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Bamboo: A potential source of lignocellulosic biomass for production of advanced biofuels

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Abstract

Advanced biofuels or second-generation fuels are considered as promising means for providing sustainable mobility. Switchgrass, energy cane and poplar are some prominent biofuel crops which have been improved for biofuel traits through genetic engineering and genotype-assisted breeding. Dedicated biofuel crops have yet to emerge at industrial scale and some plants such as bamboos are exceptionally designed by nature and attracting an incredible level of attention. Bamboo is a fast-growing woody grass and a rich source of lignocellulose and can play a significant role in energy conversion. The conversion of lignocellulosic biomass to ethanol provides a sustainable energy production system. Moreover, it is a low-cost and easily available bioresource in India. Bamboo has a chemical composition of 40-48% cellulose, 24-28% hemicellulose, and 20-26% lignin, implying that there is a massive pool of cell wall sugars available for bioethanol synthesis. They are harvested and re-grown from the same stand quickly without causing damage to the plant because of their tremendous growth rate. Hence, bamboo being a rich source of lignocelluloses has the potential to be used as a feedstock for producing bioethanol using technologically and economically feasible techniques.

Keywords Bamboo; Lignocellulose; Fermentation; Biofuel

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1. Introduction

First-generation liquid biofuels produced primarily from cereals, sugar crops and oil seeds have now come under careful examination because of high processing cost, competition for land and water used for production of food and fibre crops, increased commodity prices for food and animal feeds etc. The collective impacts of theses several issues have aroused the interest in producing second-generation biofuels produced from non-food lignocellulosic biomass (Sims et al. 2010). Lignocellulosic biomass is considered as a potential source of second-generation biofuel and a promising alternative to petroleum-based fuel (Yousuf et al. 2020). Though, sugar cane bagasse, forest residues and cereal straw are prominent examples of lignocellulosic biomass, a dedicated biofuel source have yet to emerge at industrial scale.

Bamboo is a rich source of cellulose, hemicellulose and lignin and considered as an ideal candidate for production of second-generation biofuel. Other inherent features that make bamboo a potential second-generation biofuel source include its high abundance, rapid growth rate, perennial nature, low maintenance requirements and biochemical composition similar to wood (Scurlock 2000). Bamboo belongs to the family Poaceae and subfamily Bambusoideae has 116 genera with approximately 1575 species. It differs from conventional grass in terms of height, width and size (Singh et al. 2013; Xiu-hua et al. 2017) and best known for its fast growth, flowering, and exceptional physical and mechanical properties (Hung and Wu 2010). It is the fastest growing plant on the planet, and matures considerably faster than other plants. In terms of the entire bamboo population, India is the second largest producer country, with 160 species, after China, which has 500 species (Bystriakova 2003; Bystriakova et al. 2004).

Biofuel production from lignocellulosic biomass derived from agriculture has been studied all over the world. In terms of quality, the fuel produced is trustworthy, but it does come with the requirement of a pretreatment techniques. Bio-ethanol production from bamboo follows the same general procedure as ethanol synthesis from lignocellulosic biomass, which includes pretreatment, enzymatic hydrolysis, and fermentation (Keshwani and Cheng 2009). For producing sustainable transportation fuels from bamboo, technologically and economically feasible techniques are required (Hsu et al. 1980; Littlewood 2014). The present study was planned to briefly discuss the properties and applications of bamboo as a raw material for production of advanced biofuels.

2. Bamboo as a potential source of lignocellulosic biomass

Bamboo is a fascinating feedstock for bioethanol production, as it contains high lignocellulosic content and low ash content. Lignocellulose has plentiful sugar reserves including pentose and hexose and can be transformed to alcohol. Its rapid growth and high productivity also make it a promising source of second-generation biofuels (Sumardiono et al. 2022). Bamboos grow worldwide except in Antarctica and mainly concentrated in Asia, Africa and Latin America. Most of them grow in tropical and subtropical regions with good monsoon and heat conditions and few are grown in temperate and sub-arctic regions. Southeastern China, Southwestern China and the Indian subcontinent have concentrated 80% of the world's bamboo species and 90% of the total bamboo forest area. India, Japan and China are the best Asian countries for bamboo production. India accounts for roughly half the total area of bamboo reported in Asia and approximately 70% together with China. Due to large-scale planting of bamboo in China, the bamboo area has increased by 10% in Asia over the last 15 years. India is the second largest bamboo producing country after China with total 148 species in 29 genera out of which 90 species of bamboo are distributed in the northeastern states alone (FSI 2011).

