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Preparation and Characterization of Microcrystalline Cellulose for Pharmaceutical Excipient: A Review

ABSTRACT

Microcrystalline cellulose (MCC) is widely used as an additive excipient in the pharmaceutical, cosmetic, and food industries. Previous studies have been conducted on the extraction of natural MCC from plant fibers, stem powder, seeds, husks, and organic waste. This review was aimed at discussing the preparation and characterization of MCC for pharmaceutical excipients. Google, Science Direct, PubMed, and Scopus search were conducted using specific keywords to find recent information published between 2010 and 2022. MCC is produced in four stages: delignification, bleaching, cellulose hydrolysis using a dilute acid solution while keeping reaction conditions in mind, and drying. Researchers have produced MCC from tea waste with an extraction yield of 86.7%, an acid to ingredient ratio of 1:20, an HCl concentration of 1.5 mol/L, a processing time of 90 min, and a temperature of 65°C. Several analytical techniques have been developed to characterize MCC, including Fourier transform infrared, scanning electron microscopy, energy-dispersive X-ray spectrophotometry, and X-ray diffractometer to calculate the crystallinity index and predict the type of cellulose produced. The properties such as true, bulk, and tapped densities, as well as flow properties (Carr's index, angle of repose, Hausner index, and compressibility index) indicate that MCC from natural materials such as grounut husk, corn stalks, ensete glaucum, wheat straw, water hyacinth, and sugarcane bagasse has the potential as tablet excipients when compared to the characteristics of commercial MCC. Therefore, they can be used as a reference for direct compression.

Keywords: Characterization, Delignification, Hydrolysis, Microcrystalline cellulose, Pharmaceutical excipient.

Introduction

Microcrystalline cellulose (MCC) is a tasteless and odorless white crystalline powder made up of porous particles. MCC is slightly soluble in a 5% w/v solution of sodium hydroxide (NaOH) but practically insoluble in water, acid solutions, and some organic solvents. It is relatively stable physically and chemically in ambient conditions, and it is normally stored in dry and cool environments.[1] MCC is an essential supplementary excipient in the pharmaceutical sector, particularly as a tablet excipient, in addition to being an ingredient in food and cosmetic products.[2]

Microcrystalline cellulose preparation involves the hydrolysis of alpha-cellulose pulp with mineral acids. In recent years, research has been conducted to produce MCC from natural components such as plant fibers,[3] stem powder, seeds, husks, and organic waste, including coffee husks,[4] date seeds,[5] ensete glaucum,[6] giant reeds,[7] rice straw and banana plant wastes.[8] Furthermore, *Saccharum spontaneum* (Kans grass),[9] tea wastes,[10] parawood sawdust,[11] wheat straw,[12] water hyacinth,[13] and sugarcane bagasse,[14] have all been reported as ingredients for the synthesis of MCC. Both wood and non-wood sources can produce plant fibers, and both types of fibers have good biodegradability, renewability, low density, high strength, and high stiffness.[15]

Cellulose is a fibrous, tough, water-insoluble substance that is essential for maintaining the structure of natural fibers.[16] The majority of wood and non-wood fibers are made of cellulose, which is present in natural sources in amounts equivalent to 1.5 x 10 tons of the annual biomass production.[11] It is a linear homopolymer made up of homo monosaccharide macromolecules known as anhydroglucose that are connected by (1-4)-glycosidic bonds. It can be degraded by microbial and fungal enzymes. Amorphous and crystalline regions can be seen in the structure of cellulose.[1] Apart from cellulose and hemicellulose, the other major lignins are

components of plant fiber. Hemicellulose consists of various types of cyclic saccharides, whereas lignin is an amorphous polymer consisting of aromatic units such as guaiacyl, syringyl, and phenylpropane.[11] The aim of the present review was to discuss the preparation and methods used for the characterization of MCC for pharmaceutical excipients.

