The Open Biotechnology Journal
DOI: 10.2174/0118740707372946250430102601, 2025, 19, e18740707372946
ISSN: 1874-0707
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RESEARCH ARTICLE **OPEN ACCESS**

Production of Bacteria Cellulose from Hydrolysate of Banana, Sago, and Potato Wastes

Mustapha Akil[1], Dayang Radiah Awang Biak[1] and Halimatun S. Zainuddin[1,*]

[1]*Department of Chemical and Environmental Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia*

Abstract:

Introduction: This article studies the bacterial cellulose (BC) produced using hydrolysates obtained from three Malaysian domestic agricultural wastes which are banana peels, potato peels, and sago effluent.

Methods: The wastes were hydrolysed using sulphuric acid at concentration of 4% (v/v) or 6% (v/v) for 20 minutes at two different temperatures, 105°C and 121°C, before being used as a carbon source in a culture media for the production of BC.

Results: Banana peel hydrolysate produced the highest BC yield (2.89 g/L) compared to potato peel hydrolysate (2.42 g/L) and sago effluent (0.38 g/L). However, the potato peel hydrolysate contains a higher glucose concentration (43.44 mg/mL) than banana peel hydrolysate (19.15 mg/mL). It was investigated that pH 6 as the initial pH of fermentation media and 2.0% of initial carbon source concentration are the best conditions for the fermentation of BC using banana peel hydrolysate as a carbon source. The morphology of BC produced from banana peel hydrolysate captured by SEM has ultrafine fibrils and a pore-like reticulated structure, similar to BC produced from standard HS media.

Conclusion: This study showed that banana peel hydrolysate is a promising carbon source for BC production, yielding the highest BC yield with desirable characteristics. In addition, the optimal fermentation conditions were identified in this study, which is useful for large-scale or industrial production.

Keywords: Bacterial cellulose, Waste hydrolysate, SEM, TGA, FTIR, Sulphuric acid.

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*Address correspondence to this author at the Department of Chemical and Environmental Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia; Tel: +603-89466286; Fax: +603-97694397; E-mail: halimatun_zai@upm.edu.my

Cite as: Akil M, Biak D, Zainuddin H. Production of Bacteria Cellulose from Hydrolysate of Banana, Sago, and Potato Wastes. Open Biotechnol J, 2025; 19: e18740707372946. http://dx.doi.org/10.2174/0118740707372946250430102601

Received: December 12, 2024
Revised: March 18, 2025
Accepted: March 19, 2025
Published: May 08, 2025

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1. INTRODUCTION

Bacterial cellulose (BC) is a biopolymer produced by bacteria from various strains, such as *Komagataeibacter, Rhizobium, Acetobacter, Agrobacterium,* and *Sarcina* [1-3]. BC is a unique polymer with good crystallinity, excellent mechanical strength, and high water-holding capacity. In addition, BC is pure cellulose. Compared to plant cellulose, which contains lignin, pectin, hemicellulose, and other compounds, BC does not require any purification methods to recover pure cellulose [4]. These characteristics made BC the center of attention for applications in food, medicine, and cosmetics [4-10].

The primary carbon source for BC production was glucose [3, 11]. Later, researchers shifted to using other saccharides and alcohol [8] as carbon sources for fermentation. In the food industry, BC is produced in *nata de coco* from coconut juice [5]. Hence, this pioneered BC production from various juices such as date, orange, pineapple, apple, pear, and other fruits [12, 13]. From here, researchers also ex-

plored the usage of agricultural waste such as rice, wheat, corn, sorghum, barley, cotton, groundnut, jute, legumes, and palm oil for the production of BC [14-16].

Malaysia's three abundant agricultural biomass wastes are bananas, potatoes, and sago. Banana is the second most produced fruit in the world, next to citrus, and is identified as one of the primary exports in Malaysia [17]. In Malaysia, a small banana processing facility can produce up to 27.15 kg of banana peel waste per month, the highest waste produced among other crops in the same facility [18]. Potato peels are not the highest agricultural waste recorded in Malaysia, but they contain a lot of starch, cellulose, hemicellulose, and lignin, which have been utilized by many studies to produce high-value products [19, 20]. It was estimated that potato peels account for about 73.3% of total carbohydrates [21], and these high carbohydrate contents can be utilized for BC production. Meanwhile, in East Malaysia, the sago starch production facilities generated approximately 1000 m^3 of effluent per day for the production processes [22]. Since the effluent contains sago pitch and starch, it can be used as a carbon source for BC production.

The abundant amount of these three wastes in Malaysia from various agricultural sectors can be utilized as carbon sources for BC production. One way to do this is to convert the carbohydrates in the agricultural wastes into simple sugars such as glucose *via* hydrolysis. Acid hydrolysis is one of the best options for converting starch and lignocellulose into simple sugars as the process is cheap, simple and effective with a readily available catalyst [23, 24]. Important parameters that need to be observed for acid hydrolysis are temperature, acid concentration, and reaction period [25].

In this study, acid hydrolysis is used to convert agricultural wastes into glucose and simpler carbohydrates, which can then be used as carbon sources to produce BC. The strain used in this study is *Acetobacter xylinum* 0416, isolated by the Malaysian Agricultural Research and Development Institute (MARDI). The production of BC from three different carbon sources, which were sago effluent, banana peel, and potato peel hydrolysate was investigated in this study. Then, the BC was analyzed for its characteristics using SEM, TGA, and FTIR.

2. MATERIALS AND METHODS

2.1. Cultivation

Acetobacter xylinum 0416, used for this study, was obtained from the Malaysian Agricultural Research and Development Institute (MARDI). Hestrin and Schramm (HS) medium was used to produce seed cultures, which are composed of 2% (w/v) glucose, 0.5% (w/v) yeast extract, 0.5% (w/v) bacto-peptone, 0.27% (w/v) disodium hydrophosphate, and 0.115% (w/v) citric acid [11]. The cultivation method was followed by Lotfiman *et al*. [12], where the seed culture was prepared in a 250 ml conical flask with an initial pH of 6. The seed culture medium was then sterilized before being inoculated with 10% (v/v) of cell suspension culture obtained from MARDI. The seed culture was incubated at 30°C and left for 3 days.

2.2. Preparation of Hydrolysate

The diluted acid hydrolysis method used in this study was based on the study by Aguilar *et al*. [26]. 4% (w/v) and 6% (w/v) of sulphuric acid were used to hydrolyze the waste at a ratio of 1:10 (w/v). The hydrolysis reaction was performed at 105°C or 122°C for 20 minutes in an autoclave machine. Then, the autoclaved beaker containing the hydrolysate was immediately quenched in an ice-water bath [27] after autoclaving. The pH of the mixture was adjusted by adding sodium hydroxide (NaOH). The glucose concentration for each hydrolysate was analyzed using HPLC (Agilent, USA) with RCM-Monosaccharide Ca^{+2} 8% column (Rezex, USA).

2.3. Fermentation

Three hydrolysates derived from sago effluent, potato peel, and banana peel using acid hydrolysis were used as carbon sources to produce BC. These hydrolysates replaced the glucose content in the HS medium. 10% (v/v) of seed culture was inoculated in the modified medium with an initial pH of 6.0. The incubation was conducted at 30°C for 21 days. The preliminary study indicates that banana peel produced the highest yield of BC. Therefore, it was used as a main carbon source in this work. As illustrated in Table **1**, the parameters were selected and operated for 21 days incubation time.

