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Research Article

Comparative studies on the pharmacopoeial and flow properties of powdered celluloses extracted from maize cob using different chemical procedures

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ABSTRACT

In this work a comparative study on different methods of extraction of α -cellulose from agricultural residue- maize (*Zea mays*) cob was carried out. α -Celluloses were extracted from the agricultural residue using various chemical procedures based on:- nitric acid/ sodium hydroxide, sodium hydroxide, organosolvent and ionic liquid (IL) [1-butyl-3-methylimidazolium chloride ([C₄mim]Cl)]. The chemical composition and flow properties of the extracted α -celluloses were estimated using the known standard methods. The α -celluloses extracted from the agricultural residue using nitric acid/ sodium hydroxide and sodium hydroxide methods, respectively, were relatively free from other lignocellulosic contents (lignin content < 0.70% and hemicelluloses < 1.30%) compared to the organosolvent method (lignin content 1.54-4.03 % and hemicelluloses 4.50-10.05%), and IL method (lignin content 3.45% and hemicelluloses 12.50%). Apart from the α -cellulose obtained with IL, others showed poor flow properties. The results show that the IL method is a promising process for the extraction of cellulose with improved flow characteristics from maize cobs, however, the cellulose method obtained with this method failed pharmacopoeial requirement in terms of purity. Since the ionic liquids can be almost 100% recycled, this might be a low cost, fast, simple and environmentally friendly chemical procedure that can increase significantly the competitiveness of α -cellulose extraction if the purity of the obtained cellulose can be improved upon.

Keywords: Agricultural residue; Cellulose extraction; Ionic liquid; Physicochemical properties

INTRODUCTION

Agricultural residues represent abundant, inexpensive, and readily available source of renewable lignocellulosic biomass. The clean separation of the major components of lignocellulosic biomass (cellulose, hemicellulose and lignin), using a viable and environmentally-friendly method is highly desired. Such a technology would allow the development of processes using the pure biopolymers as feedstock. However, the method to be employed will depend largely on the desired physicochemical properties of the desired lignocellulosic component. One of the major difficulties when dealing with these raw materials is related to the need of pre-treatments to dissociate the biomass structure. These components are assembled in a complex three-dimensional structure remarkably resistant against

chemicals and microbial attacks that makes them very difficult to hydrolyze, which is key for its future utilization (Himmel *et al.*, 2007). An effective dissociation of these components and their separation can lead to the production of several high value products with desired physicochemical properties. A facilitated and more efficient access to natural biopolymers, and subsequent materials technology platform based on renewable sources, is a major step towards sustainability and is now generally recognized as a worldwide goal (Sun *et al.*, 2011).

To separate cellulose from lignocellulosic biomass, the most prevalent process is still chemical pulping, which accounts for more than 70% of worldwide production of pulp (Sun *et al.*, 2011). Chemical pulping includes the Kraft, sulphite, soda, and organosolv processes, among which Kraft pulping accounts for 80% of chemical pulping (Sun *et al.*, 2011). In Kraft pulping, an aqueous solution of caustic sodium hydroxide and sodium sulphide with pH > 12 is used to extract lignin from the wood in large chemical digesters. Even after pulping, bleaching is required to remove the residual lignin. Moreover, the odour from sulphur compounds, high water use, and the large plant size are additional problems associ-

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ated with this process. The search for better pulping processes led to the development of several organosolvent methods, capable of producing pulp with properties near those of Kraft pulp (Young, 1998). The problems for organosolvent methods are the high operation cost and the recovery of expensive solvent at the high temperatures and pressures required in the processes (Young, 1998).

Recently, much attention has been focused on the use of ionic liquids (ILs) as environmentally benign reaction media. In particular, ionic liquids are capable of dissolving complex macromolecules and polymeric materials with high efficiency (Liu *et al.*, 2005, Phillips *et al.*, 2004, Swatloski *et al.*, 2002, Xie *et al.*, 2005). ILs offer a new and attractive route for the dissolution of lignocellulosic biomass. Although a number of ILs have been shown to directly dissolve lignocellulosic material, with partial separation of the constitutive major biopolymers, still a clean separation of cellulose cannot be attained (Sun *et al.*, 2009, 2010). Since the ILs can be almost 100% recycled, this would be a low cost, fast, simple and environmentally friendly pre-treatment method if cellulose with desired physicochemical properties can be obtained. Moreover, the integrity of other lignocellulosic components is maintained with IL pretreatment of the biomass.

