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Characterization and pre-leaching effect on the peels of predominant cassava varieties in Uganda for production of activated carbon

R. Kayiwa [*], H. Kasedde, M. Lubwama, J.B. Kirabira

Department of Mechanical Engineering, College of Engineering, Design, Art and Technology, Makerere University, P.O. Box 7062, Kampala, Uganda

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ABSTRACT

Activated Carbon (AC) remains a key material for both industrial and domestic applications. The aim of this work was to characterize the peels of predominant cassava varieties grown in Uganda for production of AC. The selected varieties were; NASE 1, NASE 3, NASE 14, NASE 19, NAROCAS 1, and NAROCAS 2 due to more guaranteed raw material availability and potential for sustainability for AC production. The peels were characterized through proximate and ultimate analysis, bulk density, water-binding capacity, and lignocellulosic composition. Pre-leaching was done using NaOH of 1–4% w/v concentrations on two representative peel varieties. The dry basis (db) values of ash content, volatile matter and fixed carbon percentages of the peel varieties ranged from 1.93 to 4.36%, 77.93–81.93% and 13.78–15.34%, respectively. The ash content values were below 5% and hence may not necessitate pre-leaching to remove any ash forming agents. The dry basis char yield from the peels at 400 °C is in the range of 27.76–31.09%, qualifying them for AC production. The lignin, cellulose and hemicellulose compositions are in the ranges 9.0–16.0%, 5.5–15.0%, and 41.0–65.0%, respectively. The varieties with higher cellulosic content may be more suitable for highly porous AC production. Pre-leaching showed no remarkable reduction in the ash content but increased the volatile matte and char yield at low NaOH concentrations. Predominant Ugandan cassava peel varieties have potential for production of AC with alkaline pretreatment required in applications where high char yields are required.

1. Introduction

The search for low-cost, eco-friendly sustainable sources of activated carbon (AC) is on the increase. Activated carbon remains a key material applied domestically and industrially in various processes. These processes include; gas adsorption, water purification [1–3], electro-chemicals [4,5], dye removal from aqueous solutions [6], adsorption of heavy metals from solutions [7], food sweetener decolorization and catalysis [8]. The suitability of activated carbon for the mentioned applications is based on at least one of the following properties; its extended surface area, micro porous structure, high adsorption capacity and high degree of surface reactivity [9]. However, commercially available activated carbons are very expensive and that limits their applications. In recent years, there has been a growing interest to produce ACs from lignocellulosic agricultural residues [10–14] This is majorly attributed to their availability at a low cost, their high carbon content, and low inorganics that suit them as precursors for production of ACs [8].

Over the past decade, growth in cassava production has accelerated with global estimates at 277 million metric tons [15]. This has partly been due to its technological potential of being utilized as a raw material for agro-industrial products [16]. Cassava peel constitutes 10–15% weight composition of the tuber weight. This implies that 27.7 to 41.5 million metric tons of cassava peel are expected to be generated. Cassava peels (CP) find application in a number of processes including; animal feeds, biogas production [17], bioethanol fermentation [18], pyrolysis and gasification [19]. Besides animal feeds, most of the processes have been reported as uneconomical and the development technology still at infancy [18]. The main competing application of these peels therefore is in animal feeds. However, their low protein content (<6%) limits them as feed supplements and hence not recommended beyond certain levels in animal feed [20] or should be used with other high protein feedstuffs [21]. Moreover, cassava peels contain anti-nutrients like hydrocyanic acid and tanic acid [22]. A number of studies have been conducted on the characteristics of cassava peels that suit them as precursors for AC [23–27]. However, like with other lignocellulosic agricultural precursors, variations in the physical and chemical compositions of cassava peels are inextricably dependent on the variety, climatic and weather

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[*] Corresponding author.
E-mail address: kronald@cedat.mak.ac.ug (R. Kayiwa).

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conditions of an area [28,29]. More over studies have shown that the factors that influence the textural properties of the elaborated char and resultant activated carbon are preponderantly its starting biomass [30–32] besides the process conditions. The varietal differences in chemical and physical compositions have significantly been reported to have effects on the food derivatives from cassava [33]. Moreover, each component of the lignocellulose complex within the raw precursor contributes to the porosity of the chars and activated carbons whatever is its weight contribution [34,35].

