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Original Research Article

Characterization of Physicochemical and Micromeritics Properties of Carboxymethylated Starches Derived from *Vigna unguiculata* Seeds and *Pennisetum glaucum* Grains with an Intermediate Degree of Substitution

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ABSRTACT

Conventional commercial sources of starch for industrial applications are mainly based on staple foods, due to the worsening economic situation, there is a need to explore other underutilized unconventional sources. This study aims to extract, modify, and characterize starch from unconventional sources: cowpea (*Vigna unguiculata*) seeds and pearl millet (*Pennisetum glaucum*) grains.

Starch was extracted from cowpea seeds and pearl millet grains by milling and precipitation in sodium hydroxide solution and water respectively. Carboxymethylation of the starch was carried out using monochloroacetic acid. The native starch, modified starches, and commercial brand-sodium starch glycolate were subjected to physicochemical and micromeritic characterization as well as spectroscopic and thermal analysis. The starch yields of 16.01 and 46.60% were obtained from cowpea seeds and pearl millet grains respectively. Starch samples with an intermediate degree of substitution (0.52-0.60) were obtained from both sources. The starch samples complied with British Pharmacopoeia specification and carboxymethylation generally resulted in improved properties (reduced gelatinization temperature, increased swelling capacity and flow properties). The pearl millet was made of oval-shaped granules with higher starch yield, reduced moisture content, and improved flow than the cowpea starch, however, the latter contained cuboid-shaped granules, had higher densities, and reduced redispersion time. Carboxymethyl functional group was introduced, and the structure of starch was intact upon modification.

Carboxymethyl starches obtained from cowpea seeds and pearl millet grains have desirable properties and can be potential sources of low-cost excipients for pharmaceutical formulations.

Keywords: starch, carboxymethylation, cowpea seeds, physicochemical, pearl millet grains

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Introduction

Starch is a carbohydrate biopolymer consisting of glucose units that are linked by α-1,4 and α-1,6 glycosidic bonds. It is contained in many plants' leaves, stems, roots, flowers, fruits, and seeds.[1] Starch is accumulated as water-insoluble particles (starch granules) and it is a versatile biomaterial of special interest due to its abundance, cheapness, non-toxic properties, and biodegradability. It exists with diverse forms and characteristics which offer a great scope of its applications with high technological value in biopolymer industries.[2] In the pharmaceutical industries, starch is used as excipients such as fillers, binders, disintegrants, and anti-adhesives in tablet manufacturing, as a thickener in oral liquid, and as gelling agents in gels.[3] It is also utilized in novel drug delivery systems for prolonged circulation time and reduced dosing frequency, thereby improving patient compliance and acceptability.

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Starch is widely employed in the pharmaceutical industry because of its affordability, simplicity of modification, biocompatibility, the convenience of use, biodegradability, inherent physicochemical qualities, non-toxicity, and non-irritant properties.[4] The versatility of starch as food and raw materials in other industries may bring about a shortage in the supply of common sources of starch such as corn, wheat, potato, and cassava. Therefore, exploring underutilized crops as alternatives to traditional cereal and tuber sources will reduce the strain on these reserves, boost local starch production, and have a positive impact on the country's agricultural industry and economy.

Seed of *Vigna unguiculata* (Fabaceae) commonly known as cowpea seeds is an herbaceous legume cultivated in Africa, Southeast Asia, Southern United States and Latin America. Nigeria is regarded as one of the world's leading producers of cowpeas.[5,6] Cowpea seeds are commonly consumed in West Africa as boiling seeds alone or in conjunction with other foods (e.g., plantain, maize, and rice), as a fried paste (*Akara*) or as a steamed paste (*Okpa*). [7] There are different varieties of cowpeas with different starch compositions. It has been reported that starch yields for different varieties of cowpea vary from 11% to 66% depending on the extraction methods.[8] Underutilization of different varieties of Cowpea in food industries had been reported mainly due to high levels of antinutrients and hard-to-cook defect.[9]

Pennisetum glaucum (Poaceae) is a drought-resistant crop commonly called pearl millet. It is a native African millet that is cultivated in Africa and Asia continents.[10] Pearl millet, an underutilized crop is a good source of starch, its starch content is reported to range from 62.8% to 70.5% in different genotypes.[11] Modification and isolation of the starch from pearl millet can provide a new direction for polymer-based industries. Cowpea seeds and pearl millet grains are examples

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of an underutilized starch source; these crops being relatively cheap, abundant and of relatively high starch content can be exploited as sources of starch for use in the pharmaceutical industry.