Among the major components of lignocellulosic biomass, cellulose and its derivatives are largely used as a raw material in numerous industrial applications, e.g., in the paper, paint, textile, food, and pharmaceutical industries (Focher *et al.*, 2001, Richardson and Gorton, 2003). In pharmaceutical industry, among other uses, powdered cellulose is used as excipient in solid dosage forms. Cellulose acts as a bulking agent to increase the physical size of the dosage form for the formulations containing a small amount of active substance. Powdered cellulose has good compression properties although its flow properties are poor. The quality of medicines depends not only on the active principles and production processes, but also the performance of the excipients. Excipients are now chosen to perform a variety of functions to guarantee the stability and bioavailability of the drug substance from the drug product and its manufacturability on a production scale. Beyond the dosage form necessities, excipients are required to perform important and specific technological functions particularly in the case of solid dosage forms (Pifferi *et al.*, 1999).

It has been found out that there are differences in the physical properties of celluloses extracted from different sources; in addition, the method and processing conditions during manufacturing play a great role in the physical properties of cellulose (Azubuiké *et al.*, 2012). The major challenge in the isolation of cellulose for pharmaceutical use is to obtain cellulose with desired physicochemical properties. In addition, the isolation process must be eco-efficient, sustainable, and

environmentally-friendly and other components of the lignocellulosic biomass can also be separated.

In this study, attempt has been made to isolate cellulose from an agricultural waste (maize cob) using different chemical procedures based on inorganic substances, organic solvents and IL methods. A detailed characterization of the different cellulose samples (chemical composition and physicochemical properties) were carried out. These properties were used to evaluate the cellulose potentials as pharmaceutical excipient.

MATERIALS AND METHODS

Materials

Maize cob, an agricultural waste, was kindly supplied by local farmers in Benin-City, Edo State, Nigeria. Sodium hydroxide (ACS reagent, pellets, $\geq 98.0\%$), calcium hypochlorite (technical grade), nitric acid (ACS reagent, $\geq 90.0\%$), sodium nitrite (ACS reagent, $\geq 97.0\%$), sodium sulphite (ACS reagent, $\geq 98.0\%$), acetic acid (technical grade), ethanol (technical grade), formic acid (technical grade), and hydrochloric acid (AR grade, 37.0%) were supplied by Sigma-Aldrich, UK and used as received. 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 formed. IL [C₄mim]Cl was prepared by alkylation of 1-methylimidazole with 1-chlorobutane, following an analogous procedure to that reported elsewhere (Bradley *et al.*, 2002).

Methods

Isolation of cellulose from the maize cob

The agricultural residues were cut into small pieces, dried at 60°C for 24h, and then further broken down in a mill (Fitzmill, Manesty Machines, UK) to particles passing through 4.75mm sieve. The isolation of cellulose was carried out from the milled maize cob using the following methods:

Method 1 (Sodium hydroxide method)

500 g of the maize cob material was treated with 5 L of a 2 % w/v aqueous solution of sodium hydroxide for delignification, in a stainless steel vessel immersed in a water bath set at 100 °C for 3 h. Completion of the removal of lignin, as well as removal of β - and γ -celluloses, was carried out by further digesting the material with 4 L of a 17.5 % w/v aqueous solution of sodium hydroxide for 1 h at 80 °C. After thorough washing with distilled water, the remaining solids were filtered off and dried in an oven at 60 °C for 16 h. The product (unbleached cellulose) was bleached with 625 mL of a 3.2 % w/v aqueous solution of sodium hypochlorite in the stainless steel vessel at 40 °C for 1.5 h. The bleached sample was thoroughly washed with distilled water until obtaining a neutral pH, fil-

tered, and then dried in the oven at 60 °C for 16 h. The product (α -cellulose) was milled in a Kenwood blender, sifted through a 212 μ m aperture sieve, further dried at 60 °C for 1 h, and stored in a tightly closed container. The bleached cellulose sample was labelled **MCS**.

