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REVIEW ARTICLE

A review on renewable energy sources for production of bioethanol

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Abstract

Industrial development has led to several advantages like economic growth, ease of operation, a wide range of products, etc. Simultaneously, it has increased the demand in the energy sector, which is highly dependent on non-renewable energy sources like fossil fuels to meet this demand. Unfortunately, the availability of fossil fuels is nearing depletion and hence the scientific community is in search of potential renewable energy sources to reduce the dependency on non-renewable energy sources. Bioethanol is a renewable energy source and can be produced from a wide range of renewable raw materials. Production of bioethanol has benefits like; environmental safety, socio-economic benefits and energy security. Bioethanol is currently produced from sugar-rich and starch-rich agro-residues. Agro-industries which contribute significantly to the country's GDP generate waste in large quantities and share 10-15 % of the cause of pollution. The agro-industry waste originating from crop plants are nutritionally rich (lignocellulosic) and hence could be potentially used as a raw material for bioethanol production. Currently, the production of bioethanol from low-cost renewable agro-industry wastes has gained considerable attention. Sugar-rich materials such as sugarcane, sugar beet, sweet sorghum, molasses, etc are largely used for bioethanol production. Lignocellulosic materials are available in large quantum and serve as a potential source for the production of bioethanol.

Keywords

agro-industry; bioethanol; lignocellulose; renewable energy

Introduction

Mechanization in industrial sectors has increased energy demand and this led to the alarming situation of fossil fuel depletion. Industrial sectors and the scientific community are now searching for alternative renewable energy resources to balance the energy demand. Bioethanol is one of the emerging renewable energy resources that have a wide range of non-polluting features (carbon neutral biofuel, high octane number, low boiling point, high heat of vaporization & energy content) and cost-effectiveness. Bioethanol is a green fuel produced by the microbial fermentation of simple sugars. Presently, bioethanol is expected to have a promising future and is considered to be a fuel to overcome the energy crisis. This fuel has a wide array of applications and it can be blended with gasoline, owing to a greater efficiency than fossil fuels. The global ethanol production in 2018 was 98.4

billion litres (UNIDO, 2022) (1). According to Renewable Fuel Reports (2021) (2) India ranks fifth in the world in terms of production of bioethanol, with 850 million gallons during 2021. The main application of bioethanol in the energy industry is that it can be blended with gasoline and this gives greater efficiency to the vehicles (3). Bioethanol can further be used as chemical feedstock and industrial solvent. It iseco-friendly as it holds the advantage of biodegradability. This has driven a greater demand for bioethanol production.

In the modern epoch, the world strives towards industrialization to create ease in our daily activities. This revolution continued to the agricultural sector which led to a generation of more byproducts. Agro-industries play a major role in the Indian economy, contributing over 14 % of the country's GDP. However, these agro-industries also generate a large quantity of waste products. Agricultural waste is emerging as a threat to the environment, as dumping of untreated wastes is causing severe pollution problems. As an effective waste management strategy and alternative to fossil fuels, these agricultural wastes are used as renewable sources for generating energy. A vast variety of substrates can be used for bioethanol production. Bioethanol can be produced from a wide range of feedstocks; the promising and efficient way is the production from agroresidues. Recently intense research has been conducted to utilize different substrates *viz.,* lignocellulose,cellulose, sugary and starchy feedstock for bioethanol production. This review presents the potential renewable energy resources for bioethanol production comprehensively.

Ethanol production from different waste materials

Sugar industry waste : Sugar is an indispensable component of the human diet that plays a vital role in culinary and most importantly, nutritional aspects. Each year, the global sugar industry produces 275 million tons of these compounds to meet insatiable demand. However, the sugar production process has generated its fair share of waste and byproducts and over time has shown to be a threat to ecological processes as they found their way into the environment and into different ecosystems. There is a shift of trends in the global demand towards sustainable and renewable energy sources due to which the sugar production byproducts have gained newfound attention. Among these byproducts, molasses has emerged with a high significance.

Molasses typically contains 40 to 50 % sugar content and 5 to 15 % ash content. Over the past decade, researchers have made substantial strides in the commercialization of bioethanol production using molasses, primarily through the utilization of *Saccharomyces cerevisiae,* which is more commonly referred to as baker's yeast (Fig.1).

