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Original Research Article

Characterization of hydroxypropylated cassava and potato starches: Functional and physicotechnical properties

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Abstract

Introduction: Starch modification is achieved using physical and chemical means to improve the physicochemical characteristics and stability of the molecule with potential applications in specialized drug delivery systems.
Purpose: This study aimed to characterize cassava and potato starches modified via hydroxypropylation.
Method: Native cassava and potato starches were subjected to initial pre-gelatinization before being hydroxypropylated (HP) using propylene oxide. The native and HP-starch powders were characterized for their physicochemical properties, powder properties as well as high-resolution analyses using differential scanning calorimetry (DSC), Fourier transform infrared (FTIR) spectroscopy and scanning electron microscopy (SEM).
Results: Organoleptic evaluations indicated that native starches were white and smooth while HP-starches were off-white, coarse and glassy. The HP-cassava and potato starches significantly increased in solubility by 79.4 and 14.7%, respectively. The HP-starches also exhibited a reduction in the volume of sedimentation, while only the HP-cassava starch showed a reduced water retention capacity of 1.7133 g/g. Percentage syneresis was lower in both HP-cassava and potato starches with 4.16 and 1.08%, respectively. The HP-cassava and potato starches showed excellent flowability with corresponding Carr's indices of 5.96 and 5.23% and angles of repose of 19.98 and 20.50°, respectively. DSC and FTIR results confirmed starch modification while SEM showed smooth flat particles.
Conclusion: Hydroxypropylation enhanced the solubility, reduced the volume of sedimentation and improved the freeze-thaw stability of the native starches. It also increased the water retention capacity and moisture sorption of potato starch.

Keywords: Cassava, potato, starch, hydroxypropylation, physicochemical

Introduction

Starch is a polysaccharide derivative of natural origin, known to have numerous agricultural, and industrial applications [1]. It is a source of energy, which is stored in numerous parts of a plant, including the leaves, roots, nuts, bulbs, stems, stalk, and crop seeds, as well as in staple crops, consisting of cassava, potato, wheat, corn and rice [2].

The numerous industrial uses of starch are as a result of its versatility, biodegradability, safety, and cost-effectiveness as the molecules possess specific technological properties, including the propensity to serve as a gelling and forming material, and also as a film former, thickener, fat-mimicking material, etc [3].

Maize is the most common source of starch globally, contributing about 82% of total world starch production. Wheat (8%), potatoes (5%), and cassava (5%) are the next closest sources to maize as an industrial raw material. Starch is used in either of two major forms, which include "native starch", encompassing the fresh plant extracts, and "modified starch", which undergoes some form of modifications to attain specific characteristics. The global starch (native and modified forms) market was estimated at

48.5 million tons as at the year 2000 and with an expected yearly output of $16 billion [4,5].

Native starches exhibit some shortcomings in industrial applications, because the granules hydrate easily, swell rapidly, rupture, loose viscosity and subsequently generate weak, stringy and cohesive paste [6]. Conversely, modification has continuously been adopted to circumvent these limitations, as the starch is tailored to the specified requirements of end-users, therefore facilitating the versatile application in a wide range of specialty products [7].

Hydroxypropylation of starch is a frequently adopted chemical modification method and it requires the development of nucleophilic starch -O- alkoxide in an alkaline medium, which serves as an activating catalyst [8]. This reaction intermediary is further reacted with propylene oxide to evoke a bimolecular substitution product, termed hydroxypropylated starch. The resulting derivatized granular structure have improved functionalities, including enhanced freeze-thaw stability, paste clarity, reduced temperature of gelatinization and elevated values of peak viscosity [9,10].

Cassava (*Manihot esculenta* Crantz) and sweet potato (*Ipomoea batatas* L.) are edible underground storage tuber that are perennially grown throughout subtropical and tropical regions worldwide. Their starch contents which vary between 15-33% for cassava and 33-64% for sweet potato, coupled with their low cost and abundance makes them attractive alternatives as industrial raw material for starch extraction [11-14].

