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Physicochemical Properties of Microcrystalline Cellulose from *Saccharum officinarum*: Comparative Evaluation with Avicel® pH 101

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ABSTRACT

The aim of the work is to produce microcrystalline cellulose (MCC) from sugarcane bagasse (*Saccarhum officinarum*) and to characterise the MCC and compare with Avicel®. MCC was produced from α-cellulose produced by alkaline hydrolysis from sugarcane bagasse and bleached with sodium hypochlorite. The MCC were identified by BP (2009) method and characterised in terms of pH, moisture and ash content respectively. The physico-technical properties of MCC were studied including the particle size and flowability and compared with that of Avicel®. Also, the phytochemical properties of MCC were studied. The results of the phytochemical analysis of MCC from bagasse showed the presence of alkaloid in low concentration while, carbohydrates and glycosides were seen in very large concentrations, while flavonoids, saponin, tannin, resins, steroids, terpenoids, reducing sugars, proteins, fats and oil and acidic compounds were absent. MCC produced had a pH of 7 and moisture content of 7 % and exhibited mean particle diameter of 200.00 ± 0.05 µm. The results of the true density of the MCC showed that the differences in density between the MCC from bagasse and Avicel® were not significant ($p < 0.05$). The results of angle of repose, Carr's index and Hausner's quotient showed that the MCC from bagasse and Avicel® exhibited poor flow which could be improved by use of glidants. Therefore, MCC from bagasse could be used as diluents-binder in direct compression tableting and as diluents and or disintegrant in wet granulation tableting.

Keywords: Microcrystalline cellulose, sugarcane bagasse, *Saccharum officinarum, phytochemical analysis*

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INTRODUCTION

Sugarcane bagasse is a residue produced in large quantities by sugar industries from *Saccharum officinarum* L. (Poaceae). In general, I ton of sugarcane bagasse generates 280 kg of bagasse, the fibrous by-product remaining after sugar extraction from sugarcane[1]. However, the utilization of sugarcane bagasse is still limited and is mainly used as fuel to power the sugar mill [2-3]. The stockpiled bagasse is of low economic value and constitutes an environmental problem to sugar mills and surrounding districts, especially if stockpiled for extended periods, due to the risk of spontaneous combustion occurring within the pile [4]. Thus, several processes and products that utilize bagasse as a raw material have been reported. Among them are pulp and paper production and products based on fermentation[5-8]. *Saccharum officinarum* contains 43.8 % of cellulose, 28.6 % of hemicelluloses and 23.5 % of lignin [9].

The name cellulose was coined by Anselme Payen, a French chemist, physicist and mathematician in 1838[10]. Cellulose is the most abundant naturally occurring biopolymer[11-13]. Cellulose is a polysaccharide consisting of anhydroglucose units (AGU) linked together by (1→4)-β-D-glucosidic bonds. Unlike the β-D-glucosidic linkages in starch, the β-D-linkages in cellulose cannot be broken by the human digestive system. Cellulose is insoluble in water and most common solvents[12], and the poor solubility is attributed primarily to the strong intramolecular and intermolecular hydrogen bonding between the individual chains[11]. In spite of its poor solubility characteristics, cellulose is used in a wide range of applications including composites, netting, upholstery, coatings, packing, paper, etc[11, 14]. In order to increase their use and to fulfill the various demands for functionality of different cellulose products, they are often modified by physical, chemical, enzymic or genetic means. Modification leads to changes in the properties and behaviour of the polymer and consequently, improvement of the positive attributes and reduction of the negative characteristics[14]. The properties of modified cellulose depend on several factors, such as the modification reaction, the nature of the substitution group, the degree of substitution (DS) and the distribution of the substitution groups[14]. Chemical modification can be used to varying some other cellulose properties, such as hydrophobic or hydrophilic character, elasticity, adsorption, microbial resistance, heat and mechanical resistance[15].