Method 2 (Nitric acid/Sodium hydroxide method)

500g of the material was treated with 5L of 3.5% nitric acid containing 50mg of sodium nitrite for 2h in a stainless steel vessel immersed in a water bath set at 90°C. The sample was then washed twice with distilled water, filtered and then digested with 5L solution containing 2% w/v each of sodium hydroxide and sodium sulphite at 50°C for 1h. The resulting material was again thoroughly washed with distilled water, filtered and then treated with 625ml of 17.5% w/v sodium hydroxide solution for 0.5h at 80°C. The residue obtained was also thoroughly washed with distilled water, filtered and dried in an oven at 60°C for 16h. The product (unbleached cellulose) was bleached, dried and stored as described earlier in Method 1. The bleached cellulose sample was labelled **MCN**

Method 3 (Organosolvent method)

1kg of the material was first extracted with 5L of toluene–ethanol (2:1, v/v) in a Soxhlet extractor for 6h and then delignified in a 500ml glass reactor at atmospheric pressure by treating 20g of the powder with 400ml of a mixture of acetic acid–water (65/35, v/v) using 0.1% HCl as a catalyst at 85°C for 4h. The step was repeated with the following solvents; acetic acid–water (80/20, v/v), acetic acid–water (90/10, v/v), formic acid–acetic acid–water (20/60/20, v/v/v), formic acid–acetic acid–water (30/60/10, v/v/v).

The residue was thoroughly washed with distilled water and ethanol, then oven dried at 60°C for 16h. The product (unbleached cellulose) was bleached, dried and stored as described in earlier in Method 1. The bleached cellulose samples obtained from above were labelled as **MCOa**, **MCOb**, **MCOc**, **MCOd** and **MCOe** respectively.

Method 4 (Ionic liquid method)

10g of degraigned maize cob powder (fraction passing through 250 μ aperture sieve, 5-10% moisture content) was suspended in 190g of an ionic liquid, [C₄mim]Cl, and heated in an oil bath set at 90°C. A magnetic bar was added to the cell and the mixture was magnetically stirred till dissolution took place after about 8 h. The solution was quickly added into an excess of rapidly stirred distilled water. The precipitated material was then filtered using a Buchner funnel, washed thoroughly with distilled water and then oven-dried at 60 °C for 16h. The product (unbleached cellulose) was bleached, dried and stored as described in earlier in Method 1. The bleached cellulose sample was labelled **MCIL**.

Yield of α -cellulose

The amount of α -cellulose extracted from the agricultural wastes was related to the quantity of starting material and the percentage yield was calculated.

Estimation of the chemical composition of α -cellulose

The determination of the chemical composition of α -cellulose of the products was carried out using known standard methods (Browning, 1967).

Physicochemical characterization

Bulk and tapped density: For the determination of the bulk and tapped densities, the methods employed in an earlier study were adopted (Azubuike *et al* 2012). The bulk density, D_{bulk} , and tapped density, D_{tap} , were determined using Eqs. (1) and (2):

$$D_{bulk} = w/v_0 \quad (1)$$

$$D_{tap} = w/v_1 \quad (2)$$

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 three 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) (Azubuike *et al* 2012). The true density, D_{true} , was calculated using Eq. 3

$$D_{true} = w/v_p \quad (3)$$

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 (Carr, 1965) and Hausner ratio (Hausner, 1967) for cellulose were calculated from bulk and tapped densities using Eqs. 4 and 5, respectively:

$$Carr's\ Index = \frac{D_{tap} - D_{bulk}}{D_{tap}} \times 100 \quad (4)$$

$$Hausner\ Ratio = \frac{D_{tap}}{D_{bulk}} \quad (5)$$

Powder porosity: The porosity (P_b) of the tested powders was evaluated from the true and tapped densities, by means of Eq. 6:

$$P_b = 1 - \frac{D_{tap}}{D_{true}} \quad (6)$$

Angle of repose: The measurement of the angle of repose was carried out using a long cylindrical tube open at both ends as detailed in our earlier study [Azubuike *et al* 2012] The height, h , and radius, r , of the conical heap formed were measured, and then the angle of