Starch obtained from plants can be used in their natural state; these are referred to as 'native' or 'unmodified' starch. However, unmodified starches have unfavourable properties such as insolubility in cold water, abnormally high viscosity after heating, proclivity for retrogradation, sensitivity to shearing, low pH, brittleness and lack of specialized functional groups that may interact with various groups or substances.[12,13] These properties limit their commercial application thereby necessitating their modification. Starches are modified using physical, chemical, genetic, and enzymatic methods. Chemical modification of starch involves the incorporation of functional groups through oxidation, crosslinking, esterification, etherification, or acid treatment into starch molecule resulting in a change in its physicochemical and functional characteristics.[14, 15]

Carboxymethylation of starch is a chemical modification in which carboxymethyl groups are added to the starch molecule. This modification yields starch with decreased gelatinization temperature, increased solubility in cold water, decreased retrogradation rate, high quality and functional applicability and improved storage stability over the native starch.[12, 16, 15]Although the effects of carboxymethylation of starch obtained from different sources have been examined, there is little information available on the physiochemical and micromeritics properties of carboxymethylated cowpea seed and pearl millet grain starch. This study was aimed at characterizing native and carboxymethylated starches obtained from cowpea seeds and pearl millet grains for potential pharmaceutical applications.

Materials and Methods

Materials

Cowpea seeds and pearl millet grains were purchased from local markets in Lagos state, Nigeria. The materials were subsequently identified and authenticated in the Department of Botany of the University of Lagos and a voucher specimen numbers LUH 8716 and LUH 8715 were assigned to the cowpea seeds and pearl millet grains respectively. Samples were also deposited in the herbarium. Ethanol (99%), hydrochloric acid and sodium hydroxide were purchased from Merck (Darmstadt, Germany); iodine and monochloroacetic acid were procured from Loba Chemie Pvt, India; acetic acid and acetone were purchased from BDH chemicals, Poole, England. Sodium starch glycolate was a gift from Phamatex Industries Limited, Lagos, Nigeria. Other reagents were of analytical grade and were used as received from their suppliers.

Methods

Extraction of starch from Cowpea seeds and Pearl millet grains

Starch extraction from cowpea seeds (VUSo) was based on the method described by Ratnaningsih et al. [17] with some modifications. Briefly, the cowpea seeds were ground and soaked in 0.1% NaOH solution in a ratio of 1:3 and allowed to stand for 20 h. The starch dispersion was stirred vigorously in distilled water for 2 min. The resulting slurry was filtered using a muslin cloth and was allowed to stand for 1 h. The supernatant was discarded; the precipitate was resuspended in 0.1% NaOH solution and allowed to stand for 1 h after which the supernatant was discarded. The washing of the precipitate with 0.1% NaOH solution was repeated twice; the extracted starch was dispersed in distilled water and the supernatant was discarded. The starch was washed several times with distilled water until the starch was white in colour. The starch was oven-dried at 40°C, pulverized and the yield was calculated. It was stored for further analysis.

Starch was extracted from pearl millet (PGSo) as previously described by Suma & Urooj with some slight modification.[11] Briefly, 5 kg of pearl millet was sieved to remove excess bran. The sieved millet was soaked overnight in distilled water. The soaked millet was ground and screened through 60 and 150 mesh size British standard sieves. The slurry obtained was washed several times with distilled water and allowed to settle. The supernatant was removed by decanting and discarded. The pH of the slurry was adjusted to 9.5 with 0.1 N NaOH and stirred for 15 min. The slurry was washed several times with distilled water to remove alkali. The white starch obtained was air dried, the yield was calculated, and the starch was stored for further analysis.

Modification of the starch extracted from Cowpea and Pearl Millet by carboxymethylation

Cowpea and pearl millet carboxymethyl starches were obtained as a product of the reaction of the native starch and monochloroacetic acid (MCA) in the presence of NaOH using a procedure reported by Yanli et al. .[18] Four different samples of carboxymethylated starch were obtained by altering the molar concentration of sodium hydroxide or the reaction time; namely VUSa (cowpea carboxymethyl starch, 0.1 M NaOH, 1 h), VUSb (cowpea carboxymethyl starch, 0.1 M NaOH, 4 h), PGSa (pearl millet carboxymethyl starch, 0.05 M NaOH, 1 h), PGSb (pearl millet carboxymethyl starch, 0.2 M NaOH, 1 h).

Physicochemical and functional properties of the starch

Determination of degree of substitution (DS)

The degree of substitution carboxymethyl starch was determined employing a method described in an earlier study.[15] Briefly, 100 mL of acetone and 30 mL of HCl were added to 10 g of carboxymethyl starch. The DS was determined by acid-base titration of the obtained sample dissolved in 0.1 M NaOH as described by Stojanović *et. al.*[19]

Scanning Electron Microscopy (SEM) analysis

Starch granule morphology was obtained using a scanning electron microscope (Pro X, Netherlands). Starch samples were prepared and mounted on the aluminum stub and then inserted into the sample holder slot. The sample was then transferred automatically to the optical imaging position. The optical camera was activated, and the image was displayed and captured.

