Physicotechnical, spectroscopic and thermogravimetric properties of powdered cellulose and microcrystalline cellulose derived from groundnut shells.

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Technical Note

ABSTRACT

α-Cellulose and microcrystalline cellulose powders, derived from agricultural waste products, that have for the pharmaceutical industry, desirable physical (flow) properties were investigated. α–Cellulose (GCN) was extracted from groundnut shell (an agricultural waste product) using a non-dissolving method based on inorganic reagents. Modification of this α -cellulose was carried out by partially hydrolysing it with 2N hydrochloric acid under reflux to obtain microcrystalline cellulose (MCGN). The physical, spectroscopic and thermal properties of the derived α-cellulose and microcrystalline cellulose powders were compared with Avicel® PH 101, a commercial brand of microcrystalline cellulose (MCCA), using standard methods. X-ray diffraction and infrared spectroscopy analysis showed that the α-cellulose had lower crystallinity. This suggested that treatment with 2N hydrochloric acid led to an increase in the crystallinity index. Thermogravimetric analysis showed quite similar thermal behavior for all cellulose samples, although the α-cellulose had a somewhat lower stability. A comparison of the physical properties between the microcrystalline celluloses and the α-cellulose suggests that microcrystalline cellulose (MCGN and MCCA) might have better flow properties. In almost all cases, MCGN and MCCA had similar characteristics. Since groundnut shells are agricultural waste products, its utilization as a source of microcrystalline cellulose might be a good low-cost alternative to the more expensive commercial brand.

INTRODUCTION

During the past decade, there has been a dramatic increase in cellulose research due to significant advances in cellulosic modifications (mechanical, chemical and even enzymatic), and subsequent products with unique chemical, physical and physiological properties. This renewed focus on cellulose and its derivatives is based on several factors, such as the increased awareness of the availability of cellulose sources, for example agricultural waste products, the development of new solvent

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systems for cellulose activation/ soulbilization and the development of regioselective modification methodolgies (1, 2).

Cellulose is used widely as a raw material for a number of excipients used in the pharmaceutical industry. Microcrystalline cellulose (MCC), a purified, partially depolymerised, non-fibrous form of cellulose, is perhaps the best filler-binder currently available. MCC is available from different manufacturers using different trade names, for example Avicel®, Emcocel®, Comprecel® and Microcel™. It is prepared by hydrolysing native α-cellulose, a fibrous, semi-crystalline material, with dilute mineral acids. During hydrolysis, the accessible amorphous regions are hydrolized and a lower degree of polymerization product is obtained. MCC works as an excellent filler/binder and exhibits a high dilution potential (3). Preparation of MCC from materials other than wood pulp and cotton linters such as reed stalks (4), wheat and rice straws (5, 6), jute (7), water hyacinth (8), sugar cane bagasse (9, 10, 11, 12) coconut shells (13), Indian bamboo (14), soybean husk (2), luffa fibers and flax straw (15), cylindrica (16), bagasse, rice straw, and cotton stalks (17), groundnut husk (18), and orange mesocarp (19) have been reported. It is generally understood that the differences in the properties of MCC between different manufacturers are due to the type of pulp used as raw material, and processing conditions. Since cellulose from different sources have different properties, for example crystallinity, moisture content, surface area and porous structure, molecular weight, and so on, it is expected that MCC obtained from different sources would also have different properties. These differences can affect their functionality when used as excipients.

Excipients are generally chosen based on their compatibility and functionality to ensure the stability and bioavailability of the finished drug, as well as, the potential for large scale manufacturing. Beyond general requirements, excipients must exhibit specific functionalities, particularly when formulating oral solid dosage forms. Consequently, their characterization must go beyond simple tests for identity, purity and strength as stated in various Pharmacopoeial monographs.

Physical characterization of solid materials is now possible using high resolution analytical techniques, at the molecular, particulate and bulk levels (20). This systematic approach is useful in predicting the behavior of the excipient during formulation and final production of the finished medicinal product. Infrared spectroscopy is of particular interest for the determination of the molecular structure and possible chemical interactions. Thermogravimetric analysis (TGA) and Differential scanning calorimetry (DSC) are often used to clarify stability, compatibility, and transitions of phase of the excipients. The structure of the powder or a single crystal can be examined with absolute certainty using X-ray diffraction. It provides information on the degree of crystallinity of the powder. The degree of crystallinity in the cellulose is important because it influences various properties, including compactibility and absorption of water, which in turn influences flowability and the stability of the final medicinal product (20). The chemical composition and physical structure of MCC depends significantly on the characteristics of the raw material used, and the processing conditions (21). As a result, several types of microcrystalline cellulose with different crystallinity, granulometry, morphology and water content are available. These have different functionalites and may therefore be suitable for different applications.