In the production of activated carbon, high carbon content, low level of ash, high thermal stability, small pore diameters, high porosity, as well as a high specific surface area are some of the properties highly considered. Like with other potential AC precursors, this study focused on the core physical, proximate and bio-chemical properties of each cassava peel variety. The physical properties include; bulk density, water binding capacity and moisture content. Proximately the ash content, volatile matter and fixed carbon percentage compositions were studied due to their determinant importance in the selection of the prospective AC's application. For example, a high ash content could be a hindrance to pore development in the activation process implying low surface area in the resultant AC [36]. This limits the application of such AC in adsorption related processes. The lignocellulosic composition (cellulose, hemicellulose and lignin) is equally important in understanding the treatment needed to precisely break the complex structure to release free carbon. For example an AC precursor with high lignin content is preferred due to a high carbon content hence high prospective char yield. However, unlike cellulose, lignin is not easily hydrolysable and may require relatively more advanced thermal treatment during the AC production processes [20]. There are over 200 cassava varieties grown in Uganda [37]. Characterization of the peels of predominant cassava cultivars for AC production and other economic benefits would be beneficial in selecting cassava varieties for specific AC qualities, processing and other ultimate industrial applications.

The study purposively focused on predominant varieties in Uganda including; NASE 1, NASE 3, NASE 14, NASE 19, NAROCAS 1 and NAROCAS 2 due to guaranteed raw material availability and implied potential for sustainability of AC production. In this study we obtained cassava from the pilot gardens of the four varieties at the National Crops Resources Research Institute (NaCRRI) - Namulonge Uganda. The main objective in this work was to determine the suitability of the cassava peels from the selected predominant varieties in Uganda for production of AC and the effect of pre-leaching on the chemical and physical properties of the peels that accrue to AC production and other economic applications.

2. Materials and methods

2.1. Sample collection and preparation

100 kg of tubers for each of the six predominant cassava varieties were collected from NaCRRI pilot gardens located at Namulonge central Uganda (coordinates: 0.5201885343136564, 32.62651272590588). The planting period for NASE1, NASE 3 and NASE 19 was March–April where as for NASE 14, NAROCAS 1 and NAROCAS 2 was April–May 2019. They were all harvested in June–July 2020.

The tubers were peeled separately at the Center's nutrition lab to yield 20 kg of peel for each variety. The peels were washed with distilled water to a debris free level by gravitational flow method. They were dried in an oven at 40 °C for 12 h to reduce the moisture content and pulverized to 0.5 mm average particle size. They were separately packed and sealed in water and airtight high-density polyethylene (HDPE) bags for further analysis. The bags were code named according to the variety names; NASE 1, NASE 3, NASE 14, NASE 19, NAROCAS 1 and NAROCAS 2.

2.2. Characterization

2.2.1. Bulk density

Each of the milled cassava peel varieties were packed into a pre-weighed tube furnace crucible of mass m_1 and trimmed to the top to flash with the top most rim of the crucible. The crucible and its contents were transferred into an oven set at 105 °C for 24 h. After drying, the filled crucibles were weighed and the mass recorded as m_2. The dry sample mass, m_3 was obtained from; $m_3 = m_2 - m_1$.

The inside diameter (d) and the height (h) of the crucible were measured using a vernier caliper and the volume calculated from $v = \pi(d/2)^2 h$

$$\text{Bulk density, } (\text{kg/m}^3) \text{ was calculated from} = \frac{m_3}{v} \times 1000 \tag{1}$$

2.2.2. Water binding capacity

5g of cassava peel flour were weighed into pre-weighed falcon tubes. 50 ml of water as a supernatant was added and vortexed to make a homogenate and shaken in an orbital shaker for 2 h. The homogenate was left to stand for 24 h at room temperature followed by centrifuging at 4 °C for 10 min at 1000 rpm.

The supernatant was drained out with tubes inclined at an angle of 45° on adsorbent paper for 2 h to remove any remaining water droplets.

Water absorption percentage was determined according to Eq. (2)

$$\text{Water absorption } \% = \frac{B - A}{5} \times 100 \tag{2}$$

Where:

A = 5g of sample + weight of corresponding falcon tube
B = Weight of sample after drying + weight of the falcon tube.

