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Chemical Modification and Characterization of Starches from Soursop as Potential Water-Based Drilling Fluid Additives

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Abstract

Starch reduces fluid loss while enhancing viscosity in drilling fluid formulation. Starch obtained from soursop (SS) was chemically modified by carboxymethylation methods (SC1 & SC2) and acetylation method (SA) and compared with cassava (CN). The physicochemical properties: swelling power, gelatinization temperature, thermal stability, and particle size; rheological properties: yield point (YP), gel strength, and plastic viscosity (PV), and also fluid loss control of the starches were investigated to determine their performance as viscosity enhancer and fluid loss control ability in drilling fluid. The results revealed that modified starches (SC1 and SC2) demonstrated better physicochemical properties than SA, SS, and CN. Thus, carboxymethylation improved the thermal stability and gelatinization temperature of the starches. The morphology result revealed that modification reduced the starches' particle size, thereby increasing their surface area and reactivity. In addition, the native and modified soursop starches exhibited good rheological properties and fluid loss control as required by API standards. However, modified starch, SC2, exhibited better rheological properties in PV, YP, gel strength, and controlled filtration-loss than other starches, SC1, SA, and native soursop and cassava. The possession of these excellent properties places soursop and its modified starches (SCI and SC2) as potential replacements for cassava as additives in drilling fluid formulation. Ultimately, this will help improve efficiency in drilling operations and, on the other hand, help to reduce the negative impact on food security in Nigeria since soursop is mainly consumed as a dessert..

Keywords: Cassava, Drilling Fluid, Modified Starch, Physicochemical Properties, Rheology, Soursop.

Introduction

The discovery of petroleum as an energy source has led to the development of diverse skills, techniques, instruments, and materials for drilling [1,2]. One of these improved techniques implemented over the years for sufficient and efficient drilling is using drilling fluids. Drilling fluids circulate through a well to remove cuttings from a wellbore [3]. One of the primary functions of drilling fluid is to clean the wellbore while serving as a cooling agent [4,5]. Starch, a polymer, is majorly used in drilling crude oil and gas procedures [6]. Starch is obtained from different sources and has been used daily for centuries [7]. Starch from different sources has been used as an additive to improve the mud viscosity and control the fluid loss [8,9]. The starch action is triggered by free/high water absorption from two components, amylose, and amylopectin, leading to its swelling capacity [10]. Many polymers have been used as drilling fluid additives, and they tend to help with diverse drilling problems. Although, there is no particular drilling fluid that can provide solutions to all drilling problems [4,11]. Carboxymethyl cellulose (CMC) and lignosulfonate are modified natural polymers, while synthetic ones include polyacrylamides and polyalphaoleins [6,12-14]. The most widely used additive is carboxymethyl cellulose (CMC), which is very expensive, thereby increasing the cost of drilling fluids. Thus, there is a need for an alternative source. Al-Hameedi et al. [15] carried out comprehensive real-cost data of drilling fluid (using a conventional additive such as CMC) from the total cost of the drilling operation. The data revealed that drilling fluid accounted for two-tenth (20 %) of the total drilling cost (i.e., $14.3 of the $71.5 total drilling cost of nine wells of Basra Oil Company in 2016). Thus, the author strongly recommended using local polymer (Mandarin peel powder) as a substitute to reduce the cost of conventional additives.

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Starch derived from corn is the first and most widely used starch source as a drilling fluid additive with bentonite. After examining its physiochemical properties, Ashaye et al. [16] .posited that starch has the potential to improve the efficiency of drilling fluid. Furthermore, many high-starchy food crops used as drilling fluid additives include cassava, potato, yam, cocoyam, guar gum, and grain crops like millet [17-19]. As mentioned above, most starches used as drilling fluid additives are major staple foods for human consumption. Utilizing these starches as drilling fluid additives would lead to a scarcity of raw materials and high costs due to high demand, which is not beneficial to society [20]. The high cost of corn or cassava can also increase the cost of drilling fluids, which may not be economically viable [9,10,21]. Therefore, an alternative starch source has to be considered. This alternative would be a crop with less economic benefits in addition to high starch content. Plants like soursop (Annona muricate) and jackfruit (Artocarpus heterophyllus Lam) are envisaged to be perfect alternatives with diverse Artocarpus species in abundance [22]. Fruits and other naturally occurring plants are well known as vital parts of a nourishing, healthy diet. They are also utilized for industrial purposes, which inspired numerous countries to commence initiatives to boost the increased production of these plants [23]. Fruits are good sources of chemical compounds, e.g., carbohydrate micronutrients, vitamins, and fiber for humans; hence, they are essential for the overall well-being of man and other purposes [24]. Soursop (Annona muricate) is an evergreen, terrestrial plant with a glossy, large, round canopy and dark green leaves. The edible part of the tree is a large heart-shaped fruit consisting of a white fibrous juicy pulp and smooth, hard black seeds (1–2 cm) long [25]. In Nigeria, soursop is a fruit mainly consumed as a dessert; therefore, its use as a potential starch source for drilling fluid formulation will help reduce the effects of food insecurity in society and lower the cost of producing drilling fluids.