Table 1. Parameters set to find the suitable pH range for different concentrations of banana peel hydrolysate.

Conical Flask	pH	Carbon Source (%)
BH1	5	0.5
BH2	6	0.5
BH3	7	0.5
BH4	8	0.5
-	-	-
BH5	5	1
BH6	6	1
BH7	7	1
BH8	8	1
-	-	-
BH9	5	2
BH10	6	2
BH11	7	2
BH12	8	2

2.4. Preparation of Dried BC

Harvesting of the BC was conducted using the method described by Hwang *et al*. with some modifications [28]. The BC was washed with distilled water and then soaked and boiled in 0.5 M sodium hydroxide (NaOH) solution for 30 minutes to kill and eliminate the bacteria on the BC [11, 12]. Then, the sheet was soaked in distilled water overnight to remove the remaining NaOH. The BC was dried at room temperature until a constant weight was obtained. The dry weight of the pellicle was recorded to report the BC yield. Yield was calculated as dry weight over culture volume or nutrient volume.

2.5. Characterization

A scanning electron microscope (SEM) was conducted to observe the fibrils' BC structure, morphology, and diameter [29]. The SEM model used in this work is S-3400 (Hitachi Ltd., Japan). BC was freeze-dried, cut into small pieces, and gold-coated for 3 minutes under vacuum conditions. It was operated at 5.00 kV at a magnification of 10000.

A thermogravimetric analyzer (TGA), a thermal weight change analysis instrument, was used to determine the thermal stability of the product. TGA analysis was conducted using a Mettler Toledo (Switzerland) instrument. Approximately 8 mg of BC sample was kept in a crucible and heated in a furnace. The flow rate of inert gas, pure nitrogen, was set at 10 ml min^{-1}. The sample was heated from 25°C to 900°C at 10°C min^{-1}. The decomposition temperatures and associated weight loss were determined based on raw and derivative data obtained.

The chemical structures using the existences of functional groups in the samples were identified using FTIR (Nicolet Nexus 470, USA) technique with an attenuated total reflectance (ATR) mode in the range between 4000 to 800 cm^{-1} averaging 64 scans at a resolution of 8 cm^{-1} was operated to analyze the sample. Each air-dried BC sample in the form of a thin film placed across a hole in the sample holder before analyzed.

2.6. Statistical Analysis

Glucose concentration and BC yield measurement were conducted with duplicates. The mean and standard deviation (σ) were computed using Microsoft Excel. The coefficient of Variation (CV) was calculated to check the variability of the replicate samples from the mean value using the Eq. (**1**) below:

$$CV = \frac{\sigma}{Mean} \times 100\% \quad \textbf{(1)}$$

Using Aronhime *et al*. (2014) as a reference, CV ≤10% was considered excellent reproducibility and low variability, CV between 10–20% was considered moderate variability, and CV >30% was considered low variability and poor reproducibility [30].

3. RESULTS AND DISCUSSION

Hydrolysis of sago effluent, potato peels, and banana peels was conducted using 4% and 6% H_2SO_4 at 105°C and 121°C. This range was chosen based on the range used by Aguilar *et al*. (2002) [12]. The reaction converts lignocellulosic and starch materials into simple sugars [31], such as glucose, which *Acetobacter xylinum* will use to produce BC. Fig. (**1**) below shows that the hydrolysis reaction on potato peels produces more glucose than other wastes. Hydrolysis conducted at 121°C for peels produces higher glucose concentration than at 105°C because high temperature can facilitate the breakdown of hemicellulose to cellulose, thus increasing the amount of cellulose to be converted to glucose in the hydrolysate [32].

Compared to potato and banana peel waste, which typically contain 46%-52% of starch [33-35] and 12% to 30% of starch [36-38], the starch content in sago effluent is much lower. Awg.-Adeni *et al*. mentioned that sago wastewater contains 94%-97% water and the rest is hampas [39]. Two different sources have reported that hampas contain 49% starch and the rest is lignocellulose [40, 41]. Acid hydrolysis targets these starches and converts them to glucose. Since the starch concentration in sago effluent was small, the hydrolysis product from this waste yielded the lowest glucose concentration.

Hydrolysates with the highest glucose concentrations from the previous experiment were used as carbon sources for BC production: sago effluent (1.68 mg/mL), potato peel (43.65 mg/ml), and banana peel (19.15 mg/ml). Despite the higher glucose concentration in potato peel hydrolysate, banana peel hydrolysate produced the highest BC yield after 21 days with 2.89 g/L, which is 1.2 times and 7.6 times higher than potato peel (2.42 g/L) and sago effluent (0.38 g/L), respectively. The lower BC yield from sago effluent is due to insufficient glucose, while potato peel's high glucose leads to excess gluconic acid formation, lowering the pH and reducing BC production. This confirms that an optimal glucose concentration is necessary for high BC yield, as supported by Masaoka *et al*. [42] and Jeff Sumardee *et al*. [43]. Both groups agreed that a high initial glucose concentration causes the excess glucose to be converted to gluconic acid during fermentation [42, 43]. Formation of a high amount of gluconic acid causes the pH of the media to drop, thus decreasing the BC yield; this statement is supported by the two groups and a study from Oikawa *et al*. [44]. A review from Zikmanis *et al*. (2021) [45] commented that a growth environment below pH 5 inhibits the growth of the bacteria and causes a reduction in BC yield. This explains the lower BC yield from potato peel hydrolysate despite its higher glucose concentration than banana peel hydrolysate (Fig. **2**).

Carbon source concentration plays a vital role in BC production. Several researchers found different carbon source concentrations that enhance BC production. Keshk *et al*. [8] found that 1.0% of glucose as carbon source concentration is the optimum condition for BC production, while Pourramezan *et al*. (2009) and Son *et al*. found it as 1.5% of sucrose and glucose respectively [46, 47]. Many authors suggested 2.0% of glucose as a carbon source concentration for their BC production [2, 11, 28].

Banana peel hydrolysate gives the highest BC yield among those hydrolysates, so it was chosen as a carbon source in this study. According to the HPLC result, the highest glucose was found to be 19.15 mg/ml, which can be defined as almost 2.0% from the culture medium. Therefore, it was used as a stock solution and diluted into 0.5% and 1.0% to find the suitable carbon source concentration for BC production.

For all glucose concentrations, four different initial pH levels were selected: 5, 6, 7, and 8. The typical pH for BC production is 4-7 [48, 46]. Before that, it was investigated and found that at initial pH 3 and 4, the amount of bacterial cellulose produced was low. From the result illustrated in Fig. (**3**), which is according to the dry weight of BC, pH 7 is the optimum among others for 0.5% and 1.0% of glucose concentration, where 0.65 g/L and 1.12 g/L of BC can be

produced, respectively. For 2.0% of glucose concentration, pH 6 was found as the optimum pH for BC production, producing about 2.93 g/L of BC, which is 4.5-fold and 2.6-fold higher than 0.5% and 1.0% of glucose concentration, respectively.