2.2.3. Proximate analysis

Thermo-gravimetry was employed to study the proximate properties of the peels. About 5–10 g sample of each cassava peel variety (size 0.5 mm) was placed in a platinum crucible, and heated in hot box oven (STUART SCIENTIFIC; S/N: R00002) from ambient temperature to 600 °C at a ramping rate of 20 °C min^{-1} under nitrogen flow of 60 mL min^{-1} while monitoring the weight losses at particular temperature ranges. At the same ramping rate, heating was continued up to 900 °C but under airflow to allow for char oxidation. This temperature was held constant for 3 min until there was no further change in mass of the remaining residue. Moisture content was obtained as weight loss due to dehydration of cassava peels from room temperature to temperatures ranging from 105 to 120 °C.

$$\text{Moisture } (\%) = \frac{Wt.of\,original\,sample - Wt.of\,dried\,sample\,between\,105\,to\,120^\circ\text{C}}{Wt.of\,original\,sample} \times 100 \tag{3}$$

Volatile matter content was obtained as weight loss due to thermal degradation between 120 and 600 °C. Fixed carbon content was obtained as the weight loss due to combustion of the remaining organic material at temperatures ranging from 600 to 900 °C. Char yields of the different cassava peel varieties were determined as the ratio of dry sample weight after pyrolysis to the weight of the dry raw sample (Lua et al., 2004). The remaining residue after combustion of the organic material represented the ash content.

2.2.4. Bio-chemical analysis

The direct method of determining the cellulose, hemicellulose and lignin was applied [38]. 2g of each cassava variety were boiled in ethanol 4 times for 15 min in each run, washed thoroughly with distilled water and kept in an oven at 40 °C for 12 h. The resultant residue was divided into two parts with one recorded as fraction **A**. The Second duplicate of the residue was treated with 24% KOH for 4 h at 25 °C, washed thoroughly with distilled water and dried at 80 °C for 12 h and the resultant dry weight taken as fraction **B**. The same samples were again treated with 72% H_2SO_4 for 3 h to hydrolyze the cellulose and the refluxed with 5% H_2SO_4 for 2 h. H_2SO_4 was removed completely by washing with distilled water, dried at 80 °C in oven for overnight and dry weight taken as fraction **C**.

Cellulose = B-C 4(a)

Hemicellulose = A-B 4(b)

Lignin = C 4(c)

2.2.5. *Ultimate analysis*

The CHS elemental analyzer (Perkin-Elmer 2400) was used to determine the Carbon (C), Hydrogen (H) and Sulphur (S) elemental compositions of the peels. The nitrogen (N) content was determined using the Kjeldhal method by converting the CP inherent nitrogen to ammonia and titrating it with hydrochloric acid. The oxygen content in the cassava peel varieties was determined by difference.

2.3. *Pre-leaching*

The dry cassava peel varieties NASE 1 and NAROCAS 1 representative of the NASE and NAROCAS families were subsequently used to study the pre-leaching effect on cassava peel physical and chemical properties. Each of the oven dried samples were alkaline pretreated by soaking 5 g of each of the selected cassava peel varieties in 40 ml of 1.0, 2.0, and 4.0% w/v NaOH. This was followed by mixing and heating at 400 rpm and 50 °C, respectively, in a centrifuge shaker-HERMLE Z326K for 3 h, and allowing the samples to stand for 12 h. The alkaline pretreated cassava peel samples were then transferred to a chromatographic column, with a filter at its bottom and rinsed with distilled water until a neutral pH was obtained, followed by oven drying of the samples at 105 °C for 12 h. The alkaline pretreated cassava peel samples were milled to fractions of particle size 0.5 mm, and subsequently employed to determine the proximate properties, char yield, as well as the ultimate composition.

3. Results and discussion

3.1. *Physical properties*

3.1.1. *Bulk density*

The bulk densities ranged from 59.75 to 60.95 kg/m^3 with NAROCAS 2 having the lowest bulk density and NAROCAS 1 the highest. There was no remarkable difference in the mean bulk densities of the powdered cassava peel varieties as shown in Table 1. Bulk density determines the ease with which a material can be transported especially in terms of container space for the material. However, more advanced correlations have shown bulk density as a key predictive indicator in determining the suitability of a material for absorption purposes in water treatment systems [39] with materials of lower bulk densities reported to have a higher adsorptive capacity. Compared with bulk densities reported by other researchers [40], the bulk densities of the peels of Ugandan cassava varieties can be harnessed for synthesis of adsorbents [41].