Native or unmodified starches have shown a strong trend of decomposition and retrogradation. Moreover, several starch granules are inactive, mainly resistant to enzymatic hydrolysis, and highly insoluble in water at ambient temperature, thereby deficient in functional properties [26, 27]. Thus, modification of native starches is essential in developing specific properties such as thermal stability, solubility, adhesion, particle size, and texture in industrial processes. Numerous methodologies have been adopted to produce modified starches with variability in characteristics and applications. The techniques generally modify the starch's polymer chains, making them highly flexible, altering their physicochemical properties, and, thus, increasing their food value and industrial application [28, 29]. This work aims to modify, characterize, and compare the physicochemical and rheological properties of native and modified starches of soursop (Annona muricate) with those of cassava (Manihot esculenta) as potential additives in water-based drilling fluid formulation.

Materials and Methods

Matured but unripe fruits of soursop and cassava tuber were purchased at Zuba market, Abuja. The reagents used for this study were of analytical grade.

Starch Extraction

The soursop fruits were washed, peeled, weighed, and cut into irregular smaller sizes; the starch was extracted using the procedures of Omojola et al. [30]. The extraction of starch from cassava was achieved using the wet method as described by Noorfarahzilah et al. [31].

Starch Modification

The specific type of modification used in this study was the chemical method.

Starch Acetylation

Starch acetylation was attained through the methods developed by Bolade and Oni [32]. Starch (100 g) was dispersed in 500 ml, and the mixture was continuously stirred for one (1) hour at 30 °C. After that, 3% Sodium Hydroxide was drop-wisely added to the suspension to achieve a pH of 8.0; instantaneously, 12g of acetic anhydride was also added to the mixture at the same time sustaining the pH value within the range of 8.0–8.4. The mixture was stirred continuously for 10 minutes, and the pH was adjusted to 4.5 with the addition of 0.5 M Hydrochloric acid. The starch was allowed to settle, and the precipitate formed was rinsed thrice with water, after which 95 % ethanol was used once to neutralize the acid.

Starch Carboxymethylation (SCM Procedure 1)

The SCM procedure 1 was obtained using the wet methods of Nwokocha and Ogunmola [33] with slight modification. Starch (100 g) was dispersed in an isopropanol/water mixture in an 80:20 ratio while adjusting the pH with a 2 M solution of NaOH. Subsequently, 40 % (w/v) monochloroacetic acid was added, and consecutively, the solution was incubated at 30 °C while stirring continuously. Washing and filtering were carried out numerous times until little or no chloride was detected in the filtrate using a silver nitrate test. The cake obtained was washed thoroughly with absolute ethanol and dried to constant weight at 313 K in an oven for 48 hours.

Starch Carboxymethylation (SCM Procedure 2)

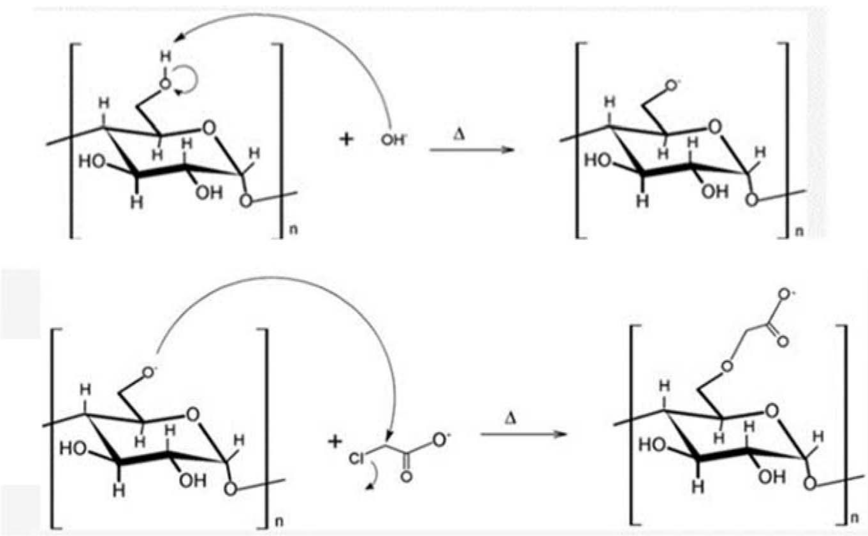
The SCM procedure 2 was done in an electric blender, as Li et al. described [34]. A blender was used to blend the solid NaOH and the starch, forming a uniform powdery mixture. Then, a small quantity of absolute ethanol (2 wt%) was added and stirred for 1 hour. After that, powdered sodium monochloroacetate (SMCA) was added, and the reaction proceeds at 28 °C for an hour. As soon as the reaction concluded, the modified product was carefully rinsed with 85 % ethanol solution and sieved to eliminate the salt formed during the reaction. After numerous washing and filtering were carried out, little or no chloride was detected in the filtrate using the silver nitrate test. The cake obtained was washed thoroughly with absolute ethanol and dried to constant weight at 313 K in an oven for 48 hours. The mechanism of the carboxymethylation process is shown below (Scheme 1):

Determination of the Swelling Powers (SP) of the Starch Molecules

The swelling power of the starch samples was evaluated according to Sreeletha et al. [35] with slight modifications. 0.5 g of starch was spread in 25 ml of distilled water in a test tube, and the mixture was heated at a temperature range of 50-90 °C for 30 minutes using a water bath.