Ethanol production conditions with *Saccharomyces cerevisiae* and *Zymomonasmobilis*were optimized (4). It wasconcluded that *Zymomonasmobilis* has 90% fermentation efficiency under the pH of 5 and 34°C and *Saccharomyces cerevisiae* has 92% fermentation efficiency under 5.5 pH and 30°C (Table 1). However, both the microorganisms showed enhanced bioethanol production in addition of nutrients, DAP and urea. *Zymomonasmobilis* showed optimal results with 2 gl^{-1}nutrients and *Saccharomyces cerevisiae* showed optimal results with 1 gl^{-1}nutrients.The bioethanol production from a mixed culture of yeast was also studied in detail (5). They supplemented sugarcane bagasse hydrolysate with molasses and observed the bioethanol yield. The ethanol yield was 59 gl^{-1} (Table1).

The effect of fermentation of sugarcane molasses with nutrient supplementation was assessed and temperature and nitrogen sources *viz.,* urea and yeast hydrolysate (YH) were optimized (6) (Table 1). They also evaluated the combined effect of urea and YH for enhanced ethanol production. By using HPLC, the composition of molasses total sugars as inverts (TSAI) was found to be 39 % (m/v). Optimal ethanol generation was seen at 30, 35 and 40°C for urea concentrations of 4, 2 and 3 gl^{-1}, respectively. An ethanol yield of 8.7 % (m/v) and fermentation efficiency of 85.12 % was attained at 0.5 gl^{-1} YH concentration. At 35°C, significant enhancements were noticed with 7.8 % (m/v) ethanol yield and 76.3%efficiency.

Isolation and characterization of *Saccharomyces cerevisiae* Y17 strain from molasses were done and ethanol production using sugarcane molasses and sugar beet

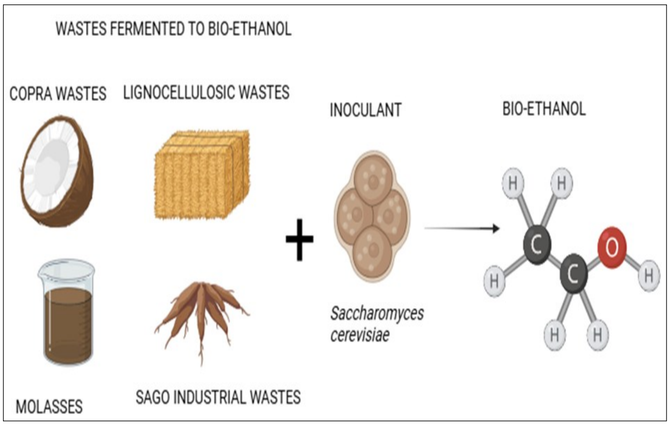

Fig. 1. Bioethanol production process from agro-industry wastes.

Table 1. Sugar industry waste and ethanol yield

Crop/Commodity	Byproduct Used	Organism involved	Optimal Conditions	Ethanol Yield
Sugarcane	Molasses	Saccharomyces cerevisiae	pH 5.5, 30°C, 1 g/L DAP	59 g/L (Gutiérrez-Rivera)
Sugarcane	Molasses	*Zymomonasmobilis*	pH 5, 34°C	200g/L
Sugar Beet	Molasses	*Saccharomyces cerevisiae Y17*	pH 4.5 30°C	9.55%
Sugarcane Bagasse	Hydrolysate supplemented with molasses	Mixed Yeast Culture	Pretreated in 121°C for 40mins Fermented in atmospheric conditions	59 g/L
Sugarcane	Molasses	*Saccharomyces cerevisiae*	0.5 g/L Yeast Hydrolysate, 35°C	7.8% (m/v)

molasses was also assessed (7) (Table 1). They concluded that *Saccharomyces cerevisiae* Y17 strain is very potential and effective strain for commercial-scale ethanol production.

Sago industry waste **:** Sago waste, a byproduct originating from processing facilities within the sago industry, presents a good avenue that can be explored. This is mainly due to its composition. Daily production yields approximately 110 tons of sago waste, which is characterized by its constituents: cellulose (approximately 23 %), hemicellulose (9.2 %), lignin (4 %) and starch (58 %). This composition makes sago waste a good candidate for bioethanol production, primarily due to the favorable ethanol yield potential associated with its starch component, although it has to be subjected to requisite preparatory procedures.

The preparation phase, known as pretreatment, has an important role in enhancing the suitability of sago waste for subsequent ethanol production. Several pretreatment procedures are available that include physical, chemical, physiochemical and biological approaches. Notably, chemical pretreatment has emerged as an effective method, showing signs of being able to break down the complex structural matrix of sago waste and making its constituent parts more accessible for the generation of ethanol.