3.1.2. *Water binding capacity*

The peel varieties have quite high water binding capacities ranging from 175.41 to 239.04% with NAROCAS 1 having the lowest water holding capacity and NASE 3 and 14 with the highest. The relatively lowest water binding capacity of NAROCAS 1 is partly due to the high lignin composition that is the highest of all the six varieties at 16.0%. The lignin contents are presented later under bio-chemical composition in section 3.3. Unlike cellulose and hemicelluloses based on carbohydrate units, lignin performs the key role of repelling water in lignocellulosic materials. The varieties with the highest water binding capacity have correspondingly high cellulose contents. This is due to the cellulose fibrils that have a large surface area to trap a lot of water. The fibrillation resultant surface area, cellulose chains have hydroxyl (OH) groups that form bonds with water molecules leading to binding of the water molecules onto the fibril surfaces. Despite the high water binding capacity of the two varieties (NASE 3 and NASE 14), these may not be most suitable for production of AC for absorption purposes especially at nano scale. This is because during drying processes, the prevalent cellulose chains tend to form hydrogen bonds that lead to irreversible agglomeration [42]. Based on the water binding capacities, the suitability for production of AC from the cassava peel varieties is in the order NAROCAS 1>NASE 19>NASE 1>NAROCAS 2>NASE 3>NASE 14. However, the higher the water binding capacity the higher the potential of being applied in hydrates inhibiting applications. In a study on methane hydrate induction time in the presence of cassava peel as a hydrate inhibitor, cassava peel showed a high potential to disrupt any potential entrapment of gas molecules [43]. Hydroxyl groups play a significant role in kinetic hydrate inhibitors as they delay the formation of hydrates by forming hydrogen bonds with water molecules.

3.1.3. *Moisture content*

The dry basis moisture content of the cassava peel varieties ranges from 9.93 to 11.46%. These values are in the same range reported by other scholars [44,45]. Other scholars have reported values out of this range [46–48]. This could be to the difference in the drying conditions like higher temperature and longer drying times where as the average particle size difference could also have led to differing moisture content

Table 1

Bulk density, proximate and ultimate properties of predominant cassava peel varieties in Uganda.

Cassava variety	Peel thickness (mm) wb	Mean bulk density (kgm^{-3})(db)	Water binding capacity (%)	Mean moisture content (%wt) (db)	Proximate analysis			Char yield (% db)	lignocellulosic analysis		
					Ash (% wt)	FC	VM		Lignin	Cellulose	Hemicellulose
NASE 1	2.30 ± 0.17	60.75	192.77 ± 4.29	10.67 ± 0.05	3.55 ± 0.03	14.53 ± 0.23	79.23 ± 0.26	29.44 ± 0.25	0.075	0.055	0.56
NASE 3	2.47 ± 0.17	60.80	210.42 ± 10.35	11.44 ± 0.06	4.36 ± 0.04	14.72 ± 0.19	77.93 ± 0.22	31.09 ± 0.12	0.065	0.060	0.55
NASE 14	2.55 ± 0.50	60.75	239.04 ± 5.07	10.68 ± 0.10	4.31 ± 0.10	14.24 ± 0.44	78.78 ± 0.56	29.74 ± 0.21	0.080	0.055	0.50
NASE 19	2.70 ± 0.36	60.65	186.82 ± 1.96	10.50 ± 0.04	3.11 ± 0.17	15.34 ± 0.17	78.84 ± 0.16	30.47 ± 0.07	0.095	0.145	0.41
NAROCAS 1	1.78 ± 0.23	60.95	175.41 ± 0.43	9.93 ± 0.16	1.93 ± 0.08	13.78 ± 0.34	81.93 ± 0.38	27.76 ± 1.18	0.160	0.145	0.56
NAROCAS 2	2.17 ± 0.16	59.75	200.44 ± 1.17	11.45 ± 0.05	3.42 ± 0.09	14.07 ± 0.36	79.58 ± 0.34	28.04 ± 0.02	0.090	0.150	0.65

db = dry basis, wb = wet basis.

even under the same drying conditions. For example the moisture content reported by Owamah., (2014) is 8.76% and the average particle size is 128 μm [46].