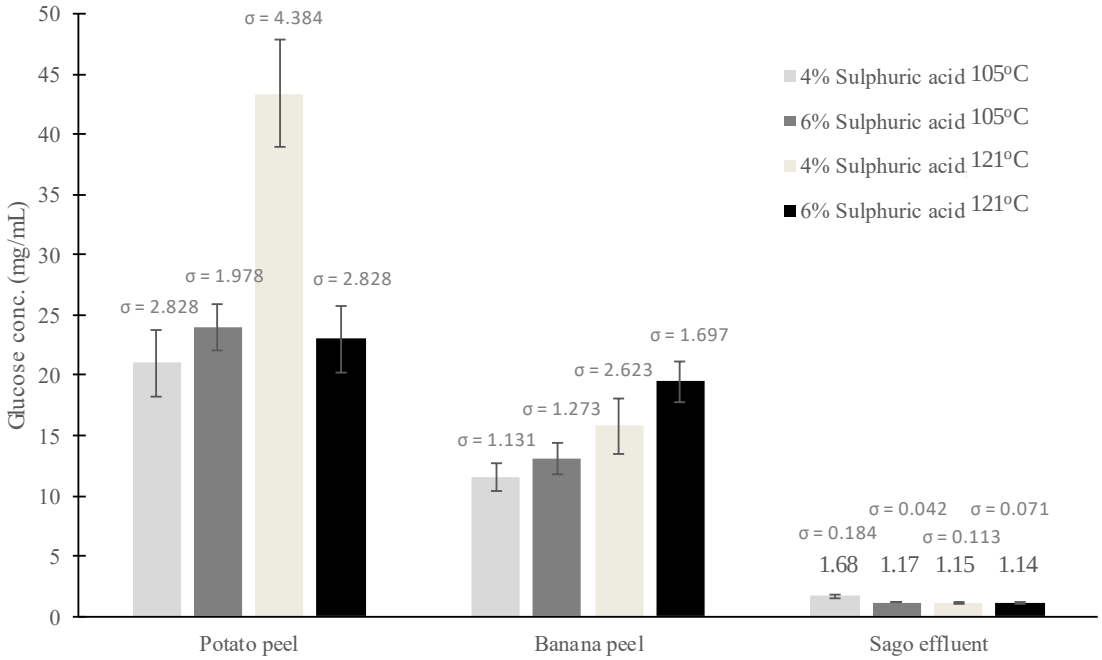


Fig. (1). Glucose concentration from acid hydrolysis reaction using three different wastes at two sulphuric acid concentrations and two reaction temperatures.

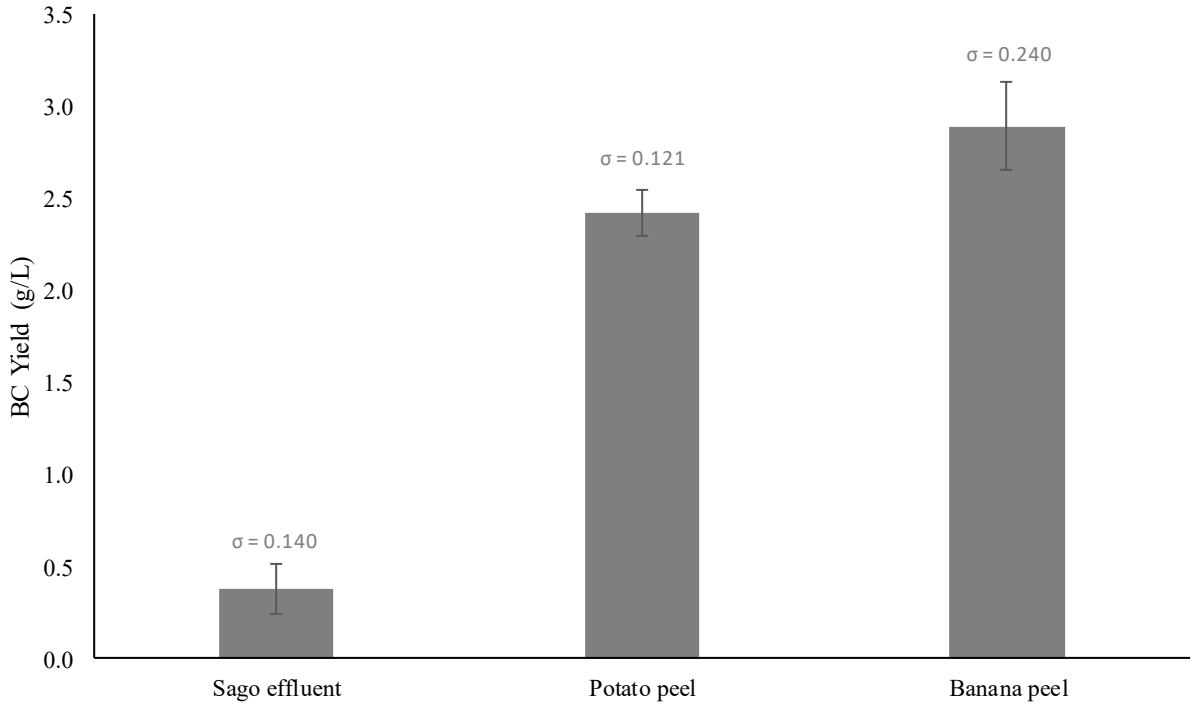


Fig. (2). Dry weight (g/l) of BC fermented from sago effluent, potato peel, and banana peel.

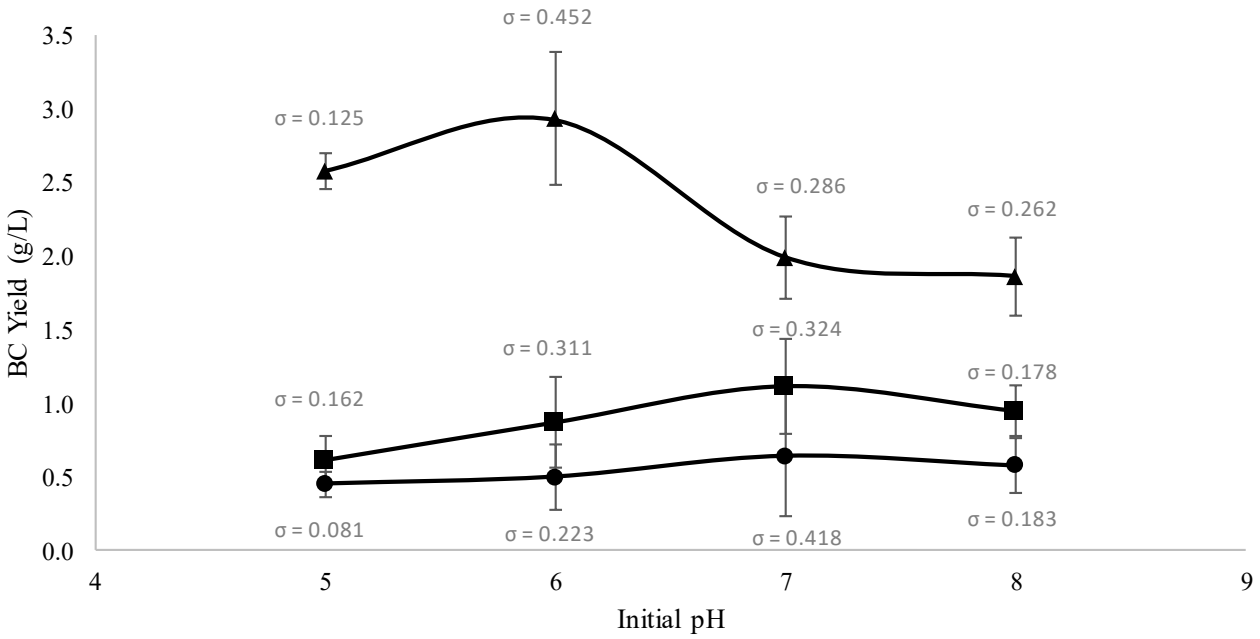


Fig. (3). Dry weight of BC at different initial pH for (●) 0.5%, (■) 1.0% and (▲) 2.0% of glucose as carbon source concentration after 21 days of incubation.