The study aimed to carry out a physicochemical and powder characterization of hydroxypropylated cassava and potato starches as well as employing high-resolution analytical techniques such as differential scanning calorimetry (DSC), Fourier transform infrared (FTIR) spectroscopy and scanning electron microscopy (SEM).

Materials

Propylene oxide (Sigma-Aldrich International Gmbh, Buchs, Switzerland), sodium hydroxide (Indenta Chemicals India Pvt, Mumbai, Maharashtra, India), sodium sulphate and barium chloride (Shanxi Xihui Technology Co. Ltd, China), sodium chloride (Royal Salt Limited, Lagos). Cassava and potato tubers were purchased from a local market in Ughelli, Delta State, Nigeria and their starches were extracted in the laboratory.

Methods

Starch extraction

The method by Deetae *et al*. was adopted in starch extraction [15]. This involved washing the cassava tubers, followed by peeling them, and subsequently dicing them into smaller pieces with a kitchen knife. This procedure was similarly conducted on the potato tubers, which were then protected from discolouration by soaking the pieces in sodium hypochlorite solution.

The pieces were milled with a blender and the resulting slurry was filtered with a muslin cloth. The filtrate was allowed to stand overnight and the resulting sediment was collected by decanting the supernatant. The cake sediment was re-dispersed in water, allowed to stand for 4 hours and the supernatant decanted. This washing procedure was carried out repetitively and the resulting starch sediment was dried at 65°C in an oven for 3 days.

Hydroxypropylation

Prior to hydroxypropylation, preliminary pre-gelatinization of the native starches was carried out. The individual starch sample was pregelatinized using a technique by Herman *et al*. with some modifications [16]. This involved making an aqueous slurry, comprising of 500 g starch powder in 500 ml of distilled water. This was continuously stirred over a hot water bath for 10 minutes, with temperature maintained at 75°C. The paste formed was dried in a hot-air oven maintained at 60°C for 48 hours. This was then milled and sieved with a 250-mesh sieve before use.

The process adopted to achieve hydroxypropylation was a slightly modified technique of Woggum *et al*. [17]. A total of 250 g of the pre-gelatinized starch sample was weighed into a 1.0-liter volumetric flask and made up to 500 ml with distilled water to form a slurry. A 50 g quantity of sodium sulphate was added, and the mixture was stirred for 30 minutes. Subsequently, a pH adjustment was made to 11.4 using 1.0 M NaOH solution. Propylene oxide (50 ml of 20% v/w) was added

to the mixture. The slurry was maintained at 40°C with continuous shaking through a 24-hour duration in a water bath. The medium was neutralized with 0.1 M hydrochloric acid, and the resulting modified starch was centrifuged at 3500 rpm for 15 minutes. Distilled water was then used to wash the product until a negative sulphate content was ascertained using a barium chloride test reagent. Subsequently, the starch cakes were dried at 65°C in an oven over a period of 3 days.

Characterization of native and hydroxypropylated starches

Organoleptic properties

The following organoleptic properties of odour, taste, colour and texture of the native and hydroxypropylated starches were assessed by five individuals with the consensus response from three recorded and assigned.

Iodine test

The native and hydroxypropylated starches were subjected to iodine test by introducing 1-2 drops of iodine solution (iodine dissolved in aqueous potassium iodide solution) to about 2-3 ml of their starch dispersions. The resulting colour change was recorded.

Powder properties

The native and hydroxypropylated starch powders were subjected to the following bulk and flow properties evaluations;

Bulk and tapped densities

Exactly 30 g of starch powder was transferred into a 250 ml measuring cylinder and the occupied volume was recorded. The ratio of starch weight to volume was calculated and recorded as the bulk density of the sample while the tapped density was calculated as the ratio of the starch weight to the occupied volume of the same cylinder tapped on a work bench for 100 times.

Carr`s compressibility index and Hausner's ratio

Carr's indices and Hausner's ratios of both the native and hydroxypropylated starch powders were calculated with values obtained for the bulk and tapped densities of the samples. The difference between tapped and bulk densities, divided by the tapped density and expressed as a percentage was recorded as the Carr's index while the ratio of the tapped to the bulk density was calculated as the Hausner's ratio.

