Original Article

Characterization and Application of *Borassus aethiopum* (*Arecaceae*) Shoot Pregelatinized Starch as Binding Agent in Paracetamol Tablets

Abstract

Aims: The study sought to characterize the physicochemical properties and assess the binding properties of pregelatinized starch (PGSb) derived from *Borassus aethiopum* shoot at various concentrations in paracetamol (PCM) tablet formulation. **Methods and Materials:** PGSb was obtained by suspending 100 g of the native starch (NS) in 100 ml of deionized water at 55°C for 10 min. PGSb was characterized using different techniques and compared with a commercial brand of pregelatinized starch (PGSs). The compatibility of PGSb with PCM powder was evaluated using Fouriertransform infrared (FTIR) spectroscopy and differential scanning calorimetry (DSC) techniques. Three batches of PCM granules containing different concentrations of the PGSb as test binder were formulated and compared with two batches containing 1.78% polyvinylpyrrolidone and 1.78% NS as binder, respectively. **Results:** The evaluated parameters of PGSb were comparable to PGSs. PGSb had improved solubility, lower gelatinization temperature, and better hydration capacity properties compared to the NS. FTIR and DSC studies confirmed the modification of the NS and its compatibility with PCM powder. The tablets formulated were within acceptable limits for the parameters evaluated (tablet thickness, uniformity of weight, hardness, friability, disintegration, and dissolution profile) except the batch that contained NS as binder that failed uniformity of weight and friability tests. All the batches released more than 70% of the active drug at 30 min. The dissolution study indicated that there were variations in the drug release profiles among tablets formulated with different binding agents. **Conclusions:** The findings of this study indicate that PGSb has desirable physicochemical and binding properties.

Keywords: *Binding potentials, Borassus aethiopum shoot, physicochemical characterization, pregelatinized starch*

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Introduction

Starch, the second most abundant organic compound found on the earth, is composed of two kinds of polysaccharides: linear amylose and branched amylopectin. It is partially crystalline and its size, shape, morphology, and other physicochemical properties are dependent on its biological source.[1] Starch is biodegradable, biocompatible, relatively inexpensive, and widely used in food and pharmaceutical industries.[2] Starch is a very important and widely distributed natural product, occurring in the leaves of green plants, seeds, fruits, stems, roots, and tubers.[3]

Native starch (NS) is starch isolated from its botanical source with minimal treatment such that the intrinsic physicochemical properties are maintained after processing.[4] For those characteristics which are unattainable with NS, modified starch can be used for other industrial applications through a series of techniques: chemical, physical, and enzymatic modifications.[5,6] Physical methods involve the use of heat and moisture, and chemical modifications introduce functional groups into the starch molecule using derivatization reactions.[7]

Pregelatinized starch is a common type of physically modified starch with wide applications in polymer industries.[8-10] Studies on pregelatinized starches have shown that some factors including the botanical source of starch, processing conditions, amylose leaching, among others influence the functional properties of starch products.[2,11,12] Pregelatinized starch has advantages such as cold-water swelling capacity, strong water absorption, high viscosity as well as desirable pasting, and texturizing properties.[2,12]

Borassus aethiopum (family *Arecaceae*) is a palm tree with huge fan-shaped leaves.

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Fruits and shoot of the plants are major constituents of traditional medicine, and *B. aethiopum* shoots are readily available in the northern part of Nigeria with little or no nutritional value.[13]

To date, most sources of commercially available pregelatinized starches have nutritional value, for example, corn, wheat, potato, and rice. Sourcing of pregelatinized starches from other botanical sources with little or nonfood value may yield low-cost starch with special and desirable physicochemical properties as well as a wide range of functional properties. To the best of the authors' knowledge, no work has been done to investigate the physicochemical properties and binding potentials of *B. aethiopum* shoot native and pregelatinized starches. This study was aimed at assessing the physiochemical as well as binding properties of *B. aethiopum* shoot pregelatinized starch (PGSb) in paracetamol (PCM) tablet formulation.

Materials and Methods

Materials

B. aethiopum shoots were collected from Mubi, Adamawa State, Nigeria. It was identified and authenticated at Department of Botany, University of Lagos, Nigeria. Voucher specimen number LUH 7409 was assigned, and samples were deposited in the herbarium. Amylose powder, standard pregelatinized starch (PGSs), PCM powder, sodium starch glycolate, and magnesium stearate were gift from Phamatex Industry Limited, Nigeria. All other reagents used were of analytical grade and were used as received.