The carbon absorbed by bamboo is primarily stored in the form of cellulose, hemicellulose and lignin and they contribute around 90% of the total bamboo mass however, content may vary from species to species depending on the environmental conditions and age of the bamboo species. Chemical composition of various bamboo species has been studied by several researchers, results indicate that the mass fraction of cellulose, hemicellulose and lignin in various species varied in the ranges from 30% to 60%, 15% to 50% and 18% to 40% respectively (Table 1). Furthermore, the average calorific value of bamboo pellets is 17,650J/Kg, which satisfies the minimum requirement for commercial use (Akinlabi et al. 2017). Bamboo is therefore considered a feasible substitute to fossil fuels. It has also reported that 143 L of ethanol can be extracted from each dry ton of bamboo. However, for maximum release of sugar and ethanol yield from bamboo, optimal transformation process is yet to be identified. The lignocellulose biomass can be converted into ethanol by following three main steps viz. pretreatment of biomass, enzymatic saccharification to release cell wall sugars and fermentation to change sugars into ethanol. Pretreatment is crucial to ensure sufficient yields of fermentable sugars. According to Littlewood (2014), when bamboo is pretreated with liquid hot water and dilute acid, a higher level of sugar can be generated. Besides, strong governmental support, research and development, abundant raw materials and labour also play a key role in bioethanol production from bamboo (Alexander and Torres 2011).

Table 1. Chemical composition (%) of various bamboo species.

Species	Cellulose	Hemicellulose	Holocellulose	Lignin	References
Bambusa balcooa	43	-	70	22	Hossain et al. 2022
Bambusa blumeana	40-45	-	65-72	22	Liese and Tang 2015
Bambusa tulda	46	-	68	28	Hossain et al. 2022
Bambusa tuldoides	35	32	67	23	Corriea 2011
Bambusa vulgaris	43	-	67-69	23	Liese and Tang 2015
	45	-	72	28	Jansiri et al. 2021
	42	-	68	27	Hossain et al. 2022
Bambusa vulgaris Var *vulgaris*	<40	<50	>80	-	Maulana et al. 2020
Bambusa vulgaris Var *striata*	>40	>30	70	>30	Maulana et al. 2020
Bambusa longispiculata	50	27	74	-	Jansiri et al. 2021
Dendrocalamus longispathus	43	-	68	27	Hossain et al. 2022
Dendrocalamus asper	44	18	74-80	28	Liese and Tang 2015; Fatriasari 2016
	<50	30	<80	>30	Maulana et al. 2020
	41	30	-	27	Leenakul and Tippayawong 2013
Dendrocalamus giganteus	40-47	15-21	-	26	Wang et. al. 2016; Xiao et. al. 2013
	40	>30	>70	<40	Maulana et al. 2020
Dendrocalamus latiflorus	42	-	65	26	Lin et.al. 2016
Dendrocalamus membranaceus	47	-	71	29	Jansiri et al. 2021
Dendrocalamus sp.	47	16	-	18	Kuttiraja et al. 2010
Gigantochloa apus	50	<30	80	<25	Maulana et al. 2020
Gigantochloa	<60	>20	<80	>25	Maulana et al.

atroviolacea					2020
Gigantochloa brang	51	-	79	25	Wahab et. al. 2013
Gigantochloa levis	33	-	84	26	Wahab et. al. 2013
Gigantochloa scortechinii	47	-	74	33	Wahab et. al. 2013
	55	-	81	-	Salim et al. 2008
Gigantochloa pseudoarundinacea	>30	<40	70	<30	Maulana et al. 2020
Gigantochloa wrayi	38	-	84	30	Wahab et. al. 2013
Neosinocalamus affinis	45	-	-	28	Yang et al. 2019
Oxytenanthera abyssinica	52	17	-	23	Tolessa et al. 2017
Phyllostachys bambusoides	-	21	-	21	Kerschbaumer2014
Phyllostachys makinoi	46	-	-	29	Lin et.al. 2016
	45	-	-	25	Fengel and Shao 1984
Phyllostachys nigra	41	15	-	24	Kerschbaumer, 2014
Phyllostachys pubescens	41	-	-	29	Lin et al. 2016
	46	23	-	26	Yamashita et al. 2010
	46	-	70		Li et al. 2007
Phyllostachys heterocycla	37	22	-	24	Li et. al. 2012a
	47	23	-	31	Li et al., 2014
Thyrsostachys oliveri	44	-	67	27	Hossain et al. 2022

(-) data not available

3. Bamboo over other feedstocks

The most common feedstocks for conventional bioethanol synthesis are crops with high sugar and starch content, such as maize and sugarcane. However, because these crops have a strong predilection for specific climatic and soil conditions in order to reach large yields, countries with less favorable growth circumstances are turning to other resources including wheat, sugar beet, potato, and cassava (Lee and Lavoie 2013). Because many of the feedstocks used in fuel production also serve a role in food production, it's been alleged that diverting agricultural food crops away from food and toward biofuels has resulted in higher food costs (Sims et al. 2008). A complicated nexus has emerged as a result of an expanding global population paired with increasing demand for food and energy, prompting controversy about how these limited resources should be distributed between competing demands (Murphy et al. 2011).