Simultaneously, it is imperative to acknowledge the existence of biological pretreatment techniques, encompassing enzyme hydrolysis and native microbial degradation, although their implementation has been less frequent. These biological methods tend to be protracted and economically cumbersome when compared with chemical pretreatment. In recent years, microwave-assisted treatment, an innovative pretreatment approach has emerged, offering expeditious and efficacious preparation of sago waste for ethanol production. This novel technique holds promise as a transformative element in the research and development efforts for sustainable and cost-effective bioethanol production processes. As research and innovation continue to advance, sago waste stands assured to assume a crucial role within the renewable energy sector, thereby fostering a sustainable and ecologically conscientious future.

Simultaneous saccharification and fermentation of sago waste were evaluated (8). Initial studies have shown the compositional contents of sago waste *i.e.* starch (55.40±0.02 %), cellulose (23.64±0.77 %), hemicellulose (9.07±1.18 %), lignin (4.01±0.51 %) and ash (2.23±0.01 %). The highest ethanol production of 17.79 g/l was observed at 48hours (Table 2).

The microwave-assisted acid hydrolysis of sago waste for bioethanol production was well documented (9). They calculated the energy required to hydrolysate sago waste and reported that 54 kJ of energy is required to produce 1g of glucose. The overall energy consumption for fuel-grade bioethanol production from SPW was 31.77 kJ per g ethanol, which was slightly higher than the lower heating values of ethanol, 26.74 kJ/g (Table 2).

High ethanol production from wet solid sago waste with baker's yeast was reported in the literature (10). The highest ethanol production of 45 % is observed, which lasted up to 14 days (Table 2).

The enzymatic hydrolysis of spent *Saccharomyces cerevisiae* from sago bioethanol fermentation using alcalase and cellulase was also investigated in detail (11). The study optimized enzyme concentrations (0.4 % and 0.5 %, respectively), achieving 1.1-1.8-fold and 3.5-5.6-fold improvements in protein and carbohydrate recovery compared to autolysis. SEM analysis confirmed cell wall disruption, highlighting the potential for valorizing fermentation waste into value-added products, supporting sustainability in bioethanol production

The suitability of sago effluent as a carbon source and fermentation medium for bioethanol production was studied (12). Using enzymatic hydrolysis, they achieved an 82.5 % starch-to-glucose conversion yield, generating 50.57 g/L of glucose. Fermentation with *Saccharomyces cerevisiae* yielded 23.14 g/L of ethanol, representing a 91 % theoretical yield. This study highlights sago effluent as a sustainable and cost-effective raw material for bioethanol production while reducing waste and environmental impact.

Lignocellulosic waste **:** Lignocellulosic feedstock stands as a prominent and sustainable source for the production of bioethanol that represents a novel paradigm in the landscape of biofuel substrates. The potential and challenges embedded within lignocellulosic feedstocks underscore their prominence as an efficient and promising source for bioethanol production, thus contributing to the broader discourse on sustainable bioenergy solutions. These feedstocks primarily consist of agricultural residues, forestry byproducts and marine algae, collectively constituting lignocellulosic biomass. This biomass primarily comprises cellulose, hemicellulose, lignin and a myriad of organic compounds (13). Nonetheless, it is important to know the intricate nature of these lignocellulosic feedstocks, which makes them unsuitable for direct utilization by fermentative microorganisms.

Table 2. Sago industry waste and ethanol yield

Crop/Commodity	Byproduct Used	Pretreatment Method	Organism involved	Ethanol Yield	Efficiency
Sago Waste	Wet solid sago waste	None	Baker's yeast (Saccharomyces cerevisiae)	45% ethanol (8)	Prolonged fermentation (14days)
Sago Waste	Sago waste	Microwave-assisted acid hydrolysis	Saccharomyces cerevisiae	3.1g per 10g of Sago waste (7)	Energy consumption: 31.77 kJ/g ethanol
Sago Waste	Sago waste	Simultaneous saccharification and fermentation (SSF)	Saccharomyces cerevisiae	17.79 g/L ethanol (6)	Observed at 48 hours

To facilitate their transformation into viable bioethanol precursors, it is essential to depolymerize two of the principal lignin components into simpler fermentable sugars, necessitating a preliminary pretreatment process. Among the vast number of pretreatment methods available, chemical treatment has emerged as the most effective and economical choice. This approach involves the judicious application of acids and alkalis to effectively dissolve lignin and hemicellulose, rendering the feedstock amenable to subsequent conversion (14). Consequently, chemical pretreatment has firmly established itself as the preferred method within the scientific and industrial communities.