3.2. Proximate analysis

The ash content, volatile matter and fixed carbon percentages of the cassava peel varieties ranged from 1.93 to 4.36%db, 77.93 to 81.93%db and 13.78 to 15.34%db, respectively. The ash content values compare well with those reported by some researchers in the ranges of 2.3–3.7% [47,49–52] but the volatile matter content is above that reported by the same researchers in a range of 59.4–74.5%. The ash content is higher than the ash content value of 0.3% reported by Sudaryanto et al. [44] where as the same study and Ki et al. [47] report higher fixed carbon content of 28.9% and 21.4% respectively [44,47]. By virtue of their ash content being less than 5%, all are suitable precursors for production of AC. The ash content of cassava peel that is lower than 5% weight composition is suitably applicable for activated carbon production [41]. This is further supported by the fact that cassava peels with such ash content may not require alkaline pretreatment to remove ash forming elements [53]. Moreover this eliminates potentially hazardous bi-products of alkaline pre-treatment. However, cassava peel ash content values above 5% have been reported elsewhere with ranges 7.0–12.8% [20,54]. Such discrepancies in composition profiles have been attributed to climatic [28] and harvesting season [55] variations. NAROCAS 1 would be the best for AC production owing to its ash content of 1.93%db but has a relatively low char yield. This is because it has the highest volatile matter yet prolonged devolatilization to an extent leads to low char yields [56]. NAROCAS 1 could be the most ideal for production of highly porous carbon it being with the highest volatile matter composition. Besides AC, NAROCAS 1 proximate properties can be harnessed for bio-oil production under slow pyrolysis [47]. The order of suitability for AC production based on ash content is as follows; NAROCAS 1>NASE19> NAROCAS 2>NASE 1>NASE14>NASE 3.

NASE 14 and NASE 3 with the highest ash content at 4.31%db and 4.36%db respectively are suitable for synthesis of geopolymers applicable in manufacture of bio-composite eco-friendly cements and strengthening of earth bricks [57]. Cassava peel ash has been reported as a suitable substitute for volcanic ash in a geopolymer synthesis due to its ability to reduce the setting time and increase the compressive strength [58].

The dry basis char yield from the peels at 400 °C is in the range 27.76–31.09%. These are appreciably viable for mass utilization in AC production. Char yield in the same ranges was reported by other researchers [32,47]. Char yield by slow pyrolysis of cassava peel was reported by Ki et al. [47] in the range 20.8–37.5% with yields reducing with increasing temperatures from 400 to 600 °C. A similar trend was reported by Kotaiah Naik et al. (2017) on sorghum bagasse [14]. The diminishing char yields are due to the on-set of cracking reactions and decomposition of cellulose and hemicellulose at higher temperatures. Researchers have reported significantly higher char yields from biomasses with relatively higher lignin compositions [31,59–62]. This is due to the thermal resistance of lignin compared to cellulose and hemicellulose. Relating to these findings, the studied cassava peel varieties with relatively higher lignin content (NAROCAS 1, NASE 19 and NAROCAS 2) are expected to elaborate higher char yields. However, the results showed relatively lower char yields. This is because the individual peel varieties have higher cellulose and hemicellulose compositions yet cellulose and hemicellulose is highly liable to thermal degradation hence counteracting the expected relatively higher percentage char yield. The rest of the varieties with lower cellulose contents (NASE 1, NASE 3 and NASE 14) have higher char yields despite their relatively lower lignin compositions. In a torrefaction study on the energetic and exergetic evaluation of biomass, banana rachis, coffee waste and oil palm fibre had a higher mass loss compared to saw dust, sugarcane bagasse and rice husk. This was attributed to the higher hemicellulose content in the former biomass group [63]. A similar observation was made by Chen at al., (2012) on coffee residue and rice husk [64].

3.3. Bio-chemical composition

3.3.1. Lignin

The lignin, cellulose and hemicellulose compositions are in the ranges 9.0–16.0%, 5.5–15.0%, and 41.0–65.0% respectively. The lignin and cellulose values are close to other researchers' reported values of 10.88% and 14.17% respectively [49] but the hemicellulose composition is above 23% as reported in the same study. Moreover the hemicellulose compositions are higher than those reported in some studies [51,52], with ranges of 7.5–10.8% hemicellulose composition. These differences could be due to varietal differences, climatic differences, soil profiles and fertility. Lignin being the major contributor of chars and activated carbon [34,62], NAROCAS 1 may be the most suitable for AC production since its lignin composition is distinctly higher than the rest at 16.0%. Moreover, cassava peels and other precursors with in the same/close to this lignin composition were precursors for high surface area and total pore volume AC in other studies [65,66]. Other varieties with lignin percentages higher than their respective cellulose contents may also be suitable for AC due to better possibilities of char yield subject to suitable thermal treatments. Char production has been reported as higher in the biomass that has more lignin as compared to cellulose [67]. This is due to the rich carbon content of lignin [13]. Lignin can be incorporated in other polymers as biodegradable filler due to its compatibility with many other polymers owing to the prevalence of OH and carboxylic groups in its structure. Overall, besides AC production, the order of preference for applications that require a precursor rich in lignin like improving starch water resistance [68], enhancement of the mechanical properties of polymeric composites [69], carbon fibres [70] and others is; NAROCAS 1>NASE 19> NAROCAS 2> NASE 14>NASE 1>NASE 3.