Methods

For this review article, Google, Science Direct, PubMed, and Scopus search using keywords like "extraction," "isolation," "preparation," "characterization," "properties," "microcrystalline cellulose," and "pharmaceutical excipient" were used to find recent information. The content was limited to the preparation of natural MCC, the use of acid-base preparation methods, and characterization using predetermined tools. Only articles published between 2010 and 2022 were consulted.

Results and Discussion

Various sources of microcrystalline cellulose

Microcrystalline cellulose is a derivative product of pure cellulose with a crystal structure that is chemically derived from lignocellulosic biomass. Initially, wood and cotton were the primary sources of MCC, but as technology advanced, lignocellulosic biomass, a type of non-wood biomass, became a popular alternative. MCC can be found in coffee husks,[4] date seeds,[5] ensete glaucum,[6] giant reeds,[7] rice straw, and banana plant wastes,[8] *Saccharum spontaneum* (Kans grass),[9] tea wastes,[10] parawood sawdust,[11] wheat straw,[12] water hyacinth,[13] sugarcane bagasse,[14] groundnut husk,[17] cornstalks,[18] and betung bamboo.[9] The MCC produced from various alternative sources exhibits characteristics that are acceptable by the standard, so the

search for additional natural sources is currently being encouraged more and more. MCC has unique mechanical and physicochemical features, including renewability, biodegradability, non-toxicity, high mechanical properties, low density, large surface area, good biocompatibility, and hygroscopicity.[15]

Various preparatory methods of microcrystalline cellulose

Microcrystalline cellulose is typically produced through the controlled hydrolysis of cellulose obtained as a pulp from fibrous plant materials in a diluted mineral acid solution. The hydro cellulose is filtered and then washed with water after hydrolysis. After that, a dry powder is created by spray-drying the aqueous slurry. Hydrolysis using mineral acids on various α-cellulose precursors is a simple method of MCC preparation to reduce the degree of polymerization.[19] Alpha-cellulose itself is not available as a free form but is bound to lignin, which is called lignocellulose. For lignin to be released from the complex during hydrolysis, the lignocellulose must first undergo delignification. This process is important because lignin can inhibit acid penetration for hydrolysis to take place. The efficiency of the delignification process is influenced by heating time, solvent solution concentration, solvent-to-raw material ratio, temperature, and pressure. Heat mechanics, acid treatment, alkaline treatment, and treatment with organic solutions are all pretreatment options for lignocellulosic waste.

Conventional delignification can be done by hydrolyzing lignocellulosic materials using strong acids. However, this method is not as effective as the use of bases because of several drawbacks, which include low cooking yields, high production costs, low delignification rates, and environmental pollution from cooking solution waste. As shown in Figure 1, NaOH acts by breaking the lignin structure to release cellulose from its bonds. The hydroxyl ions (OH^-)

released from NaOH breaks the bonds from the basic structure of lignin while sodium ions (Na^+) binds with lignin to form sodium phenolics that will dissolve easily to form a black-colored solution known as a black liquid.[20] In research conducted by Cheng et al., it was established that the lignin and cellulose bonds could be broken more successfully during the delignification process by first treating the acid catalyst in the solvent. It was reported that the yield could be increased up to six times at 98.0%.[21] As presented in Table 1, delignification processes using bases like NaOH are thus commonly employed in recent studies. All of them use NaOH solution with a concentration of 3 to 17.5% and a solid-to-solution ratio of 1:10 and 1:20 at 80-170°C over a range of 30 min to 14 h. It has been demonstrated that the release of lignin and hemicellulose is aided by a combination of physical structural damage, mechanical fragmentation, and chemical structure depolymerization by alkali treatment. Under these conditions, higher cellulose content and crystal transformation from cellulose I to II require a lower NaOH concentration. This process happens in wheat straw.[20]

Bleaching is required to remove the black color from the solution. It can remove lignin and carbohydrates that are not completely separated from the pulp. The procedure involves submerging plant fiber in hydrogen peroxide (H_2O_2) or sodium hypochlorite (NaClO) solution, both of which are strong oxidizers that can degrade dye molecules by reacting with the oxygen they release. Free radicals created by hydrogen peroxide can be unstable and can interact with molecules of dye or other large, highly pigmented organic compounds.[22]