Angle of repose

Using the fixed retort stand method, starch powder sample was poured into a funnel fixed at a height onto a retort stand. The powder was then allowed to flow onto a horizontal base forming a heap. The angle of repose was then calculated by determining the height and base radius of the cone heap and substituting the values in Equation 1.

$$\text{Angle of repose } (\theta) = \tan^{-1}\frac{\text{Height of cone (cm)}}{\text{The radius of the cone (cm)}} \quad \ldots (1)$$

Where h is the height of the heap in cm and r is the radius of the heap circular base

Physicochemical properties

Solubility

Exactly 100 mg of starch was dispersed in 10 ml distilled water contained in a test tube at room temperature. The dispersion was shaken intermittently for 24 hours and filtered using a pre-weighed filter paper. The resulting residue on the filter paper was air-dried and weighed. Solubility was calculated as the percentage difference between the initial weight of the starch sample and the final weight of the filter paper residue.

Moisture sorption

The Deetae *et al*. method was adopted to determine the starch moisture sorption properties [15]. This involved creating environments with varied relative humidities (RHs) at room temperature, using desiccators containing a saturated solution of sodium chloride (20% RH) or distilled water (100% RH). Both native and hydroxypropylated cassava and potato starches were pre-dried for 4 hours at 120°C in an oven.

Then, 2.0 g of pre-dried starch was transferred into a dry Petri dish of known weight. This was then transferred into a specified humidity chamber. All samples were allowed to equilibrate over one week, and their final weights were documented. The moisture sorption characteristic was determined as the differences in weight before and after equilibration under predetermined relative humidities and expressed in percentage.

Volume of sedimentation

The volume of sedimentation was estimated using the technique by Damat *et al*. [18], where the starch sample was dispersed to form a 1.0% suspension (0.5/50 g) and was subjected to heat

treatment in a water bath while stirring for 15 minutes at 95°C. Subsequently, more distilled water was introduced until a final dispersion weight of 100 g was reached. This mixture was then stirred and transferred to a 100 ml cylinder, which was then covered with aluminium foil and stored at room temperature for 24 hours. Thereafter, the volume of sediments characterized by swollen granules was determined as the sedimentation value.

Freeze-thaw stability

Freeze-thaw stability was determined for all samples by heating the starch suspension (5.0 g in 100 g of distilled water) to 95°C for 30 minutes while stirring. The paste formed was cooled down to room temperature before 15 g was weighed and transferred to individual centrifuge tubes. Each tube was moved to a -18°C freezer and maintained under this controlled condition for 24 hours. All frozen paste samples were then thawed in a water bath retained at 30°C for 1.5 hours, before subjecting to centrifugation at 3500 rpm for 15 minutes. The liquid component was then decanted before weighing the residue. The percentage syneresis was estimated by evaluating the ratio between the weight of the liquid decanted and the total sample weight, multiplied by 100% [15].

$$\% \text{ syneresis} = \frac{\text{Weight of the liquid decanted}}{\text{Total weight of sample}} \times 100 \quad \ldots. (2)$$

Water retention capacity

The water retention capacity of both native and modified starch samples was evaluated by measuring 0.5 g into a pre-weighed centrifuge tube. A slurry was formed by adding 10 ml of distilled water and then transferred to a hot water bath maintained at 90°C for 15 minutes with constant swirling. Subsequently, the heated mixture was subjected to centrifugation at 3500 rpm for 15 minutes and the supernatant was decanted. The remaining gel in the tube was then weighed and the water retention capacity was evaluated using the following equation.

$$\text{Water retention capacity} = \frac{\text{Starch gel weight - Sample weight}}{\text{Sample weight}} \quad . (3)$$

High-resolution analysis

Differential scanning calorimetry (DSC)

DSC analysis of the starches was carried out using the Netzsch DSC 204F1 Phoenix apparatus (Netzsch-Geratebau GmbH, Selb, Germany). Ten milligrams of the samples were weighed into aluminium pans and sealed. The seals were pierced and calibration of the calorimeter was done with indium and the purge gas was nitrogen. Heating of the sample was carried out at the rate of 10°C per minute from 30 to 350°C under nitrogen at a flow rate of 70 ml/minute. The analysis was carried out on the native and hydroxypropylated starch powder samples.