3.3.2. Cellulose

Three of the cassava varieties (i.e. NASE 19, NAROCAS 1 and NAROCAS 2) exhibit relatively higher cellulosic content with range 14.5–15.0% close to the value of 14.00% reported by Adekunle et al. [20] and the value of 14.17% reported by Pooja & Padmaja [49]. Cellulose is a linear organic polysaccharide that is hydrophilic and insoluble in water and most organic solvents. For pyrolysis related applications of which AC production is part, cellulose contributes to the porosity of the resultant char. In the early stages of pyrolysis at relatively lower temperatures, cellulose is volatilized easily since it structure is composed of mainly polysaccharide chains and no aromatic rings. This further qualifies NAROCAS 1 most suitable for AC production due to its high Cellulose content. More so, the structure of cellulose is chiral and the compound is biodegradable. The cassava varieties with high cellulose contents may be applicable in making thin films rather than AC. The agglomeration tendency of hornification of nano cellulose during drying is viable for films due to the hydrogen bonding that enhances the film strength [71]. These varieties could also be applicable in production of bioethanol due to their cellulose composition preferably if alkaline or acid hydrolysis is employed [18]. Rattanachomsri et al. [72] produced bio-ethanol from cassava pulp with a cellulose percentage composition of 15.7%(adf).

3.3.3. Hemicellulose

Hemicellulose possesses a heteropolymeric structure (with a lower molecular weight than cellulose) that is composed of various sugar monomers. The precise ratio of various monomers differs from specie to specie and renders it amorphous with little resistance to hydrolysis and other chemical attacks. Hemicelluose enhances properties of cellulose-based composites like strength, flexibility and UV blockage [73] This is because the sugar polymer interacts with cellulose by hydrogen bonds to provide higher strength. However, the formed hydrogen bonds reduce porosity due to the reduced number of free hydroxyl groups. This however does not preclude the highly hemicellulosic varieties from absorptive applications including AC since hemicellulose can easily be hydrolyzed.

3.4. *Ultimate analysis*

The carbon, hydrogen, nitrogen, oxygen and sulphur contents in the six cassava varieties ranged from 52.91 to 59.40%(db), 5.54–10.19%(db), 1.02–3.32%(db), 32.27–36.40%(db) and 0.08–0.17%(db) respectively. This ultimate composition is close to those of other biomasses summarized and reported by Vasilev et al. [74] and in the same range with other cassava peel varieties as shown in Table 2.

The carbon content in all the peels renders them viable for AC production. The higher the C content the more viable a material is for AC precursor [75]. The presence of relatively higher C in some peel varieties rhymes well with their lignin contents as shown in Table 1 owing to the rich carbon content in lignin. Based on the C composition, the suitability for AC production for the peel varieties is in the order NAROCAS 1> NASE 19> NAROCAS 2> NASE 1> NASE 3> NASE 14.

The Oxygen composition in all the peels suits them for better reactivity during AC production. The presence of oxygen influences the reactivity of bio-mass during pyrolysis, which consequently affects the final product yield and quality. Studies have suggested that the more the presence of oxygen in the biomass, the more will be the reactivity [61]. The oxygen and hydrogen compositions for all the varieties suit them for chemical activation. Oxygen and hydrogen compositions above 25% and 5% respectively predictably imply better activation chemically [8].