Methods

Preparation of Borassus aethiopum native and pregelatinized starches

The method of Madu *et al*.[14] was employed for the extraction of starch from peeled fresh shoots of *B. aethiopum* (2 kg) while the method of preparation as described by Herman *et al*.[15] was adopted with some modifications for the pregelatinization of the *B. aethiopum* starch. Aqueous slurry of the starch was prepared by suspending 100 g of the NS in 100 ml of deionized water and heated at 55°C with constant agitation for 10 min. The resulting paste was crisp-dried in a hot air oven (B and T, Australia) at 60°C for 48 h. The flakes were powdered, passed through a sieve of 150 μm, and stored in dry container till further use.

Characterization of the starch samples

Pharmacopoeial characterization

Some pharmacopoeial characterization (solubility, iodine test, pH, moisture content, and amylose content) of the three starches were carried out.

Solubility

Aqueous solubility of the three starch samples (NS, PGSb, and PGSs) was measured by stirring an aqueous suspension of the starch (2% w/v initially prepared in a beaker) in water bath (Surgifriend Medicals, England) maintained at 77 ºC for 1 h. The suspension was then cooled to room temperature and centrifuged at 5000 rpm for 9 min. The liquid supernatant was poured out carefully and evaporated for 65 h at 60°C. The swollen starch sediment was weighed. Solubility was calculated using Equation 1.

$$\text{Solubility}(\%) = \frac{\text{Weight of dried supernatant}}{\text{Weight of dry starch}} \times 100 \qquad \text{Equation (1)}$$

Iodine test

Two drops of 50 N iodine were added to 2 ml slurry of NS, PGSb, and PGSs in separate test tubes. The mixtures were warmed individually and allowed to cool. The observations made were recorded in each case.

pH determination

The pH of 1 g in 5 ml slurry of each of the sample starch powders (NS, PGSb and PGSs) was determined using a pH meter (Hanna instruments, USA), and the result was recorded.

Ash value

Ash values of the samples were determined by pouring a 2 g weight of each starch powder sample (NS, PGSb, and PGSs) into a nickel crucible and placed in an incinerator (Carbolite Germany). The temperature was increased to 550°C and was constant at that temperature for 5 h. The weight of the ash was then determined, and the percentage ash value was calculated using Equation 2.

$$\text{Ash value}(\%) = \frac{\text{Weight of ash formed}}{\text{Initial weight of starch powder}} \times 100 \qquad \text{Equation (2)}$$

Moisture content

The moisture content of the NS, PGSb, and PGSs was determined using a moisture analyzer (Sartorius AG, Germany). Three grams of each sample powder was poured into the moisture balance and evenly distributed on the tray. The readings were recorded when the machine automatically stops at 15 min.

Amylose content

The amylose content of the NS, PGSb, and PGSs was determined using the colorimetric method employed by Williams *et al*.,[16] with some modifications. Fifty milligrams of sample were transferred to a 50 ml volumetric flask, to which was added 0.5 ml 95% ethanol and 4.5 ml 1N NaOH. The sample was heated for 15 min in a boiling water bath to gelatinize the starch, cooled, and made up to volume with water. A 2.5 ml portion of the starch solution was transferred to a 50 ml volumetric flask, to which was added 0.5 ml 1N acetic acid and 1 ml iodine solution, and

the volume was made up to 50 ml with distilled water. The solution was shaken for 5 min, and the absorbance at 620 nm wavelength was determined using the UV/VIS spectrometer (JP Selecta, Barcelona, Spain).

Micromertics properties

The bulk density, tapped density, Carr's index, and Hausner's ratio of the NS, PGSb, and PGSs were determined as detailed in an earlier study.[17]

Rheological and related properties

Hydration capacity

For determination of hydration capacity, 1 g of starch powder was poured into centrifuge tubes and 10 ml of distilled water was added and then centrifuged (Micro Centrifugette 4214, Italy) for 10 min at 1000 rpm. The supernatant obtained was decanted and the sediment weighed.[18]

Viscosity and water binding capacity

The viscosity of the starch powders was determined using a digital viscometer (DV-E, China). The procedure reported by Nattapulwat *et al*.[19] was employed; the viscosity of the starch samples was determined using a viscometer with an acceptable range of 20%–90%. A 2% w/v starch suspension was prepared, and the viscosity was determined at a 100 rpm.

The water-binding capacity of the starch powders was assessed using the method described by Sandhu and Singh.[20]

Fourier-transform infrared spectroscopy

The NS, PGSb, and PGSs (5 mg) were individually analyzed using Fourier-transform infrared (FTIR) Spectroscopy (Bruker, South Africa) under dry air at room temperature. The starch samples were individually blended with 50 mg of solid KBr and compressed into discs. The spectra were scanned from 500 to 4000 cm^{-1}.[21] Compatibility of PGSb and PGSs powder with PCM powder was evaluated using FTIR technique. The physical mixtures (1:1) of the pregelatinized starches and PCM powder were used.