MATERIALS AND METHODS

Materials

Groundnut shell was kindly supplied by local farmers in Benin-City, Edo State, Nigeria. Avicel® PH 101 (a commercial brand of microcrystalline cellulose), Sodium hydroxide (reagent grade, ≥ 98 %), hydrochloric acid

(ACS reagent, 37%) and calcium hypochlorite (technical grade) were supplied by Sigma-Aldrich and used as provided. An aqueous solution of sodium hypochlorite was prepared by dissolution of calcium hypochlorite and sodium hydroxide in water, with subsequent filtration of the calcium hydroxide precipitate.

Methods

Isolation of cellulose from the groundnut shells

Powdered cellulose was obtained from groundnut shells using inorganic reagents, following the procedure reported by Landis *et. al.* (22). Groundnut shells were cut into small pieces, dried at 60°C for 24 hours, and then further broken down in a mill (Fitzmill, Manesty Machines, UK) to particles passing through a 4.75 mm sieve. Deliginification of the cellulose was carried out by first suspending 500 grams of the material in 5 liters of 3.5% nitric acid containing 50 mg of sodium nitrite for 2 hours in a stainless steel vessel immersed in a water bath set at 90°C. To complete the removal of lignin, as well as the removal of β- and γ-celluloses, the material was digested in 5 litres of a solution containing 2% each of sodium hydroxide and sodium sulphite held at 50°C for 1 hour. The resulting material was again thoroughly washed with distilled water, filtered and then suspended in 625 ml of 17.5% sodium hydroxide solution for 0.5 hours at 80°C. The residue obtained was also thoroughly washed with distilled water, filtered and dried in an oven at 60°C for 16 hours. This product (unbleached cellulose) was bleached with 625 ml of 3.2% sodium hypochlorite in a stainless steel vessel at 40°C for 1.5 hours. The bleached sample was thoroughly washed with distilled water, until it was neutral to litmus paper, filtered and then dried in an oven at 60°C for 16 hours and weighed. The product was milled in a Kenwood® blender, sifted through a 212 μ sieve, further dried at 60°C for 1 hour and stored in a tightly closed container, pending further analysis. This product was labeled GCN.

Production of microcrystalline cellulose

α-Cellulose (powdered cellulose) powder obtained from the groundnut shells was hydrolyzed with 2N hydrochloric acid under reflux for 15 minutes (9), the solid-liquor ratio was 1:10. The hydrolyzed cellulose was thoroughly washed with cold distilled water until neutral to a litmus paper and then air-dried. The microcrystalline cellulose obtained using this process was labeled MCGN.

Characterization

The spectroscopic (powder X-ray diffraction and infrared spectroscopy) and thermal (thermal analysis) characterization of the cellulose samples was carried out, together with a exhaustive physical characterization. OriginPro 8 SR2 v. 0891 (B891) software (OriginLab Corporation USA) was used for statistical evaluation. One-way analysis of variance was used to differentiate between samples and determine where significant differences were found .

Powder X-ray diffraction

X-ray diffraction patterns of the cellulose samples were obtained using an X-ray diffractometer (Philips X-ray Analytical). Samples for analysis were prepared by pressing the powder into the cavity of a sample holder and smoothing with a glass slide. They were scanned from 5-40° $2q$ with a Cu anode X-ray operated at 40 kV and 40 mA in combination with a Ni filter to give a monochromatic Cu-Kα radiation ($l = 1.5418$ Å). The crystallinity index (*CI*) was calculated using Equation 1, as proposed by Segal *et al.* (23):

$$CI = 100 \times \frac{1_{002} - 1_{am}}{1_{002}} \qquad \text{Eq. 1}$$

where;

1_{002} is the maximum intensity of the principal peak (002) lattice diffraction (at 22.7° of 2θ for cellulose I, and 21.7° of 2θ for cellulose II), and 1_{am} is the intensity of diffraction attributed to amorphous cellulose (at 18°of 2θ for cellulose I, and at 16° of 2θ for cellulose II). Integration of the crystalline reflection was carried out using OriginPro software.