Fourier transform infra-red (FTIR) spectroscopy

The FTIR analysis of the starch samples was carried out using Fourier transform infrared spectrophotometer (Spectrum BX, Perkin Elmer, Beaconsfield Bucks, England). The potassium bromide (KBr) pellet method was used. Five milligrams of the samples were blended with potassium bromide to 200 mg. The powder was compressed using a press into a tablet shape. The tablet was placed in the sample compartment and the IR scan was read. The native and hydroxypropylated starch powder samples were scanned at a range of 4000 - 500 cm^{-1}.

Scanning electron microscopy (SEM)

This was conducted on the starch powder using a scanning electron microscope (EVO/MAIO, Carl Zeiss Germany). Two milligrams of each sample were placed on the sample holder and a vacuum was created using the vacuum pump. Electron gun was then aligned to finely focus the electron beam on the sample and different magnifications (×500, ×1000 and ×1500) were employed to examine the sample. The operating voltage was limited to 5kV to minimize the charging effect on the resolution of the images.

Statistical analysis

Descriptive statistics were performed for all data using GraphPad Instat (v. 3.06). The mean and standard deviations of all replicate determinations were computed, and the differences between means were determined using one One-way Analysis of Variance (ANOVA), where $p < 0.05$ was considered significant.

Results and Discussion

Organoleptic properties and iodine test

Results from the organoleptic evaluation of the native and hydroxypropylated cassava and potato starch powders showed that native cassava starch was white in colour while that of native potato starch was off-white after extraction. Both starches were smooth in texture, odourless and tasteless. But the hydroxypropylated forms of both starches were off-white in colour, glassy (crystalline) in texture, odourless and tasteless.

Hydroxypropylation conferred on the native starches an off-white colouration and a crystalline and gritty texture. The crystalline nature of the hydroxypropylated starches may be the result of the modification process affecting the amorphous region of the native starch molecule. This result is congruent with that of Kaur *et al*. [19], where hydroxypropylation conferred significant changes in the size and surface properties of the starch granules and consequently its crystalline pattern. However, a study has attributed the crystalline appearance of the modified starch sample to an increase in the birefringence property of the starch, which is often caused by the disruption of molecular bonds, which consequently facilitates water holding capacity of the hydrogen bonds [20].

Additionally, results from iodine test performed on the starches showed changes in colour of the starch dispersions to blue-black colouration following the addition of iodine solution. This outcome was attributed to the presence of polysaccharides in both the native and hydroxypropylated cassava and potato starch. Result indicates that the process of hydroxypropylation had not changed the core characteristics of starch powder and it further be inferred that the samples have not been hydrolysed or broken down into smaller units after processing.

Bulk and flow properties of the starch powders

Table 1 showed the bulk and flow properties of the native and hydroxypropylated starches. The native cassava and potato starch powders demonstrated a higher volume reduction capacity in contrast with the hydroxypropylated variants with their bulk and tapped densities values. But the Carr's indices (≤ 5.96%) and Hausner`s ratios (≤ 1.06) of the hydroxypropylated samples were less than 25% and 1.25, implying samples with good flow characteristics. These low values credited to the modified starches may be attributed to the hydroxypropylation process, which may have increased the coarseness of the powder and thereby improved flow [21]. The good flowability of the hydroxypropylated starches as against the native forms was further confirmed by the angle of repose (≤ 20.50°) of the modified as against the no flow of the native starches.