Morphological properties

The granule morphology of NS, PGSb, and PGSs was observed in a scanning electron microscope (Pro X, The Netherlands). The starch powders were mixed with ethanol to obtain a 1% suspension. The micrograph was obtained using a method described in a previous study.[21]

Differential scanning calorimeter

The thermal properties of the NS, PGSb, and PGSs were analyzed using Differential Scanning Calorimeter (Mettler Toledo, UK) as described by Sindhu and Khatkar.[22] Approximately, 6 mg of each of the starch samples 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 120°C with an empty-sealed pan as a reference. Onset (To), peak (Tp), and conclusion (Tc) temperatures were determined. Compatibility of PGSb and PGSs powder with PCM powder was evaluated using differential scanning calorimetry (DSC) technique. The physical mixtures (1:1) of the pregelatinized starches and PCM powder were used.

Microbiological quality

The determination of microbial load in the starch samples was carried as described in USP 41 NF 36 monograph.[23] Colonies were counted using the Anderman colony counter. All plates intended for bacterial load and total plate count were incubated at 37°C ± 2°C for 72 h. Tryptone soy agar was used for the detection of total aerobic microbial counts (TAMCs), Salmonella Shigella agar (SSA) for *Salmonella typhi* and *Shigella dysenteriae*, Eosin methylene blue agar (EMBA) for *Escherichia coli*, and Cetrimide Agar (CET) for *Pseudomonas aeruginosa.*

For the detection of total yeast and mold counts in the sample, Sabouraud dextrose agar (SDA) medium was used. The plates were incubated at 27°C ± 2°C and observed daily for 7 days.

Binding potential of the Borassus aethiopum starches

The binding potential of the PGSb starch was evaluated and compared with polyvinylpyrrolidone (PVP) and NS. Five batches of granules/tablets [Table 1] containing PCM 500 mg as active ingredient were prepared using wet granulation method. Formulation F1, F2, and F3 contained 0.89%, 1.78%, and 3.56% w/w, respectively, of PGSb as binding agent while F4 (standard PCM formula of a pharmaceutical company) and F5 contained 1.78% w/w of PVP and NS, respectively, as binders. The granules were compressed into tablets using a compression machine (BB/D/B/ADEPT, Mumbai, India). All batches were compressed at the same compression settings.

Evaluation of the paracetamol tablets

The diameter and thickness of the tablets were determined using a Vernier caliper, five determinations were made, and the mean value was obtained.

For determination of uniformity of weight, 30 tablets were selected randomly from each batch and weighed individually. The mean and the standard deviation in each tablet were determined.

Tensile strength of tablets was calculated using Equation 3.

$$T = \frac{2Fc}{\pi dt} \quad \text{Equation (3)}$$

Where: Fc = Crushing strength/Hardness, d = Diameter, t = Thickness of tablet.

Friability test was carried out by dusting and weighing 12 tablets randomly selected before testing, the tablets were

Table 1: Composition (% w/w) of different batches of paracetamol tablets

Ingredients	F1 (%)	F2 (%)	F3 (%)	F4 (%)	F5 (%)	Function
Paracetamol	89.29	89.29	89.29	89.29	89.29	Active ingredient
PGSs	4.50	3.63	1.85	3.63	3.63	Bulking agent
SSG	1.28	1.28	1.28	1.28	1.28	Intragranular disintegrant
PVP	0.00	0.00	0.00	1.78	0.00	Binder
PGSb	0.89	1.78	3.56	0.00	0.00	Binder
NS	0.00	0.00	0.00	0.00	1.78	Binder
SSG	3.58	3.58	3.58	3.58	3.58	Extragranular disintegrant
Magnesium stearate	0.53	0.53	0.53	0.53	0.53	Lubricant

PGSb: Pregelatinized starch obtained from *Borassus aethiopum*, PVP: Polyvinylpyrrolidone, SSG: Sodium starch glycolate, NS: *Borassus aethiopum* native starch, PGSs: Standard Pregelatinized starch

placed in the Friabilator drum, and the drum was rotated 100 times. The tablets were then removed and weighed accurately. The friability of the tablets was determined using Equation 4.

$$\text{Friability}(\%) = \frac{W_i - W_f}{W_i} \times 100 \qquad \text{Equation (4)}$$

Where W_i is the initial weight of the tablets and W_f is the final weight of the tablets.

The British Pharmacopoeia[24] method was adopted for the determination of disintegration time. A dosage unit was placed in each of the 6 tubes. The apparatus was operated using the specified medium, maintained at 37.0°C ± 2.0°C, as the immersion fluid. At the end of the specified time (when all of the dosage units have disintegrated completely), the basket was lifted from the fluid and the dosage units were observed. The time taken for each batch to disintegrate was recorded.