Microcrystalline cellulose (MCC) is a purified partially depolymerised non-fibrous form of cellulose that occurs as a white, odourless, tasteless, crystalline powder composed of porous particles[16]. It is widely used in pharmaceuticals, primarily as binder/diluents in oral tablet and

capsule formulations where it is used in either wet or dry formulation and direct compression processes like spheronization/ pelletisation[16-17]. It also has some lubricant and disintegrant properties[16-18] and can be used in cosmetics and food products, especially as fat replacers. MCC, produced from a naturally occurring substance (cellulose) has proven to be stable, safe, and physiologically inert and has revolutionized tabletting [16]. Microcrystalline cellulose is one of the few materials used in tabletting that combines two properties of tablet vehicle; it can produce very hard tablets and yet these tablets disintegrate rapidly due to swelling of the MCC particles and destruction of the bonding forces holding them together [19]. Woody plants and cotton were the major sources of MCC, but cost has made it imperative that other materials be investigated as potential sources. MCC can be made from any material that is high in cellulose ranging from pure cellulose, commercial grade cellulose to lignocellulosic materials. Reports have shown that MCC can be produced from soybean, oath and rice hulls as well as sugar beet pulp[20], bagasse and corn cob[22-22], wheat, barley and oath straw [23], groundnut shell and rice husks[24], reed stalks[25], and cereal straw[26]. Indian bamboo[27], luffa cylindrica[28] and orange mesocarp have also been studied as potential sources of MCC[16].

The aims of the present study are to produce microcrystalline cellulose (MCC) from sugarcane bagasse (*Saccharum officinarum*) and to characterize the MCC and compare its functions with with Avicel®.

MATERIALS AND METHODS

Hydrochloric acid, ethanol, sodium hydroxide and acetic acid (BDH Chemicals Ltd., England), Avicel® PH 101 (a commercial brand of microcrystalline cellulose). All the chemicals used were analytical grade and were used as supplied. Sugarcane bagasse was purchased from Nsukka market, Enugu state, Nigeria.

Production of α-cellulose from bagasse

Sugarcane bagasse was cut into pieces, it was soaked in 70 % ethanol in order to remove the chlorophyll, dried in an oven at 105 ^{o}C until brittle to touch, milled in a hammer mill and delignified with a 3.5 % (w/w) sodium hydroxide for about 2 h at 80 ^{o}C. The pulp obtained was washed with distilled water, and further treated with 17.5 % of sodium hydroxide for 2 h at 80 ^{o}C and neutralized with 0.1 M acetic acid to obtain the α-cellulose. Bleaching was carried out with 3.2% Sodium hypochlorite at 40 ^{o}C for 1.5 h [16].

Preparation of microcrystalline cellulose

The cellulose obtained was subjected to the hydrolytic action of 2.5 M HCl (which is able to

specifically cleave 1–4 glucosidic linkages) at the boiling temperature of about 105 ^{o}C for 15 min. During treatment with dilute mineral acids, the acid penetrates the amorphous regions relatively fast and hydrolyses these regions, yielding water-soluble fragments or oligomers [16]. The time allowed for the hydrolysis to take place is just enough such that it will not penetrate the crystalline regions appreciably to destroy the crystallites. The MCC was collected by filtration, washed with distilled water to neutral pH, dried at 69 ^{o}C for 1 h. and stored in an airtight container in a desiccator.

Physicochemical properties of the MCC

Identification test of MCC

About 10 mg of the powder was dispersed in 2 ml of placed on iodinated zinc chloride in a petri dish and the colour was observed [29].

Organoleptic studies

A 10 g quantity of MCC was weighed with the aid of a balance and the organoleptic properties were checked including the colour, taste, odour and texture.

pH determination

A 5 g quantity of the MCC powder was weighed with the aid of a weighing balance (Ohaus Adventurer) and dispersed in 100 ml of distilled water in a 250 ml beaker and the pH was determined using a pH meter (ep ® Hanna Instrument, Padova, Italy) at room temperature. The measurement was made in triplicate to reduce the degree of error.

Moisture content determination

A 5 g sample of the powder was heated at 105 ± 2 ^{o}C to a constant weight in a microwave oven and the percent loss of moisture on drying was determined as the ratio of moisture loss (g) to weight of original sample expressed as percentage.

Determination of total ash

The total ash of the MCC was determined by introducing a 5 g quantity of uniform bed spread of the powdered in a crucible and igniting by way of continuous increase in temperature above 450 ^{o}C until the powder turned white, showing absence of carbon. The crucible was put in a desiccator and allowed to cool. The total ash (mg) in the crucible per gram of dried cellulose was calculated [29]. This test was repeated using Avicel® as the reference sample.