Table 1: Micromeritic properties of native and HP-modified cassava and potato starches

Starches	Bulk density (g/ml)	Tapped density (g/ml)	Carr's index (%)	Hausner's Ratio	Angle of repose (°)
Native cassava	1.6993 ± 0.0566	2.5549 ± 0.2788	33.1155 ± 5.2322	1.5012 ± 0.1172	No flow
HP-cassava	0.7947 ± 0.0074	0.8452 ± 0.0168	5.9649 ± 0.9924	1.0635 ± 0.0112	19.98 ± 0.00
Native potato	1.7825 ± 0.0309	2.5857 ± 0.2403	30.7487 ± 5.0802	1.4494 ± 0.1094	No flow
HP-potato	0.7843 ± 0.0072	0.8276 ± 0.3536	5.2290 ± 0.0483	1.0552 ± 0.0005	20.50 ± 0.25

Physicochemical characteristics of the starches

Results from the physicochemical evaluation of native and modified cassava and potato starches are presented in Table 2.

Solubility

The native cassava starch had a lower solubility compared to the hydroxypropylated cassava starch with 0.21 ± 0.02% and 79.40 ± 1.01% solubility, respectively. A similar outcome was observed with the native and hydroxyproplyated potato starches with 0.20 ± 0.00% and 14.20 ± 0.82% solubility, respectively. The hydroxyproplyated potato starch had a significantly higher level of solubility. These results agree with that of Senanayake *et al*. [8], where an increase in solubility was observed after hydroxypropylation and they attributed it to the loosening of the internal structural components of the starch, resulting from the presence of hydrophilic hydroxypropyl substitutions. This is assumed to cause increased attraction for water molecules into the

rearranged starch granular structure, consequently causing early granule swelling, rapid rupture and increased water solubility [22].

Volume of sedimentation and water retention capacity

Results show a significant difference between the sedimentation volume of native cassava and potato starches at 50.00 ± 2.00 and 31.33 ± 1.15%, respectively. This effect is possibly due to the relative difference in granule size. A study by Abdullah *et al.* [23] identified the respective granule diameters of cassava and potato starches as 15.3 and 26.9 nm. The result obtained in this study is in line with the outcome of a study by Waterschoot *et al*. [24], where a correlation was established between granule size and granule swelling capacity.

Smaller granules were shown to have a higher potential for rehydration, while the inverse is reported for starch molecules with larger granule sizes. In addition, a relatively lower volume of sedimentation was recorded in modified cassava and potato starches, compared to the native varieties.

This property is possibly attributed to changes in the molecular structure that might have ensued during the pregelatinization and hydroxypropylation processes. These treatments led to the disruption of starch granules and reduced tendency for rehydration. Furthermore, there was an increase in the water retention capacity after hydroxypropylation. Hydroxypropylation treatment is assumed to enhance the water-trapping potential of native potato starches.

Syneresis (Freeze-thaw stability)

Syneresis is a measure of the percentage water loss following the freezing of starch semi-solid gel paste which was stored over a specified period (24 hours), thawed and subsequently exposed to centrifugal force. A higher degree of syneresis indicates elevated retrogradation potentials, crystallite perfection, and starch network disruption by the ice crystals formed during freezing.

The controlled fluctuations in temperature and the phase change demonstrated by the water component play a role in gel matrix deterioration [25]. The effect reduces the forces of attraction between hydroxyl groups on adjacent chains and thus prevents close associations between the dissolved linear starch molecules. Consequently, this leads to the reorganization of the starch structure to a highly concentrated meshwork or sponge-like filaments, with the potential to expel the liquefied water content [26].

Table 2: Physicochemical characteristics of native and HP-modified cassava and potato starches (n = 3)

Starches	Solubility (%)	Volume of sedimentation (%)	Water retention capacity (g/g)	Syneresis (%)	Moisture sorption	
					100% RH	20% RH
Native cassava	0.21 ± 0.02	50.00 ± 2.00	6.6067 ± 0.9874	23.64 ± 5.63	56.70 ± 1.41	40.60 ± 2.12
HP-cassava	79.40 ± 1.01	35.00 ± 1.00	1.7133 ± 0.9572	4.16 ± 2.34	83.20 ± 4.81	40.15 ± 0.92
Native potato	0.20 ± 0.00	31.33 ± 1.15	4.9267 ± 1.1455	34.64 ± 2.51	30.85 ± 2.33	12.30 ± 2.55
HP-potato	14.20 ± 0.82	29.33 ± 0.58	5.9867 ± 2.2646	1.08 ± 0.96	188.00 ± 4.67	118.00 ± 0.42
p-value	< 0.0001	< 0.0001	0.0135	< 0.0001	< 0.0001	< 0.0001