An extensive inquiry into bioethanol production from lignocellulosic biomass, utilizing the yeast strain *Saccharomyces cerevisiae* was performed (15). Their findings revealed ethanol yields ranging from 7 % to 10 %. However, notable progress in membrane separation techniques were demonstrated (16), which has yielded substantially enhanced ethanol yields, reaching levels of up to 20 % when employing lignocellulosic biomass as a substrate. A study on the production of ethanol using cabbage and onion peel waste was conducted and found that the treated waste was able to generate up to 26.51±0.02 % of ethanol (17). This shows a promising result for the utilization of waste materials from large food industries. The bioethanol production from waste paper, leveraging *Saccharomyces cerevisiae* for fermentation was also reported (18). Their study optimized pretreatment and hydrolysis processes, achieving ethanol yields with 90 % purity, demonstrating waste paper's potential as a sustainable lignocellulosic substrate.

The eco-friendly bioethanol production from lignocellulosic waste, emphasizing agricultural residues and forest biomass was reviewed (19). The study highlighted advanced pretreatment techniques, enzymatic hydrolysis and microbial fermentation, showcasing their potential to enhance bioethanol yields while reducing environmental impacts and promoting sustainability. The lignocellulosic biomass (LCB) valorization as a sustainable substrate for second-generation bioethanol production was reviewed (20). They discussed the challenges of LCB recalcitrance, optimized pretreatment, hydrolysis and fermentation techniques and emphasized the circular bioeconomy approach. Their analysis highlighted the production of bioethanol alongside value-added products like biogas, organic acids and lignin derivatives, reinforcing the potential of biorefineries for sustainable waste management and renewable energy.

A 3-liter bubble column bioreactor (BCB) for bioethanol production from hydrothermally pretreated wheat straw using a simultaneous saccharification and fermentation (SSF) strategy was designed and evaluated (21). The pretreated biomass, containing 49.83v% cellulose, underwent SSF with *Saccharomyces cerevisiae* strain PE-2 at 40 °C, achieving an ethanol concentration of 9.31 g/L with 10v% (w/v) solid loading and 15 FPU/g substrate enzyme loading. This study demonstrates the potential of combining robust yeast strains, pneumatic bioreactors and hydrothermal pretreatment for efficient bioethanol production from lignocellulosic biomass

The advancements in consolidated bioprocessing (CBP) for converting lignocellulosic biomass into bioethanol were reviewed extensively (22). CBP integrates enzyme production, polysaccharide hydrolysis and sugar fermentation into a single process, potentially reducing costs and improving efficiency. The authors discussed various biomass pretreatment methods, process enhancements, recombinant microbial catalysts and metabolic engineering strategies to optimize CBP. They concluded that while CBP offers a promising approach for sustainable and cost-effective bioethanol production, further research is needed to address existing challenges and achieve industrial-scale implementation.

The advancements in industrial technologies for bioethanol production from lignocellulosic biomass was studied (23). They emphasized integrated processes involving selective fractionation, synergistic enzymatic hydrolysis and simultaneous saccharification and co-fermentation with inhibitor-tolerant *Saccharomyces cerevisiae*. These methods reduced feedstock and enzyme costs by 19.4 % and 25 %, respectively, achieving ethanol concentrations exceeding 4 % (w/w) and a 72.3 % theoretical yield. Co-production of lignin plastic composite materials and compressed natural gas enhanced economic viability, demonstrating the potential for sustainable and cost-effective bioethanol production.

Bioethanol production from sawdust, a lignocellulosic waste, using enzymes from *Hypocreaestonica* and fermentation by *Saccharomyces cerevisiae* was explored in detail (24). Acid hydrolysis followed by enzymatic treatment optimized at pH 6.19, 29°C and 8.16 IU/mL enzyme concentration yielded 78.56 % glucose. Subsequent fermentation under optimized conditions (36.5°C, 102 h, 330 rpm) achieved 85.6 % bioethanol (55.2 g/L). His study highlights sawdust as a cost-effective substrate and emphasizes the potential of marine-derived enzymes for sustainable bioethanol production.

Bioethanol production from lignocellulosic agricultural wastes, specifically corncob and soybean cake, using *Kluyveromycesmarxianus* 6556 was assessed (25). Through acid and enzymatic hydrolysis, they achieved maximum sugar releases of 888 mg/g for corncob and 552 mg/g for soybean cake. Simultaneous saccharification and fermentation yielded 5.68 g/L ethanol from corncob and 2.14 g/L from soybean cake after 48 hours. His study highlights the potential of agricultural wastes as cost-effective feedstocks for sustainable bioethanol production.