Fourier transform infrared (FTIR) analysis

The FTIR spectra of starch samples were obtained using the FTIR spectrophotometer (Bruker, South-Africa). About 5 mg of each sample was individually blended with solid KBr pellets (50 mg) and compressed into discs. The spectra were scanned from 400 – 4000 cm^{-1} in a FTIR spectrometer.

Differential scanning calorimetry (DSC)

The thermal properties of the starch samples were obtained using the Differential Scanning Calorimeter (Mettler Toledo, UK). The starch sample of 2 mg was weighed into an aluminum pan. The pan was hermetically sealed and equilibrated at room temperature for 1 h, then heated at the rate of 10°C/min from 30°C to 250°C with an empty sealed pan as a reference. Parameters such as initial (T_o), peak (Tp) and conclusion (Tc) temperatures were determined.

Pharmacopeial parameters

The pharmacopoeial properties investigated are organoleptic properties, solubility, moisture content, Ash content, pH, and test for starch. All characterizations were carried out in triplicates.

Solubility

Two grams of each starch sample was transferred into labelled test tubes containing 3 mL of distilled water and the solubility was determined. The procedure was repeated using 99% ethanol as solvent.

Moisture content

The procedure described by Oluwasina *et al.*, was adopted with minor modifications.[20] Two grams of each starch sample was placed in a pre-weighed empty petri dish; the petri dish was transferred into the oven operated at 105˚C for 3 h. The petri dish and its content were weighed, and the moisture content was determined using equation 1.

Moisture content (%) = ____ x 100 .....Equation 1

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Where w1 – initial weight of starch sample (g); w - weight of the oven-dried starch sample

pH of starch samples
A 10% w/v dispersion in water (20 mL) of each starch sample were prepared and shaken vigorously for 5 min. The pH of the dispersion was determined using a pH meter (Hanna, USA).

Test for starch
A 2 mL dispersion in water of each starch sample was placed in separate test tubes, 2 drops of 0.5 N iodine was added and shaken. The mixture was warmed, allowed to cool and observations were recorded.

Micromeritics
The bulk and tapped densities, Hausner's ratio, Carr's compressibility index, angle of repose of starch samples were determined according to previous study by Azubuike *et al*. [4]

Hydration and swelling capacity
The hydration and swelling capacities of the starch samples were determined using the methods described by Azubuike *et al*.[4] and Oluwasina et al., [20] respectively.

Redispersion time
Distilled water (10 mL) was added to the sediments obtained from the determination of the hydration capacity. The tube was gently agitated with the same intensity until the sediment was re-dispersed. The time taken for the sediment to re-disperse was recorded as the re-dispersion time.

Statistical analysis
The determinations were carried out in triplicates and expressed as means ± standard deviation (SD). The mean comparison of the test samples with the standard was carried out using one-way analysis of variance (ANOVA) using the GraphPad® prism 5 software (GraphPad® Software, La Jolla, CA). Significant differences ($p < 0.05$) were determined using Tukey post hoc test.

Result and Discussion

Starch yield
The percentage yield of native starch obtained from cowpea seeds and pearl millet grains was 16.01 and 46.60% respectively. The low yield observed in cowpea can be improved through the optimization of parameters utilized in the extraction process. However the starch yield of the cowpea seeds is within the limit reported in literature.[17]

Degree of Substitution
The degree of substitution (DS) values obtained for VUSa, VUSb, PGSa and PGSb were 0.52, 0.67, 0.61 and 0.55 respectively. Increase in reaction time of the cowpea increased the DS, however, there was no significant difference in an increase in the concentration of NaOH for pearl millet carboxymethylated starch. The factors affecting the DS of carboxymethylated starches had been well established in literature. [18,21] High DS is desirable in starch polymer because it confers improved physicochemical properties and functionality such as prolonged drug release, [21] while carboxymethylated starches with low DS exhibited good excipient potentials in immediate release solid dosage forms. [15]

Morphological study
The SEM micrographs showing the morphology of native and modified cowpea and pearl millet starches are presented in Figures 1 and 2. The native and modified cowpea starches contained clusters of intact elliptical to oval shaped granular particles having smooth surfaces with no holes or fissures (Figure 2). On the other hand, the pearl millet starch contained cuboidal to oval shaped granules like commercial brand sodium starch glycolate (SSG). The modified pearl millet starch had rough surfaces and few alveolate pores (Figure 2) when compared with SSG, this is indicative of loss of crystalline structure by exposure to high alkaline environment.[22] Hence, the exposure of native pearl millet starch to an alkaline environment during the carboxymethylation process might have altered its glandular morphology.[18] This is similar to the findings of Madu *et al*.[16]

