Indian Journal of Experimental Biology
Vol. 61, October 2023, pp. 729-738
DOI: 10.56042/ijeb.v61i10.1795

Mini-Review

Pineapple leaves waste — a potential feedstock for production of value-added products in biorefinery

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Received 11 January 2023; *revised 30 April 2023*

The pineapple leaves (PL) left over in the fields after pineapple harvest or burnt out, generate waste which contributes to the release of greenhouse gases. As pineapple is one of the most harvested crops in the world, the quantity of pineapple trash and its disposal methods are challenging. The composition of PL waste makes it unique to encounter the increasing demand for renewable energy and other useful products. This review is focused on the production of different biorefinery products and miscellaneous products from PL waste. The high cellulose content in PL makes it a potential feedstock for the production of different biorefinery products like bioethanol, oligosaccharides, nitrocellulose, and humic acid apart from this, waste is also useful for the production of different products like pineapple leaf fibres, fake eyelashes, organic leather, pulp and paper. Although the opportunities, future perspectives, and challenges concerning PL waste utilization to value-added goods were also addressed. It has been demonstrated that pineapple waste conversions lower waste creation, and the products produced by the conversion would promote the 'waste-to-wealth' notion.

Keywords: Bioethanol, Biorefinery products, Feedstock, Lignocellulosic biomass, Oligosaccharides, Organic leather, Paper, Pulp, Pineapple leaves waste

Introduction

Maximizing the effectiveness of raw material utilization and reduction of waste production recently received more attention as part of the search for sustainable development. Academics and industry have conducted extensive research on the use of biomass leftover as feedstock for the production of energy and other value-added products[1]. Repurposing these feedstocks to create value-added goods can lessen the amount of trash produced and the adverse environmental effects[2]. These feedstock conversion through biorefinery via cellulase into glucose offers opportunity to further convert it into bioethanol which may be proved as an excellent alternative to petroleum fuel[3,4].

Pineapple is the second topmost harvest after banana that contributes over 20% of worldwide production. There are about 24.8 million tons of pineapple produced worldwide. According to international surveys, the top 10 countries producing pineapple globally are Costa Rica, Brazil, Philippines, Thailand, Indonesia, India, Nigeria, China, Mexico, and Columbia[3]. About 70% of the pineapple is consumed as a fresh fruit in the country where it is produced.

Currently, pineapple production in the world is mostly focused on fruits and juices. In addition, a lot of useless trash is produced when pineapples are processed. According to reports, between 40 and 80 percent of pineapple fruit is wasted including stem, crown, core, and notably leaves as garbage because it has high BOD and COD values as a result[5].

Most of the post-harvested residues include PL, either composted or left to rot after being burned to get rid of fungi and other parasites. This is due to the absence of technology for this purpose and lacking of awareness of the commercial uses of pineapple leaves (PL) that can be a good source of extra income[6]. There are different kinds of value-added products can be produced from discarded parts of pineapple like core is a good source of bromeline and organic acids, crown has the qualities of soluble and insoluble

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dietary fibres, peel is a source of different enzymes, and residual sugars and fibres can be extracted from the pomace part[7].

The pineapple leaves (PL) are biodegradable, abundant, cheap, rarely used, and at present of little value agricultural leftover that is regenerated every year. Additionally, PL trash is still underutilized after harvesting, which presents a number of challenges for growers. There is a high need to utilize these agricultural cellulosic wastes for valuable products. According to a number of research, PL has a high holocellulose content of between 40 and 87.7%, making it a potentially advantageous feedstock for the circular economy[8].

Prior to conversion, it is essential to comprehend the characteristics and features of waste feedstock. Researchers must evaluate a wide range of factors when producing and developing the aforementioned value-added product, including productivity, purity, stability, and suitability for industrial marketing. It is crucial to choose the most appropriate and economical approach to generate a higher yield of these items in order to satisfy the market demand by utilizing the pineapple's composition for the use of non-edible components. The PL waste is a potential source to develop different biorefinery value-added products.

This comprehensive review provides a comprehensive overview of pineapple’s commercial use, waste production, characteristics and composition of pineapple waste and pineapple waste conversion value-added products. With the help of these findings, researchers and pineapple growers may be better equipped to investigate novel ideas for managing pineapple by-products in a sustainable manner.