Step 1: Base catalyzed reaction

Step 2: Nucleophilic attack on monochloroacetate



Scheme 1: Scheme for the synthesis of carboxymethylated starch

The mixture was stirred continuously throughout the analysis, allowing it to cool. At room temperature, the filtrate was filtered off, and the residue dried at (105 °C) for at least 5 hours to obtain a constant weight of the starch. The calculation of the SP was obtained from Equation 1.

Swelling power (g/g) = weight of wet residue/weight of dry residue (1)

Determination of the Rheological and Filtration Properties of the Starches

Rheological experiments to determine the properties of the drilling fluids materials (native and modified starches) were carried out by adopting the method of Al-Hameedi [15]. Water-based fluids were formulated with bentonite (60 kg/m^3), sodium hydroxide (1kg/m^3), barite (10 Kg/m^3), and 4 % (24 g) native and modified soursop starches, and their properties were compared with that formulated with 4 % cassava starch and bentonite. The composition of the based fluid sample was water (600 cc), caustic soda (0.6 g), bentonite (36 g), calcium chloride (50 mg/l), and sodium chloride (182 mg/l). The pH of the based fluid was 10.0. Rheological properties such as yield point, plastic viscosity, and initial and final gel strength were evaluated in a rotary viscometer. The filtration features, such as fluid loss (cc/30 min) and the thickness of the filter cake, were achieved by adopting a standard API filter press at 100 psi, whereas the mud weight was obtained with the mud balance.

Equations (2-4) were used to interpret the PV readings, apparent viscosity (AV), and YP.

$$AV = \Phi\ 600/2 \quad (2)$$

$$PV = \theta_{600} - \theta_{300} \quad (3)$$

$$YP = \theta_{300} - PV \quad (4)$$

Starch Characterization

The thermal characteristics of the starch samples were determined using differential scanning calorimetry (DSC) analysis using Shimadzu DSC-60 (Shimadzu, Japan). The thermal stability was determined using thermogravimetric analysis (TGA) WW and the MCE TA instrument TGA Q50. The surface structure was carried out using scanning electron microscopy (SEM) (S-3400N; Hitachi, Tokyo, Japan). The Fourier transform infrared spectroscopy (FTIR) analysis was carried out using a Perkin Elmer 3000 MX spectrometer.

Results and Discussion

Swelling power profile of Native and Modified starches

Fig. 1 presents the swelling capacity data of native and modified soursop starches. The result showed a generally increasing trend in the starches' swelling capacity. However, modified starches performed better in terms of swelling power, with SC1 having the highest swelling power at 90 °C. The increasing trend of the starches at 90 °C is as follows: SC1>SC2 >CN>SS>SA.

The increase observed in the modified starch could be due to the addition of acetyl and carboxymethyl groups that led to the variation of the starch structure due to the alteration of the glucose granule structure, which permits easy water penetration to the starch. This is comparable to the work reported by Carmona-Garcia et al. [36], where cross-linked starches exhibited greater swelling power in comparison to their native counterparts and at higher temperatures. However, some disadvantages observed in the native starch include low shear stress resistance, syneresis, thermal disintegration, and high retrogradation. Henceforth, modification of soursop starch, accomplished through acetylation and carboxymethylation, has been used to reduce these restrictions. In this study, it could be seen that modified starches SC1 and SCI performed better than cassava, which is currently used and thus has the potential to enhance the viscosity and fluid loss properties of water-based fluid.

Morphology determination of modified and native starches at 8000x, 9000x, and 10000x magnification

Fig.s 2-4 show the morphological images for native and modified starch for soursop starches and native cassava starch at 8000x, 9000x, and 10000 magnifications.

It can be observed from the SEM results that modification reduces the particle size and increases the surface area (number of particles). There are reduced interstitial spaces, forming more clusters than their native counterparts.