Infrared spectroscopy

Fourier transform infrared (FT-IR) spectra were recorded using KBr discs on a Perkin-Elmer FT-IR spectrometer. KBr pellets containing 1 % of the samples were prepared. The scanned range was 4000-400 cm^{-1}, with a resolution of 4 cm^{-1} and 32 scans per sample. For the determination of crystallinity in the cellulosic materials, the ratio A_{1372}/A_{2900} was considered, where A_{1372} and A_{2900} are the areas of the peaks at 1372 cm^{-1} and 2900 cm^{-1} respectively (24). Integration of the peak areas was carried out using OriginPro software.

Thermal analysis

The thermal properties of the cellulose samples were investigated by thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC) on a simultaneous thermal analyzer (Mettler-Toledo AM). Samples weighing between 6 and 10 mg were used. Each sample was heated from room temperature to 600°C at a rate of 5°C/min under nitrogen.

Physical properties

Bulk and tapped density

25 grams of the cellulose powder was accurately weighed and poured into a 100 ml graduated cylinder. The cylinder was stoppered and the bulky density recorded. For tapped density, the cylinder was tapped from a height of 2.5 cm on a hard surface to a constant volume (i.e., until no more settling of the material occurred). The final (constant) volume was noted and the tapped density was calculated. The bulk density, D_{bulk}, and tapped density, D_{tap}, were determined using Equations 2 and 3.

$$D_{bulk} = w / v_0 \qquad \text{Eq. 2}$$

$$D_{tap} = w / v_1 \qquad \text{Eq. 3}$$

Where;

w is the weight of the powder, and v_0 and v_1 are the volumes of the bulk and tapped powders, respectively. The arithmetic mean of four replicate determinations was taken in each case.

True density

The true density of the cellulose samples was determined using a model MPY-2 helium displacement pycnometer (Quantachrome Corporation, Syosset, NY, USA). The true density, D_{true}, was calculated using Equation 4.

$$D_{true} = w / v_p \qquad \text{Eq. 4}$$

Where w and v_p are the weight of the sample and the true volume of the powder, respectively.

Carr's index and Hausner ratio

Carr's index (25) and Hausner ratio (26) for cellulose were calculated from the bulk and tapped densities using Equations 5 and 6, respectively.

$$Carr's\ Index = \frac{D_{tap} - D_{bulk}}{D_{tap}} \times 100 \qquad \text{Eq. 5}$$

$$Hausner\ Ratio = \frac{D_{tap}}{D_{bulk}} \qquad \text{Eq. 6}$$

Powder porosity

The porosity (P_b) of the tested powders was evaluated from the true and tapped densities, using Eqaution 7.

$$P_{b} = 1 - \frac{D_{tap}}{D_{true}} \qquad \text{Eq. 7}$$

Angle of repose

To obtain the angle of repose a long cylindrical tube, open at both ends, was used. The tube was perpendicularly placed on a clean cardboard paper and filled flat with the cellulose powder. The tube was then gradually lifted away, vertically, from the cardboard. The height h, and radius r, of the conical heap formed were measured, and then the angle of repose, θ, was calculated from Equation 8. Determinations were done in triplicate, and the average was taken.

$$\theta = \tan^{-1}(h/r) \qquad \text{Eq. 8}$$

Moisture content

The moisture content of the cellulose powders was calculated from the weight loss on heating from room temperature to 225°C using a a Perkin Elmer series 7 thermal analyzer. All tests were carried out in triplicate.