Pineapple production and waste generation

In this review, we have covered this subject in a comprehensive manner including brief about different wastes from pineapple crop and major discussion on the pineapple leaves (PL).

Table 1 — Top 10 countries in pineapple production during 2019 and 2020

		Production (tons)	
World rank	Country	2019	2020
1	Philippines	2747856	2702550
2	Costa Rica	3328100	2624.20
3	Brazil	2426526	2455690
4	Indonesia	2196456	2447240
5	China	1727607	2220260
6	India	1711000	1799000
7	Thailand	1679668	1532510
8	Nigeria	1671440	1508200
9	Mexico	1041161	1208250
10	Columbia	1008687	882630

[faostat3.fao.org 2022; FAO Statistical Database, 2019]

The world is evolving toward a circular economy, which emphasizes lowering waste and extending the useful life of commodities. Recent boom in urbanisation, economy, and global population are the major factor for waste production rapidly[9]. Global garbage production is predicted to roughly quadruple by 2050 and triple by 2100 compared to the year 2016[10]. Due to the adverse effect of agricultural waste on the environment, economy, and society, agricultural wastes are a major problem on a global scale. The world is currently dealing with two linked problems, first the production of massive agricultural waste and second depletion of fossil fuel stock. However, the management of agricultural waste is a difficult task produced annually ca. 1 billion tons[11].

Recently, the tropical fruit industry is essential to world agriculture and high in demand due to its growth and contribution to food security. The second-most popular tropical fruit consumed worldwide is the pineapple[12]. Thus top 10 countries production of pineapple along with their ranking is mentioned in Table 1. Notably, pineapple waste is one of the most prevalent lignocellulosic wastes out of the vast amount of agricultural waste produced globally (Fig. 1). Several economically viable biological processes are available for the appropriate utilization of these wastes[13]. The importance of lignocellulosic biomass (LCB) has significantly increased as a widely accessible and affordable non-edible feedstock for

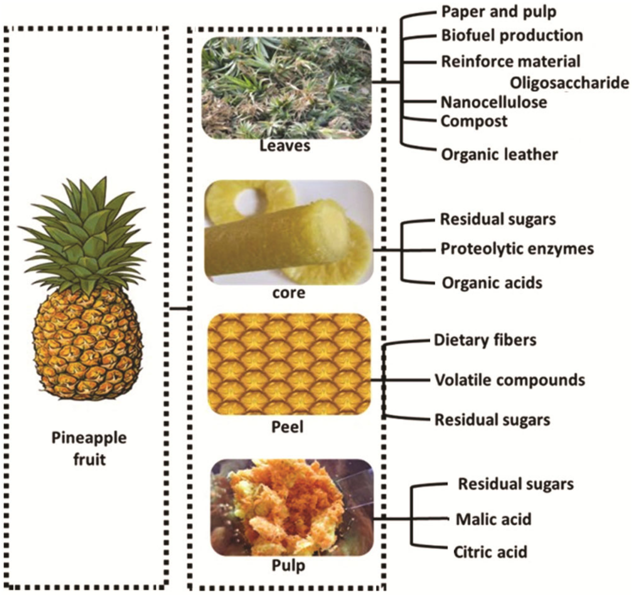

Fig. 1 — Types of pineapple fruit waste and its applications

second-generation (2G) bioethanol. Valorization of pineapple waste is an opportunity and challenge both, through additional processing until it is transformed into profitable products utilizing ecologically responsible methods. Pineapple waste is a potential source of metabolites for cosmetic, functional food, and medicinal uses[14].

The utilization of PL is very fascinating these days due to the production of biodegradable fibres. These fibres are used to make Pinatex® as a by-product of the current pineapple harvest, these leaves don't require any more environmental resources to grow. Pinatex® (so-called mushroom leather) is being developed and proposed as a potential replacement for leather[15].