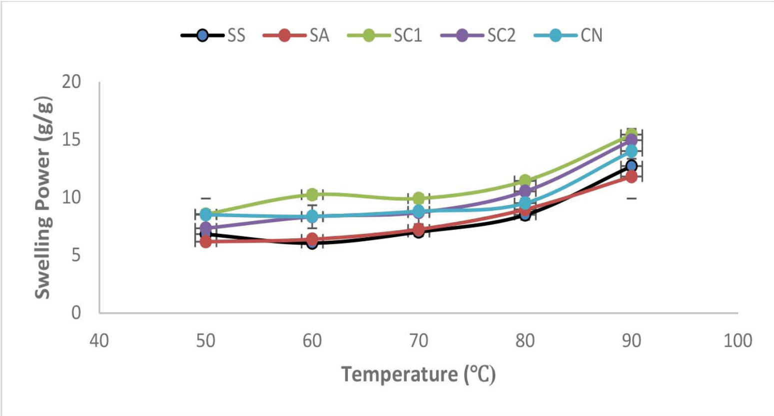


Fig. 1 Swelling power profile of native and modified soursop and cassava

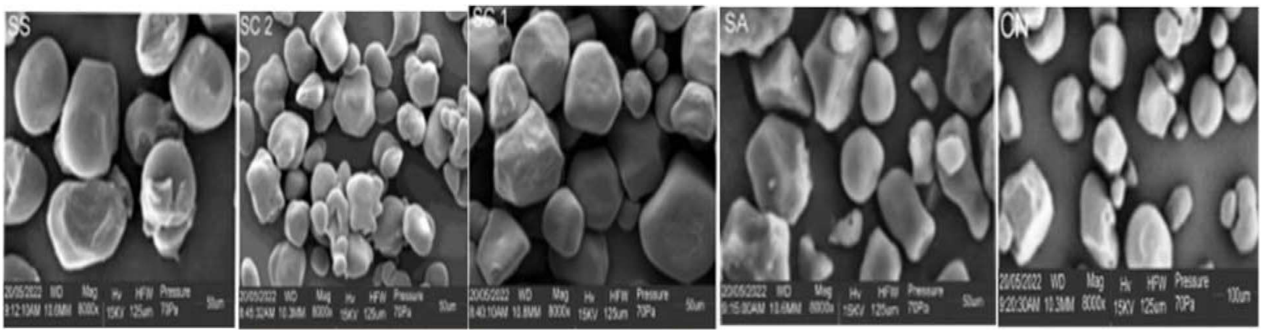


Fig. 2 Scanning Electron Microscope Image of the starch samples at 8000 magnifications.

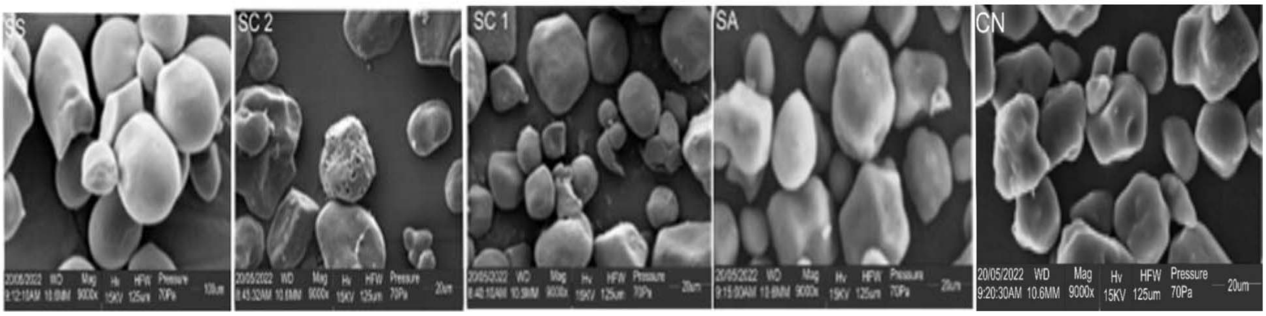


Fig. 3 Scanning Electron Microscope Image of the starch samples at 9000 magnifications.

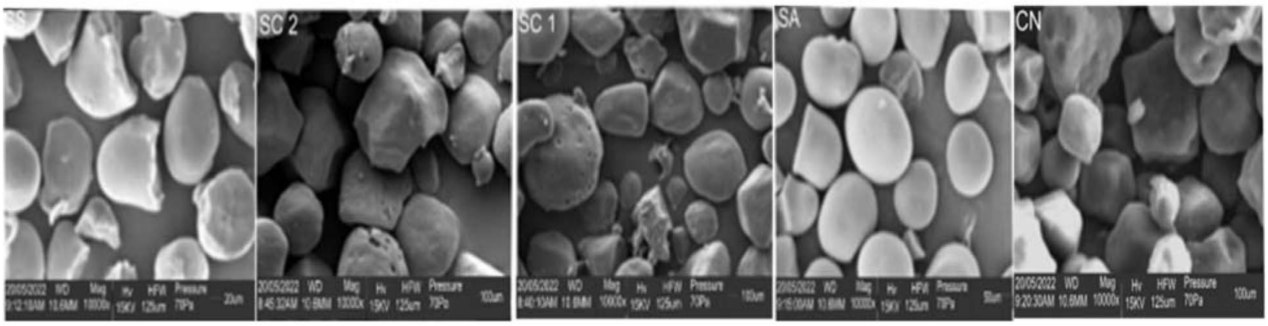


Fig. 4 Scanning Electron Microscope Image of the starch samples at 10000 magnifications.