PHYTOCHEMICAL SCREENING

Alkaloids

A 20 ml quantity of sulphuric acid (5 %) in 50 % ethanol was added to 2 g of the powder material and heated for 10 min; the mixture was allowed to cool and filtered. About 10 ml of the

filtrate was placed in a separating funnel and made alkaline with 3 ml of dilute ammonia solution. The alkaline solution was separated and extracted with two 5 ml portions of dilute sulphuric acid. The extract was tested with few drops of Meyer's reagent [30-31].

Flavonoids

About 10 ml quantity of ethyl acetate solution was added to a small quantity of the MCC powder and heated for 3 min**;** the mixture was allowed to cool and filtered. About 4 ml of filtrate was shaken with 1 ml of dilute ammonia solution. The layers were allowed to separate and the ammoniacal layer was colourless [30].

Saponin

About 1 g of the MCC was shaken with 5 ml of distilled water and then heated to boil. Frothing (appearance of creamy miss of small bubbles) indicates the presence of saponins [30].

Carbohydrate

About 0.1 g of powder material was boiled with 2 ml of water and the mixture was allowed to cool and filtered; few drops of Molisch's reagent were added. About 2 ml quantity of concentrated sulphuric acid was gently poured down the side of the test tube to form a lower layer. A purple interfacial ring indicates the presence of carbohydrate [30].

Reducing sugars

About 0.1 g of powder was shaken vigorously with 5 ml of distilled water and filtered. About 1 ml of the filtrate was collected and an equal volume of Fehling's solution 1 and 11 was added to the filtrate and boiled for few minutes on a water bath. A brick red precipitate indicates the presence of reducing sugars [30].

Tannins

To 0.5 ml of MCC solution 1 ml of water and 1-2 drops of ferric chloride solution was added. Blue color was observed for gallic tannins and green black for catecholic tannins [30-31].

Resins

About 0.2 g of the powder sample was extracted with 1.5 ml of 96 % ethanol, the alcoholic extract was transferred into 20 ml of distilled water and a precipitate indicates the presence of tannins [30-31].

Glycosides

Glycosides are compounds which upon hydrolysis give rise to one or more sugars (glycones) and a compound which is not a sugar (aglycone or genine). To the solution of the extract from MCC in glacial acetic acid, few drops of ferric chloride and concentrated sulphuric acid are added, and observed for a reddish brown coloration at the junction of two layers and the bluish green color

in the upper layer [30-31].

Proteins

Two drops of millions reagent were added to the MCC extract and a white precipitate indicates the presence of protein. The filtrate also gave yellow precipitate with picric acid [30-31].

Terpenoids and steroids

About 1 g of powder was treated with 0.5 ml of acetic anhydride and 0.5 ml of chloroform. Then concentrated solution of sulphuric acid was added slowly to 0.5 ml of filtrate and red violet color was observed for terpenoid and green bluish color for steroids [30-31].

Fats and oil

About 0.1 g of MCC powder was pressed between filter paper; translucency of the filter paper indicates the presence of oil. Few drops of suddan III reagent were added to the filtrate and formation of precipitate indicates the presence of fats [30].

PHYSICOTECHNICAL TESTS

Particle size analysis

The particle size of the MCC was determined using nest of sieves (numbers 16, 52, 100 and 200) arranged in descending order of aperture size with a pan collector underneath. About 18 g quantity of each batch of granulations was accurately weighed using an electronic weighing balance (Ohaus Adventurer, SNR – 1121 R53860, China), and transferred to the top most of a series of sieves. The sieve arrangement was transferred to an Endecott mechanical sieve shaker (Endecott 1 MK 11, 6315, London, England) and shaken for 5 minutes. The fraction of powder retained by each sieve was weighed. Three determinations were carried out and the mean particle diameter (d_{av}) determined using the relation [32-33]:

$$d_{av} = \frac{\sum(\text{Percentage powder retained x Mean aperture size})}{100} \qquad (1)$$

True density determination

The true density of the MCC and Avicel® respectively were determined using a specific displacement pycnometer (25 ml) field with a non solvent (distilled water). The true density, D_{True}, was calculated using Equation 2.

$$D_{True} = \frac{\text{Weight of powder}}{\text{True volume of powder}} \qquad (2)$$