Dissolution test was carried out using USP apparatus (USP dissolution apparatus/EDT-08 Lx/Electrolab, Navi Mumbai 400 710, India). Nine hundred millilitres of Phosphate buffer pH 5.8 thermostatically maintained at 37.0°C ± 0.5°C was employed as dissolution media. The basket which was adjusted 25 mm away from the base of the glass jar was set to rotate at 50 rpm. One tablet was placed into each glass jar. Samples of the dissolution medium (5 ml) were withdrawn at 5, 10, 15, 30, 45, and 60 min, and spectrophotometrically (Biomate 6 UV-Vis Spectrophotometer, Thermo scientific, England) analyzed for PCM at 257 nm.[24] Aliquots withdrawn for analysis were replaced with 5 ml of fresh medium at 37°C.

Statistical analysis

Experiments were carried out in triplicates; mean comparison of the test samples with the standard was evaluated using one-way analysis of variance. Significant differences ($P < 0.05$) were determined by Tukey test. OriginPro 2016 software (OriginLab Corporation Northampton, MA 01060 USA) was used for statistical evaluation and for plotting of the graphs.

Results and Discussion

Characterization of pregelatinized starches

Results of pharmacopoeial and physicochemical properties of the starch samples are presented in Table 2. The solubility (%) of the two pregelatinized starches (PGSb and PGSs) increased considerably as opposed to the NS. These findings are in concordance with the results of Ashogbon and Akintayo,[5] who reported that the principal properties of pregelatinized starches are an increase in swelling capacity, solubility, and cold water dispersion. However, the percentage solubility of the PGSb varied from that of PGSs which might be attributed to modification conditions and the source of starch materials. A dark blue coloration was observed on the addition of two drops of iodine to the starch samples, thus confirming the presence of starch.

The pH of PGSs (6.82) was within the British Pharmacopoeia specification which states that the pH of pregelatinized starch should be ranged from 4.50 to 7.50.[24] Although the pH of the NS was not in this range, on pregelatinization, the pH of the PGSb was within the British Pharmacopoeia (2017) specifications. This indicates that pH of the starch increases when fully pregelatinized.

The ash values of NS, PGSb, and PGSs are shown in Table 2. Ash value (total ash) according to Kar[25] designates the presence of organic salts as well as inorganic matter derived from external sources. The ash value of the PGSb was lower than that of the NS which implies that pregelatinization reduced the amount of inorganic matter in starch hence improving its purity. However, the ash value of the commercial brand, i.e. PGSs was significantly lower than that of PGSb.

The moisture content as presented in Table 2 showed that only PGSb exceeded the upper limit of 15% as specified by the British Pharmacopoeia[24] while the moisture content for both NS and PGSs were within the acceptable limit.

The concentration of amylose was highest in NS and lowest in the PGSs [Table 2]. According to Singh *et al*.,[26] when starch molecules are heated in water, the semicrystalline structure is broken, and water molecules

associate by hydrogen bonding to hydroxyl groups exposed on the amylose and amylopectin molecules. This association causes swelling and increases granule size and solubility. This explains the reduction in amylose content of the NS on pregelatinization. Amylose content affects the physicochemical properties of not only the NSs but also the modified starch which in turn has an impact on its potential as a pharmaceutical excipient.

Micromeritics properties of the starch samples

The values of bulk and tapped density of PGSb were less than those of the PGSs and NS, respectively. This might be attributed to the change in granular structure of the starch which could affect the starch powder property, different particle sizes, and shapes which affected the packing arrangement of the powder particles.[27]

Powders with Carr's index values of 16–20 and 21–25 have been classified to have fair and passable flow character, respectively, while those with Hausner's ratio values of 1.19–1.25 and 1.26–1.34 have fair and passable flow character.[24] Carr's index values [Table 2] for both PGSb and NS had a passable flow while the PGSs had a fair flow. Hence, the physical modification had only a slight impact on the flow of the powder. Therefore, granulation of the starch powder will be needed to impart good flow property. The Hausner's ratio results obtained for PGSb, NS, and PGSs were found to be between 1.25 and 1.5, indicating a passable flow character; hence, addition of a glidant will be needed to improve their flow property. These findings are fairly consistent with those Carr's index.