The morphological structure of native soursop starch is large-spaced, smooth, and spherical, while that of the modified soursop starches is smaller, clustered, smooth, irregular, and spherical. At 8000x (Fig. 2), it can be observed that SS has larger starch particle sizes that were not clustered together compared to its modified counterparts that displayed smaller starch particle sizes, closely clustered, and will result in an increased surface area for better drilling fluid formulation. The starch particle size for CN showed similar structures with the modified soursop starches but revealed large interstitial spaces between the particles. At 9000x (Fig. 3), it can be observed that native SS has larger starch particle sizes that are clustered together compared to its modified counterparts, which are smaller in size but not closely clustered. SC1 had the smallest starch particle size and had a delicate texture among the modified starches. The results at 10000x (Fig. 4) confirmed the effect of modification on starch structure and application. While modification by acetylation changed in both size and appearance (irregular and rough), modification with acetylation maintained the smoothness of the native starch, though it was relatively smaller than SS. Afolayan et al. [37] reported that small starch is more reactive than its larger counterparts and is found helpful in many industrial applications. The shapes and sizes of starch granules determine their area of application. The morphological changes in the modified starch positively impacted the physical and chemical properties, such as high gelatinization temperature, swelling power, and water absorption characteristics. These improved properties, however, make the modified starches more useful in industrial applications, especially in drilling fluid formulation, where starches with stronger gels and high stability at high temperatures and pressure are utilized in oil wells during drilling.

Fourier Transform Infrared Spectroscopy (FTIR) Analysis

The FTIR analysis results on native and modified soursop, native cassava and starches are presented in Fig. 5.

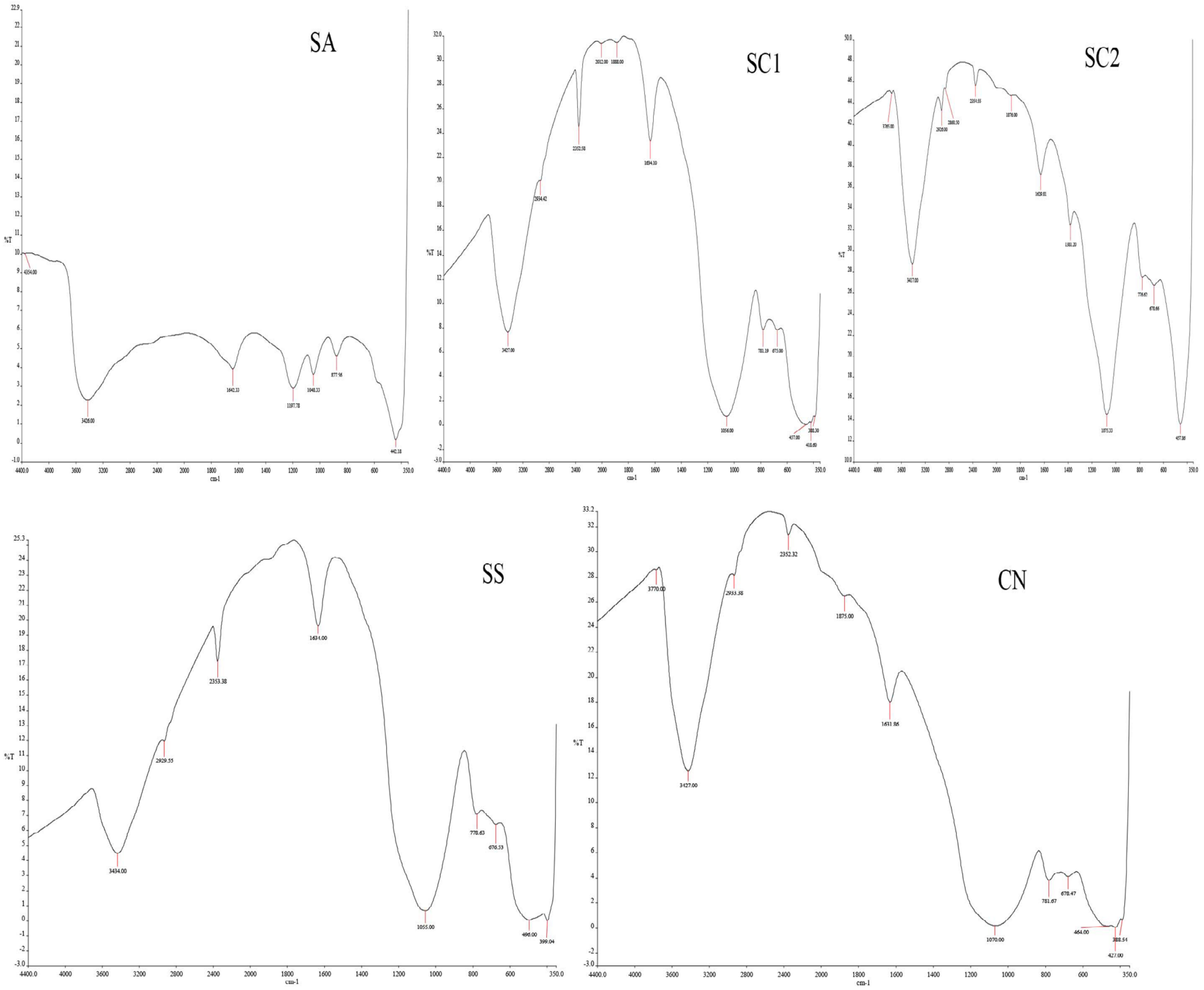


Fig. 5 FTIR spectra of native and modified soursop and cassava.

The results demonstrated the presence of two major characteristic vibrational bands of 3600 -3300 cm^{-1} and 1200-1000 cm^{-1}, indicating the presence of O-H and C-O stretching vibrations, respectively. The peaks came due to the higher density of strong hydroxyl (O-H) and carboxyl (C-O) bond vibrations present in starch molecules. The stretching vibration at 1641 -1629 cm^{-1} for all the native and modified starches could be attributed to the strong vibrational bonds between water (H_2O) and the starch granules [38].