Energy crops (Hu and Ragauskas 2011), woody biomass (Lai et al. 2020), agricultural residues (Zhu et. al. 2020), and some underutilized plants like bamboo have all been studied for their possibility in production of bioethanol to date (Table 2). Bamboo has been identified as a potential source of bioethanol due to its high lignocellulosic content, high productivity, and rapid growth and being used as a raw material for large-scale production in several countries. Bamboo easily adapts to different environmental conditions and can grow on marginal land which is not suitable for other agricultural and forestry crops hence, no need of substantial amounts of cultivable land and supply of fresh water for irrigation. Furthermore, bamboo is available throughout the year, which makes it facile for biomass suppliers and ensures continuous work of biorefinery throughout the year.

Table 2. Lignocellulose composition (%) of various feedstocks.

Species	Cellulose	Hemicellulose	Lignin	Reference
Bamboo	30-60	15-50	18-40	Yamashita et al. 2010; Maulana et al. 2020; Hossain et al., 2022
Macroalgae	6-90	2-47	0.5-4.5	IIyas and Mahamud 2021
Microalgae	16-19	1-14	-	IIyas and Mahamud 2021
Grasses	25–40	25–50	10-30	Kuhad et al. 1997
Corn stalk	39-47	26-31	3-5	Reddy and Yang 2005
Corncobs	34-41	32-36	6-16	Pssoth and Sandgren 2019
Sugarcane bagasse	42	25	20	Kim and Day 2011
Sweet sorghum bagasse	34-45	18-28	14-22	Li et al. 2010
Industrial hemp woody core	37	20	12	Xie et al. 2017
Hardwood	45–47	25–40	20–25	Pettersen 1984
Poplar wood	43	18	25	Xu et al. 2020
Eucalyptus globules wood	41	14	28	Schneider et al. 2020
Rice straw	32.1	24	18	Prassad et al. 2007
	28-36	23-28	12-14	Reddy and Yang 2005
	29-35	12-29	17-19	Pssoth and Sandgren 2019
Rapeseed straw	30	13	21	Tan et al. 2020
Wheat straw	33-38	26-32	17-19	Reddy and Yang 2005
	29–35	26–32	16–21	McKendry 2002
	33-40	20-25	15-20	Talebnia, et al. 2010
	35-39	23-30	12-16	Pssoth and Sandgren 2019
Barley straw	31-45	27-38	14-19	Reddy and Yang 2005
	36-43	24-33	6-9	Pssoth and Sandgren 2019
Sorghum straw	32	24	13	Reddy and Yang 2005
	32-35	24-27	15-21	Pssoth and Sandgren 2019

4. Bioethanol production from bamboo

The general process for production of bioethanol from bamboo involves three main steps namely pretreatment of bamboo biomass to obtain an enzymatically-digestible material, enzymatic saccharification to release cell wall sugars and fermentation to convert sugars into ethanol. Pretreatment is a key step to make cellulose microfibrils more accessible to enzymatic digestion. Choosing the right pretreatment technique can reduce costs and also have minimal environmental impact. Dilute sulphuric acid, biological pretreatment with white rot fungi, steam explosion, organosolv and alkali pretreatment have been used by various researchers on different bamboo species. It has been reported that, concentrated sulphuric acid pretreatment is most effective with 98% sugar recovery followed by organosolv and alkali pretreatment with 95% sugar yield (Sun et al. 2011; Li et al. 2012a).

Pretreatment removes lignin and hemicellulose and increases the contact area of cellulase on cellulose surface. Enzymatic hydrolysis converts cellulose into sugars and during fermentation; sugars are converted into ethanol by various microorganisms. While, bamboo is rich in xylan hence the activity of xylanase is very essential to enhance the overall process of enzymatic hydrolysis. Littlewood (2014) compared three pretreatments viz liquid hot water pretreatment, soaking in aqueous ammonia pretreatment and dilute acid pretreatment under optimal conditions and found that bamboo pretreated with liquid hot water and dilute acid at optimal conditions showed similar responses in that 84% of xylan was solubilised during the pretreatment stage as compared to 31% of lignin content removed during soaking in aqueous ammonia pretreatment. It was also found that the effect of high temperature and short times is much more effective than lower temperatures and longer times in improving cell wall accessibility and total sugar release from bamboo.