Microcrystalline celluloses can be prepared by the chemical method of acid hydrolysis, the biological method of enzymatic hydrolysis, and the mechanical method of steam explosion. Acid hydrolysis is reported to be the most efficient method because it is cheaper and faster.[7] It involves the reaction of hydronium ion (H_3O^+) with the amorphous form of cellulose, which

causes the hydrolytic breakdown of the glycosidic bonds.[15] The crystalline form of cellulose, however, cannot be affected by ions in the same way because it is more acid-resistant and thus remains intact.[23] While using strong acids like hydrochloric acid (HCl),[5,6,10,12] sulfuric acid (H_2SO_4),[4,8,9] and combinations of acids such as HCl/ H_2SO_4/ nitric acid (HNO_3) will improve the hydrolysis efficiency, but it will not affect the properties of the MCC produced,[7] (Table 1). According to studies, the amounts of cellulose produced after alkaline-acid and acid-alkaline treatments, respectively, 41.3-52.5% and 43.6-48.5%, did not significantly differ.[8]

Similar to the delignification stage, it is important to pay attention to several factors, including acid concentration, time, reaction temperature, and the proportion of pulp to the acid solution during hydrolysis. Table 1 displays the results of the optimal hydrolysis conditions. Tea waste has an acid to ingredient ratio of 1:20, an HCl concentration of 1.5 mol/L, a processing time of 90 min, a temperature of 65°C, and an extraction yield of 86.7%.[10] Meanwhile, for *Saccharum spontaneum* (Kans grass), the optimal processing conditions are 5% H_2SO_4, at a temperature of 50°C, with a pulp solution ratio of 1:15 for 120 min, with an MCC yield of 85%.[9] Water hyacinth yield was 91.71% when processed optimally with 1.5 N HCl for 30 min,[13] and sugarcane bagasse yield was 44.2% with 4% HNO_3 for 2 hr (1:8).[14] In addition to acid hydrolysis, MCC from water hyacinth can also be prepared by enzymatic hydrolysis with properties resembling those of commercial MCC.[24] The final stage in the preparation of MCC is drying, which can be accomplished through air drying, oven drying, or freeze drying.

Characterization of microcrystalline cellulose

Many analytical techniques have been developed using Fourier transform infrared (FTIR), a sensitive, fast, and inexpensive infrared spectroscopy instrument to study polymers by

142 measuring the absorption intensity and the wavelength of infrared (IR) radiation transformation.
143 This has allowed a better understanding of the characteristics of natural MCC. Recently, Fourier
144 infrared spectroscopy has been widely used to determine the chemical structure and functional
145 groups of lignocellulose compounds.[17] The results of an FTIR analysis are shown in Table 2. It
146 demonstrates that while hemicellulose and lignin were expelled during chemical treatment, the
147 MCC from the hydrolysis of all the materials studied retained its cellulose structure. These
148 results also indicate that the use of different types of acids in the pulp hydrolysis process does
149 not alter the chemical structure of cellulose. It implies that all MCC produced by the hydrolysis
150 of various types of acids would exhibit FTIR spectra that were similar to those of Avicel PH 101
151 or commercial cellulose, which is the preferred form of cellulose for marketing.[6,7,11,13]