Table 1: Yield and chemical composition of the celluloses*

Cellulose Sample code	α -cellulose % yield	α -cellulose purity (%)	Lignin (%)	Hemicellulose (%)	Ash value (%)
MCN	29.08 (1.71)	98.03 (1.36)	0.18 (0.03)	1.25 (0.04)	1.09 (0.03)
MCS	26.07 (1.35)	97.8 (1.39)	0.69 (0.02)	1.23 (0.04)	0.55 (0.02)
MCOa	32.70 (1.91)	84.03 (2.06)	4.0 (0.03)	10.05 (0.89)	1.49 (0.03)
MCOb	30.07 (1.51)	85.75 (1.32)	3.43 (0.03)	8.05 (0.69)	1.60 (0.02)
MCOc	28.84 (1.27)	87.03 (0.06)	2.65 (0.07)	6.5 (0.19)	1.25 (0.04)
MCOd	26.45 (0.84)	90.05 (0.89)	1.75 (0.06)	5.5 (0.36)	1.28 (0.01)
MCOe	25.76 (0.81)	93.12 (3.02)	1.54 (0.09)	4.5 (0.17)	1.28 (0.02)
MCIL	55.50 (7.31)	82.08 (1.27)	3.45 (0.04)	12.5 (0.44)	1.09 (0.01)

* Standard deviation is in parenthesis

repose, θ , was calculated from Eq. (7). Determinations were done in triplicate, and the average was taken

$$\theta = \tan^{-1}(h/r) \quad (7)$$

Moisture content: The moisture content of the cellulose powders was calculated from the weight loss on heating from room temperature to 225°C on a Perkin Elmer series 7 thermal analyzer. Triplicate determinations were carried out.

Statistical Analysis

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 decide where significant differences were established.

RESULTS AND DISCUSSION

Yield and chemical composition of the celluloses

The celluloses were odourless, tasteless, and white or off white in colour. These conform to the British Pharmacopoeia (1993), description of organoleptic properties of α -cellulose. The yield (%) of the celluloses is presented in Table 1 along with their chemical compositions. The yield for the cellulose (MCIL) obtained by IL method (55.50%) was significantly higher than for other celluloses isolated using other methods (21.45 to 32.70%). There were also significant differences among the yields of celluloses extracted using organic solvents at different concentrations. Differences in the yields of maize cob cellulose extracted by different methods can be as a result of the effects of extracting chemicals which varied from method to method. The results showed that treatment with nitric acid/sodium hydroxide (MCN), sodium hydroxide (MCS) and organic solvents containing acetic acid / formic acid / water (MCOd, MCOe) gave relatively lower yields of α -cellulose than the other methods probably because more hemicellulose and lignin were removed during isolation. Thus, chemical treatment of the agricultural residues with nitric acid/sodium hydroxide (MCN), sodium hydroxide (MCS) and organic solvents containing acetic acid/formic acid/water (MCOd, MCOe) were more effective in dissolving or solubilising lignin and hemicellu-

lose than treatment with IL (C₄mim)Cl (MCIL) and organic solvents containing acetic acid/water mixture (MCOa, MCOb, MCOc).

Also, as shown in Table 1, the purity of the α -celluloses varied significantly from one another in some cases. The purity of MCN (98.03 \pm 1.19) and MCS (97.8 \pm 1.39) met the British Pharmacopoeia (1993) purity specification for α -cellulose (97.0 to 102.0) %. This implies that both the nitric acid and sodium hydroxide methods yielded α -cellulose of pharmacopoeial quality in terms of purity. On the other hand, MCIL cellulose, obtained by the IL method, showed the lowest purity (82.08%). The purity may be correlated to the extraction efficiency of the methods.

The lignin content of the celluloses also varied significantly, depending on the extraction method and ranged from 0.18 to 4.00% (Table 1). Generally, celluloses isolated using inorganic methods (nitric acid and sodium hydroxide) yielded celluloses with the lowest % lignin contents (MCN 0.18%, MCS 0.69%). This indicates that the inorganic methods were effective in delignifying the biomass. Furthermore, there seems to be a direct relationship between the delignifying power of the method used and the purity of the cellulose obtained. Increase in the content of formic acid used in the organic solvent method, yielded celluloses (MCOe) with lower lignin contents.