RESULTS AND DISCUSSION

Groundnut shell powdered cellulose (GCN) and Groundnut shell microcrystalline cellulose (MCGN) samples were prepared and their characteristics were compared with Avicel® PH 101(commercial grade) (MCCA).
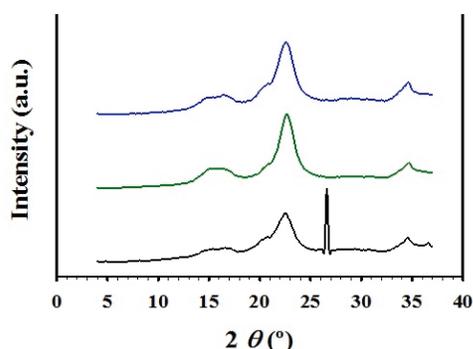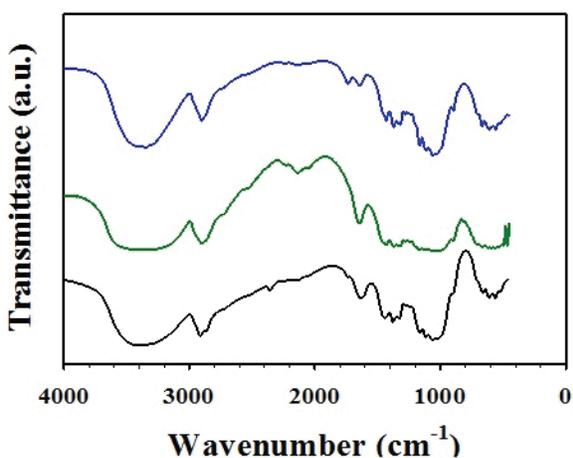

Black: GCN, Green: MCCA, Blue: MCGN

Figure 1 X-ray diffractograms of the cellulose samples

Structural characterization

The powder X-ray diffraction spectra of the three cellulose samples are shown in Figure 1. The diffractograms for all the samples exhibit diffraction patterns typical of cellulose I, with diffraction peaks of the $2q$ angles at 15.0, 16.6 and 22.4°, which can be assigned to the 101, 10Î, and 002 reflections, respectively (27). However, the peaks in the MCGN and MCCA are more pronounced than that of GCN. This was confirmed by the high crystallinity indices (*CI*) of MCGN and MCCA samples. The *CI* gives a quantitative measure of the crystallinity in powders which can be related to the strength and stiffness of fibers (28). Here, the partial hydrolysis of the GCN with hydrochloric acid led to an increase in *CI* (67 % for GCN, 78 % for MCCA, and 74 % for MCGN). High crystallinity indicates an ordered compact molecular structure, which translates to dense particles, whereas lower crystallinity implies a more disordered structure, resulting in a more amorphous powder. These *CI* values are therefore consistent with the relatively high true density of the microcrystalline celluloses described under physical properties. In addition to the normal diffraction pattern typical of cellulose I exhibited by GCN sample, a sharp peak around 26.2° is shown. This could be as a
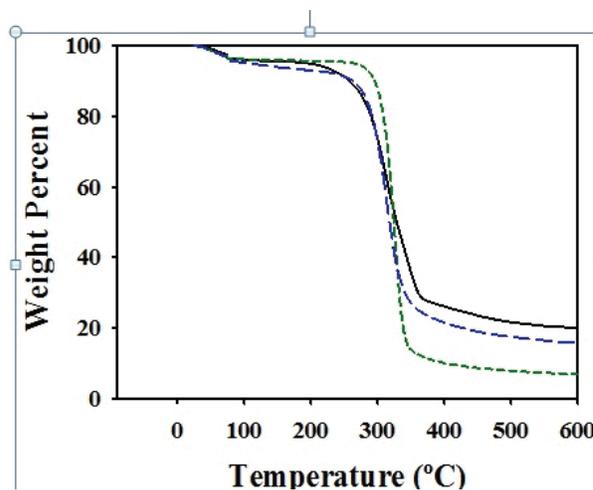
Black: GCN, Green: MCCA, Blue: MCGN

Figure 2 FTIR spectra of the cellulose samples

result of contamination of the sample by residual solvent during ethe xtraction of cellulose from the groundnut shells.

Despite minor differences between them, the FT-IR spectra of the celluloses show the general characteristic spectrum of cellulose (Figure 2). For example, absorption bands are clearly observed at ca. 900 cm^{-1} (corresponding to b-glycosidic linkages), 1060 cm^{-1} (ring vibration and C–OH bending), 1650 cm^{-1} (–O– tensile vibration neighboring hydrogen atoms), 2900 cm^{-1} (C–H asymmetric and symmetric tensile vibration) and the broad peak at 3300-3500 cm^{-1} (OH stretching, hydrogen bonds). A more detailed description of the FT-IR spectrum of cellulose can be found in the literature (29).