152 Information about the chemical composition and crystallographic structure of MCC can
153 be identified using X-ray Diffraction (XRD) based on a solid crystal analysis of the atomic-scale
154 structure of the material. X-rays have a wavelength equal to the distance between the atoms,
155 which causes the diffraction of the crystalline solid. By measuring the height between the
156 intensity of the crystal peak and the total intensity of the non-crystal peak, it is possible to
157 determine the index crystallinity. The diffraction pattern under this condition exhibits many
158 sharp points known as Bragg diffraction peaks. According to Table 2, the crystallinity index of
159 MCC that came from different sources was between 50 - 82.4%. Using various MCC
160 preparations, interesting results were produced on rice straw and banana plant waste, which
161 produced different crystallinity indices of 60–66.7 (alkaline–acid) and 66–82.4% (acid-
162 alkaline).[8] The results of Type I and Type II cellulose are displayed in the identification of the
163 type of cellulose.[5,6,7,10,11] Based on the degree of purity, Type I and Type II cellulose are
164 distinguished from one another. Type I cellulose, or α-cellulose, is long-chain cellulose, which is

insoluble in 17.5% sodium hydroxide solution or strong alkaline solutions with a degree of polymerization of 600-1500. The function of α-cellulose is to determine the level of purity of the cellulose. The higher the α-cellulose content, the better the quality of the material. Type II cellulose, or β-cellulose, is short-chain cellulose, which can dissolve in a 17.5% sodium hydroxide solution or a strong base with a degree of polymerization of 15-90 and can precipitate in neutral acidity.[15]

Scanning electron microscopy (SEM) of micrographs revealed cellulose microcrystals from various materials having a rod-shaped and uniform structure similar to the reference MCC observed in the day-reported analysis.[6,7,9,11] Zhao et al.,[10] reported shorter results with some holes on the rough surface, while Ibrahim et al reported smoother results.[8] However, it was also demonstrated that the effectiveness of each step in the preparation of the cellulose structure would affect its morphology. In date seeds, aggregation and irregular elongated or semi-spherical morphology were shown.[5] The average particle size, according to the SEM results, was between 3.6 - 500 μm. Thermal properties are crucial in the characterization of bio-composites because a relatively high temperature is needed in the processing process. All of the materials in this discussion had good thermal stability, as determined by Thermogravimetric analysis (TGA) on MCC, which indicates that cellulose can be processed using acid hydrolysis to obtain a relatively high crystallinity index.[19]

Properties of microcrystalline cellulose for pharmaceutical excipient

Microcrystalline cellulose has a very wide range of applications in the pharmaceutical industry, especially in the formulation of solid dosage form.[25] When comparing MCC-filled tablets to those made with other diluents, researchers found that MCC-filled tablets had better

qualities like hardness, low brittleness, quick disintegration time, and high drug release rate. Direct pressing in tableting is widely used as it provides a uniform particle size, does not require a granulation process, produces more stable tablets, and is economically profitable. However, not all excipients can be used for the direct compression technique. MCC is the material of choice for direct pressing tableting because of its excellent flow property.[26] Furthermore, MCC is also widely used in suspensions and dry syrups because it can reduce the rate of sedimentation of the solid particles. MCC is also co-processed with other excipients to be used as a direct-compressed tablet filler-bidder, such as with Kollidon ®K30,[27] colloidal silicon dioxide,[28] lactose and StarCap 1500,[29] *Cedrela odorata* Gum, alginic acid[31] and lactose- Kollidon ®K30.[32]

Numerous studies have been conducted to investigate the properties of MCC for pharmaceutical excipients, including pH, moisture content, density, and flow properties, which are critical benchmark parameters for the quality of MCC given its broad function in the pharmaceutical industry. Table 3 displays the properties of MCC for pharmaceutical excipient made from groundnut husk,[17] cornstalks,[18] *Ensete glaucum*,[6] betung bamboo,[2] wheat straw,[12] water hyacinth,[13] and sugarcane bagasse,[14] The flow properties of MCC from acid hydrolysis were good based on the Carr's index, Angle of repose, and Hausner index, which are equivalent to commercial MCC, which is the standard marketed form. Therefore, MCC from plants can be developed as excipients in pharmaceutical preparations, especially for solid dosage forms such as tablets.