The hemicellulose contents of the various α -celluloses are listed in Table 1 and ranged from 1.23 – 12.5%. Hemicellulose content also was dependent on the cellulose extraction method. Generally, celluloses isolated by inorganic methods yielded celluloses with the lowest % hemicellulose content (MCN 1.25 \pm 0.04, MCS 1.23 \pm 0.04). This indicates that inorganic methods were more effective in eliminating hemicellulose from the biomass. For the organic solvent method, the addition of formic acid in increasing amounts, yielded celluloses with lower hemicellulose content as shown by the hemicellulose content (%) of MCOa (10.05 \pm 0.89) and MCOb (8.05 \pm 0.69) (in which formic acid was excluded) which are higher than those of MCOc (6.50 \pm 0.19), MCOd (5.50 \pm 0.36) and MCOe (4.50 \pm 0.17) which entailed the use of formic acid. MCIL, which was isolated using ionic liquid technology, gave cellulose

Table 2: Physicochemical properties of α -celluloses*

Cellulose Sample code	Bulk density (cm ⁻³)	Tapped density (cm ⁻³)	True density (cm ⁻³)	Angle of repose (deg)	Moisture Content (%)	Powder porosity	Carr's index	Hausner ratio
MCN	0.22 (0.03)	0.32 (0.02)	1.48 (0.05)	46.3 (1.11)	5.55 (0.70)	0.78	33.33	1.45
MCS	0.21 (0.02)	0.30 (0.02)	1.46 (0.04)	44.5 (2.42)	5.40 (0.60)	0.79	30.00	1.43
MCOa	0.29 (0.03)	0.35 (0.06)	1.48 (0.02)	44.9 (1.67)	5.30 (0.04)	0.76	22.86	1.27
MCOb	0.28 (0.03)	0.33 (0.06)	1.41 (0.12)	44.5 (2.52)	5.00 (0.46)	0.77	21.21	1.30
MCOc	0.29 (0.03)	0.35 (0.05)	1.38 (0.03)	44.5 (2.88)	5.00 (0.30)	0.76	22.86	1.30
MCOd	0.30 (0.04)	0.39 (0.03)	1.43 (0.07)	46.2 (1.82)	5.40 (0.20)	0.73	23.02	1.30
MCOe	0.29 (0.03)	0.38 (0.06)	1.45 (0.06)	46.5 (1.37)	5.20 (0.44)	0.74	23.37	1.31
MCIL	0.32 (0.05)	0.39 (0.03)	1.40 (0.10)	45.4 (1.91)	5.90 (0.36)	0.72	17.95	1.22

* Standard deviation is in parenthesis.

with the highest hemicellulose content (12.5%). This suggests that this method was the least effective in the removing of hemicellulose from the maize cob biomass.

It is clear, therefore, that based on the data in Table 1, that although the ionic liquid technique produced the highest yield of cellulose, it was also the least efficient extraction method. Furthermore, the organic solvent methods significantly degraded lignin and hemicellulose. To improve selectivity of delignification, formic acid was added to acetic acid in the organic solvent method. The results (see Table 1) show that composition of formic acid/acetic acid/water (20/60/20% v/v) was more effective in the delignification of maize cob than acetic acid/water (80/20% v/v) mixture as shown by a decrease in the lignin content from 2.65% (MCOc) to 1.75% (MCOd). Interestingly, increase in formic acid concentration during aqueous acetic treatment from 20 to 30% resulted in a decrease of lignin and hemicellulose contents (Table 1). The reason for this increasing trend of degradation of lignin and hemicellulose (which translates to a decrease in their contents) is that the formic acid essentially plays the role of a proton donor, which has the effect of hydrolyzing lignins and hemicellulose. While acetic acid serves as a solvent for lignin and hemicellulose fragments. The water intervenes at the level of the dissociation of the organic acids and also participates in the hydrolysis of hemicellulose (Lam *et al.*, 2001).

Physicochemical characteristics

The bulk densities of the celluloses were dependent on the type of biomass and method used. There was significant difference among some of the cellulose samples (Table 2).