Table 2: Pharmacopoeial, physicochemical, and microbial properties of the sample starch powders

Parameter	NS	PGSb	PGSs
Solubility (%)	7.00±2.50	20.35±5.75	27.00±1.30
pH	3.49±0.02	5.98±0.02	6.82±0.01
Ash value (%)	1.55±0.35	1.18±0.63	0.79±0.03
Moisture content (%)	13.71±0.05	15.63±0.73	11.65±0.07
Amylose concentration (µg/ml)	20.69±0.09	18.05±0.11	12.68±0.01
Bulk density (g/ml)	0.74±0.05	0.49±0.07	0.66±0.02
Tapped density (g/ml)	0.97±0.08	0.64±0.08	0.82±0.02
Carr's index (%)	23.33±1.97	23.07±1.94	19.80±2.90
Hausner's ratio	1.33±0.19	1.30±0.03	1.33±0.00
Hydration capacity	1.73±0.07	2.78±0.37	5.35±0.65
Viscosity (mPa.s)	41.00±3.10	47.50±3.60	57.45±0.75
SSA	0	0	-
TSA	0	2×10^2	-
EMBA	0	0	-
CET	0	0	-
SDA	1×10^2	2×10^2	-

NS: *Borassus aethiopum* shoot starch, PGSb: *Borassus aethiopum* pregelatinized starch, PGSs: Standard pregelatinized starch. SDA: Sabouraud dextrose agar, EMBA: Eosine methylene blue agar, TSA: Tryptone soy agar, CET: Centrimide agar, SSA: Salmonella Shigella agar, PCM: Paracetamol, PGS: Test pregelatinized starch, PGSs: Standard pregelatinized starch

The hydration capacities of PGSb and PGSs were 1.5 and 3 times, respectively, higher than that of NS. The increased hydration capacity of PGSb and PGSs could be due to the gelatinization caused by heating.[28] Pregelatinization reduces the size of the starch granules and reduced molecular weight of starch granules. This will lead to the formation of small molecules which have more affinity for water molecules when compared to starch polymers[12] and produce softer gels, have improved flowability, higher packing densities, swelling ability, and hydration capacity than natural starches. However, hydration capacity of PGSb was significantly lower than that of PGSs. This can be attributed to the differences in pregelatinization conditions and the source of the starch.

The viscosity of the PGSb was lower than that of PGSs but higher than the NS. This implies that pregelatinization increased the viscosity of the starch. The increase in viscosity caused by pregelatinization is in line with Odeku *et al.*'s[12] findings.

Fourier-transform infrared spectroscopy

Although there were some minor differences in some signals and band intensities, the FTIR spectra of *B. aethiopum* shoot native and pregelatinized starch samples showed general characteristic spectrum of starch [Figure 1]. For example, the spectral pattern in the region of 970 and 1200 cm^{-1} is typical of starch molecule;[29] the peaks around 1078 and 1160 cm^{-1} observed in all the samples can be attributed to the vibration peak of C-O groups and CH_2 symmetrical stretching vibrations, respectively, and also associated the peaks with the ordered structures of starch.[30] The absorption bands at 2928, 2931, and 2926 cm^{-1} for NS, PGSb, and PGSs, respectively, can be attributed to the C–H stretching. The peak around 3286–3318 cm^{-1}

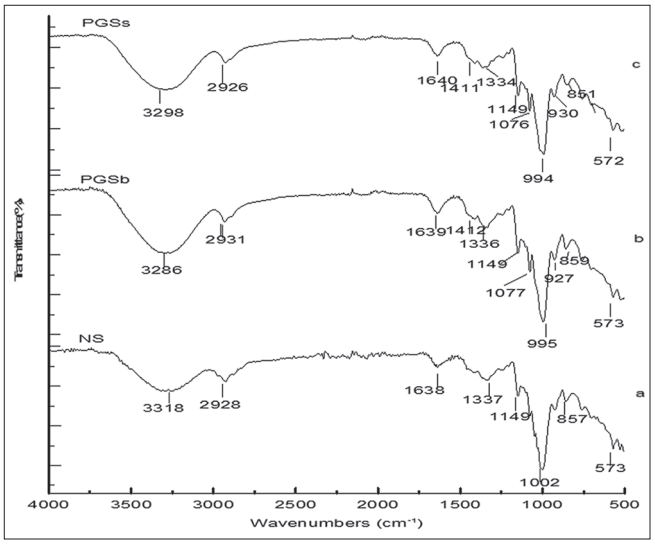

Figure 1: Stacked Fourier-transform infrared spectroscopy spectra of the starch samples; (a) *Borassus aethiopum* shoot native starch, (b) *Borassus aethiopum* shoot pregelatinized starch, and (c) standard pregelatinized starch

in the spectra of the three samples can be attributed to hydrogen-bonded hydroxyls on the starch molecules. However, the peaks at that region (3286–3318 cm^{-1}) for PGSb and PGSs are sharper and more prominent than that of NS. Weak absorption at 1639 cm^{-1} for PGSb and 1640 cm^{-1} for PGSs are probably features of the tightly bound water molecules present in pregelatinized starch molecules.[31] FTIR was also used to check compatibility of PCM with the PGSb and PGSs. The two mixtures of PCM and pregelatinized starches gave similar spectra with the spectrum of PCM alone [Figure 2]. Both PGSb and PGSs were compatible with PCM as they caused an insignificant shift in wavenumbers of some functional groups which was however still in the range. PCM is an aromatic compound containing OH and HN-CO-R functional group, and all these groups were identifiable in the FTIR spectra.