The current raw materials for the pharmaceutical industry are active ingredients and excipient, which also play an important role in determining the quality of the preparations. There are numerous ways to make tablets, each of which has advantages and disadvantages. One of them is the direct compression method, which requires less time and lower cost to produce than

other methods due to its formula and manufacturing process efficiency. One drawback of this method is that not all active ingredients can be directly compressed due to their poor flowability and compressibility. It is estimated that less than 20% of the active substance can be compressed directly into tablets. The remaining 80% are made up of active ingredients that flow poorly and compress poorly, making it impossible to directly compress tablets. This problem can be overcome by using the right additives and can be directly compressed to produce quality tablets, one of which is microcrystalline cellulose .[33]

In tablet preparations, cellulose microcrystals are primarily used as a filler.[25] As a direct compression tablet excipient, its high affinity for cellulose microcrystals is a factor to be taken into account.[34] This is because the tablet surface has free hydroxyl groups, which improve the binding, adhesion, and film strength of the substance.[35] MCC is additionally utilized in tablet formulation as a lubricant.[36] The tableting ability of MCC decreases when used in conjunction with magnesium stearate in hand mixing.[37] MCC is a multifunctional excipient, and the concentration at which it is used in the formula determines how hard the final tablet will be without affecting how quickly the drug will be released.[38] The preparation method for MCC affects tablet strength as well, with aqueous solutions producing stronger tablets than hydroalcoholic solutions.[39] The cavity created by the arrangement of microcrystalline cellulose particles allows relatively high levels of water permeation into the 3D tablet, lengthening the time before disintegration.[40] Meanwhile, it functions as a standard tablet disintegrant with a swelling mechanism as a result of the tablet absorbing water.[41] Due to their size falling under the category of microparticles, cellulose microcrystals can ensure uniformity of the dosage content and improve the dispersibility of paracetamol in tablets.[42] The performance is even better if it is co-processed together with polyvinyl pyrrolidone (PVP), which exhibits excellent flowability,

tablet ability, and low ejection force.[43] Although the co-processed with colloidal silicon dioxide results did not demonstrate an improvement in the tablet strength.[44] MCC is excellent for direct printing because it has many advantages over other tablet excipients. The efficient direct molding method is the preferred method, which has encouraged many manufacturers of raw materials to produce cellulose microcrystals with various physical and chemical characteristics. The compressibility index, which is the most important factor, is described by the physical and morphological properties of MCC in the relationship between tablet application performance.[45]

Conclusion

The steps in MCC preparation are delignification, bleaching, and hydrolysis. To optimize the quality, various strong acids, such as hydrochloric acid, sulfuric acid, or nitric acid, can be used for hydrolysis by varying the concentration, temperature, time, and ratio of the acid to pulp solution. The MCC yield was 33.0 to 91.71%. The characterization of the produced MCC revealed that it was comparable to commercial MCC, which is the standard marketed form. This indicates that the MCC may be developed as an excipient in pharmaceutical preparations, particularly for solid dosage forms like tablets. Carr's index was between 18.57 and 40.11%, the angle of repose ranged from 20.69 to 50.20°, and Hausner's index was between 1.08 and 1.65. Microcrystalline cellulose has several functions in tablet formulations, including as a diluent, filler-binder, disintegrant, and lubricant, making it very effective for direct compression.

Conflict of Interest

The authors declare no conflict of interest.

Authors' Declaration

The author declares that the work in this article is original and that all responsibility related to the content of this article will be borne.

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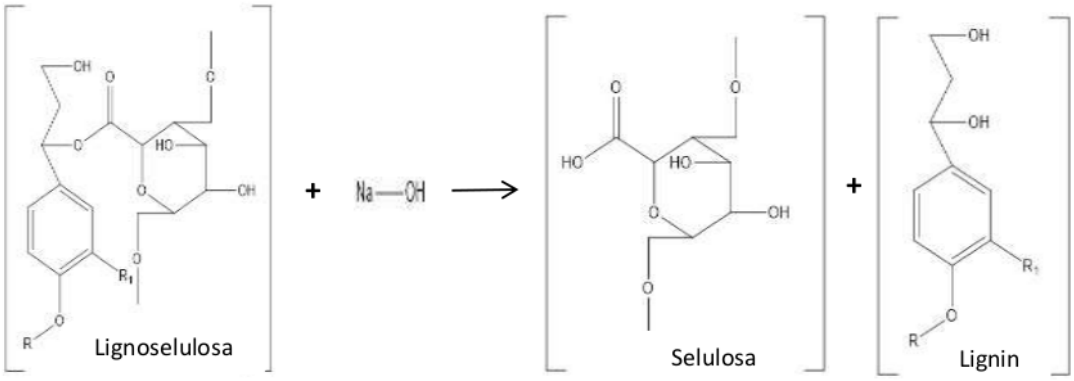