Bulk and Tapped Densities

A 25 g quantity of the MCC powder was placed in a 100 ml measuring cylinder and the volume occupied by the sample was noted as the bulk volume. The bulk density(ℓ_B) was calculated using

the relation [33-36]:

$$\text{Bulk density } (\ell_B) = \frac{\text{Mass of powder (M)}}{\text{Bulk volume of powder } (V_B)} \qquad (3)$$

The tapped volume was determined by tapping the cylinder on a wooden flat surface from a height of one inch at 2 seconds interval until there was no significant change in volume reduction. The volume occupied by the sample was then recorded as the tapped volume. The tapped density (ℓ_T**)** was calculated using the formula:

$$\text{Tapped density } (\ell_T) = \frac{\text{Mass of powder (M)}}{\text{Tapped volume of powder } (V_T)} \qquad (4)$$

Angle of repose

The static angle of repose was determined using the fixed base cone method [34]. About 25 g of MCC was transferred into an open-ended cylinder placed on a static base cone on a horizontal surface. The cylinder was gradually withdrawn vertically and the sample formed a cone-shaped heap. The height of the sample was determined using a cathetometer; the radius was obtained by dividing the fixed diameter by two. Angle of repose (ɵ) was calculated using the formula:

$$\theta = \tan^{-1} \frac{\text{height of powder heap}}{\text{radius of powder}} \qquad (5)$$

Compressibility index and Hausner's quotient

Hausner's quotient was determined using the Equation:

$$\text{Hausner's quotient} = \frac{\ell_T}{\ell_B} \qquad (6)$$

Where ℓ_T and ℓ_B are tapped and bulk density respectively.

Carr's compressibility index (%) was obtained using the formula:

$$\text{Carr's index } (\%) = 1 - \frac{\ell_B}{\ell_T} \text{ x } 100 \qquad (7)$$

Statistical analysis

Data were analyzed by one-way ANOVA. Differences between means were assessed by a two-tailed student's T-test. $P < 0.05$ was considered statistically significant.

RESULTS AND DISCUSSION

The results of the organoleptic properties of MCC from sugarcane bagasse showed that the MCC was white, odourless, tasteless and coarse. These results however agree with the BP specifications for microcrystalline cellulose [29]. The test for identification of MCC with iodinated zinc chloride gave a violet-blue colouration in accordance with BP, specifications. The results

confirmed that MCC was actually produced from sugarcane bagasse.

The results of the phytochemical analysis of MCC from bagasse are shown in Table 1, and show the presence of alkaloid in low concentration while, carbohydrates and glycosides were seen in very large concentrations. Cellulose is a polysaccharide consisting of anhydroglucose units (AGU) linked together by (1 → 4)-β-D-glucosidic bonds. Therefore, the presence of high amount of glycosides was due to its constituent as the building block of cellulose. However, other phyto-constituents tested including flavonoids, saponin, tannin, resins, steroids, terpenoids, reducing sugars, proteins, fats and oil and acidic compounds were however, absent in the MCC produced as shown in Table 1.

Table 1: Phytochemical content of MCC from sugarcane bagasse

Phytochemical constituent	Remark
Alkaloids	++
Flavonoids	-
Saponin	-
Carbohydrates	+++
Reducing sugars	-
Tannins	-
Resins	-
Glycosides	+++
Proteins	-
Steroids and terpenoids	-
Acidic compounds	-
Fats and oil	-

+++High concentration, ++ Low concentration; MCC: Microcrystalline cellulose

The results of some physicochemical properties of the MCC from bagasse are shown in Table 2. The results revealed that the MCC produced had a pH of 7. However, the BP specified pH range of between 5 to 7.5 for microcrystalline cellulose [29]; therefore, the results complied with specifications for the pH of MCC. These results show that the physicochemical properties of the MCC were not compromised by any form of treatment during manufacturing. Hence, MCC from sugarcane bagasse could be compared to any other commercial brand of MCC and could be used as excipient in different drug delivery systems. It could be used as binders, disintegrants, lubricant and bulking agent in wet granulation tableting or as diluent-binders in direct compression tableting.

The results of ash contents of the MCC from bagasse are shown in Table 2 and the results show that it was comparable to Avicel®. Also, the result of moisture content (loss on drying) of MCC from sugarcane bagasse are shown in Table 2 and revealed that MCC produced had 7 % moisture content exactly the value specified for MCC in BP [29]. However, the moisture content of the

reference sample shows that it contains 7.8 % of moisture. The results revealed that the MCC from bagasse had high purity and is comparable to Avicel®.