3.5. *Effect of pre-leaching*

3.5.1. *Effect on ash content*

Pre-leaching of NASE 1 and NAROCAS 1 reduced the ash content by 0.16 and 0.5%, respectively. Table 3 shows an increase in ash conent for both varieties when treated with higher concentrations of NaOH. This is attributed to the differences in the lignocellulosic compositions of the two varieties. The lower reduction in ash content for NASE 1 is due to the relatively lower lignin content. The increase in ash content after alkaline treatment was also observed by other researchers [65] The increase in ash content could have been due to the release of more acid soluble lignin [76]. The use of NaOH in the pretreatment could have created more pores and hence availed the acid soluble lignin. This contributed to the increase in ash content. More still, the availability of Na in its mineral form in the NaOH may be another factor that contributed to the increase in ash content. This is always dependent on the biomass: NaOH ratio though it was not studied in this work. At lower biomass: NaOH ratios, there are higher chances of mineral sodium from NaOH to contribute to the total inorganic and mineral content which forms ash in the subsequent analysis. Iroba et al. [76] found a significant effect ($p < 0.05$) of biomass to NaOH solution ratio and temperature on the ash content of barley straw. However, since ash content of the pre-treated peels is still below 5%, this still suits it for AC with increased porosity due to higher cellulose and correspondingly higher VM compositions. The results here also imply that NASE 1 despite its high ash content after the alkaline treatment may be applied in production of bioethanol and other reducing sugar precursor based products if acid hydrolyzed to breakdown the acid soluble lignin.

Table 2
Elemental compositions of the cassava peel varieties in this study compared with cassava peel compositions from other studies.

Biomass	Elemental composition (%)					Reference
	C	O	H	N	S	
CP	47.21	43.70	7.74	1.35	0.04	[48]
NASE 1 (CP)	54.15	34.56	8.38	2.82	0.09	This study
NASE 3 CP)	53.14	33.27	10.19	3.32	0.08	
NASE 14 CP)	52.91	36.40	7.43	3.12	0.14	
NASE 19 CP)	56.22	35.93	5.54	2.14	0.17	
NAROCAS 1 CP)	59.40	33.32	6.17	1.02	0.09	
NAROCAS 2 CP)	54.62	34. 83	8.35	2.09	0.15	
CP	59.31	28.74	9.78	2.06	0.11	[44]
CP	53.70	37.90	7.10	1.20	0.10	[47]
All biomass varieties	51.30	41.00	6.30	1.20	0.19	[74]

Mean values from three observations, CP = Cassava peel.

3.5.2. *Effect on volatile matter and fixed carbon content*

Pre-treating the selected peel varieties generally increased the VM and FC contents as shown in Table 3. This is attributed to the reduction in ash content. A similar trend was observed by Menya et al. [53]. The increase in VM and FC renders these peel varieties applicable more in the production of high surface area AC and other torrefaction products like syngas and bio oil.

3.5.3. *Effect on char yield*

The char yield increased as expected due to the removal of ash forming components from the peels at 1% NaOH. However the yield reduced at 2% NaOH for both with NASE 1 and NAROCAS 1and remained almost the same even at 4%. This is due to the break down of lignin that is largely contributive to the char yield. Moreover NAROCAS 1 with a higher lignin composition showed a relatively lower increase in char yield when NaOH treated. During the pretreatment reaction, NaOH dissociates into Na^+ and OH^- ions, and the hydrolysis rate increases with increase in OH^- ions [77]. This is more significant at lower concentrations. The possibility of the presence of mineral Na from the higher concentrations of NaOH could also have contributed to more ash content and hence relatively reduce the char yield.

3.5.4. *Effect on lignocellulosic composition*

The alkaline pre-treatment of the peels simultaneously reduced the hemicellulose % composition and increased the cellulose percentage composition for the two varieties as shown in Fig. 1. The alkaline treatment of lignocellulosic substances disrupts the cell wall architecture by dissolving hemicelluloses and lignin. It also enhances the swelling of the cellulose, decreases its crystallinity; and cleaves the α-ether linkages between lignin and hemicelluloses [78].The lignin composition for NASE 1 increased by 0.7% and from 1% to 2% NaOH concentration but dropped by 4.3% when treated with 4% conc. NaOH. The cellulose percentage composition for the raw NASE 1 peels is 5.5%. It increased to 30.8% on treating the peels with 1% NaOH. This was due to the availability of more cellulose from the solubilization of hemicellulose that dropped from 56.0% of the raw peels to 31.2%.

Generally alkaline pretreatment of the cassava peels shows no significant effect on the lignin content for NASE 1, but a significant reduction in the hemicellulose composition with 4% NaOH for NASE 1 with a reduction of hemicellulose from 56% (raw peel) to 6.7% (treated peels with 4% NaOH). However, the lignin composition for NAROCAS 1 increased with increase in the concentration of NaOH with 42.8% at 4% NaOH concentration. The optimum treatment concentration of NaOH for NAROCAS 1 is 2% with the maximum hemicellulose composition to 10.2% (treated with 2% NaOH) from 56% (raw peel). The reasons behind this difference should be studied further.