Chemical composition and structure of PL

Lignocellulosic biomass is an abundant and renewable biomass that is made by plants through the process known as photosynthesis in which plants use CO_2, water, and sunlight. Several million tons of LCB are produced annually in the form of forestry, and agro-wastes, posing a significant environmental challenge in terms of appropriate disposal[16]. Due to the above advantages mentioned, the LCB could be considered as a potential feedstock for the production of biorefinery products (eg. Bioethanol, oligosaccharides and biochemicals) and other value-added products like fibres, organic leather, etc. Sustainability is a major focus of LCB-based biorefineries, and under this strategy, various LCB biomass components are valorized to create multiple valuable products in a cost-effective and environmentally friendly way. Lignocellulosic biomass can be divided into different categories like unblemished biomass, waste biomass, and energy crops. The categories of virgin biomass include trees, bushes and sand grasses, while the types of waste biomass include stover, sugarcane bagasse, PL and farming residues like (rice straw, wheat straw, cotton stalk, leftover leaves, etc.).

Among these categories, PL are underutilized lignocellulosic biomass. PL have a multicellular and ribbon-like structure that is made up of polysaccharides, lignin, and other components like wax, pectin, inorganic substance, etc. Structurally, PL contain cellulose (22-87%), a homopolymer of glucose units joined to each other by β-1,4-glycosidic bond; hemicellulose (10-26%), a curved heteropolymer of xylose and arabinose, which have five carbons, glucose, mannose, galactose, and other sugars with six carbons; and lignin (3-15%), a complicated heteropolymer made up of hydroxyphenyl, guaiacyl, and syringyl units, which are phenolic components. It mechanically strengthens the structure of LCB, by performing the action of 'glue' between cellulose and hemicellulose and covalent link with hemicellulose, thereby, providing recalcitrance to microbial and chemical damage (Table 2[17-23]) which reveals that the PL has a high holocellulose. The chemical composition of PL (different components such as cellulose and hemicellulose) varies in each study which basically discuss on the type of PL used, the species, the location, and the weather.

Pretreatment process

The pre-treatment process is a key step for conversion of biomass into fermentable sugars. Usually, a pretreatment process followed by mechanical processing of the biomass, which uses a variety of milling techniques such as willy-, ball-, roller-, or knife-mills is required to abolish the complex structure of lignocellulosic biomass to make it porous and increase the surface area[24,25]. After the pretreatment process, each component of lignocellulosic biomass (cellulose, hemicellulose, and lignin) can be recovered in separate fractions by adopting various processes[26].

Several pretreatment technologies are available to deconstruct the recalcitrant structure of biomass, including physicochemical, biological, and chemical pretreatment. Physicochemical pretreatment improves the biomass's digestibility by partially breaking down lignin and hemicellulose, reducing cellulose crystallinity, increasing porosity and pore size, and decreasing cellulose crystallinity. This loosens up the

Table 2 — Chemical composition of pineapple leaves(17-23)

Biomass	Cellulose (%)	Hemicelluloses (%)	lignin (%)	Moisture content (%)	Ash (%)
Pineapple leaf[17]	22.6	26.1	7.3	-	6.1
Pineapple leaf[18]	41.15	21.02	13.05	-	-
Pineapple leaf[19]	62.37±0.59	22.38±0.82	5.45±0.38	-	1.57±0.73
Pineapple leaf fiber[21]	68–85	16–19	5–12	10–12	0.8–4
Pineapple leaf[20]	46.17±0.76	19.28±0.54	2.8±0.70	-	8.82±1.46
Pineapple leaf[22]	56.90±2.10	10.88±0.35	14.2±0.42	-	-
Pineapple leaf[23]	74.5–87.2	12.3–20.4	3.46–8.7	-	-

biomass's complex structure, which increases the accessibility of enzymes to the components of the biomass. Physicochemical pretreatment is carried out by employing water alone or can be combined with acids (sulfuric-, hydrochloric-, nitric acids, etc.), alkali (sodium or potassium hydroxide, ammonia, etc.), or oxidizing agents (hydrogen peroxide, ozone, etc.)[27]. Steam explosion does not require any addition of catalyst but result in better digestibility using pressure (1-3.5 MPa) and hot steam (~150-200°C), wherein the explosive decompression of biomass to air pressure results in its rupture and ultrastructural alterations[28]. From an economic and environmental standpoint, hydrothermal pretreatment is superior to other physicochemical pretreatment methods, due to its simple and affordable nature, shorter cycle, and lower inhibitor production[29]. The liquid and solid fractions obtained after the pretreatment process are separated by filtration or centrifugation. The liquid phase of the hydrolysate contains solubilized hemicelluloses and cellulose in monomeric as well as oligomeric forms, which are advantageous for biorefineries by successfully utilizing hydrolysate components[30]. The solid part contains pentose and hexose polysaccharides along with lignin that can be hydrolyzed by cellulolytic enzymes into monomers[31]. Liquid hot water pretreatment is a part of the hydrothermal technique that breaks down the LCB structure to facilitate cellulose access by enzymes. Liquid hot water pretreatment takes place at temperatures between 160 –270°C and pressures more than 5 MPa along with water or any acid or alkali catalyst. The biomass-to-solvent ratio is an important parameter to be optimized during such a pretreatment process[32].