Table 2 showed a higher percentage syneresis for the native cassava starch compared to the hydroxypropylated variant; hence native cassava starch is relatively less stable. This characteristic demonstrated by the hydroxypropylated cassava is possibly attributed to the improvement in hydrophilicity and water-holding capacity conferred by the hydroxypropyl group, and the tightly bound interaction between the gel matrix and the water molecules at high temperatures.

This outcome is congruent with a report by Chotipratoom *et al*. [27], which showed a lower percentage of syneresis and highlights improvements in the stability of corn starch samples treated with hydrostatic high pressure-assisted hydroxypropylation, compared to the native corn starch. Hence, samples with low percentage syneresis have better stability under low-temperature conditions.

In addition, a similar outcome was observed with the potato starch samples. Higher water quantity was expelled in the native samples. This result is in line with the outcome of a study by Senanayake *et al*. [8], which showed better freeze-thaw stability amongst different hydroxypropylated potato starch cultivars, in contrast with the native samples. The native potato starch demonstrated a significantly higher

percentage syneresis when compared with the native cassava starch, while the hydroxypropylated cassava starch sample demonstrated higher percentage syneresis values, compared to the hydroxypropylated potato starch samples.

Moisture sorption

The results indicated that all the hydroxypropylated starches demonstrated a statistically significant increase in moisture sorption characteristics under 100% relative humidity (RH) compared with the native starch.

In addition, a similar result was observed between the native and hydroxypropylated potato starches exposed to 20% RH with 12.30 ± 2.55%, and 118.00 ± 0.42%, respectively, while the cassava starch demonstrated very similar results between the native and hydroxypropylated variety with 40.60 ± 2.12%, and 40.15 ± 0.92%, respectively.

Moisture sorption is a parameter indicating the stability of starch samples under varied environmental conditions. This experiment was designed to simulate dry and moist environmental conditions and the results show no significant difference between the sorption capacity of native and hydroxypropylated cassava under conditions with lower relative humidity.

High-resolution analysis results

DSC

Results obtained from thermal analysis of starches are shown in Figure 1. The thermograms of both native cassava and potato starches exhibited a single sharp trough at 150 and 74 °C, respectively. Meanwhile, the hydroxypropylated starches demonstrated multiple troughs, which indicates an increase in the level of crystallinity of the starch after modification. This explains the glass-like appearance of the modified starch, as more hydroxyl moieties in the native starch have been substituted with the hydroxypropyl group.