Figure 1: Mechanism of delignification with NaOH solution**.**

Table 1: Various preparation methods of microcrystalline cellulose.

No	Raw Material	Preparation conditions				Yield (%)	Ref
		Delignification	Bleaching	Hydrolysis	Dried		
1	Coffee husk	Solid : 4% NaOH (1:20) 3h	Solid : 1.7% NaClO (1:20) 4h	H_2SO_4 64% , 50°C, 40 min	Nd	61.8	4
2	Date Seeds	17.5% NaOH , 90°C, 3h	$NaClO_2$ (≈10–15%) , 80°C, 45 min	Solid : 2.5 N HCl (1:11) 105 °C ± 2 °C, 45 min	freeze-dried	63	5
3	Ensete glaucum	NaOH	Sodium hypochlorite and hydrogen peroxide	2.5 M HCl , 105°C, 15 min	Nd.	33	6
4	Giant reed	NaOH (1.25M), room temperature 24h and 90°C 5h	Solid: 2.6 M H_2O_2 and 4.4 M CH_3COOH solution (1:20) 5h Solid: 2.1 M H_2O_2 and 1 M NaOH solution (1:20)	Solid : 2.5 M acid used single HCl, HNO_3, H_2SO_4, and the mixture (HCl / HNO_3 (2: 1, v / v), HCl / H_2SO_4 (2: 1, v / v)) (1:20) 100°C 30 min	Oven	34.5 (cellulose)	7
5	Rice straw and banana plant waste	Solid : 10% NaOH (1:10) 170°C, 2h	Solution equivalent to 60%) sodium hypochlorite	Solid : 5% H_2SO_4 (1:10) 170°C, 2h	air-dried.	41.3-52.5 (Alkaline-acid) 43.6-48.5(Acid-Alkaline)	8
6	Saccharum spontaneum	Solid : 3% NaOH (1:20) 14h	Hydrogen peroxide (H_2O_2)	5-25% H2SO4 within 2 - 8 hours temperature 50 - 120 Pulp: solution ratio (g / ml) 1:15 to 1:50. optimum of 5% H_2SO_4, at50 ° C in 1:15 120 min.	oven	83	9
7	Tea waste	Solid : 10 mol/L NaOH (1:20) , 75°C, 4h	Solid : 5% NaClO solution (1:20) Solid : 0.45% H_2O_2 solution (1:20)	0,5 - 1,5 mol/L HCl within 1 - 2 h , 65- 85 ° C material:solid ratio 1:15 to 1:25. optimum of 1.5 mol/L, HCl, at 65 ° C in 1:20 ,90 min.	vacuum-freezing	86.7	10
8	Parawood sawdust	Solid : 0,5M NaOH (1:10) 80°C 2h	Solid : 5% NaClO solution (1:10) room temperature, 2 h	Solid : 2 N HCl or H_2SO_4 (1:10 and 1:15) 80°C, 2 and 4 h. optimum HCl 1:15,80°C 2h	oven	76.89-77.67 (cellulose)	11
9	Wheat Straw	Solid : 2% NaOH (1:20) 2 h	Solid : 0.7% NaClO solution (1:20) 1 h	H_2SO_4 65% 1h ; 2 h and HCl 2,5 N 1h then continue H_2SO_4 65% 1h ; 2 h	Freezing -drying	Nd	12
10	Water Hyacinth	17.5% NaOH 80 ° C, 30 min	Solid : 3.5% NaClO solution (1:1) 100°C, 5 min	1-2 N HCl within 30-60 min , optimum of 1,5 N HCl 30 min	oven	91,71	13
11	Sugarcane Bagasse	NaOH 80 ° C, 1 h	15% H_2O_2	HNO_3, H_2SO_4, and HCl (3%, 4%, 5%) 80° C , 2 h optimum HNO_3 4% (1:8)	60° C , 24 h	44.20	14

Nd: Not detected

Table 2: Characterization of microcrystalline cellulose.