Many previous studies are available on the production of different products by applying hydrothermal pre-treatment mentioned in Table 3[17,19,21,23,33-41]. When LCB is pretreated with dilute acid (DA), the hemicelluloses are specifically removed to make the cellulose more accessible to cellulolytic enzymes. It promotes the depolymerization of hemicellulose into its component sugars, hexose and pentose by acting on the ester linkages and glycosidic bonds of hemicellulose[29]. Biological pre-treatment is a green, cost-effective pretreatment method because it requires low energy and also obtains less waste as compared to other methods. This pretreatment method only requires ligninolytic microbial cells or their enzymes such as laccase, lignin peroxide and manganese peroxide, cellulase, etc. for lignin degradation. White rot fungi such as *Phanerochaete* sp., *Pycnoporous* sp., *Ceriporiopsis* sp. and *Ganoderma* sp. are well known for the excretion of such types of enzymes. This method is more efficient in terms of lignin removal, it is lengthy process which makes it less advantageous from an industrial standpoint than physicochemical techniques, however; it is regarded as the most sustainable pretreatment due to environmental benefits of not utilizing any chemicals and energy[42]. Biorefinery scheme promotes the cascades of products from these biomasses in a sustainable way.

Biorefinery products

Oligosaccharides

In the present era, lack of healthy food habits has increased the importance of functional foods to boost

Table-3 — Different value-added products from pineapple leaves(17,19,21,23,44-52)

Biomass	Pretreatment method	Product	Application
Pineapple leaf[44]	Decortication machine	PALF	Particleboard, composites reinforcement agent and papermaking
Pineapple leaf[45]	Decortication	PALF	Textile industries
Pineapple leaf[17]	Mechanical extruder method	Bioethanol	Biorefinery
Pineapple leaf[46]	Silane based pretreatment	PALF-based polyester composites	Textile industries
Pineapple leaf[47]	Scrapping, retting and decorticating	PALF	Substitute of cotton
PALF[48]	Steam explosion	Nanocellulose	Biomedical application
Pineapple leaf[23]	Hydrothermal pretreatment	Nanocellulose	Heavy metal adsorption
Pineapple leaf[19]	Acid-catalyzed liquid hot water	Bioethanol	Biorefinery
Pineapple leaf[49]	Dilute acid hydrolysis	Sugar and organic acid	Biorefinery
PALF[50]	Alkaline pre-treatment method with sodium hydroxide (NaOH)	Fermentable sugars	Probiotic growth and bioethanol production.
Pineapple leaf[51]	Compositing using KOH	Humic acid	Compost
Pineapple leaf[52]	Compositing using 0.1M NaOH	Humic acid	Compost
Pineapple leaf[21]	Simultaneous saccharification and fermentation (SSF) using cellulolytic enzyme	Bioethanol and Biomanure	Biorefinery

[PALF, Pineapple leaf fiber]

health. Pharma industries are interested in developing functional foods that improve health as well as reduce the risk of disease. Prebiotics also known as nondigestible oligosaccharides are the main attraction of this kind of food. Nondigestible oligosaccharides are short chains of polymers that have more or less than 10 DP (degree of polymerization)[43]. Due to the increasing interest in these kinds of health-promoting foods, production is moving towards utilization of sustainable sources. In the 21st century, lignocellulosic biorefineries are promoted where agro-based biomass is used as a renewable-based material. Lignocellulosic biomass composed of different pentose and hexose sugars could be a potential source for the production of different kinds of oligomers like xylooligomers, cello oligomers, arabino oligomers, etc.[44].