Scanning electron micrograph

The scanning electron micrographs [Figure 3] of PGSs showed no evidence of the presence of starch granules as opposed to those of the NS as well as the PGSb. This phenomenon was attributed to the process of gelatinization that causes substantial changes in both the chemical and physical nature of granular starch due to the rearrangement of intra- and inter-molecular hydrogen bonding between water and starch molecules leading to collapse, deformation, and loss of granule structure.[12] This phenomenon was not however evident in PGSb probably as a result of variation in modification conditions.

Differential scanning calorimeter analyses

The DSC thermograms for the NS, PGSb, and PGSs are shown in Figure 4. There was a shift in the onset temperature of the first endothermic peak of the NS on pregelatinization. PGSs however had the onset of its first endothermic peak higher than that of NS but lower than PGSb. There was also an increase in the midpoint peak and endset peak of the NS on pregelatinization. The PGSs had higher midpoints and endset temperatures than PGSb and NS. The value of onset temperature represents the internal structure of the granule during its disintegrations, which results in the release of polysaccharide into the immediate medium.[32] During pregelatinization of starch due to the presence of water and heat, the intermolecular bonds break down. The penetration of water decreases the number and size of crystal regions, which diffuse, and the chains begin to separate into amorphous form.

The thermograms [Figure 5] of PCM, pregelatinized starches, and their mixtures with PCM allowed the determination of the onset temperature (To), peak temperature (Tp), conclusion temperature (Tc), and the enthalpy of gelatinization. Gelatinization temperature and enthalpy of starches are known to depend on microstructures, presence of crystalline regions of different degrees of organization in the granule, granule size, and amylose-to-amylopectin ratio.[33] Compared with other samples, PCM showed the highest gelatinization temperature (To, Tp, and Tc) which indicated that it had a higher level of crystallinity, while the blend of PCM + PGSb had the lowest gelatinization temperature which could be due to the degree of crystallinity of the pregelatinized starch. The thermogram of the blend of PCM + PGSb suggests that there was a well-defined interaction between PCM and PGSb which was observed by the shift of the endothermic melting peak. Thus, it can be said that PGSb increased the thermal degradation of PCM. This observation does not however agree with the findings from FTIR analysis which showed no noticeable interactions between PCM and PGSb. The differences between the findings from FTIR and DSC analyses may be attributed to the different temperatures employed in the two different methods.[34] It has been reported that although it is accepted that any changes in DSC thermogram may be as a result of interaction, such changes are not always due to incompatibilities between the samples.[34]

Microbial analysis

The results of the microbial evaluation of the starches are shown in Table 2. There was no growth on EMBA, CET, and

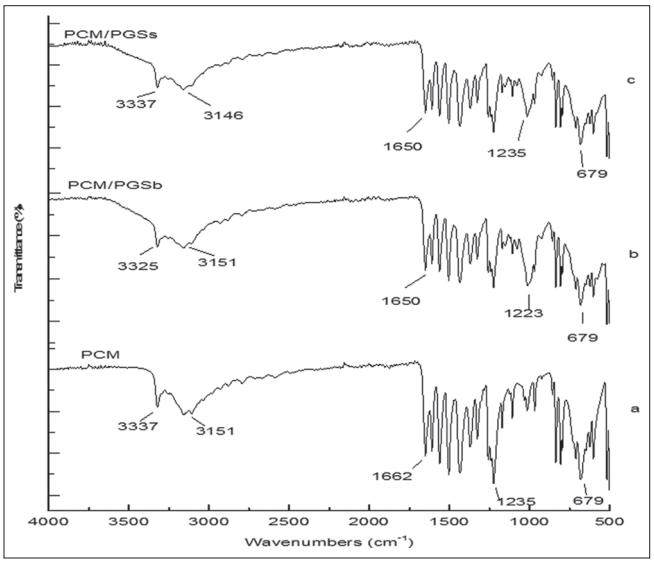

Figure 2: Stacked Fourier-transform infrared spectroscopy spectra of (a) paracetamol powder, (b) blend of paracetamol + *Borassus aethiopum* shoot pregelatinized starch, and (c) blend of paracetamol + standard pregelatinized starch

