SUGARCANE BAGASSE: A PROMISING SOURCE FOR THE PRODUCTION OF NANO-CELLULOSE

Anuj Kumar[1], Yuvraj Singh Negi[1], Veena Choudhary[2] & Nishi Kant Bhardwaj[3]
[1] Department of Polymer and Process Engineering, Indian Institute of Technology Roorkee, India
[2] Centre for Polymer Science and Engineering, Indian Institute of Technology Delhi, India
[3] Avantha Centre for Industrial Research and Development, Yamunanagar, Haryana, India

Abstract: *This paper reviews the recent studies of extraction of nano-cellulose (cellulose nanofibres, nanocrystals, nanowhiskers, nanocrystalline cellulose, etc.) from sugarcane bagasse as agro-waste by different extraction methods such as acid-hydrolysis, alkaline-hydrolysis, enzymatic-hydrolysis, sonication, high-pressure homogenization, and shear ultrafine friction grinding, Disk-Grinder.*

Keywords: *Sugarcane bagasse, Nano-cellulose, Nanofibres, Nanocrystals, Acid-Hydrolysis, Biocomposites.*

1. Introduction

In the last decade, because of increasing environmental awareness, natural fibres have attracted a great attention of the researchers due to the advantages with availability, low cost, low density, biodegradability, and other specific properties over traditional reinforcement fibres such as glass fibre [1,2]. However, natural fibres have been used for different potential applications but cellulose fibres (macro-, micro- and nano-scale size) isolated from these fibres offer the potential applicability in terms of mechanical performance for industrial and biomedical applications [3,4,5]. Extraction of nano-cellulose from lignocellulosic biomass and their application in bio-nanocomposites has captured the attention due to superior properties than that of cellulose fibres reinforced biocomposites retaining mostly same properties as that of cellulose. For the extraction of nano-cellulose, there are many suitable resources including wood and non-wood but non-wood resources such as agro-waste has attracted the great attention due to the shortage of natural resources which may impact on environmental concern [6,7]. As non-wood resource, sugarcane bagasse is a low value agro-waste [8] and can be utilized for the production of nano-cellulose.

2. Sugarcane Bagasse

Sugarcane bagasse (SCB) is an abundant agro-industrial-waste and a fibrous residue produced in the process of sugar extraction [9,10]. Annually, in general, 5.4×10^8 dry ton of sugarcane processed to extract sugar juice and produce 280 Kg of sugarcane bagasse from 1 ton of sugarcane [11]. About 50% of produced bagasse has mainly been utilized as a fuel to generate heat and power to run sugar mill, ethanol and distillery plants, and remaining is usually stockpiled causing the environmental problem due to the risk of spontaneous combustion of the bagasse [12,13]. Therefore, it is necessary to use this waste to convert into value-added products alongwith the utilization for the production of fuel, chemicals, papers, newspapers, etc. Sugarcane bagasse is complex composite of cellulose (40-50%), hemicellulose (25-35%), and lignin (15-35%) with other impurities [14,15] and is a good source of cellulose fibre which can be converted into nano-scale particles, called nanocrystalline cellulose, nanofibres, nanowhiskers, nanocrystals, microcrystals, etc. depending on the source and processing methods. However, for the convenience, this will be called in further sections as “Nano-Cellulose” [16]. Cellulose is the most abundant and available homopolysaccharide organic polymer and comprised of β (1,4-)-linked glucopyranose unites [17]. The importance of nano-scale crystals for potential applications is due to its biodegradability, renewability [18], high potential of reinforcement, high specific surface area [17], high specific strength and stiffness [19,20].