The pineapple leaves (PL) have a considerable content of pentose and hexose sugars. Although it has a significant high content of cellulose and hemicellulose this potent biomass is not explored in the area of the production of functional foods. Few studies are available on the production of oligosaccharides from different lignocellulosic biomass. Hydrothermal (HT) pre-treatment of wheat straw with or without catalyst was reported as the best approach for the production of oligosaccharides and fermentable sugars[45]. HT of wheat straw was carried out at 180°C for 0.5 h combined with alkaline ethanol extraction explored an effective and novel approach in which an optimal mixture of cellulase and esterase was used for the production of short-chain oligosaccharides. Hydrothermal alkaline treatment (35°C with 4.5% w/v) was resulting in oligosaccharide production with a max yield of 61.69 g XOS per kg used to valorize sugarcane straw and coffee husk resulted in 92% cellulose recovery and delignification close to 91%. Cello-oligosaccharide yield was around 63.56 mg/g of the substrate and low glucose concentration with an efficient enzyme mixture[46]. Enzyme reaction engineering is another efficient approach that can be used to produce cellobiose or short-chain cello oligosaccharides. Karnouri and group used this approach to produce cellooligosaccharides from birch wood biomass that was pretreated by the organosolv pre-treatment method, enzyme reaction engineering (pH, multi-stage hydrolysis with buffer exchange, addition of β-glucosidase inhibitor) showed a cellobiose-rich product with a high cellobiose-to-glucose ratio (37.4) product having a prebiotic potential when used as a sole carbon source to check the growth of two lactobacilli probiotic strains[31].

Nanocellulose

Naturally, the fibres are made up of cellulose, hemicellulose and lignin. Lignin and hemicellulose has an amorphous structure whereas cellulose has a semi-crystalline. The chemical structure of these components are different from each other cellulose is a polymer of glucose that is linked together with Beta 1-4 glycosidic bonds however hemicellulose is a heteropolymer and lignin is a polyphenolic structure[47]. Investigations have been made on a number of widely accessible renewable cellulose-containing natural fibre sources pineapple leaf fibres has all qualities that made it suitable and potential feedstock for the production of nanocellulose. There are different pretreatment methods available for the production of nanocellulose that include the thermochemical method alone, thermochemical pretreatment along with catalyst, and chemical pretreatment.

A chemo-mechanical method was employed in which PL were treated chemically by bleaching and acid resulting in the removal of lignin followed by milling and sonication to produce commercially suitable nanocellulose. Morphological changes of biomass were observed by TEM and SEM that showed the average range of obtained nanofibres was 25-58 nm[48]. The chemical pretreatment was combined with high-Shear Homogenization and Ultrasonication was used to fabricate nanocellulose from pineapple leaf. The crystallinity of the nanocellulose fibre is 50% higher than that of the raw fibre and the thermal stability has increased to yield degradation temperatures around 320°C. These properties suggest PLF nanofibre may be an effective reinforcing material for bio composites[49]. The combination of chemical and mechanical method highly reduced the need for extensive chemical pretreatment. Single stage pre-bleaching and acid hydrolysis were sufficient to produce nanocellulose with a high degree of purity[48].

Bioethanol

Nowadays, alternative source for the production of bioethanol are required due to increasing depletion of fossil fuels. Lignocellulosic biomass is an abundant and sustainable source to produce bioethanol[26]. However, the complex structure of lignocellulosic biomass is the major hindrance to the production of bioethanol. The pre-treatment of biomass is required to deconstruct the structure of biomass and make it more accessible for enzymes to convert the polymeric sugars to monomeric sugars[50].

LHW (liquid hot water treatment) under an acid catalyst was used for the pretreatment where the optimized conditions (143.2°C for 38.4 min with 0.61 M) showed the maximum removal of hemicellulosic fraction from the biomass and the remaining cellulose content used for enzymatic hydrolysis that showed 91% hydrolysis efficiency[19-27]. The liquid fraction obtained after the LHW treatment contains pentose sugars with some inhibitors and some by-products. SSF (simultaneous saccharification and fermentation) process was applied for ethanol fermentation. In their study, they obtained a high percentage ethanol yield (94.68%) with low solid loading. Hydrothermal pre-treatment under a pressurized environment is a potential and green method for the production of bioethanol.