FTIR Spectroscopy
The infrared spectra of the native starch samples (VUSo and PGSo) and carboxymethylated samples (VUSa, VUSb, PGSa, PGSb and SSG) are presented in Figures 3a and 3b and were used to evaluate the etherification and the polysaccharide structure. The FTIR spectra of all the samples showed a characteristic spectrum of starch with pattern in the region 930 cm^{-1} and 1300 cm^{-1}, however minor differences were observed in the signal and band intensities. The absorption band at 992 cm^{-1} to 999 cm^{-1} observed in all starch samples indicated the C-O stretching from C-O-C in the glycosidic ring of starch while the band around 2930 cm^{-1} is attributed to C-H stretching vibrations. Absorption peaks between 3269 and 3350 cm^{-1} in all starch sample is attributed to O-H group. However, a decrease in band intensity and slight shift in peak observed in the carboxymethyl derivatives (3242 cm^{-1} and 3226 cm^{-1}) for VUSa and VUSb (Figure 3a); 3266 cm^{-1} for PGSa and 3268 cm^{-1} for PGSb (Figure 3b) in comparison with the native starch (3284 cm^{-1} for VUSo 3274 cm^{-1} for PGSo) is possibly due to the interaction of O-H group with $COO^{-}Na^{+}$ to form carboxymethyl groups. [22] In addition, the modified starches showed prominent absorption peaks for symmetric and asymmetric COO vibrations at 1625 cm^{-1} when compared to the native starch indicating the presence of increased number of COO bonds, [18] thus, confirms the introduction of carboxymethyl groups to the starch molecule.

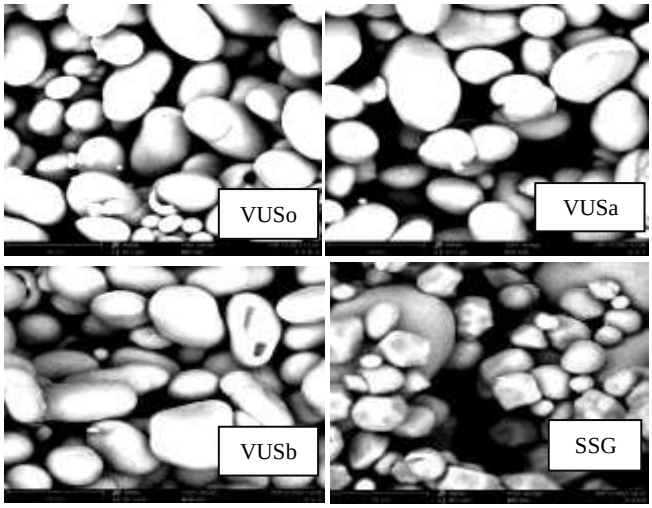

Figure 1: SEM micrograph of native and modified starches obtained from cowpea starches and sodium glycolate starch at 4000x magnification
VUSo- cowpea seed native starch; VUSa- cowpea carboxymethyl starch (DS-0.52); VUSb- cowpea carboxymethyl starch (DS-0.67); SSG- commercial brand sodium starch glycolate.

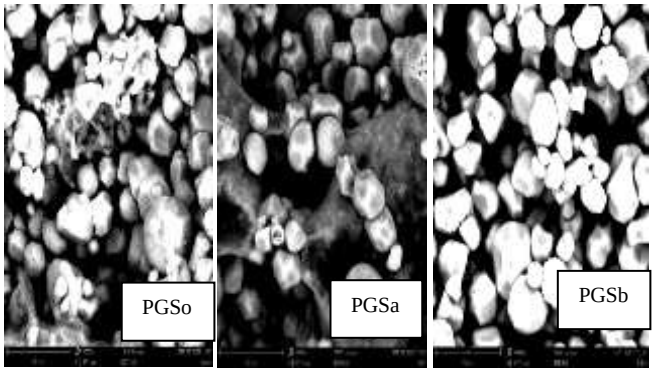

Figure 2: SEM micrograph of native and modified starches obtained from pearl millet at 4000x magnification

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PGSo- pearl millet native starch; PGSa- pearl millet carboxymethyl starch (DS-0.61); PGSb- pearl millet carboxymethyl starch (DS-0.55).

Thermal analysis

The thermal analysis (Figures 4a and 4b) of SSG, VUSo, VUSa, VUSb, PGSo, PGSa and PGSb showed an onset temperature (To) between 31.41℃ to 32.29 ℃, the peak temperature (Tp) ranged between 108.38℃ to 125.95℃ and concluding temperature (Tc) ranged between 187.2℃to 208.80℃. Gelatinization temperature (Tc – To) of all starch samples was in the range of 154.59℃ to 176.59℃. Similar onset temperature was observed in all starch samples obtained from cowpea and millet, however, there was a reduction in the gelatinization temperature of modified cowpea and millet starches when compared with native starch. High gelatinization temperature implies the presence of longer amylopectin chain, [8] presence of increased amylopectin double helices and probably increased rigidity of the amorphous region all of which are reduced and disrupted during the carboxymethylation process.[23] Hence, the reduction in the amount of heat required to cause gelatinization and by extension solubilization of starch.