The initial pH of the media plays a crucial role in maximizing the BC yield. The optimum initial pH requirement is different from strain to strain [49], and in this study, Fig. (**3**) showed that optimum pH also depends on the concentration of glucose as a carbon source in the media. A 2% carbon source is the standard glucose concentration in HS media and is commonly used in growing BC. Masaoka *et al*. (1993) have proven that 2% is the optimal glucose concentration that provides the highest BC yield when cultivating A. *xylinum,* which aligns with this study [42]. In addition, media with an initial pH of 6 resulted in the highest BC yield, which also aligned with the result from Masaoka *et al*. (1993) [42]. However, there were not many references that explain the dependency of glucose concentration on the optimal initial pH of media. Fig. (**3**) below shows that low glucose concentrations at 1% and 0.5% caused the optimum initial pH of the media to switch to pH 7. Since there was not much literature to explain this phenomenon, we can look at a study from Hutchens *et al*. (2007), where switching the carbon sources in the media from glucose to mannitol would cause the optimal initial pH to switch from pH 5.5 to pH 7 for *Gluconacetobacter hansenii* [50]. The switch in carbon sources implies that glucose starvation causes a shift in the bacteria's metabolism. Similar to this study, low glucose concentration at 1% and below would eventually shift the bacteria's metabolism and cause the bacteria to produce a slightly higher BC yield at pH 7 compared to pH 6. However, a thorough metabolism study that looks at various genes in *A. xylinum* being turned on and off during the glucose starvation process should be conducted in the future to explain this phenomenon adequately.

3.1. Statistical Analysis

Fig. (**1**) reports that potato peel hydrolyzed at 121°C resulted in the highest glucose concentration (~43.65 mg/mL), followed by banana peel hydrolysate (19.15 mg/mL) and sago effluent. The standard deviations (σ) reported variations in glucose concentration measurements across different hydrolysis conditions. The highest standard deviations (σ = 4.384) were reported for potato peel hydrolysis using 4% sulphuric acid at 121°C. However, the value is relatively small compared to the mean, which is 43.4 mg/mL glucose, approximately 10% of the coefficient variation (CV) value. This implies that most hydrolysis samples are close to the mean value and have low variability from each replicate. Fig. (**2**) reports that media containing banana peel hydrolysate produced the highest BC yield (2.89 g/L). Again, most of these samples had low CV values. Hence, most samples had values close to the mean and low variability from each replicate. Lastly, Fig. (**3**) shows a strong correlation between initial pH, glucose concentration, and BC yield, suggesting that there is a metabolic shift in response to nutrient availability, thus causing the optimal initial pH to shift to pH 7 from pH 6. The standard deviations (σ) ranged from 0.081 to 0.452, indicating a moderate variation in BC production, with CV value for some data to be higher than 10%. However, most of the data in this study has low standard deviations (σ) and low CV values, indicating that most yield values are close to the mean and have high reproducibility of results.

3.2. BC Characterization

3.2.1. Morphology of BC

The morphology of BC was observed under a Scanning Electron Microscope (SEM) and presented in Fig. (**4a-d**). The result shows that the BC produced from banana peel hydrolysate is similar to that produced in HS medium culture produced by [7]. It has irregular ultrafine fibrils and a crossed and pore-like reticulated structure [51]. In addition, it can be seen that tunnels exist where it is needed by the bacteria for the sufficiency of their movement [51, 52].

Çoban and Biyik reported that when a different type of carbon source is used, the morphology of BC produced also changes [53]. Thus, in this study, even though BC was produced from different initial concentrations of glucose, it was found that there is no difference in morphology in terms of fibrils' size for each BC. This might be due to the same type of sugar existing in each hydrolysate. BC produced from banana peel hydrolysate has microfibrils' size in the range of approximately 50-100 nm, following a previous study [54-56].

3.2.2. Thermal Stability of BC

Thermogravimetric analysis (TGA) was performed on dry BC to study its thermal stability. From the result obtained, as illustrated in Fig. (**5**), three distinct points can be observed in the weight loss of BC. The same pattern can be observed for 1.0% and 0.5% carbon source concentrations. The first stage of weight loss is an endothermic