Effect of Modification on the Starch Structure

Modification (Table 1) was found to have a pronounced effect on the peak height and size of the modified starches (SA, SC1, and SC2) when compared to native starch (SS). Modification by acetylation (SA) exhibited a great effect on both the peak height and size when compared to that of carboxymethylation (SC1 and SC2). In almost all the peaks present, SA was observed to have a lower intensity peak (height) but maintained broader peaks than the native SS. SC1 and SC2 positively affected the vibrational peak of the O-H functional group, increasing the peak height from 5 in SS to 10 and 18, respectively. Modification with carboxymethylation has been reported to create interstitial holes due to the addition of large alkyl groups, which replace OH functional groups of the starch [39].

Table 1 Effect of different modifications on vibrational frequencies of native Soursop (SS) starch

Properties	Samples		Functional Groups			
	SS					
		OH	C-H	H_2O-C	C-O	C-O
Wavelength (cm^{-1})		3434.00	2929.55	1634.00	1055.00	
Peak height		5	1	4	10	
	SA					
Wavelength (cm^{-1})		3426.00	-	1647.33	1197.78	1048.33
Peak height		2.9		1.5	1.8	1
	SC1					
Wavelength (cm^{-1})		3427.00	2934.42	1634.10	1056.00	
Peak height		10	1	5	11	
	SC2					
Wavelength (cm^{-1})		3417.00	2926.00	1629.81	1075.33	
Peak height		18	1	3	9	

Modification also affected wave number by causing a shift in the characteristic absorption bands of the functional groups of the modified starches. The characteristics absorption band around 3410 – 3450 cm^{-1} corresponding to the O-H stretching vibration of the starches exhibited a shift in the wave number from 3434 cm^{-1} for SS to 3427 cm^{-1}, 3417 cm^{-1} and 3426 cm-1 for SC1, SC2 and SA respectively. The same trend was observed for all the characteristic absorption bands of 1600-1645 cm^{-1} and 1000 – 1200 cm^{-1}, corresponding to those of strong bonds between water (H_2O) molecule and the starch granule and C – O stretching Vibrations.

Thermogravimetric Analysis of the Native and Modified Starches

The native (SS and CN) and modified (SC1, SC2, and SA) starches were evaluated to determine their thermal stability and degradation characteristics, and the results are presented in Table 2. The thermal stability of both native and modified SS starches displays a comparable trend, signifying thermal disintegration and mass loss of the starches at dissimilar phases representing specific events during heating.

The first degradation resulting from mass loss due to moisture content did not have an effect on the initial decomposition with all occurring at 99 cop with 10% loss. It was observed that modification improves the starches' stability compared to the native soursop starch at second degradation, with SC2 having the best stability at 222 °C. In comparison, SS and CN degraded at a lower temperature of 194 °C with 8% degradation for all starches. The third degradation occurs due to depolymerization of the carbon chain (formation of monomers from polymers). It was observed that modification by carboxymethylation 2 (SC2) improves the stability of the starches, whereas modification by acetylation reduces the stability compared to that of native starch. The final degradation at 85 % mass loss shows that SS at temperature and percentage residue of 390 °C and 13.80 % produced the best stability while modification SA produced the least. These results thus imply that modification by the carboxymethylation method improved the stability of the starches most, with acetylation decreasing the stability of the SS starch. Thermal stabilities of starches in drilling fluids are an essential property during drilling, especially at high temperature and pressure wells, because the fluid needs to be viscous and stable to lift drill cuttings during crude oil drilling. The thermal stabilities of 85 % at a temperature range of 340-390 °C obtained in this work show that the soursop and its modified products are potential alternatives to cassava and other edible crops like corn in drilling fluid formulation. Thus, using carboxymethylated starch 2 (SC2) for drilling fluid formulation will improve the stability of the mud at high-temperature, high-pressure HTHP wells.

Table 2 Effect of Different Modifications on Thermal Stabilities of Native Soursop Starch.

SAMPLES	MASS LOSS % (TEMPERATURE OC)				
	1ST	2ND	3RD	4TH	% RESIDUE
SS	10 (99)	8 (194)	50 (290)	85 (390)	13.80
SA	10 (99)	8 (195)	48 (220)	85 (340)	13.96
SC1	10 (99)	8 (198)	45 (289)	85 (342)	13.80
SC2	10 (99)	8(227)	50 (296)	85 (342)	12.85
CN	10 (99)	8 (194)	45 (294)	83(344)	13.92

Differential Scanning Calorimetry (DSC) Analysis of Native and Modified Starches

The results of the DSC of native and modified starches (Table 3) showed a generally increasing trend in the gelatinization temperature of all the starches. Still, the carboxymethylated starches (SC1 and SC2) performed better than the native SS and CN, with SC2 having the highest thermal stability. The peak gelatinization temperature of (70.00 °C) implies that the modified starches can stand as gel up to this high temperature before degrading, which is an excellent property compared to cassava. Not only will their use as a drilling fluid additive for drilling operations help reduce cassava use but also positively impact food security in Nigeria.