No	Raw Material	Characterization						Ref
		FTIR	X-ray diffraction (XRD) Analysis		Scanning Electron Microscopy (SEM)	Particle Size (μm)	Thermogravimetric Analysis (TGC)	
			Cellulose type	Crystallinity Index (%)				
1	Coffee husk	Nd	Nd	50	fibres are arranged in parallel and an ordered assembly	60-500	good thermal stability	4
2	Date Seeds	Similar to cellulose	Cellulose type I	70	irregular and agglomerated elongated or semi-spherical morphology	100-300	enhanced thermal stability	5
3	Ensete glaucum	Similar to Avicel PH 101	Cellulose type I and II	53.41	elongated and rod-shaped structure	294.4	lower hygroscopicity than Avicel PH 101	6
4	Giant reed	Similar to Commercial MCC	Cellulose type I allomorph	73-80	micro-sized rod-like shape morphology dan non-uniform	7.79 - 8.52	thermal decomposition of MCC at a higher temperature compared to cellulose	7
5	Rice straw and banana plant waste	Similar to cellulose	Nd	60-66.7 (alkaline-acid) 66.7-82.4% (acid-alkaline)	smooth surface	3.6 - 7.6	there is a decrease in the degree of crystallinity	8
6	Saccharum spontaneum	Similar to cellulose	Nd	74.06	Rod-shape and uniformity structure	Nd	good thermal stability	9
7	Tea waste	Similar to cellulose	Cellulose type I	81	Rough surface with few holes and shorter fibers	Nd	good thermal stability	10
8	Parawood sawdust	Similar to Avicel PH 101	Cellulose type I	60	rod-like structure	30-100	higher thermal stability in the treatment using HCl compared to H_2SO_4	11
9	Wheat Straw	Nd	Nd	Nd	Fiber-like particles like those obtained (single-step) and irregular-shaped particles with smooth surface (two-step)	5-65	Nd	12
10	Water Hyacinth	Similar to Avicel PH 101	Nd	78.23	Nd	Nd	Nd	13
11	Sugarcane Bagasse	Similar to cellulose	Nd	59.3	Nd	Nd	Nd	14

Nd = not detected

Table 3: Properties of microcrystalline cellulose for pharmaceutical excipient.

N0	Raw Material	Properties of Microcrystalline Cellulose								Ref
		pH	True density (g/mL)	Bulk density (g/mL)	Tapped density (g/mL)	Flow Properties			Moisture content (%)	
						Carr's index (%)	The Angle of repose (°)	Hausner index		
1	Groundnut Husk	6.4	1.47	0.26	0.38	Nd	44.23	1.47	Nd	17
2	Cornstalks	6	1.59	0.33	0.43	23.26	41	1.3	5.6	18
3	Ensete glaucum	5.3	1.48	0.33	0.56	40.11	49.01	1.65	5.75	6
4	Betung Bamboo	6.8	Nd	0.32	0.47	31	31.39	1.45	4.36	2
5	Wheat Straw	Nd	1.58 -1.68	0.06 – 0.15	0.09 -0.19	18.57 -32.33	Nd	1.23 - 1.48	Nd	12
6	Water Hyacinth	7.3	0.36	0.52	Nd	30.91	20.69	1.44	3.22	13
7	Sugarcane Bagass	Nd	Nd	0.07	0.08	8.45	50.20	1.08	6.27	14

Nd: Not detected

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