Pharmacopoeial and physicochemical characterization of starch samples

The pharmacopoeial and physicochemical properties of native, carboxymethyl cowpea and pearl millet starch are presented in Table 1. The organoleptic property of pharmaceutical excipient affects the physical appearance of the drug formulation which in turn affects patient's acceptability of drug formulation. The colour of native starch obtained from cowpea and pearl millet was off white while modified starches from both starch source and SSG were whiter in colour. All samples had characteristic odour and taste for starch with texture ranging from fine to very fine powder. The organoleptic properties recorded conforms to the specification of British Pharmacopoeia.[24]

All carboxymethyl modified starch samples and native starch of pearl millet grain formed a translucent suspension in cold water and were insoluble in 99% ethanol while the native starch of cowpea seeds (VUSo) formed a turbid suspension and was insoluble in 99% ethanol. The enhancement in solubility observed in carboxymethylated starches when compared to the native starches might be attributed to increase in hydrophilicity by carboxymethyl substitution groups which results in swelling of the starch granule. This suggests that the starch can be used as a suitable disintegrant because it can absorb water breaking the hydrogen bonds and other interparticulate forces holding the tablet together. All samples gave a dark blue colour upon addition of iodine, this confirmed the presence of starch in all samples. The native and carboxymethyl starch samples obtained from cowpea seeds and millet grain and SSG had similar pH ranging from 6.70 – 7.20. The neutral pH observed makes the starch suitable excipients for use in oral and topical formulations as they will not cause gastrointestinal tract or skin irritation.

The moisture content of all samples ranged from 8.00 - 14.25. The moisture content of a formulation affects its microbial stability during storage and agglomeration properties. The standard starch - SSG had the highest amount of moisture; native and modified starch obtained from cowpea had similar amount of moisture. Also, similar moisture content was observed within the native and carboxymethyl modified pearl millet starch samples, however, pearl millet starch had lower moisture content than cowpea sample. This suggests that the pearl millet starch when employed as excipients in solid dosage formulations might be less prone to microbial attack and agglomeration, thus, more likely to maintain the quality of formulation during its shelf life. The bulk and tapped densities of the starch samples are between 0.41 – 0.61 and 0.47 – 0.76 respectively with higher bulk and tapped densities observed in cowpea starch when compared to pearl millet starch. High bulk powders possess improved flow properties with more quantity required to effect compression during tableting.[25]

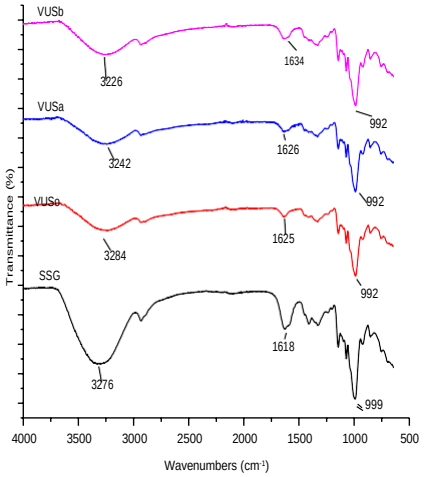

Figure 3: FTIR spectra of sodium starch gluconate (SSG), native (VUSo) and modified starches obtained from cowpea (VUSa and VUSb).

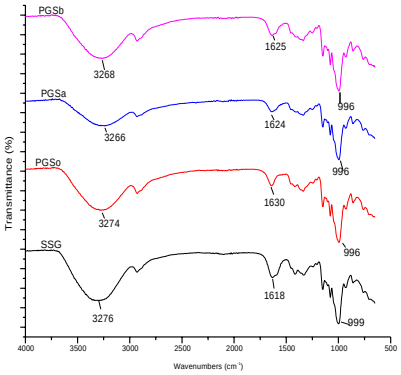

Figure 3b: FTIR spectra of sodium starch gluconate (SSG), native (PGSo) and modified starches obtained from pearl millet (PGSa and PGSb).

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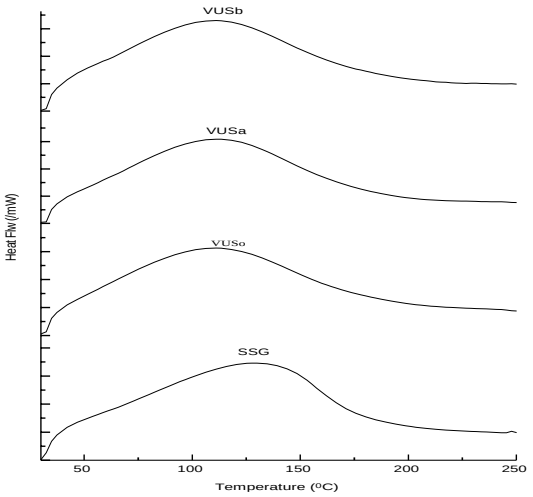

Figure 4a: The DSC thermograms of sodium starch gluconate (SSG), native (VUSo) and modified starches obtained from cowpea (VUSa and VUSb).