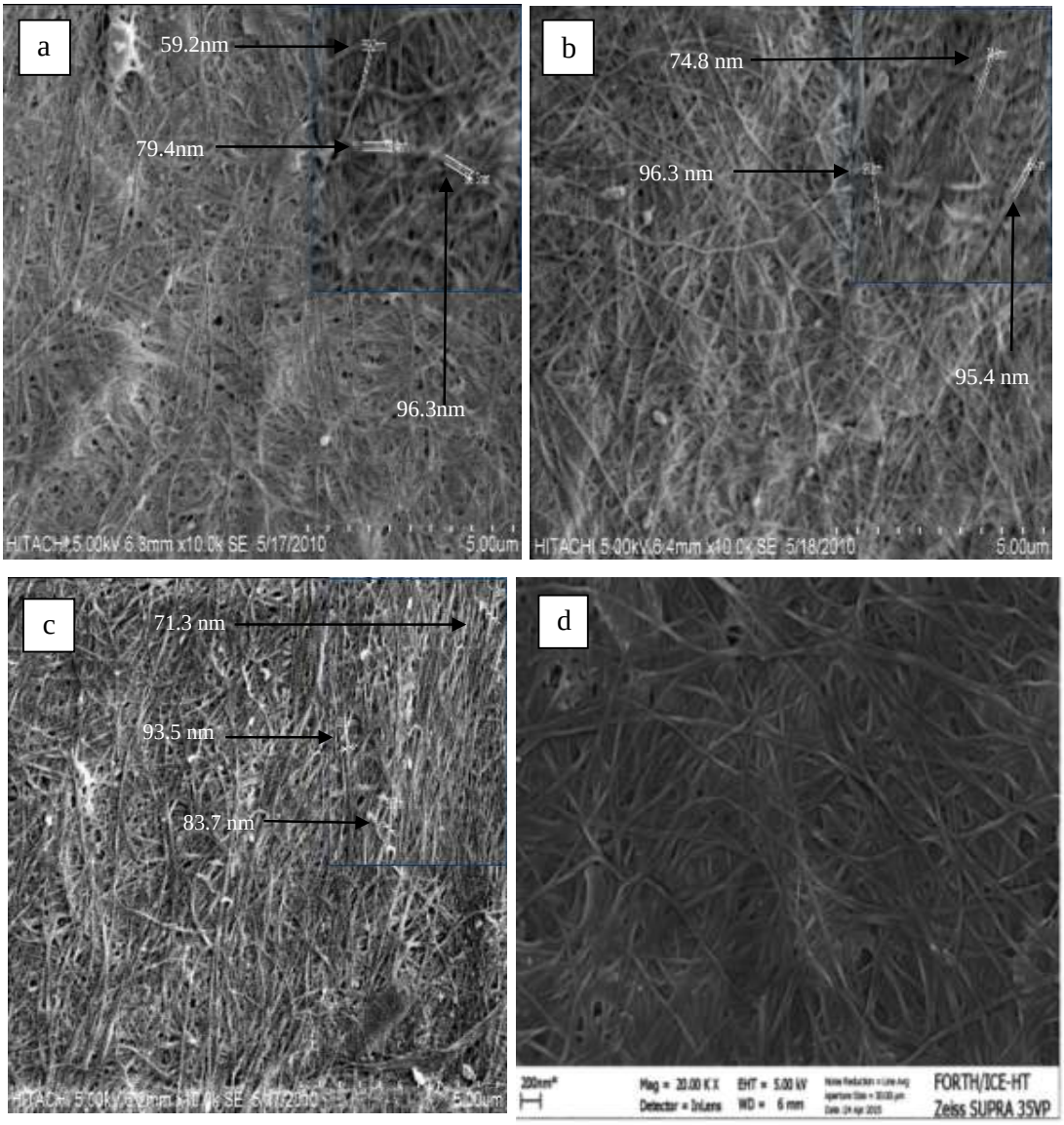


Fig. (4). BC structure under SEM. (**a**) 0.5% carbon source, pH 7, (**b**) 1.0% carbon source, pH 7, (**c**) 2.0% carbon source, pH 6, and (**d**) BC from HS medium [51].

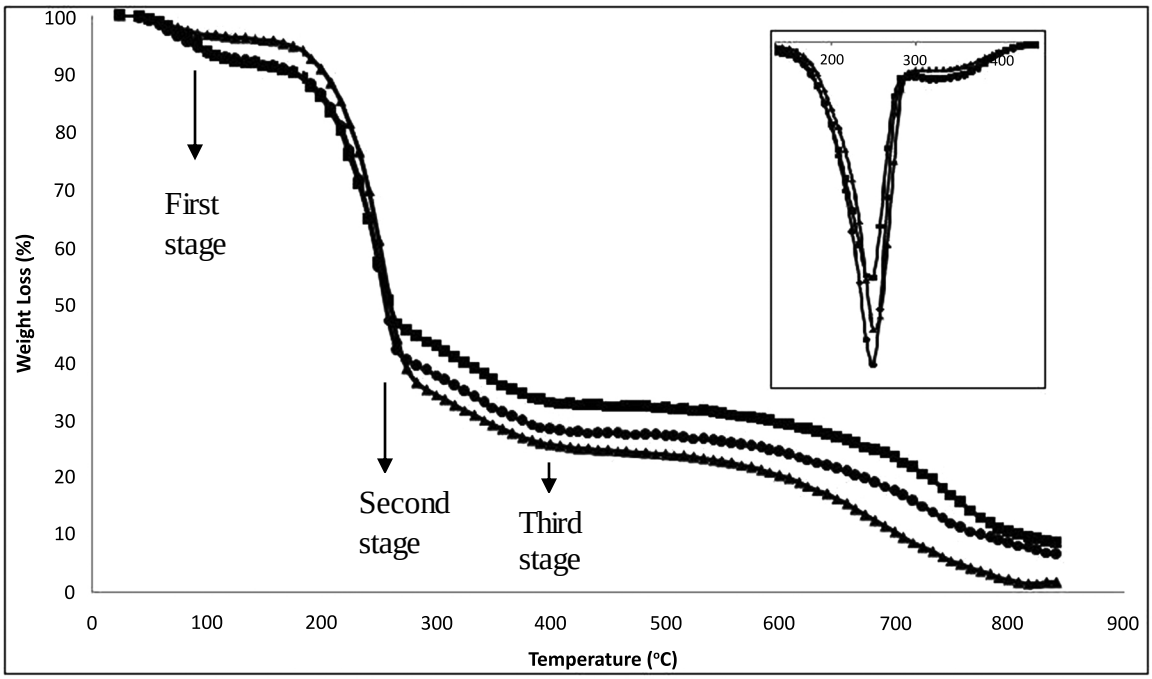


Fig. (5). The TGA curve of BC for (▲) 0.5% carbon source concentration and pH 7, (■) 1.0% carbon source concentration and pH 7, and (●) 2.0% carbon source concentration and pH 6 after 16 days of incubation period. Inset is the DTG curve for each condition.

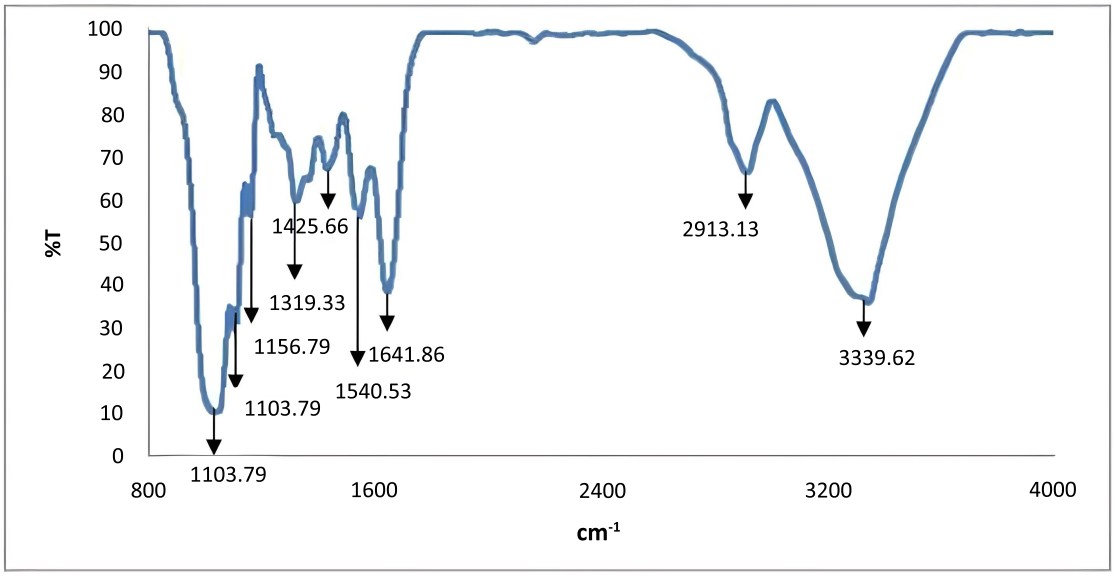


Fig. (6). FTIR spectra of BC.

process, namely dehydrocellulose [57]. It can be seen around 100 °C, indicating the loss of moisture entrapped in the microfibrils of BC. According to Cheng *et al*., the weight loss found in the range of 200 °C to 360 °C indicates the removal of small molecular fragments such as hydroxyl and methylhydroxyl groups [58]. In this stage, a depolymerisation reaction took place and yielded levoglucosan (1,6-anhydro-ß-D-glucopyranose) as an essential intermediate. This study found this stage at 250°C, as illustrated in the inset image in Fig. (**5**). The third weight loss stage, which is almost from 400 °C until the end, represents the degradation of the polymeric chain and pyran, the six-member cyclic structure.