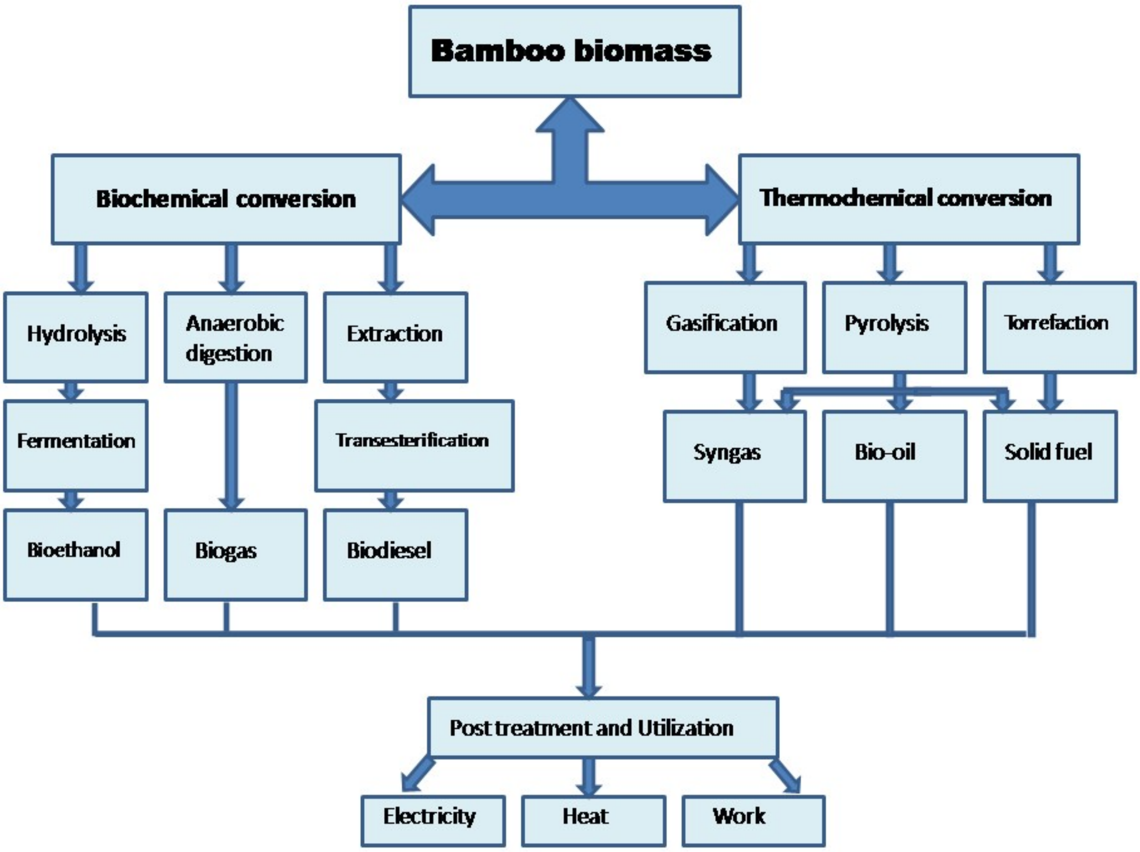

Figure 1. Process configurations for conversion of bamboo biomass to bioenergy.

Conclusion

Bioethanol is a good contender for replacing or complementing petroleum-based liquids since it can be utilized in motors with up to a 10% gasoline mixture without requiring engine modifications. Although first-generation biofuels such as sugarcane and corn-based ethanol are viable options, their production is being scrutinized since they compete with the food crops, which poses a danger to global food security. Bioethanol of the second generation, which is produced from lignocellulosic rich biomass such as bamboo, could overcome the aforementioned challenges because bamboo is a non-food plant, rich source of cellulose, hemicellulose, and lignin, its high abundance, rapid growth rate, perennial nature and low maintenance requirements. Furthermore, liquid biofuels from bamboo may help in the reduction of greenhouse gas emission, increase employment, strengthen regional economies, and ensure supply security.

Conflict of Interest

The authors declare there is no conflict of interest

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