Table 3 Effect of Modification on Thermal Properties of Native Soursop Starch.

Sample	T_o (°C)	T_p (°C)	T_c (°C)	ΔH (J/g)
SS	58.90	65.50	68.50	12.5
SA	57.10	63.10	66.50	11.2
SC1	50.50	60.50	70.00	14.3
SC2	60.50	70.00	76.90	16.8
CN	45.90	51.00	55.80	7.9

* T_o - onset temperature, T_p - peak temperature, T_c - conclusion temperature ΔH- Enthalpy change

Gelatinization temperature is an important parameter when selecting starches and other viscosifiers to formulate drilling fluids. Drilling fluids must be viscous enough to lift drill cuttings to the surface for a successful drilling operation. The choice of any viscosifiers depends on the oil well's temperature, which varies based on the reservoir's depth. Akpabio et al. [40] reported the temperature variations in depobelts wells across different regions in Nigeria to be 52-90 °C for offshore wells, 36-86 °C for coastal wells, 32-102 °C for central wells and 32-110 °C for Northern wells. The peak gelatinization of both the native and modified soursop (60-70 °C) reveals the potential of the starch as a suitable alternative to cassava and corn. Thus, its use as a drilling fluid additive for drilling operations will help reduce the frequent use of cassava and corn. This will further improve food security in Nigeria.

Rheology and Fluid Loss Properties of the Native and Modified Starches

A laboratory evaluation of the drilling fluid's rheological and filtration properties was carried out using the API-recommended standard procedures. The rheological properties of the native and modified starches were investigated to determine which would offer better properties as an additive and enhance the performance of drilling fluid under HPHT conditions. The results obtained are presented in Table 4.

Effects of the Starches on Apparent Viscosity

The simulation of flow conditions of a drilling fluid when any driving force is applied is referred to as apparent viscosity. Owing to the shear-thinning physical appearance of water-based fluid, apparent viscosity reduces with an increase in the shear rate. This action can be described as a result of long-chain additive polymers' capacity to line up at higher shear [41]. Furthermore, this characteristic is crucial for drilling fluids to remove cuttings and weighting materials through two flow conditions: stand-by condition (simulating low shear rate) and mud circulation (simulating high shear rate) [42]. The result (Table 4) reveals that the modified soursop starch SC2 exhibited the highest apparent viscosity and CN the least.

Table 4 Rheology and Fluid Loss Properties of Native and Modified Starches.

Properties	RF	SS	SC1	SC2	SA	CN
Viscosity (cp) 600 rpm	30.74	42.18	54.61	63.56	43.84	37.50
Viscosity (cp) 300 rpm	22.53	33.08	42.37	48.40	34.62	28.64
Apparent Viscosity (cp)	15.37	21.09	27.31	31.78	21.92	18.75
Plastic Viscosity (cp)	8.21	9.10	12.24	15.16	9.22	8.86
Gel Strength (Ib/100ft2) 10 sec	25.45	34.10	44.17	48.24	33.48	31.15
Gel Strength (Ib/100ft2) 10 min	44.48	50.33	63.22	66.51	48.00	46.90
Yield point (Ib/100ft2)	14.32	23.98	30.13	33.13	25.40	19.78
Mud weight (ppg)	8.00	8.55	8.90	9.11	8.65	8.58
Fluid Loss (ml)	12.08	8.29	6.14	5.85	8.43	10.70
Mud Cake thickness (mm)	2.40	2.46	2.64	2.66	2.46	2.48
Mud Temperature (°F)	73	73	74	74	73	73
Ph	10	10	10	10	10	10

* RF: Reference fluid.

Effects of the starches on Plastic Viscosity (PV) and Yield Point (YP)

One of the vital drilling fluid rheological properties is plastic viscosity (PV). PV indicates the machine-driven friction produced by interactions of liquids and solids within the drilling fluid system. Thus, the higher the solid content is, the higher the PV is. Among all the starches, SC2 was observed to produce the highest PV, revealing a higher contribution towards stronger mechanical interaction.

On the other hand, the transportation capacity of the drill cuttings depends largely on the drilling fluid YP. A higher YP is frequently needed to advance the fluid-carrying capability and enhance wellbore cleanup. Table 4 shows the potential of all the starches to clean up drill cuttings from the hole during drilling according to the API standards (15-25 cP). Nevertheless, SC2 exhibited the highest YP when compared with cassava (CN), which is currently used as an additive with corn. The high value of YP in SC2 may reduce the differential sticking and hole filling with drill cuttings and enhance the chance of producing thin filter cakes [42]. These results suggest the starches' potential applicability, especially SC1 and SC2, as viscosity modifiers during drilling operations, especially in HPHT conditions.

Effects of the Starches on Gel Strength

The capacity of drilling fluid to hold drill cuttings and weighting materials is evaluated by gel strength. It is a measure of the electrochemical force strength of a fluid in a static state. As illustrated in Table 4, the difference between the gel strength of both the native and modified starches at 10 sec and 10 mins is in the range of 14.52 to 19.05, which is within the AP1 standard (of maximum 20); thus, more pump pressure is not required to restart circulation after the static state. Hence, the gel strength of the starches is described as progressive for better pump pressure management and wellbore stability [43]. The result obtained from the gel strength agrees with the earlier results obtained from the gelatinization temperature and thermal stabilities of the starches.