The *CI* values obtained from FITR, indicates that the partial hydrolysis of GCN led to the increase in the value (GCN 63%, MCGN 70%, and MCCA 73%). Thus, this observation agrees fairly well with the results from the X-ray diffraction measurements previously mentioned.
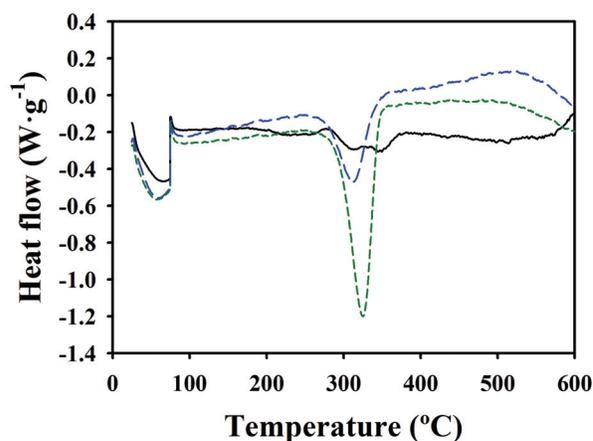

Black: GCN, Green: MCCA, Blue: MCGN

Figure 3 TGA thermograms of the cellulose samples

Thermal properties

The thermograms in Figures 3 and 4 show that all three cellulose samples follow similar degradation patterns. The numerical data from the TGA experiments (Table 1) reveal that powdered cellulose is slightly less stable than the MCCA and MCGN. A more notable difference, in particular between the GCN sample and the microcrystalline celluloses, is

Black: GCN, Green: MCCA, Blue: MCGN

Figure 4 DSC thermograms of the cellulose samples

observed at the temperature at which 5% of the mass of the sample is decomposed, $T_{on5\%}$. This temperature is lower for the GCN sample, compared to the microcrystalline celluloses, whereas lesser differences appear between the microcrystalline samples (shown in Table 1).

Table 1 Thermal properties obtained from TGA experiments for celluloses studied

PARAMETER	CELLULOSE POWDER SAMPLES		
	GCN	MCGN	MCCA
$T_{5\%,onset}$ (°C)[a]	212	260	280
$T_{50\%}$ (°C)[b]	305	320	325
$W_{550\,°C}$ (%)[c]	20	16	8

[a] Onset temperature for 5 % decomposition, [b] Temperature at 50 % weight loss, [c] Residual char weight at 550 °C

This result might be attributed to the higher crystallinity and lower moisture contents of the microcrystalline samples. Additionally, higher onset temperatures are associated with higher thermal stability (30). Similarly, the $T_{50\%}$ data confirmed that the partially hydrolyzed celluloses (MCCA and MCGN) are more thermally stable compared to the GCN sample. Moreover, the char yield (non-volatile carbonaceous material generated on pyrolysis, which is indicated by the residual weight after the decomposition step), specified in Table 1 for the temperature 550ºC, is lower for the microcrystalline cellulose samples compared to the unhydrolyzed sample.

From the DSC experiments (Figure 4), a higher glass transition temperature was again obtained for the microcrystalline samples, whereas the values for the other GCN sample were lower. Nevertheless, these glass transition temperatures were within a range at which substantial decomposition of the samples had already occurred. Therefore the actual numerical values could not be regarded as sufficiently reliable and are not reported here.

Physical properties

The physical properties of the α-cellulose isolated directly from the groundnut shells

(GCN) and those of the microcrystalline celluloses (MCCA and MCGN) are shown in Table 2.

Table 2 Physical properties of the cellulose samples, with standard deviations (corresponding to the last significant figure) in parentheses

PROPERTY	CELLULOSE POWDER SAMPLES		
	GCN	MCGN	MCCA
Bulk density (g cm^{-3})	0.31 (3)	0.25 (6)	0.35 (5)
Tap density (g cm^{-3})	0.37 (3)	0.32 (4)	0.42 (2)
True density (g cm^{-3})	1.48 (8)	1.58 (3)	1.60 (3)
Carr's index	24.35	21.80	16.67
Hausner ratio	1.32	1.28	1.20
Powder porosity	0.75	0.80	0.74
Angle of repose (°)	47.2 (8)	42.3 (7)	41.2 (5)
Moisture content (%)	6.0 (3)	5.7 (2)	5.3 (5)

The bulk and tap densities of the α-cellulose (GCN) and Avicel® (MCCA) are significantly higher than that of the groundnut shell microcrystalline cellulose (MCGN). Bulk density provides an estimate of the ability of a material to flow from a hopper into the die cavity of a rotary compression tablet machine. Tap density is a measure of how well a powder can be packed into a confined space on repeated tapping. In general, the higher the bulk and tapped densities, the better the potential for a material to flow and to re-arrange under compression. This suggests that GCN and MCCA powders might have better flow properties than the groundnut shell microcrystalline cellulose (MCGN), although their higher bulk densities would imply a requirement of larger amounts when compressing tablets. The MCGN, with its lower bulk density, will exhibit a higher dilution potential based on weight (31).

