africana*) hulls with organic wastes on growth characteristics of Saccharomyces cerevisiae. African Journal of Biotechnology 5(16):1494-1498.

Nwokoro O (2014). Production of L-lactic acid from Cassava peel wastes using single and mixed cultures of *Rhizopus oligosporus* and *Lactobacillus plantarum*. Chemical Industry and Chemical Engineering Quarterly 20(4):457-461.

Obadina AO, Oyewole OB, Sanni LO, Abiola SS (2006). Fungal enrichment of cassava peels proteins. African Journal of Biotechnology 5(3):302-304.

Oboh G (2006). Nutrient enrichment of cassava peels using a mixed culture of *Saccharomyces cerevisae* and *Lactobacillus* spp. solid media fermentation techniques. Electronic Journal of Biotechnology 9(1):0-0.

Ofoefule AU, Eme EL, Uzodinma EO, Ibeto CN (2010). Comparative study of the effect of chemical treatments on cassava (*Manihot utilissima*) peels for biogas production. Scientific Research and Essays 5(24):3808-3813.

Ofoefule AU, Uzodinma EO (2009). Biogas production from blends of Cassava (*Manihot utilissima*) peels with some animal wastes. International Journal of Physical Sciences 4(2):105-108.

Ogbonnaya N, Anya FO, Eze IC (2013). The use of microorganisms in increasing the protein yield of cassava (*Manihot esculenta* Crantz) peel wastes. Polish Journal of Chemical Technology 15(2):112-115.

Oghenejoboh KM, Orugba HO, Oghenejoboh UM, Agarry SE (2021). Value added cassava waste management and environmental sustainability in Nigeria: a review. Environmental Challenges 4:100127.

Oghenejoboh KM, Otuagoma SO, Ohimor EO (2016). Application of cassava peels activated carbon in the treatment of oil refinery wastewater–a comparative analysis. Journal of Ecological Engineering 17(2):52-58.

Okafor N (1998). An integrated Bio-system for the disposal of Cassava Wastes. In Proceedings: Internet conference on Integrated Biosystems in Zero Emissions Applications. http://www.ias.unu.edu/proceedings/icbs.

Olanbiwoninu AA, Odunfa SA (2016). Production of cellulase and xylanase by *Aspergillus terreus* KJ829487 using cassava peels as subtrates. Advances in Microbiology 6(07):502-511.

Oloruntola OD, Agbede JO, Onibi GE, Igbasan FA (2015). Composition of cassava (Manihot spp.) peels fermented with bovine rumen liquor and different nitrogen sources. Journal of Global Agriculture and Ecology 2(1):26-35.

Olutosin DA, Kayode FJ (2021). Use of Agrowaste (Cassava Peels) to Cultivate *Aspergillus niger* for Biomass Production. International Journal of Biochemistry, Biophysics and Molecular Biology 6(1):11-17.

Orororo OC, Tonukari NJ, Avwioroko OJ, Ezedom T (2014). Effect of supplementation of animal feed with dried cassava (*Manihot esculenta*) peels, and stems of *Vernonia amydalina* and *Pennisetum purpereum* on some biochemical parameters in pigs. NISEB Journal 14(4):177-183.

Osei SA, Asiamah M, Atuahene CC (1990). Effects of fermented cassava peel meal on the performance of layers. Animal Feed Science Technology 29(3-4):295-301.

Osemwengie SO, Osagie EI, Onwukwe B (2020). Optimization of bioethanol production from cassava peels. Journal of Applied Sciences and Environmental Management 24(12):2077-2083.

Ozoegwu CG, Eze C, Onwosi CO, Mgbemene CA, Ozor PA (2017). Biomass and bioenergy potential of cassava waste in Nigeria: Estimations based partly on rural level garri processing case studies. Renewable and Sustainable Energy Reviews 72:625-638.

Panghal A, Munezero C, Sharma P, Chhikara N (2019). Cassava toxicity, detoxification and its food applications: a review. Toxin Reviews 40(1):1-16.

Prado FC, Vandenberghe LP, Woiciechowski AL, Soccol R (2005). Citric acid production by solid-state fermentation on a semi-pilot scale using different percentages of treated cassava bagasse. Brazilian Journal of Chemical Engineering 22(4)1-14.

Ruqayyah TI, Jamal P, Alam Z, Mirghani ES (2011). Valorization of cassava peels by the white rot fungus *Panus tigrinus* M609RQY. Australian Journal of Basic and Applied Sciences 5:808-816.

Sánchez M, Laca A, Laca A, Díaz M (2021). Value-Added Products from Fruit and Vegetable Wastes: A Review. CLEAN–Soil, Air, Water 49(8):2000376.

Souto LRF, Caliari M, Soares-Junior M, Fiorda FA, Garcia MC (2016). Utilization of residue from cassava starch processing for production of fermentable sugar by enzymatic hydrolysis. Food Science and Technology 37(1):19-24.

Steudler S, Werner A, Walther T (2019). It is the mix that matters: Substrate-specific enzyme production from filamentous fungi and bacteria through solid-state fermentation. Solid State Fermentation: Research and Industrial Applications 169:51-81.

Sujithra B, Deepika S, Akshaya K, Ponnusami V (2019). Production and optimization of xanthan gum from three-step sequential enzyme treated cassava bagasse hydrolysate. Biocatalysis and Agricultural Biotechnology 21(2-4):101294.

Tonukari NJ (2004). Cassava and the future of starch. Electronic Journal of Biotechnology 7(1):5-8.

Tonukari NJ, Ezedom T, Enuma CC, Sakpa SO, Avwioroko OJ, Odiyoma E (2015). White gold: cassava as an industrial base. American Journal of Plant Sciences 6(07):972-979.

Tonukari NJ, Oliseneku EE, Avwioroko OJ, Aganbi E, Orororo OC, Anigboro AA (2016). A novel pig feed formulation containing *Aspergillus niger* CSA35 pretreated-cassava peels and its effect on growth and selected biochemical parameters of pigs. African Journal of Biotechnology 15(19):776-785.

Widiarto S, Pramono E, Rochliadi A, Arcana IM (2019). Cellulose nanofibers preparation from cassava peels via mechanical disruption. Fibers 7(5):44 doi:10.3390/fib7050044

Xu X, Zhang W, Gu X, Guo Z, Song J, Zhu D, Liu Y, Liu Y, Xue G, Li X, Makinia J (2020). Stabilizing lactate production through repeated batch fermentation of food waste and waste activated sludge. Bioresource Technology 300:122709. doi.org/10.1016/j.biortech.2019.122709

Yoonan K, Kongkiattikajorn J (2004). A study of optimal conditions for reducing sugars production from cassava peels by diluted acid and enzymes. Agriculture and Natural Resources 38(5):29-35.

Yoonan K, Yowapui P, Kongkiattikajorn J (2007). Ethanol production from acid hydrolysate of cassava peels using *Saccharomyces cerevisiae*. KMUTT Research and Development Journal 30(3):405-418.

Zakariyah RF, Ojo MO, Ajijolakewu KA, Saliu KB, Ahmed RN, Agbabiaka TO, Sani A (2021). Optimisation of Lactic Acid Fermentation from Cassava Peel by *Lactobacillus casei* (ATCC334). Microbiology Research Journal International 31(6):29-42.