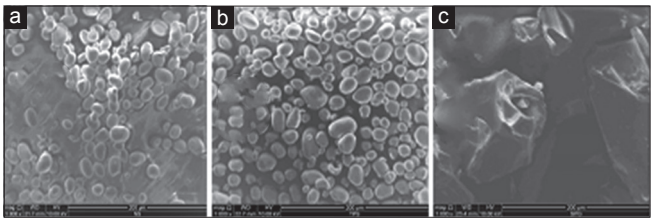

Figure 3: Scanning electron micrograph micrographs of (b) *Borassus aethiopum* shoot native starch, (b) *Borassus aethiopum* shoot pregelatinized starch, and (c) standard pregelatinized starch

SSA media for the two samples; however, the presence of *Aspergillus niger* on the SDA was observed for both samples. The absence of growth on the EMBA and CET media is indicative of the absence of *E. coli* and *P. aeruginosa*, respectively, while the absence of growth on SSA medium is indicative of the absence of *Salmonella spp* and *Shigella* spp. According to USP,[23] for microbial enumeration tests for modified starch, the TAMC should not exceed 10^3 cfu/g while total combined molds and yeasts count should not exceed 10^2 cfu/g, and for the tests for specified microorganisms, there should be absence of *Salmonella* species and *E. coli*. The two samples met the USP specifications. However, in tropical weather conditions, storage conditions for the drug product such as starch samples will determine the sustainability of microbial integrity of the product.[35] The presence of *A. niger* could be attributed to the high moisture content of the PGSb which made the sample more prone to microbial contamination. This is capable of causing spoilage on the starch and/or the final drug product in which they are used as excipient on storage.[36]

Evaluation of the formulated paracetamol tablets

The results of the properties of the PCM tablets formulated using different binder concentrations are presented in Table 3. Formulations F1, F2, F3, and F4 had thickness within the acceptable deviation (±5%)[37] while thickness of F5 containing NS as binder was not within acceptable range. This implies that the tablets formulated with PVP and PGSb as binders were identical in appearance. Similarly, from the results presented in Table 3, the weights of the tablets formulated with PGSb and PVP as binders had deviations <5% as stipulated by the British Pharmacopoeia[24] while those of NS were more than 5%.

The tensile strength of tablets formulated with PGSb as binder was between 0.39 and 0.62 while that of PVP was 0.70 and NS was 0.20; it appears that as the binder concentration PGSb was increased, the tensile strength also increased. The tablets formulated with PGSb 1.78% w/w binder have the tendency to reduce lamination similar to the tablet formulated with PVP at similar concentration.[38]

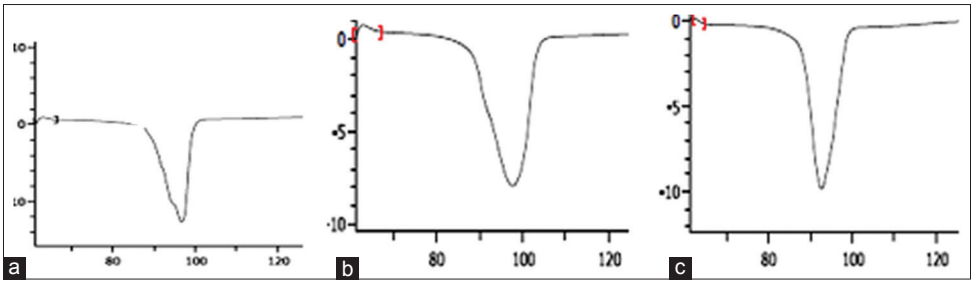

Figure 4: Differential scanning calorimetry thermograms of (a) *Borassus aethiopum* shoot native starch, (b) *Borassus aethiopum* shoot pregelatinized starch, and (c) standard pregelatinized starch

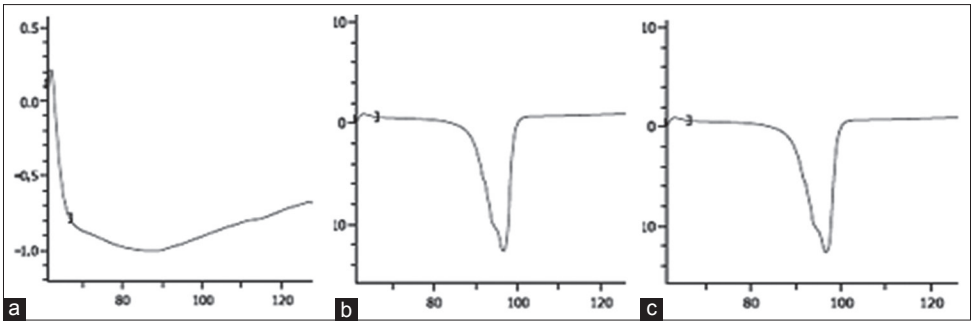

Figure 5: Differential scanning calorimetry thermograms of (a) = Paracetamol, (b) = blend of paracetamol + *Borassus aethiopum* shoot pregelatinized starch, and (c) = blend of paracetamol + standard pregelatinized starch