3. Extraction of Nano-Cellulose

There are some reports on extraction of nano-cellulose (in terms of cellulose nanofibres, cellulose nanocrystals, cellulose nanowhiskers, nanocrystalline cellulose, etc.) from sugarcane bagasse as agro-waste for its better utilization for potential applications. This research opens the wide range of possibility of exploitation of sugarcane bagasse as cellulosic material. Bras et al. 2010 reported the extraction of cellulose whiskers from sugarcane bagasse by acid-hydrolysis (H_2SO_4: 65% (w/w)) at 45°C for 45 min and were in the range of 84-102 nm in length and 4-12 nm in width (diameter). The obtained cellulose whiskers were used as reinforcing filler in natural rubber (NR) matrix. At high whiskers loading, significant improvement in tensile strength and Young’s modulus were observed as a result of addition of whiskers to the natural rubber matrix [21]. Teixeira et al. (2011) reported the extraction of CNCs from sugarcane bagasse by acid hydrolysis (H_2SO_4) at 45°C for 30 and 75 min. The produced CNCs were of ‘needle-like’ structures with an average length (L) of 255±55 nm and diameter (D) of 4±2 nm, giving aspect ratio (L/D) of around 64. The drastic acid hydrolysis of chemically purified cellulose for 75 min produced less thermally stable nanocrystals causing some degradation of crystal structure of cellulose [22]. Mandal et al. (2011) investigated the extraction of cellulose nanocrystals with reasonable content of cellulose II form sugarcane bagasse by acid hydrolysis (H_2SO_4: 60% (w/v)) at 50°C for 5 h [23]. Li et al. 2012 reported the isolation of nano-cellulose with diameter range of 10-20 nm from sugarcane bagasse by high pressure (80 MPa for 30 cycles) homogenization in homogenous ionic liquid 1-butyl-3-methylimidazolium chloride ([Bmim]Cl) media with 90% recovery under optimum refining condition [24]. Maddahy et al. 2012 reported the extraction of nanocrystalline cellulose from sugarcane bagasse based cellulose by alkaline hydrolysis (50% NaOH) at 40°C and acid hydrolysis (50%) at 40, 60, and 80°C. The results showed that crystallinity and degree of polymerization of cellulose increased as the temperature increased from 40 to 60°C and then decreased at 80°C lower than the value at 40°C [25]. Hassan et al. 2012 reported the refining of the bagasse pulp by disintegration using high-shear mixer followed by passing through the high shear ultrafine friction grinder (or so-called Supermasscolloider) up to 30 times. Then refined fibres (1 wt%) were homogenized by passing through two-chamber high-pressure homogenizer up to 10 times. The pressures in first and second chamber were 40 and 400 bar, respectively. However, cellulose nanofibres (from ~5 to 50 nm) could easily be produced through high shear refining by using ultrafine grinder without using high-pressure homogenizer. The fibrillation is not as complete in high shear refining as in homogenization step. The nanopaper sheets were prepared from these nanofibres and showed better dry tensile modulus and tensile strength properties as 6.1 GPa and 110.2 MPa for refined fibres with 30 grinding steps and 6.9 GPa and 102.1 MPa for 10 homogenized steps whereas wet tensile strengths were 18.8 MPa and 19.4 MPa for refined bagasse fibres, and homogenized bagasse fibres, respectively. The opacity (%) was 47.1 and 50.7 whereas porosity (%) was same (31%) for refined bagasse fibres, and homogenized bagasse fibres, respectively [26]. In other study by Hassan et al. 2014, these nanofibres were modified with n-octadecyl chains and were incorporated in maleic anhydride-modified polypropylene matrix by extrusion process. The mechanical properties were not as improved as expected but resulted in improved stiffness while thermal stability slightly improved [27]. Campos et al. 2013 reported the isolation of cellulose nanofibres from sugarcane bagasse by enzyme hydrolysis (combination of V (hemicell/pectinase) and F (endoglucanase)) for 70 h at 50°C followed by sonication. This enzymatic combination loading did not show any damage to the chains of bagasse cellulose [28].

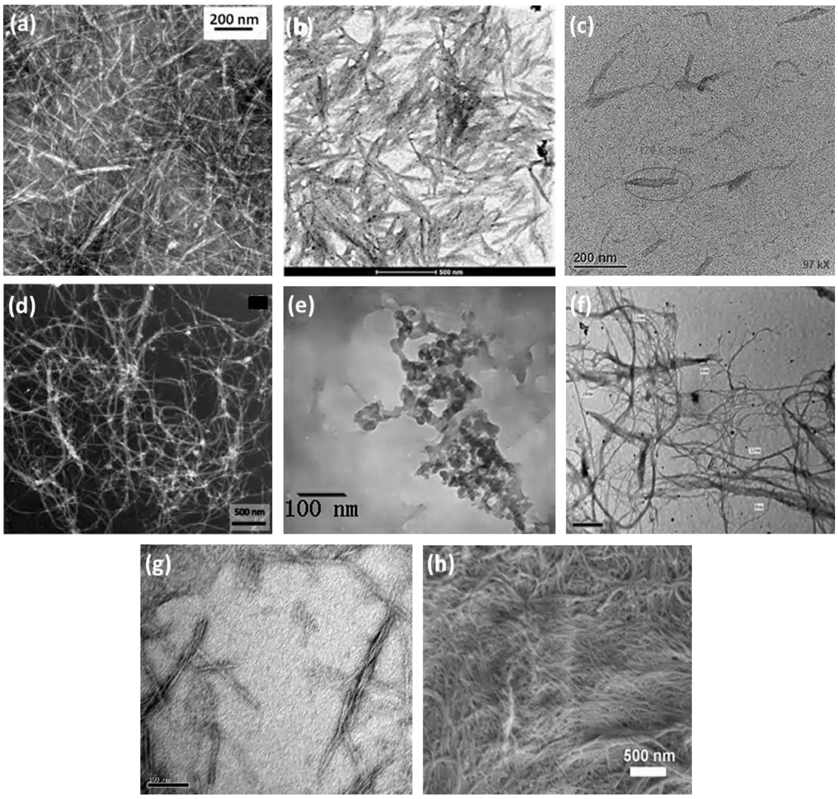

Figure 1: Morphological analysis: TEM images of nano-cellulose from sugarcane bagasse by using (a), (b), and (c) Acid-Hydrolysis [22,23,29], (d) Enzymatic-Hydrolysis [28], (e) High-Pressure Homogenization [24], (f) Shear Ultrafine Friction Grinder [27], (g) Acid-Hydrolysis [21], and (h) FE-SEM image of nano-cellulose by using Disk-Grinder [30].