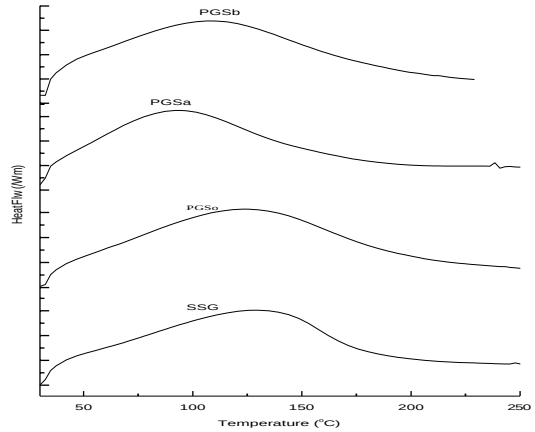

Figure 4b: The DSC thermograms of sodium starch gluconate (SSG), native (PGSo) and modified starches obtained from pearl millet (PGSa and PGSb).

Therefore, cowpea starch might generally have improved flow than the pearl millet starch. The bulk density of cowpea native starch (VUSo) varied significantly ($p<0.05$) with those of modified starch (VUSa, VUSb) and SSG ($p<0.05$). However, there was no significant difference between the tapped density of cowpea native starch and modified starches ($P>0.05$). The bulk and tapped densities of the modified pearl millet starch (PGSb) and SSG is significantly higher than PGSa its native starch (PGSo). The bulk and tapped densities (Table 1) decreased as DS increased in both cowpea and pearl millet starch; this implies that more of the starch samples of lower DS is required for compression during formulation of tablets. [25] It also implies a likelihood of the lower DS having a better flow compared to those starch samples with higher DS.[15]

The Carr's index, Hausner's ratio, and angle of repose of all starch samples ranges from 12.82 – 33.50, 1.15 – 1.50 and 25.68 – 39.10 respectively. Carr's index, Hausner's ratio and angle of repose are used as a measure of the flow properties of powders and granules. This is important in ensuring content uniformity and consistent drug therapeutic levels in solid dosage formulations. Carr's index of 11-15, 16-20, 21-25, 26-31 and 32-37 indicates good, fair, passable, poor, and very poor flow respectively; Hausner's ratio of 1.12-1.18, 1.19-1.25, 1.26-1.34, 1.35-1.45 and 1.46-1.59 indicates good, fair, passable, poor, and very poor flow respectively. Angle of repose of 25-30, 31-35 and 36-40 represents excellent, good, and fair flow respectively. [24] The Carr's index and Hausner's ratio suggest that the native millet starch had fair flow properties like SSG while the native cowpea starch possessed very poor flow. Carboxymethyl modification of both millet and cowpea native starch improved its flow resulting in powders with good and passable/poor flow respectively. In contrast, the result for angle of repose is not consistent with the Carr's index and Hausner's ratio; the angle of repose indicates that cowpea native had a better flow property than millet. This is characterized by good flow observed in cowpea as opposed to fair flow in millet, however, the fair flow property observed in millet is in line with Carr's index and Hausner's ratio measure of flowability for millet. Modification of native starch obtained from both sources caused improved flow (except in VUSa); the flow of modified millet starch was similar to the standard -SSG. The hydration and swelling capacity varied between 1.54 – 7.36 and 32.60 – 695.12 respectively. An increase in hydration and swelling capacity was observed upon carboxymethyl modification of cowpea and millet native starch, however SSG had the highest hydration and swelling capacity. In addition, increase in DS led to increased hydration and swelling capacities, this is in tandem with the findings of Adeyanju et al.[26] This is because increase in the number of carboxymethyl groups confers increased hydrophilicity thereby allowing more water to penetrate the starch resulting in swelling of the starch granule. Therefore, the modified starches will be a better disintegrant than the native starch in the formulation of tablets.[25]

Table 1: Pharmacopoeial and physicochemical properties of native and modified starches (standard deviations are in parenthesis)