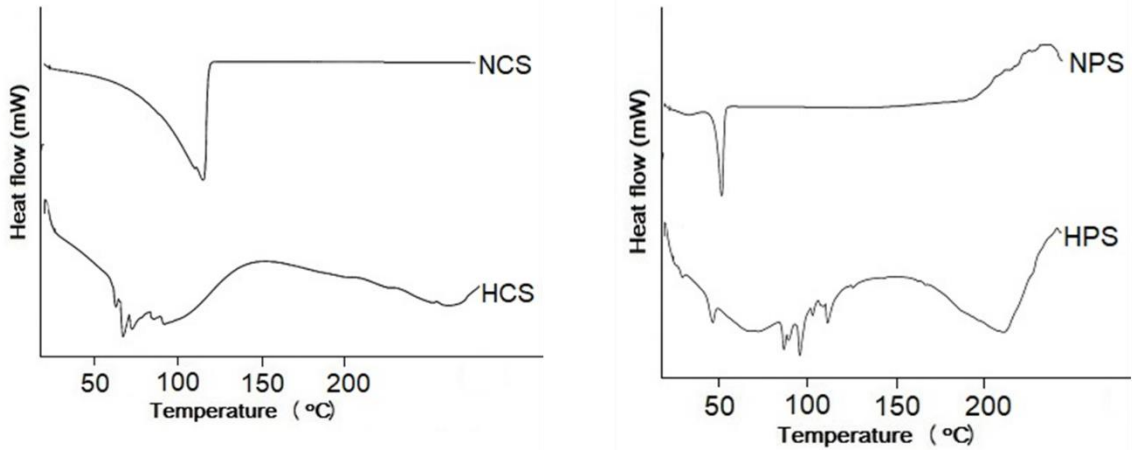

Figure 1: DSC thermograms of native cassava (NCS), hydroxypropylated cassava (HCS), native potato (NPS), and hydroxypropylated potato (HPS) starches

FTIR

Results from the FTIR analysis are shown in Figure 2. Their spectra show new peaks after the hydroxypropylation (etherification) reaction, which correspond to certain groups and indicate a hydroxypropyl substitution on the pre-gelatinized starch chains. Also, the native starches tend to demonstrate a broad trough in the –OH region (3230 - 3550 cm^{-1}) of the spectrum, which indicates a high saturation with hydroxyl moiety. Meanwhile, the spectra in this region developed a sharper trough, which shifted towards 3440 cm^{-1} for the hydroxypropylated cassava starch and 3430 cm^{-1} for hydroxypropylated potato starch. These changes recognized by the FTIR affirm the occurrence of hydroxypropylation. Thus FTIR spectroscopy revealed the hydroxypropyl substitution that may have occurred. The occurrence of differences in the spectra structures confirms the effect of hydroxypropylation on the native starches. These changes are predominantly identifiable in the areas depicting primary and secondary hydroxyl groups, as well as the aldehyde regions, which are observable in the IR spectrum.

SEM

The results from the scanning electron microscopy used to determine the form and surface characteristics for both the native and

hydroxypropylated starch samples are seen in Figure 3 at ×1500 magnifications. Round, polygonal, irregular, and granular-shaped nano-sized particles were observed with all native cassava and potato starch samples. The native starch samples comprised granules that were also more intact. The observation agrees with the earlier study of Huang [28], where polygonal and irregularly shaped native starch granule particles were also identified in native potato starch. However, these characteristics completely disappeared upon hydroxypropylation, as the microscopic images show smooth properties. Based on the result, it is possible that hydroxypropylation caused changes in the crystalline pattern and makes the granule surface morphology more porous and probably a little damaged.