4. Conclusion

This work studies the proximate, ultimate and bio-chemical composition of cassava peels from six predominant cassava varieties in Uganda and evaluates their applicability for AC production. Proximately all varieties have potential to yield AC specifically due to their ash content being below 5% and the order of preference based on the proximate values is NAROCAS 1>NASE 19> NAROCAS 2>NASE 1>NASE 14>NASE 3. Based on water binding capacity, besides AC production the peels from all six varieties have potential of being applied in hydrates inhibiting applications. The alkaline pre-treatment of cassava peels with ash contents below 5% does not reduce the ash content as intended for

Table 3
Effect of pre-leaching on proximate properties of selected cassava peel varieties.

Variety	Raw				Pre-leached			
	Ash	VM	FC	Char	Ash	VM	FC	Char
NASE1	3.58	79.49	14.76	29.69	3.42^{1}	80.73	16.54	35.4^{1}
NAROCAS 1	2.01	82.31	14.12	28.94	1.50^{2}	83.3	17.68	31.6^{1}

Note: all values are in % compositions.
^{1,2,4} are the NaOH % concentrations that produced the best proximate parameter value captured.

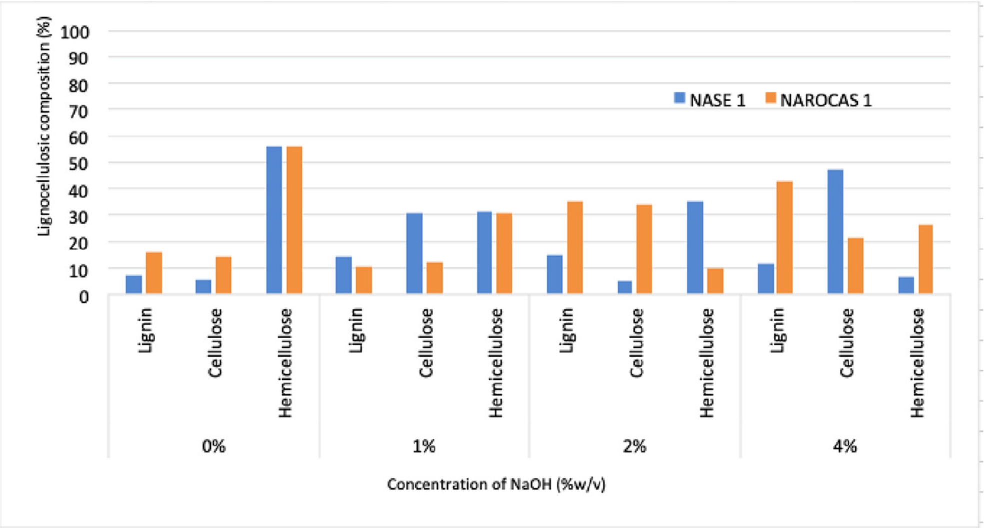

Fig. 1. Effect of alkaline pre-leaching on the lignocellulosic composition of selected cassava peels.

many alkaline treatments of AC precursors. This however may not impede their applicability in AC production since the ash contents are below 5% besides saving costs for alkaline pretreatment. In case of other potential applications that require high char yields, alkaline pretreatment may be applied since it tremendously increased char yield for all the varieties. The increase in the volatile matter when treated with NaOH implies higher surface area for the activated carbon but could also suit the peels for production of syngas. Alkaline pre-treatment had significant effect on the lignocellulosic compositions of all the two family representative varieties with cellulose content increasing due to the breakdown of hemicellulose. Low NaOH concentrations have no much impact on the Lignin content but increase the cellulose content. NAROCAS 1 could be a better precursor for AC since alkaine treatment at 4% NaOH showed a tremendous increase in lignin composition yet for NASE 1 the lignin content dropped at 4% NaOH treatment. The elemental compositions for all the varieties qualify them for AC production with carbon contents high to yield chars and the oxygen and hydrogen predictably enough for reactivity during torrefaction processes.

CRediT authorship contribution statement

R. Kayiwa: Conceptualization, Data collection, Investigation, Writing – original draft. **H. Kasedde:** Supervision, Writing – review & editing. **M. Lubwama:** Validation, Resources, Software. **J.B. Kirabira:** Funding acquisition, Methodology.

Declaration of competing interest

The authors declare that there was no conflict of interest in this work.

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