The results of the particle size analysis of the MCC produced from sugarcane bagasse are shown in Table 2, and show that the cellulose exhibited mean particle diameter of 200.00 ± 0.05 µm. However, in general, fine particles with very high surface to mass ratios are more cohesive than coarser particles which are influenced more by gravitational forces. Particles larger than 250 µm are usually relatively free flowing, but as the size falls below 100 µm, powders become cohesive and flow problems are likely to occur. Powders having a particle size less than 10 µm are usually extremely cohesive and resist flow under gravity, except possibly as large agglomerates [34]. Therefore, the particle size of the MCC showed that it had good properties to enable flow under gravity and could be used for direct compression tableting and also as disintegrant, and diluents in wet granulation.

The flow properties of MCC were studied using the indirect method of assessing flowability. The results of the bulk and tapped densities (loose densities) of MCC from sugarcane bagasse were comparable to that of Avicel® used as the reference ($p < 0.05$), there was no significant variation of the test MCC from the reference as shown in Table 2. The bulk density of a powder is always less than the true density of its component particles because the powder contains interparticle pores or voids. A decrease in bulk density may be associated with a reduction in particle size and produce a loose-packed powder bed which, although porous, is unlikely to flow because of the inherent cohesiveness of the fine particles [34]. Bulk and tapped densities are important because they are used as an indirect method of assessing powder flowability.

Table 2: Properties of MCC from bagasse

Properties	**MCC†**	**Avicel®**
Particle size (µm)*	200.00 ± 0.05	-
Bulk density (g/ml)*	0.520 ± 0.070	0.422 ± 0.090
Tapped density (g/ml)*	0.681 ± 0.020	0.662 ± 0.020
True density (g/ml)*	1.200 ± 0.030	1.500 ± 0.050
Angle of repose (°)*	68.00 ± 0.33	65.50 ± 0.25
Hausner's quotient	1.91	1.52
Carr's compressibility index(%)	42.00	38.38
Moisture content (%)	7.0	7.8
Ash content	1.0	1.4
pH	7.00	-

MCC†: Microcrystalline cellulose from sugarcane bagasse;
Values shown are mean ± SD (*n = 3)

The results of the true density of the MCC are shown in Table 2 and show that the differences in density between the MCC from bagasse and Avicel® were not significant ($p < 0.05$). Powders

normally flow under the influence of gravity; therefore, dense particles are generally less cohesive than less dense particles of the same size and shape [34]. The flow of powder during manufacturing dictates the quality of the product in terms of weight and content uniformity of the capsules [19]. The measurement of the flow properties of powders is essential before capsule filling and tableting because variation in particle flow will automatically cause variation in tablet weight, capsule weight and active ingredient variation. The flow property of bulk material results from the cohesive forces acting on individual particles such as van der Waals, electrostatic, surface tension, interlocking, and friction [19]. Hausner's quotient, determines the degree of interparticulate friction and values ≤ 1.25 indicates good flow, while Hausner's quotient > 1.25 indicates poor flow [33-36]. The results indicated that Hausner's quotient were a little above the range and could result to poor flow. Carr's index in the range of 5 – 16 % indicates good flow, 18 – 21 % shows fair flow, while values above 38 % show very poor flow [36]. The results of Carr's index revealed that both the test and the reference MCC had poor flow. Also, values for angles of repose ≤ 30 ^{o} generally indicate a free flowing material and ≥ 40 ^{o} suggest a poorly flowing material. The results show that the cellulose had poor flow; however, the flow properties of the samples may be improved by addition of glidants which will reduce the interparticulate friction and enhance the flow of the both test and reference MCC.

CONCLUSION

Microcrystalline cellulose was produced from sugarcane bagasse and the results of the physicochemical properties showed that the MCC had pH, moisture and ash content that complied with BP (2009) specifications for MCC and also were comparable to that of Avicel®. The results of the physicotechnical properties of the MCC showed it had poor flow which could be improved using glidants. However, MCC from bagasse was comparable to Avicel®, but have advantages of availability and is relatively cheap. Production of MCC from sugarcane bagasse could help to reduce pile up of waste from bagasse so that our environment would be free from litters from bagasse.

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