A few factors may affect the thermogravimetric measurement, including sample preparation. Sample size and homogeneity may affect heat transfer within the samples and consequently influence the diffusion rate of the reaction [59].

3.3. FTIR Analysis

Fourier Transform Infrared Spectroscopy (FTIR) was performed to study the molecular bonding in the BC produced from banana peel hydrolysate. By obtaining the percent transmission as a function of incident radiation wavelength, the FTIR result can provide the type of bond in the BC sample where the purity of BC can be investigated. As illustrated in Fig. (**6**), the functional group that exists in the BC was found to be similar to that found by Dobre *et al*. (2010) and Klemm *et al*. [7, 60]. The characteristic band of BC on the graph shows high absorption at 3339.62 cm^{-1}, representing the existence of the hydroxyl (OH) group [61]. C-H stretching can be seen at 2913.13 cm^{-1} while 1428.66 cm^{-1} shows the presence of C-H bending vibration [60]. A band shown at 1641.86 cm^{-1} was attributed to the existence of the carbonyl (C=O) group in the BC [62, 63]. A band that exists at 1540.53 is attributed to C-C stretching [64]. At 1319.33, C-H wagging was identified [65]. C-O-C vibration can be detected at 1103.97 and 1156.79 [66] while fingerprint region at 1029.10 cm^{-1}, C-O stretching was shown. From this result, it can be concluded that pure BC was produced using banana peel hydrolysate due to the similarity of the peak appearance with other's work [7, 60, 63].

CONCLUSION

From this study, BC was successfully produced from the hydrolysate of wastes. Banana peel hydrolysate was found to produce the highest BC yield among other wastes. Initial pH 6 and 2.0% of carbon source concentration from banana peel hydrolysate were the best parameters for BC production. SEM images show that BC has small microfibrils and a crossed and pore-like reticulated structure. TGA results indicate that BC has three distinct points that can be observed in the weight loss process, namely dehydrocellulose, depolymerisation, degradation of the polymeric chain, and pyran removal. FTIR result shows that BC produced in this study has a common functional group for typical BC.

AUTHORS' CONTRIBUTIONS

The authors confirm contribution to the paper as follows: M.A.; writing manuscript and conduct experimentation; D.R. A.B.: conceptualizing and resouces; H.S.Z.: preparation of manuscript, reviewing, and analysis of data. All authors reviewed the results and approved the final version of the manuscript.

LIST OF ABBREVIATIONS

BC	=	Bacterial Cellulose
MARDI	=	Malaysian Agricultural Research and Development Institute
HS	=	Hestrin and Schramm
SEM	=	Scanning Electron Microscope
TGA	=	Thermogravimetric Analyzer
ATR	=	Attenuated Total Reflectance
CV	=	Coefficient of Variation

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

HUMAN AND ANIMAL RIGHTS

Not applicable.

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF DATA AND MATERIALS

The data and supportive information are available within the article.

FUNDING

This research was funded by Fundamental Research Grant Scheme number 5524195 from the Ministry of Higher Education, Malaysia.

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

ACKNOWLEDGEMENTS

The authors thank MARDI and Sciencefund for their support in this project.

REFERENCES

[1] Choi SM, Rao KM, Zo SM, Shin EJ, Han SS. Bacterial cellulose and its applications. Polymers 2022; 14(6): 1080. http://dx.doi.org/10.3390/polym14061080 PMID: 35335411

[2] Zhou LL, Sun DP, Hu LY, Li YW, Yang JZ. Effect of addition of sodium alginate on bacterial cellulose production by *Acetobacter xylinum*. J Ind Microbiol Biotechnol 2007; 34(7): 483-9. http://dx.doi.org/10.1007/s10295-007-0218-4 PMID: 17440758

[3] Sraphet S, Javadi B. Bacterial cellulose from food to biomedical products. Open Biotechnol J 2020; 14(1): 124-33. http://dx.doi.org/10.2174/1874070702014010124

[4] Lahiri D, Nag M, Dutta B, *et al*. Bacteria cellulose: Production, characterization, and application as antimicrobial agent. Int J Mol Sci 2021; 22(23): 12984. http://dx.doi.org/10.3390/ijms222312984 PMID: 34884787

[5] Budhiono A, Rosidi B, Taher H, Iguchi M. Kinetic aspects of bacterial cellulose formation in *nata-de-coco* culture system. Carbohydr Polym 1999; 40(2): 137-43. http://dx.doi.org/10.1016/S0144-8617(99)00050-8

[6] Krystynowicz A, Bielecki S, Czaja W, Rzyska M. Application of bacterial cellulose for clarification of fruit juices. Prog Biotechnol 2000; 17: 323-7. http://dx.doi.org/10.1016/S0921-0423(00)80088-X

[7] Klemm D, Schumann D, Udhardt U, Marsch S. Bacterial synthesized cellulose — Artificial blood vessels for microsurgery. Prog Polym Sci 2001; 26(9): 1561-603. http://dx.doi.org/10.1016/S0079-6700(01)00021-1

[8] Keshk S, Sameshima K. Evaluation of different carbon sources for bacterial cellulose production. Afr J Biotechnol 2005; 4(6): 478-82.

[9] Oshima T, Kondo K, Ohto K, Inoue K, Baba Y. Preparation of phosphorylated bacterial cellulose as an adsorbent for metal ions. React Funct Polym 2008; 68(1): 376-83. http://dx.doi.org/10.1016/j.reactfunctpolym.2007.07.046

[10] Shen W, Chen S, Shi S, *et al*. Adsorption of Cu(II) and Pb(II) onto diethylenetriamine-bacterial cellulose. Carbohydr Polym 2009; 75(1): 110-4. http://dx.doi.org/10.1016/j.carbpol.2008.07.006

[11] Hestrin S, Schramm M. Synthesis of cellulose by *Acetobacter xylinum*. 2. Preparation of freeze-dried cells capable of polymerizing glucose to cellulose. Biochem J 1954; 58(2): 345-52. http://dx.doi.org/10.1042/bj0580345 PMID: 13208601

[12] Lotfiman S, Awang Biak DR, Ti TB, Kamarudin S, Nikbin S. Influence of date syrup as a carbon source on bacterial cellulose production by *Acetobacter xylinum* 0416. Adv Polym Technol 2018; 37(4): 1085-91. http://dx.doi.org/10.1002/adv.21759

[13] Kurosumi A, Sasaki C, Yamashita Y, Nakamura Y. Utilization of various fruit juices as carbon source for production of bacterial cellulose by *Acetobacter xylinum* NBRC 13693. Carbohydr Polym 2009; 76(2): 333-5. http://dx.doi.org/10.1016/j.carbpol.2008.11.009

[14] Urbina L, Corcuera MÁ, Gabilondo N, Eceiza A, Retegi A. A review of bacterial cellulose: sustainable production from agricultural waste and applications in various fields. Cellulose 2021; 28(13): 8229-53. http://dx.doi.org/10.1007/s10570-021-04020-4

[15] Ezejiofor T, Enebaku UE, Ogueke C. Waste to wealth-value recovery from agrofood processing wastes using biotechnology: A review. Biotechnol J Int 2014; 4(4): 418-81.