Table 3: Properties of paracetamol tablets formulated using different binder concentrations

Sample code	Thickness (mm)	Weight of tablet (g)	Hardness (kg)	Tensile strength (MPa)	Friability (%)	Disintegration time (min)
F1	4.23±0.03	0.56±0.04	3.27±0.52	0.39±0.04	0.88±0.08	0.37±0.22
F2	4.24±0.03	0.56±0.03	5.21±0.59	0.62±0.20	0.87±0.08	3.39±0.12
F3	4.12±0.03	0.56±0.03	2.65±0.19	0.31±0.08	0.79±0.13	4.90±0.62
F4	4.04±0.02	0.56±0.02	5.90±0.98	0.70±0.05	0.24±0.02	2.16±0.53
F5	4.44±0.15	0.56±0.25	2.90±0.67	0.20±0.04	1.12±0.04	6.16±0.63

Where F1:0.89%w/w of PGSb as binder, F2: 1.78%w/w of PGSb as binder, F3: 3.56%w/w of PGSb as binder, F4: 1.78%w/w of PVP (commercial formulation), F5: 1.78%w/w of NS as binder. PGSb: *Borassus aethiopum* pregelatinized starch, PVP: Polyvinylpyrrolidone, NS: Native starch

As shown in Table 3, tablets formulated with PGSb and PVP as binders have friability values <1.00 while the batch containing NS as a binder had friability of 1.12%. Lower friability values indicate the ability of tablets to withstand abrasion. It is however important to note that the relatively low value of friability of tablets formulated using PVP as binder could be attributed to the higher tensile strength of its compacts while high value of tablets formulated using NS could be attributed to the lower tensile strength.

Regarding the disintegration time, all the five batches of the tablets formulated disintegrated within 15 min as specified by the British Pharmacopoeia.[24] From the results obtained, it can be observed that as the binder concentration of PGSb was increased, the disintegration time increases. This could be attributed to reduced liquid penetration into the tablets due to an increase in tablet hardness at higher binder concentration.

Dissolution test is used for measuring the time required for a given percentage of the drug substance in a tablet to go into solution under a specified set of conditions in an *in vitro* test. The dissolution profiles of PCM tablets formulated with PGSb, PVP, and NS as binder are shown in Figure 6. It was observed that drug release from the tablets formulated decreases with an increase in binder concentration for PGSb. However, there were variations in the release profile of tablets formulated using the three different binders. Batch F1 was able to release the active pharmaceutical ingredient faster compared to the other batches. This could be attributed to the concentration of the binder employed in the formulation. However, all the batches released more than 70% of the active drug at 30 min.

Conclusion

The pharmacopoeial and physicochemical parameters of the PGSb were comparable to the PGSs and had desirable properties than the NS for potential applications as pharmaceutical excipient. The desirable parameters include improved cold water solubility, lower gelatinization temperature, better hydration capacity, and flow property. The desirable physicochemical parameters stated above could widen the functional properties of PGSb, especially in terms of its potential for pharmaceutical applications as excipient when compared to NS. However, the PGSs had better flow properties compared to PGSb.

The tablets formulated with PGSb as binder demonstrated comparable tablet properties compared to that of a commercial brand PCM tablet formulated with 1.78% w/w PVP as a binder and hence could be employed as binder in a tablet formulation.

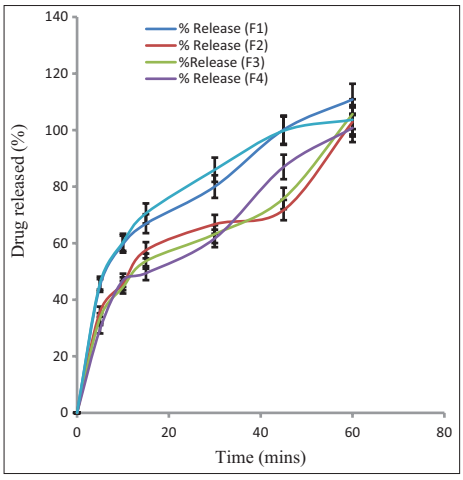

Figure 6: Dissolution profile of the formulated tablets using different of binders

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Nil.

Conflicts of interest

There are no conflicts of interest.

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