Parameter	VUSo	VUSa	VUSb	PGSo	PGSa	PGSb	SSG
pH	6.86 (0.02)	6.70 (0.00)	6.94 (0.06)	7.20 (0.08)	6.80 (0.12)	7.10 (0.20)	6.73 (0.04)
Moisture content (%)	10.33 (0.14)	11.41 (0.42)	12.25 (0.35)	8.10 (0.06)	7.20 (0.20)	8.00 (0.19)	14.25 (0.35)
Bulk density (g/mL)	0.48 (0.02)	0.56 (0.01)	0.53 (0.02)	0.41 (0.02)	0.41 (0.06)	0.51(0.03)	0.61 (0.02)
Tapped density (g/mL)	0.72 (0.04)	0.76 (0.02)	0.73 (0.02)	0.47 (0.01)	0.48 (0.03)	0.59 (0.01)	0.69 (0.04)
Hausner's ratio	1.50 (0.02)	1.36 (0.04)	1.38 (0.01)	1.22 (0.04)	1.15 (0.02)	1.17 (0.01)	1.20 (0.01)
Carr's index	33.50 (0.71)	26.50 (2.12)	27.50 (0.71)	17.74 (0.21)	12.82 (0.10)	14.29 (0.40)	16.33 (1.41)
Angle of repose (θ°)	32.70 (0.99)	38.27 (0.56)	25.68 (0.30)	39.10 (0.65)	35.20 (0.45)	30.90 (0.48)	36.10 (0.42)
Hydration capacity	3.25 (0.21)	3.58 (0.18)	5.72 (0.18)	1.54 (0.03)	4.78 (0.13)	3.62 (0.07)	7.36 (0.29)
Swelling capacity	32.60 (0.57)	41.50 (1.41)	85.75 (1.06)	39.30 (0.33)	84.60 (0.42)	103.20 (0.65)	695.12 (0.70)
Redispersion time (s)	36.66 (3.98)	45.59 (22.86)	19.06 (9.58)	85.00 (6.00)	51.00 (1.35)	49.00 (0.62)	83.16 (12.71)

VUSo- cowpea seed native starch; VUSa- cowpea carboxymethyl starch (DS-0.52); VUSb- cowpea carboxymethyl starch (DS-0,67); PGSo- pearl millet native starch; PGSa- pearl millet carboxymethyl starch (DS-0.61); PGSb- pearl millet carboxymethyl starch (DS-0.55); SSG- commercial brand sodium starch glycolate.

The redispersion time ranges from 19.06 – 83.16. The cowpea starch samples had a shorter redispersion time than the millet starches with the redispersion time for SSG comparable to native millet starch. Modification of native cowpea and millet starch resulted in a shorter redispersion time except in VUSa. Thus, modified starches can be easily redispersed and might be suitable excipients in suspension formulations in which easy redispersion of sediments is necessary for accurate dosing.[27]

Conclusion

Carboxymethyl starches obtained from cowpea seeds and pearl millet grains possessed acceptable pharmacopoeia specifications and unique physicochemical properties than their native starches. The pearl millet starch was of higher yield and improved flow than the cowpea starch, however, the later had higher densities and reduced redispersion time. The degree of substitution in the modified starches affected some of its properties such as density, hydration, and swelling capacity and as such may need to be optimized. The results obtained from the study show that the modification of starches from cowpea seeds and pearl millet grains could increase the opportunities for their utilization. Further characterization of the modified starches and subsequent use as a low-cost excipient in pharmaceutical dosage forms can be explored.

Conflict of Interest

The authors declare no conflict of interest.

Authors' Declaration

The authors hereby declare that the work presented in this article is original and that any liability for claims relating to the content of this article will be borne by them.