In a recent study, pineapple leaves were subjected to hydrothermal pretreatment at 150°C for 20 min without any catalyst[22]. After the pretreatment process, slurry (contains both solid and liquid content) and a solid fraction (obtained after centrifugation of the slurry part) both were enzymatically hydrolyzed with 5% solid loading and 10 FPU/gds of the commercial enzyme resulting in glucose yield of 13.7 and 18.4 g/L obtained, respectively. Sugar obtained after the EH were converted to bioethanol using *Saccharomyces cerevisiae* WLP300 revealing a significant ethanol production with more than 91% fermentation efficiency.

In another study, enzymatic hydrolysate of untreated PL resulted in only 36-43% glucose, whereas, organic solvent lignocellulose fractionation (COSLIF) pretreatment method significantly increases the glucose yield phosphoric acid-based (COSLIF) pretreatment applied before the hydrolysis of PL biomass resulted in 84% glucose conversion after 72 h of incubation. The ethanol yield was calculated to be 212 L from 1-ton dry leaves biomass[51]. In another study, mechanical method used to prepare the pineapple leaves juice (contains 72.5% TS) fermented by *Kluyveromyces marxianus* for the production of bioethanol[17].

Miscellaneous products

Pineapple leaf fibre (PALF)

The quality of the fibres derived from the pineapple leaves depends on the age of the plant fibres derived from the young leaves are short and less strong whereas the fibres derived from mature plants are strong, smooth, and long. Natural fibres basically consist of cellulose, hemicellulose, and lignin[33]. PL contains only 2.5-3.5% fibre that is covered by hydrophobic waxy layer. PALF is high textile grade commercial fibre that can be extracted by two different methods, mechanical method or retting method[36]. In the manual method leaves are retted and fibres are scrapped out by coconut shell or broken plate. This is a time-consuming process that needs a large labour weather, in this process lots of fibres loss occur total yield of fibres obtained only 2-3% of dry fibre that means only 20-27 kg of dry fibre from 1 ton of pineapple leaves obtained[52]. In the mechanical process the soft and green part of the leaves crushed in machine and the remaining part are the fibres that are washed in water. In the next step the fibres are combed to separate the threads last step is knotting the threads and spinning the threads with charkha. Yusof *et al.*[33] have produced PALF by a decortication machine (PALF M1). In the first and second step of the process they removed all the waxy layer from the leaves then extracted PALF scoured and dried using another machine PALF M2 apart from the removal of debris it will also dry the fibres at the same time. In this study, they also compared both methods hand scrapping and PALF produced by PALF M1 machine in which the PALF machine better with a production rate of 5760 pieces/day while the productivity of fibres was only 576 pieces/day.

Fake eye lashes

Pineapple leaf fibres are still underutilized in the field of fashion and beauty. At present false eyelashes becomes necessary for the enhancement of beauty. Human hair is a kind of waste its accumulation in the waste stream causes many environmental problems; however, hair can be recycled to make many beauty products. Many industries still use human, synthetic, and animal hair to make fake eyelashes[53]. Pineapple leaf fibres could be an organic and alternative material for making false eyelashes. Widowati & Amalia[54] who checked the feasibility of pineapple leaf fibres showed 88.75% feasibility based on experts' feasibility test.

Organic leather

This industry also demands the replacement of leather-based fashion products as this industry is facing pressure to reduce the environmental impact associated with the production of leather-based products. Pineapple fibres have a potential similar to other natural fibres. “Pinatex” is a nonwoven textile similar to leather that is derived from pineapple leaf fibre. This product is a mix of thermoplastic polyester and petroleum-based resin in which 80% is pineapple leaf fibre and the remaining 20% is polylactic acid fiber. This fibre contains 85-90% biodegradable compound and 10-15% nonbiodegradable compound. Pinatex leather has qualities similar to leather obtained from animals like heat-resistant, impermeable, flexible, soft, durable and breathable[55,56].