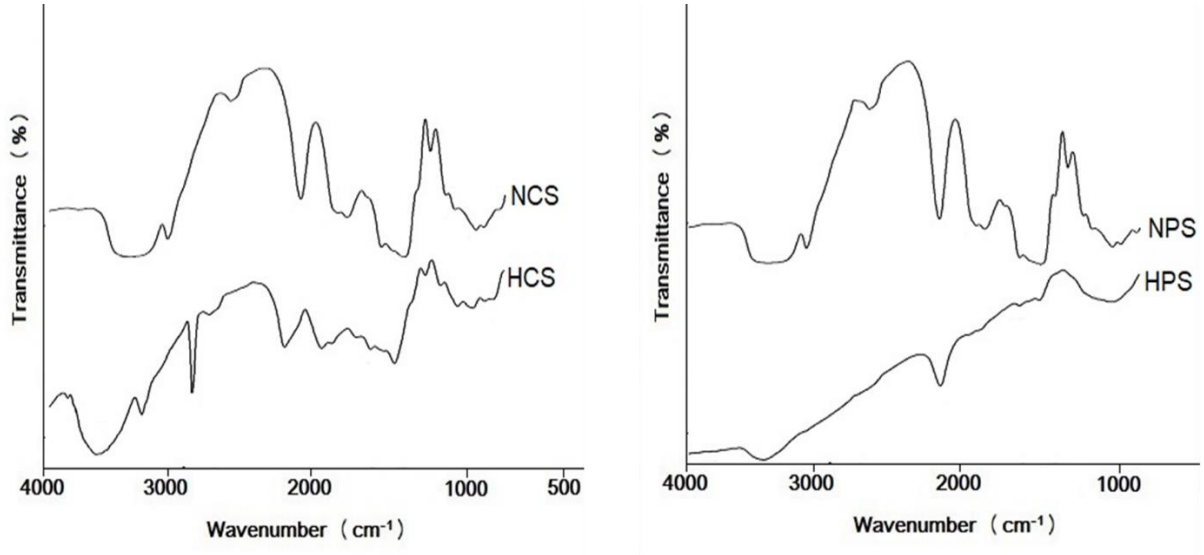

Figure 2: FTIR spectra of native cassava (NCS), hydroxypropylated cassava (HCS), native potato (NPS), and hydroxypropylated potato (HPS) starches

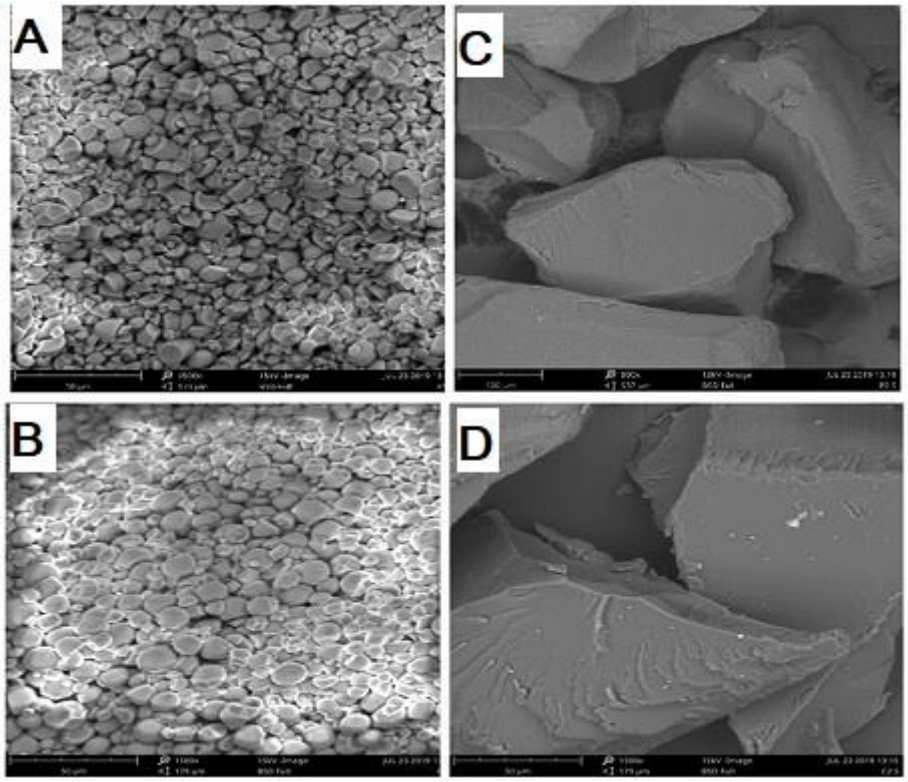

Figure 3: Scanning electron micrographs of the different starches; native cassava (A), native potato (B) hydroxypropylated cassava (C) and hydroxypropylated potato (D) (x1500)

Conclusion

Hydroxypropylation changed the starch texture and appearance to coarse and crystalline. There was also an improvement in their flow properties. Hydroxypropylation reduced the volume of sedimentation, improved the solubility and increased the freeze-thaw stability of both starches and these effects were more significant with potato starch. The hydroxypropylated potato starch had increased water retention capacity and moisture sorption, which was not observed with the cassava starch. The hydroxypropylated starch products demonstrated varied changes in characteristic properties, which potentially improved starch performance and these properties maybe essential in formulating advanced drug delivery systems.

Conflict of Interest

No conflict of interest is associated with this work.

Contribution of Authors

We declare that this work was done by the author(s) named in this article and all liabilities pertaining to claims relating to the content of this article will be borne by the authors. SOE and MAI supervised the work and contributed in data analysis. BOM collected the data and prepared the manuscript. SOE conceived and designed the study. All the authors read and approved the final draft submitted.

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