[16] Sadh PK, Duhan S, Duhan JS. Agro-industrial wastes and their utilization using solid state fermentation: A review. Bioresour Bioprocess 2018; 5(1): 1-15. http://dx.doi.org/10.1186/s40643-017-0187-z

[17] Tan BC. Can banana be a success story for Malaysia? J Agribus Mark 2022; 9(1): 13-22. http://dx.doi.org/10.56527/jabm.9.1.2

[18] Abd Kadir A, Azhari NW, Jamaludin SN. Study on composition and generation of food waste in makanan ringan mas industry. MATEC Web Conf 2016; 103: 05002. http://dx.doi.org/10.1051/matecconf/201710305002

[19] Okeke B, Frankenberger W Jr. Use of starch and potato peel waste for perchlorate bioreduction in water. Sci Total Environ 2005; 347(1-3): 35-45. http://dx.doi.org/10.1016/j.scitotenv.2004.12.041 PMID: 16084965

[20] El Sheikha AF, Ray RC. Potential impacts of bioprocessing of sweet potato: Review. Crit Rev Food Sci Nutr 2017; 57(3): 455-71. http://dx.doi.org/10.1080/10408398.2014.960909 PMID: 25975980

[21] Shukla J, Kar R. Potato peel as a solid state substrate for thermostable α-amylase production by thermophilic Bacillus isolates. World J Microbiol Biotechnol 2006; 22(5): 417-22. http://dx.doi.org/10.1007/s11274-005-9049-5

[22] Vikineswary S, Shim YL, Thambirajah JJ, Blakebrough N. Possible microbial utilization of sago processing wastes. Resour Conserv Recycling 1994; 11(1-4): 289-96. http://dx.doi.org/10.1016/0921-3449(94)90096-5

[23] Tasić MB, Konstantinović BV, Lazić ML, Veljković VB. The acid hydrolysis of potato tuber mash in bioethanol production. Biochem Eng J 2009; 43(2): 208-11. http://dx.doi.org/10.1016/j.bej.2008.09.019

[24] Zheng Y, Pan Z, Zhang R. Overview of biomass pretreatment for cellulosic ethanol production. Int J Agric Biol Eng 2009; 2(3): 51-68. http://dx.doi.org/10.1007/s13205-015-0279-4

[25] Ajani O, Agarry SE, Agbede OO. A comparative kinetic study of acidic hydrolysis of wastes cellulose from agricultural derived biomass. J Appl Sci Environ Manag 2011; 15(4): 531-7.

[26] Aguilar R, Ramírez JA, Garrote G, Vázquez M. Kinetic study of the acid hydrolysis of sugar cane bagasse. J Food Eng 2002; 55(4): 309-18. http://dx.doi.org/10.1016/S0260-8774(02)00106-1

[27] Kumoro AC, Ngoh GC, Hasan M, Ong CH, Teoh EC. Conversion of fibrous sago (*Metroxylon sagu*) waste into fermentable sugar *via* acid and enzymatic hydrolysis. Asian J Sci Res 2008; 1(4): 412-20. http://dx.doi.org/10.3923/ajsr.2008.412.420

[28] Hwang JW, Yang YK, Hwang JK, Pyun YR, Kim YS. Effects of pH and dissolved oxygen on cellulose production by *Acetobacter xylinum* BRC5 in agitated culture. J Biosci Bioeng 1999; 88(2): 183-8. http://dx.doi.org/10.1016/S1389-1723(99)80199-6 PMID: 16232595

[29] Goelzer FDE, Faria-Tischer PCS, Vitorino JC, Sierakowski MR, Tischer CA. Production and characterization of nanospheres of bacterial cellulose from Acetobacter xylinum from processed rice bark. Mater Sci Eng C 2009; 29(2): 546-51. http://dx.doi.org/10.1016/j.msec.2008.10.013

[30] Aronhime S, Calcagno C, Jajamovich GH, *et al*. DCE-MRI of the liver: Effect of linear and nonlinear conversions on hepatic perfusion quantification and reproducibility. J Magn Reson Imaging 2014; 40(1): 90-8. http://dx.doi.org/10.1002/jmri.24341 PMID: 24923476

[31] Sun Y, Cheng J. Hydrolysis of lignocellulosic materials for ethanol production: A review. Bioresour Technol 2002; 83(1): 1-11. http://dx.doi.org/10.1016/S0960-8524(01)00212-7 PMID: 12058826

[32] Purnamasari I, Supraptiah E, Daniar R, Ramayanti C, Lestari T, Nurmahdani E. Hydrolysis reaction kinetics of baggasse and banana peel in the process of bioethanol production. Proceedings of the 6th FIRST 2022 International Conference (FIRST-ESCSI-22). 2023, pp. 105-112 http://dx.doi.org/10.2991/978-94-6463-118-0_12

[33] Arapoglou D, Varzakas T, Vlyssides A, Israilides C. Ethanol production from potato peel waste (PPW). Waste Manag 2010; 30(10): 1898-902. http://dx.doi.org/10.1016/j.wasman.2010.04.017 PMID: 20471817

[34] Thakur M, Rai AK, Mishra BB, Singh SP. Novel insight into valorization of potato peel biomass into type III resistant starch and maltooligosaccharide molecules. Environ Technol Innov 2021; 24: 101827. http://dx.doi.org/10.1016/j.eti.2021.101827

[35] Rodríguez-Martínez B, Coelho E, Gullón B, Yáñez R, Domingues L. Potato peels waste as a sustainable source for biotechnological production of biofuels: Process optimization. Waste Manag 2023; 155: 320-8. http://dx.doi.org/10.1016/j.wasman.2022.11.007 PMID: 36413884

[36] Wachirasiri P, Julakarangka S, Wanlapa S. The effects of banana peel preparations on the properties of banana peel dietary fibre concentrate. Songklanakarin J Sci Technol 2009; 31: 605-11.

[37] Sultan NFK, Johari WLW. The development of banana peel/corn starch bioplastic film: A preliminary study. Bioremediation Sci Technol Res 2017; 5(1): 12-7. http://dx.doi.org/10.54987/bstr.v5i1.352

[38] Chandrasekar CM, Krishnamachari H, Farris S, Romano D. Development and characterization of starch-based bioactive thermoplastic packaging films derived from banana peels. Carbohydr Polym Technol Appl 2023; 5(100328): 100328. http://dx.doi.org/10.1016/j.carpta.2023.100328

[39] Awg-Adeni DS, Abd-Aziz S, Bujang K, Hassan MA. Bioconversion of sago residue into value added products. Afr J Biotechnol 2010; 9(14): 2016-21.