The higher bulk densities of MCIL (0.32 cm⁻³) suggest that they have better flow properties than the other celluloses. Bulk density gives an estimate of the ability of a material to flow from a hopper into the die cavity of a rotary tablet compression machine while tap density is a measure of how well a powder can be packed in 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.

The tapped densities of the α -celluloses ranged from 0.30-0.39cm⁻³. It has been reported that differences in the properties of celluloses are usually due to the kinds of pulp (biomass) used as the starting material as well as manufacturing conditions. This is because celluloses from various sources differ in properties (crystallinity, moisture content, surface area and porous structure, molecular weight, etc.) and, therefore, the properties of cellulose obtained from various sources are expected to differ.

The suggestion of better flow properties for the MCIL than for the other α -celluloses is also supported by the results of the Carr's index and Hausner ratio. In Table 2, a decrease of both magnitudes is observed for the MCIL, compared to the other celluloses. Carr's index, also called "percent compressibility," measures the potential powder arch or bridge strength and stability, and has been widely used to estimate the flow properties of powders (Carr, 1965). Values of this index in the ranges 5-10, 12-16, 18-21, and 23-28 indicate excellent, good, fair, and poor flow properties of the material, respectively. Thus, while the index for the MCIL is in the range 15-20 (fair-good flowability), the other celluloses have Carr's indices were above 21 (very poor flowability).

On the other hand, the Hausner ratio is the quotient of tap and bulk densities, providing a measure of interparticle friction, and is also used to predict the flowability of a material (Wells, 1988). 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 our case, the Hausner ratio for MCIL lies around the threshold of 1.20 (\approx good flowability). Therefore, the values obtained for the Hausner ratio are fully consistent with those of the Carr's index.

Overall, the better flow properties for the MCIL are likely to be the result of variations in the particle shape, size, and surface area of the powders (Doelker *et al.*, 1987; Landín *et al.*, 1993), directly related to the processing variables used during their production of the celluloses.

The angles of repose determined, and also reported in Table 2, are not fully consistent with the above results. The angle of repose of a powder gives 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 (Fowler, 2000). In our case, very small or no significant differences were observed between the angles of repose of the celluloses, and all of them are in a range of fair flow potential. An aspect to take into account here is that the measurement of angle of repose is sensitive to moisture content (Bhimte and Tayade, 2007). The moisture contents measured for all celluloses in this work (last row in Table 2) are less than the maximum allowable limit of 8 % (British Pharmacopoeia, 1993). The moisture content somewhat affects mechanical strength and flowability of cellulose powder when the moisture content is above 5 %, since water molecules act as a plasticizer, significantly affecting viscoelastic and mechanical properties of cellulosic material, resulting in lower tensile strength of the cellulose tablets (Peck *et al.*, 1989). The water content of the samples studied herein is slightly above that threshold, in the range 5-6 %, which may be appropriate values for an adequate balance between stability of hydrolyzable drugs and quality of mechanical and flowability properties in real tablet manufacturing processes (Peck *et al.*, 1989). The higher moisture content of MCIL compared to the other celluloses could be ascribed to the different polymorphic form, since the higher amorphous form fraction of MCIL results in a high surface area which is available for water molecules.

CONCLUSION

Chemical treatment with inorganic reagents yielded cellulose samples that met pharmacopoeial specifications in terms of purity; however, they showed poor flow characteristics. On the other hand, treatment with organosolvents led to the production of cellulose samples that failed pharmacopoeial specifications in terms

of purity and also exhibited poor flow characteristics. Although IL method yielded cellulose powders that did not meet pharmacopoeial specifications in terms of purity, they exhibited better flow characteristics, which improve their potential as tablet excipients. If the extraction conditions (e.g. reducing the particle size of the maize cob material, increasing the reaction time, microwave-assisted extraction) using IL method can be improved upon to generate cellulose of pharmacopoeial specifications in terms of purity and retain its good flow properties, it will be extraction method of choice. This will be a subject of further investigation. Moreover, since the ILs can be almost 100% recycled, this will be a low cost, fast, simple and environmentally friendly chemical procedure that can increase significantly the competitiveness of α -cellulose extraction.

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