References

1. Apriyanto A, Compart J, Fettke J. A review of starch, a unique biopolymer – Structure, metabolism and in planta modifications. Plant Sci. 2022;1(318):111223.
2. Wani IA, Sogi DS, Hamdani AM, Gani A, Bhat NA, Shah A. Isolation, composition, and physicochemical properties of starch from legumes: A review. Starch - Stärke. 2016;68(9–10):834–845.
3. Santana ÁL, Angela M, Meireles A. New starches are the trend for industry applications: a review. Food and Public Health. 2014;4(5):229-241.
4. Azubuike CP, Adeluola AO, Mgboko MS, Madu SJ. Physicochemical and microbiological evaluation of acid modified native starch derived from *Borassus aethiopum* (Arecaceae) shoot. Trop J Pharm Res. 2018;17(5):883-890.
5. Ortiz R. Cowpeas from Nigeria: A Silent Food Revolution. Outlook Agric. 1998;27(2):125–128.
6. Saka JO, Agbeleye OA, Ayoola OT, Lawal BO, Adetumbi JA, Oloyede-Kamiyo QO. Assessment of varietal diversity and production systems of cowpea (*Vigna unguiculata* (L.) Walp.) in Southwest Nigeria. J Agric Rural Dev Trop Subtrop JARTS. 2018;119(2):43–52.
7. Ashogbon AO, Akintayo ET. Isolation and characterization of starches from two cowpea (*Vigna unguiculata*) cultivars. Int Food Res J. 2013;20(6):3093-3100.
8. Oyeyinka SA, Kayitesi E, Adebo OA, Oyedeji AB, Ogundele OM, Obilana AO, Njobeh PB Review on the physicochemical properties and potential food applications of cowpea (*Vigna unguiculata*) starch. Int J Food Sci Technol. 2021;56(1):52–60.
9. Giami SY. Compositional and nutritional properties of selected newly developed lines of cowpea (*Vigna unguiculata* L.Walp). J Food Compos Anal. 2005 Nov 1;18(7):665–673.
10. Punia Bangar S, Nehra M, Siroha AK, Petrů M, Ilyas RA, Devi U, Devi PD. Development and Characterization of Physical Modified Pearl Millet Starch-Based Films. Foods. 2021;10(7):1609.
11. Suma P F, Urooj A. Isolation and Characterization of Starch from Pearl Millet (*Pennisetum typhoidium*) Flours. International Journal of Food Properties. 2015;18(12):2675-2687.
12. Anirudhan TS, Parvathy J. Carboxymethyl starch as a polymeric plant-based excipient in drug delivery. Plant Sci Today. 2014;1(4):179–182.
13. Colussi R, Pinto VZ, El Halal SLM, Vanier NL, Villanova FA, e Silva RM, Zavareze E, Dias ARG. Structural, morphological, and physicochemical properties of acetylated high-, medium-, and low-amylose rice starches. Carbohydr Polym. 2014:103:405–413.
14. Ibikunle A, Sanyaolu N, Yussuf S, Ogunneye AL, Badejo OA, Olaniyi OM. Effects of chemical modification on functional and physical properties of African star apple kernel (*Chrysophyllum albidnum*) starch. Afr J Pure Appl Chem. 2019;13(1):1-11.
15. Madu SJ, Azubuike CP, Okubanjo O, Mohammed A, Emeje OM. Physicochemical and disintegrant properties of sodium Carboxymethyl starch derived from *Borassus aethiopum* (Arecaceae) shoot. J Polym Res. 2018 Jul 7;25(8):167.
16. Li SF, Mujyambere JM, Liu M. Synthesis of carboxymethyl starch with high degree of substitution by a modified dry process. In Advanced Materials Research 2011 (Vol. 233, pp. 306-310). Trans Tech Publications Ltd.
17. Ratnaningsih N, Suparmo, Harmayani E, Marsono Y. Composition, microstructure, and physicochemical properties of starches from Indonesian cowpea (*Vigna unguiculata*) varieties. Int Food Res J. 2016;23(5):2041–2049.
18. Yanli W, Wenyuan G, Xia L. Carboxymethyl Chinese yam starch: synthesis, characterization, and influence of reaction parameters. Carbohydr Res. 2009 Sep 8;344(13):1764–9.
19. Stojanović Ž, Jeremić K, Jovanović S. Synthesis of Carboxymethyl Starch. Starch - Stärke. 2000;52(11):413–419.
20. Oluwasina O, Wahab O, Umunna Q, Nwosa O. *Dioscorea dumetorum* Pax as an Alternative Starch Source for Industrial Applications. IOSR J Appl Chem. 2017;10(5):05–13.
21. Vashisht D, Pandey A, Jayaram Kumar K. Physicochemical and release properties of carboxymethylated starches of Dioscorea from Jharkhand. Int J Biol Macromol. 2015;74:523–529.
22. Basri SN, Zainuddin N, Hashim K, Yusof NA. Preparation and characterization of irradiated carboxymethyl sago starch-acid hydrogel and its application as metal scavenger in aqueous solution. Carbohydr Polym. 2016;138:34–40.
23. Mohapatra S, Siddiqui AA, Anwar M, Bhardwaj N, Akhter S, Ahmad FJ. Synthesis and characterization of novel carboxymethyl Assam Bora rice starch for the controlled release of cationic anticancer drug based on electrostatic interactions. AAPS PharmSciTech. 2018;19(1):134–47.
24. British Pharmacopoeia 2017 pdf Free Download [Internet]. Book Of Medical. [cited 2022 Aug 19]. Available from: https://www.booksofmedical.com/2022/05/british-pharmacopoeia-2017-pdf-free.html
25. Azubuike C, Fabiyi R, Oseni B, Igwilo C, Department of Pharmaceutics and Pharmaceutical Technology, Faculty of Pharmacy, University of Lagos, College of Medicine Campus, PMB 12003, Surulere, Lagos, Nigeria. Evaluation of Disintegrant Potential of Carboxymethyl Starch Derived from *Cyperus esculentus* (Cyperaceae) Tubers. Trop J Nat Prod Res. 2019;3(7):246–251.
26. Adeyanju O, Olademehin OP, Hussaini Y, Nwanta UC, Adejoh AI, Plavec J. Synthesis and Characterization of

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Carboxymethyl *Plectranthus esculentus* Starch. A Potential Disintegrant. J Pharm Appl Chem. 2016;2(3):189–195.
27. Okunlola A, Akingbala O. Characterization and evaluation of acid-modified starch of *Dioscorea oppositifolia* (Chinese yam) as a binder in chloroquine phosphate tablets. Braz J Pharm Sci. 2013;49(4):699–708.