Kumar et al. (2014) reported the extraction of CNCs from sugarcane bagasse based chemically purified cellulose [29] by acid hydrolysis (H_2SO_4: 64% (w/w)) at 45°C for 60 min. The obtained CNCs were of ‘rodlike' shape and have average length (L) range within 250-480 nm and average diameter (D) range within 20-60 nm. Energy-dispersive X-ray (EDX) showed 0.72% sulphur impurity and obtained CNC showed higher crystallinity (%) as 72.5% [30]. Ghaderi et al. (2014) prepared the all-cellulose nanocomposite film from sugarcane bagasse based cellulose nanofibres using N,N-dimethylacetamide/lithium chloride (DMAc/LiCl) as solvent. In this study, water slurry having 1 wt% sugarcane bagasse cellulose fibres (isolated by the treatment of acidified sodium chlorite and potassium hydroxide) was passed through a disk grinder at 1500 rpm to extract bagasse nanofibres and prepared nanofibre sheets with the thickness range of 50 to 70 µm as starting material for the fabrication of all-cellulose nanocomposites (ACNC) where nanofibre sheets were submerged in a solution of DMAc/LiCl (8% LiCl) solution for six duration of dissolution time within 5-120 min at room temperature followed by treatment with ethanol. Depending on immersion time, the thickness of ACNC was 60-90 µm and demonstrated agro-waste can be converted to the high performance nanocomposite (tensile strength: 140 MPa) [31]. Morphological analyses (TEM and FE-SEM) and dimensions of nano-cellulose are given in Figure 1 and Table 1, respectively.

Table 1: Different extraction methods, parameters, and dimensions of nano-cellulose from sugarcane bagasse

Extraction Method	Parameters	Dimensions of Nano-Cellulose	Ref.
Acid Hydrolysis (H_2SO_4)	Conc. = 65 wt%, Temp. = 45°C ,Time = 45 min	L = 84-102 nm and D=4-12 nm	[21]
	Conc. = 64 wt%, Temp. = 45°C, Time = 30 min	Average length (L) of 255±55 nm and diameter (D) of 4±2 nm	[22]
	Conc. = 60% (w/v), Temp. = 50°C, Time = 5 h	AFM: 70-90 nm (D), DLS: 18.17-220 nm, TEM: 170 nm x 35 nm (L x D)	[23]
	Conc. = 64% (w/w), Temp. = 45°C, Time = 60 min	L= 250-480 nm and D= 20-60 nm	[29]
Alkaline-Hydrolysis (NaOH), Acid-Hydrolysis (H_2SO_4)	NaOH = 50%, Temp. = 40°C, Time = 60 min and H_2SO_4 = 50%, Temp. = 40°C, 60°C, and 80°C, Time = 60 min	--	[25]
High-Pressure Homogenization	Solvent = 1-butyl-3-methylimidazolium chloride ([Bmim]Cl), Pressure = 80 MPa for 30 cycles	D = 10-20 nm	[24]
Enzymatic Hydrolysis-Sonication	Combination of V (hemicell/pectinase) and F (endoglucanase) (V2F3),Temperature = 50°C, Time = 70 h	D: 40 nm	[28]
Disk-Grinder	Run = 2 Cycles, Speed = 1500 rpm	Average D: 39 nm	[30]
Shear Ultrafine Friction Grinder /High pressure homogenization	Run = 30 times for Shear Ultrafine Friction Grinder and Run = 10 times for High pressure homogenization	D: ~5 to 50 nm (Shear Ultrafine Friction Grinder)	[26,27]

4. Conclusion

Sugarcane bagasse is an agro-industrial-waste and has high potential for the value-added products. Though, it has already been utilized for many potential applications such as paper, newspaper, textiles fibres, paper board, construction, etc. but there still a wide possibility of this lignocellulosic biomaterial to be exploited for industrial and biomedical applications. This small review of the extraction of nano-cellulose from this agro-waste may provide the insight for further research.

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5. Corresponding Address

Dr. Yuvraj Singh Negi
Professor
Department of Polymer and Process Engineering,
Indian Institute of Technology Roorkee, INDIA
E-Mail: yuvrajnegi@gmail.com