The true densities of the microcrystalline celluloses were significantly different from that of the extracted α-cellulose. The higher values of the true density for the microcrystalline celluloses, compared to the α-cellulose (GCN), suggest that the microcrystalline celluloses would exhibit better compressibility. The higher

true densities of the microcrystalline celluloses and the relatively low true density of the extracted α-cellulose are consistent with the *CI* values discussed earlier.

Carr's compressibility and Hausner indices were estimated as the ratios of the difference between tapped and bulk densities. Carr's compressibility index provides an estimate of how much a powder can be compressed while the Hausner index measures/estimates cohesion between particles. The values for both are inversely proportional to particle flow (25, 32). Table 2 shows an increase of both magnitudes for the microcrystalline celluloses, compared to the cellulose directly obtained from the groundnut shell. For Carr's index, values in the ranges of 5-10, 12-16, 18-21, and 23-28 indicate excellent, good, fair, and poor flow properties of the material, respectively (25). Thus, while the α-cellulose has a Carr's index of 24.35 (poor flowability), the indices for the microcrystalline celluloses are approximately in the range 15-20 (fair-good flowability).

On the other hand, for the Hausner ratio, a value of less than 1.20 indicates good flowability, whereas a value of 1.50 or higher suggests that the material will have poor flow properties. In this study the Hausner ratio for the α-cellulose is 1.32 (poor flowability), whereas those ratios for the microcrystalline celluloses lie around the threshold of 1.20 (≈ good flowability). Therefore, the values obtained for the Hausner ratio are consistent with those of the Carr's index. However, in both cases, the MCCA showed superior flow properties compared to MCGN.

The angles of repose determined, and reported, in Table 2, are fairly consistent with the above results. The angle of repose of a powder provides a qualitative assessment of its internal and cohesive frictions. Angles of up to 40° indicate reasonable flow potential of the solid powders, whereas those samples with angles greater than 50° exhibit poor or absent flow (33). In this study, very significant differences were observed between the angles of repose of the original and microcrystalline celluloses, whereas there was no significant difference between the microcrystalline celluloses. While the angle of repose of the unhydrolysed cellulose (GCN) lies around the threshold of 50° (poor or absent flow) those of the microcrystalline celluloses lie around 40° (reasonable flow). An aspect to take into account here is that the measurement of the angle of repose is sensitive to moisture content (34). The moisture contents measured for all celluloses in this study (last row in Table 2) fall within acceptable limits of between 5 and 7%, (35, 36). Furthermore, powder flowability is known to decrease with increasing moisture content (31). Overall, the better flow properties of the microcrystalline celluloses are likely to be the result of variations in particle shape, size, and surface area of the powders (37, 21) directly related to the process of partial hydrolysis of the original cellulose. The total porosity of a powder is made up of voids between the particles, as well as, pores within the particles. The results (Table 2, line 6) obtained for all the celluloses are similar indicating poly-sized particles and easily compressible powder during tableting. This also correlates with the high tapped densities obtained in this work.

CONCLUSION

The α-cellulose and microcrystalline cellulose examined here showed to possess properties that could make its source, groundnut shells, a potentially low-cost source of α-cellulose and microcrystalline cellulose. The microcrystalline cellulose (MCGN) obtained from the groundnut shells compared favorably with Avicel® PH 101 (a commercial brand of microcrystalline cellulose), in terms of their physical, spectroscopic and thermal properties. The advantage of MCGN is its potentially lower cost because farmers generate a lot of groundnut shells as waste material. The results also confirmed that partial hydrolysis of the α-

cellulose extracted from the groundnut shells resulted, as expected, in a microcrystalline cellulose with improved physical, spectroscopic and thermal properties.

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