[40] Ozawa T, Ueno T, Negishi O, Masaki S. Chemical characteristics of hemicelluloses in the fibrous residue of sago palm. J Trop Agric 1998; 42(3): 172-8. http://dx.doi.org/10.11248/jsta1957.42.172

[41] Jenol MA, Ibrahim MF, Yee PL, Salleh MM, Abd-Aziz S. Sago biomass as a sustainable source for biohydrogen production by *Clostridium butyricum* A1. BioResources 2014; 9(1): 1007-26.

[42] Masaoka S, Ohe T, Sakota N. Production of cellulose from glucose by *Acetobacter xylinum*. J Ferment Bioeng 1993; 75(1): 18-22. http://dx.doi.org/10.1016/0922-338X(93)90171-4

[43] Jeff Sumardee NS, Mohd-Hairul AR, Mortan SH. Effect of inoculum size and glucose concentration for bacterial cellulose production by Lactobacillus acidophilus. IOP Conf Series Mater Sci Eng 2020; 991(1): 012054. http://dx.doi.org/10.1088/1757-899X/991/1/012054

[44] Oikawa T, Ohtori T, Ameyama M. Production of cellulose from D-Mannitol by *Acetobacter xylinum* KU-1. Biosci Biotechnol Biochem

1995; 59(2): 331-2.
http://dx.doi.org/10.1271/bbb.59.331

[45] Zikmanis P, Kolesovs S, Ruklisha M, Semjonovs P. Production of bacterial cellulose from glycerol: The current state and perspectives. Bioresour Bioprocess 2021; 8(1): 116.
http://dx.doi.org/10.1186/s40643-021-00468-1 PMID: 38650300

[46] Pourrameza GZ, Roayaei AM, Qezelbash QR. Optimization of culture conditions for bacterial cellulose production by *Acetobacter* sp. 4B-2. Biotechnology 2008; 8(1): 150-4.
http://dx.doi.org/10.3923/biotech.2009.150.154

[47] Son HJ, Kim HG, Kim KK, Kim HS, Kim YG, Lee SJ. Increased production of bacterial cellulose by *Acetobacter* sp. V6 in synthetic media under shaking culture conditions. Bioresour Technol 2003; 86(3): 215-9.
http://dx.doi.org/10.1016/S0960-8524(02)00176-1 PMID: 12688462

[48] Jonas R, Farah LF. Production and application of microbial cellulose. Polym Degrad Stabil 1998; 59(1-3): 101-6.
http://dx.doi.org/10.1016/S0141-3910(97)00197-3

[49] El-Gendi H, Taha TH, Ray JB, Saleh AK. Recent advances in bacterial cellulose: A low-cost effective production media, optimization strategies and applications. Cellulose 2022; 29(14): 7495-533.
http://dx.doi.org/10.1007/s10570-022-04697-1

[50] Hutchens SA, León RV, O'Neill HM, Evans BR. Statistical analysis of optimal culture conditions for *Gluconacetobacter hansenii* cellulose production. Lett Appl Microbiol 2007; 44(2): 175-80.
http://dx.doi.org/10.1111/j.1472-765X.2006.02055.x PMID: 17257257

[51] Tsouko E, Kourmentza C, Ladakis D, *et al*. Bacterial cellulose production from industrial waste and by-product streams. Intl J Mol Sci 2015; 16(7): 14832-49.
http://dx.doi.org/10.3390/ijms160714832

[52] Thompson NS, Carlson JA, Kaustinen HM, Uhlin KI. Tunnel structures in Acetobacter xylinum. Int J Biol Macromol 1988; 10(2): 126-7.
http://dx.doi.org/10.1016/0141-8130(88)90021-9

[53] Çoban EP, Biyik H. Effect of various carbon and nitrogen sources on cellulose synthesis by *Acetobacter lovaniensis* HBB5. Afr J Biotechnol 2011; 10(27): 5346-54.

[54] Sun D, Yang J, Wang X. Bacterial cellulose/TiO2 hybrid nanofibers prepared by the surface hydrolysis method with molecular precision. Nanoscale 2010; 2(2): 287-92.
http://dx.doi.org/10.1039/B9NR00158A PMID: 20644807

[55] Yamanaka S, Watanabe K, Kitamura N, *et al*. The structure and mechanical properties of sheets prepared from bacterial cellulose. J Mater Sci 1989; 24(9): 3141-5.
http://dx.doi.org/10.1007/BF01139032

[56] Czaja W, Krystynowicz A, Bielecki S, Brown R Jr. Microbial cellulose—the natural power to heal wounds. Biomaterials 2006; 27(2): 145-51.
http://dx.doi.org/10.1016/j.biomaterials.2005.07.035 PMID: 16099034

[57] Kilzer FJ, Broido A. Speculations on the nature of cellulose pyrolysis. Pyrodynamics 1965; 2: 151-63.

[58] Cheng HP, Wang PM, Chen JW, Wu WT. Cultivation of *Acetobacter xylinum* for bacterial cellulose production in a modified airlift reactor. Biotechnol Appl Biochem 2002; 35(2): 125-32.
http://dx.doi.org/10.1042/BA20010066 PMID: 11916454

[59] Bottom R. Principles and applications of thermal analysis. UK: Blackwell Publishing 2008.

[60] Dobre LM, Stoica A, Stroescu M, Jinga S, Jipa I, Dobre T. Characterization of composite materials based on biocellulose membranes impregnated with silver particles as antimicrobial agent. *U.P.B. Sci*. Bull, Series B 2010; 72(4): 55-64.

[61] Yan Z, Chen S, Wang H, Wang B, Wang C, Jiang J. Cellulose synthesized by *Acetobacter xylinum* in the presence of multi-walled carbon nanotubes. Carbohydr Res 2008; 343(1): 73-80.
http://dx.doi.org/10.1016/j.carres.2007.10.024 PMID: 18005953

[62] Phisalaphong M, Jatupaiboon N. Biosynthesis and characterization of bacteria cellulose–chitosan film. Carbohydr Polym 2008; 74(3): 482-8.
http://dx.doi.org/10.1016/j.carbpol.2008.04.004

[63] Surma-Slusarska B, Danielewicz D, Presler S. Characteristics of bacterial cellulose obtained from *Acetobacter xylinum* culture for application in papermaking. Fibres Text East Eur 2008; 16(4): 69.

[64] Rouessac F, Rouessac A. Chemical Analysis: Modern Instrumentation Methods and Techniques. (2nd ed.), England: John Wiley & Sons Ltd. 2007.

[65] Spiridon I, Teacă CA, Bodîrlău R. Structural changes evidenced by FTIR spectroscopy in cellulosic materials after pre-treatment with ionic liquid and enzymatic hydrolysis. BioResources 2010; 6(1): 400-13.
http://dx.doi.org/10.15376/biores.6.1.400-413

[66] Kim KI, Kim WK, Seo DK, Yoo IS, Kim EK, Yoon HH. Production of lactic acid from food wastes. Appl Biochem Biotechnol 2003; 107(1-3): 637-48.
http://dx.doi.org/10.1385/ABAB:107:1-3:637 PMID: 12721443