Effects of the Starches on Fluid Loss

The filtration loss test determines the extent of fluid loss to the formation under simulated high pressure. Formation damage, wellbore stability, and stuck pipes are various concerns that are directly or indirectly related to fluid loss. Therefore, adequate measures are taken to reduce permeability by increasing the thickness and nature of the mud cake formed [42]. The filtration loss of the starches was measured at 100 psi according to the API standard to evaluate the effectiveness of the native and modified soursop starches as fluid loss control agents. The result (Table 4) revealed that the modified soursop starches SC2 and SC1 possessed better fluid loss control when compared to native soursop and cassava. This may be related to better mud weight and mud cake thickness with reduced fluid permeability to the formation. The results are within the API threshold for filtrate loss in water-based drilling fluid of a maximum of 15 ml.

Research has shown that lower permeability cakes produce thicker cakes with less filtrate loss to the formation [6, 9, 10]. The effectiveness of cassava starch (especially species from Nigeria) as fluid loss control enhancers has been reported [9, 10] and is comparable to the imported agents. Dankwa et al. [6] reported an 8% improvement in fluid loss and 2 mm to 3 mm mud cake thickness, which was attained using some cassava starch cultivars. The excellent performance of native soursop and its modified product compared to cassava, as seen in this study, shows that they are more effective in reducing fluid loss of drilling fluids with native and modified soursop starches is shown in Fig. 6.

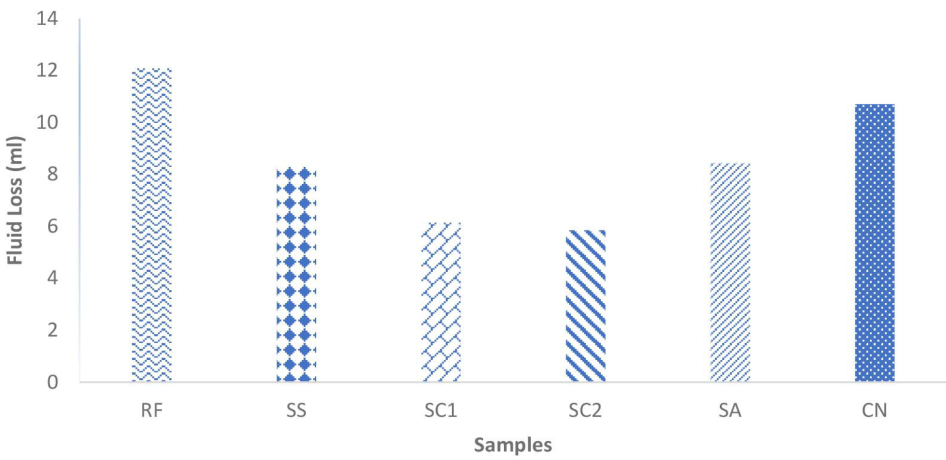


Fig. 6 Filtration loss of drilling fluids with native and modified soursop starches.

Conclusions

The intensive use of cassava and other food crops as sources of starch for industrial applications could have great consequences on food security. However, the use of alternative starch sources, especially non-food or staple crops with lower demand like soursop and its modified products, possess the potential to mitigate the effects above. This could be achieved in Nigeria, where soursop is not a primary staple food but is consumed as a dessert. The current research demonstrated that starch obtained from soursop and its modified products possesses good physicochemical, rheological, and fluid loss properties. Moreover, modification by carboxymethylation (SC1 and SC2) was found to have a better correlation to swelling power, thermal stability, and gelatinization temperature when compared to those of acetylated (SA), native soursop, and cassava starches. Carboxymethylated soursop (SC2) from the analysis exhibited the highest thermal stability and excellent peak gelatinization temperature of 70.90 °C (Tp), placing it above other modification methods.

In addition, the native and modified soursop starches exhibited good rheological properties and fluid loss control properties, meeting the API-required standards. However, the modified starch, SC2, exhibited better rheological properties (PV, YP, and gel strength) and filtration-loss control than other modified starches, SC1 and SA, as well as the native soursop and cassava. The improvement in the rheological and fluid loss control of the base fluid (RF) by the modified soursop starch hence places them as a potential alternative source of starch for the formulation of drilling fluids. It demonstrates great potential for replacing corn and cassava (native starches) and CMC as an additive in drilling fluid formulation. The use of modified starch from soursop will, in turn, reduce the use of edible crops as additives for drilling fluid formation. Using soursop and its modified product as alternative viscosifiers and fluid loss control agents will improve food availability and help reduce or eliminate hunger, one of the key sustainable development goals (SDG).

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author Contributions

James, J. O: Methodology, Investigation, Writing-Original draft preparation. Ogwuda, U. A: Investigation, Software and Formal analysis. Adewumi, C. N: Conceptualization, Project administration, Supervision, Visualization, Writing- Review and Editing. Ezebuiro, V: Writing-review and Editing.

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