Paper and pulp

Around the world, wood is a major source of pulp and paper products that is one of the leading causes of deforestation and affects the environment simultaneously. Getting rid of this major problem requires an alternative source for the production of pulp and paper. Pineapple leaf fibre could be a good source for pulp and paper production. The PALF mainly consists of 70-80% cellulose which is similar to cotton which has 82.7% of cellulose content. Pineapple leaf fibre has a good chemical composition, is hydrophilic in nature, has a good mechanical strength than jute, and has good flexibility which can be utilized for pulp and paper production. In the study of Lafta and group used different concentrations of water and acetone as a pulping agent for pineapple leaves and also check the thermal effect to improve the physical strength of paper. In their study, they investigated that the paper pulping with 3% water acetone concentration showed the highest mechanical properties, and paper strength improved by increasing the delignification time[57]. Rattanawongkun *et al.*[58] used the soda-anthraquinone process for the extraction of pulp from three different agricultural wastes, banana stems (B), Rice straw (R), and pineapple leaf fibres (P). The hot molded sheets were prepared and then test their properties. They concluded that the sheets prepared from P and R have good strength and their tensile indices range is similar to typical commercial molded pulp packaging products. In their study, they also improved the strength of B by applying the pulp blending concept. The B pulp was blended with P and R pulp in different weight ratios and formed the blended sheets. They found 30% weight ratio was sufficient to improve the properties of B pulp. The blending concept is effective to improve the quality and strength of B pulp

Reinforcement material

The creation of environmentally friendly natural fibres has been spurred by the environmental issues related to the production, disposal, and recycling of synthetic fibre-based polymer composites. Kenaf, jute, oil palm, cotton, flax, banana, hemp, sisal, and pineapple leaf fibre (PALF) are well-known natural fibres used for various applications like automotive, furniture, infrastructure, packaging, biomedical, etc.[59-61]. These fibres enhance the physical qualities of matrix materials. The researchers mostly employed synthetic fiberes and natural fibres as reinforcement materials[60]. Although pineapple fibers are a great source of natural fibres, they are still rarely used. Similar to other natural fibres, pineapple leaf fibres offer a wide range of possible uses, including plastic reinforcing and sound and thermal insulation. The internal chemical structure, cell size, microfibrillar angle, flaws (if any), voids, and cell wall structure all affect natural fibere properties and yield[59,61].

Humic acid

The main organic component of soil, peat, and coal are called humus, which is made up of humic substances (HS), which are organic molecules (and also a constituent of many upland streams, dystrophic lakes, and ocean water). For a significant amount of time in the 19th and 20th centuries, humic substances were frequently seen through the prism of the acid-base theory, which classified humic acids (HA) as organic acids and their conjugate bases, humates, as significant constituents of organic matter. Many studies are available to extract the humic acid from pineapple leaves that are composed using KOH (potassium hydroxide). Ahmed *et al.*[40,41] extracted 20% humic acid from the PL (composted with 0.1M KOH). They demonstrated that the yield of humic acid does not depend on extraction and fractionation time. The importance of this study is that it has shown that HA of compost can be isolated in 24 h or less as opposed to the current average of 48 h, which facilitates the idea of producing potassium-humate (K-fertilizer) from composted pineapple leaves rather than burning them open, a method that has negative environmental effects[40,41].

Conclusion

The pineapple leaves (PL) waste, generated after the cultivation of fruit has a unique composition contains high cellulosic content that makes it a high-value substrate. Globally the increasing demand of pineapple fruit also makes it high waste generated fruit. This review has provided comprehensive and updated information on the conversion of lignocellulosic content of pineapple leaves waste that contains 40-80% holocellulose that is enzymatically converted into next-generation bioethanol and other value-added products. Some strategies like controlled enzymatic hydrolysis by using beta-glucosidase inhibitors could be employed for the production of oligosaccharides that is still undiscovered. However, due to the recalcitrant nature of lignocellulosic biomass, researchers face numerous restrictions and difficulties when trying to produce the afore-mentioned goods. Therefore, additional processes like pre-treatment or filtration should be implemented, but the strategy used should take technical, monetary, and environmental factors into account.

Acknowledgment

Author RRS acknowledges funding support from NSTC 112-2222-E-992 -006 -MY2 and authors RS and RRS acknowledge support from NKUST School project 112A14.

Conflict of interest

Authors declare no competing interests.

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