The bioethanol production from various lignocellulosic wastes, including cassava peels, yam peels, plantain peels and sawdust was evaluated (26). Using acid hydrolysis with 13.1M H_2SO_4 followed by fermentation with *Saccharomyces cerevisiae*, they achieved maximum ethanol yields of 160 mL/kg, 211.7 mL/kg, 265 mL/kg and 280 mL/kg, respectively, with sawdust showing the highest efficiency. Their study highlights the potential of lignocellulosic wastes as sustainable feedstocks for bioethanol production and their role in reducing environmental pollution.

The suitability of various chemical pretreatments of lignocellulosic biomass for bioethanol production was studied in detail (27). Their study assessed the effectiveness of different chemical pretreatment methods in enhancing the enzymatic hydrolysis and subsequent fermentation of lignocellulosic materials into bioethanol. Their findings contribute to optimizing bioethanol production processes by identifying efficient pretreatment strategies.

Paper Mill sludge waste : One possible source of bioethanol substrate is paper mill sludge (Table 3). It is evident that this source predominantly comprises lignocellulosic material. For a long time, lignocellulosic biomass has been the main renewable resource used to produce ethanol. Large amounts of primary and secondary sludges from wood processing are produced each year in the US, making up 26 % of trash, most of which is either burnt or landfilled. Each facility has a different cost for disposing of sludge, which is determined by its solids concentration. For example, the cost of disposing of a dry ton in a landfill is about $30 (28). Assuming 350 operating days annually, a large mill producing 100 tons of sludge per day at 50 % solids may incur an annual disposal cost of $1 million. Paper mill sludge (PMS) output is expected to rise by 48 % to 86 % globally over the next 50 years, making incineration and landfilling more difficult. The expenses and complexity of various disposal techniques have increased due to stricter environmental requirements. Leachate runoff and hazardous gas emissions from landfilling frequently have the potential to contaminate surface water, groundwater and soil. However, because it pollutes the air, water and land, incineration is not a sustainable environmental solution.

Kolajo and Onovae (29) investigated the biochemical conversion of wastepaper slurries into bioethanol, including print-grade papers and corrugated cartons was tested (30). Using dilute acid hydrolysis and fermentation by *Saccharomyces cerevisiae*, they achieved ethanol with properties comparable to laboratory-grade ethanol. Their study highlights the potential of waste papers as a sustainable lignocellulosic substrate for bioethanol production.

For enzymatic saccharification of paper mill sludge using a Box-Behnken design, achieving 57.66 % efficiency with PEG-4000 as a surfactant the suitable process was optimized (31). Fermentation with *Saccharomyces cerevisiae* yielded ethanol at 91.6 % conversion efficiency. Their study underscores sludge's potential as a renewable and sustainable substrate for bioethanol production.

A method for bioethanol production from paper sludge (PS) containing antiseptics and deinking agents using subcritical water pretreatment and semi-simultaneous saccharification and fermentation was developed (32). By optimizing pretreatment conditions (240 °C, pH 4.5, 3 min), they achieved a 5.5-fold increase in glucose yield and an 11-fold improvement in bioethanol yield compared to untreated PS. This approach highlights PS as a sustainable feedstock for bioethanol, enabling efficient enzyme inhibitor removal and enhancing cellulose reactivity for renewable energy production.

Ethanol production from paper sludge (PS) waste under high-solids conditions using industrial and cellulase-producing *Saccharomyces cerevisiae* strains was assessed (33). They achieved ethanol concentrations up to 101.8 g/L with Cellusec® 2.0, demonstrating enhanced xylose utilization and a 50 % reduction in enzyme dosage. Their study underscores the viability of PS waste as a sustainable feedstock for bioethanol production, emphasizing the role of advanced yeast strains in optimizing fermentation performance.

An investigation on bioethanol production from paper water using dilute sulfuric acid pretreatment, fermentation with *Saccharomyces cerevisiae* and distillation was done (34). The study optimized conditions to achieve a 28.3 % ethanol yield at a 10:1 liquid-to-solid ratio. Additionally, bioethanol was blended with gasoline in various proportions (E5, E10, E15), enhancing octane ratings and reducing vapor pressure. Their research highlights the potential of waste paper as a cost-effective and sustainable feedstock for bioethanol production and its application in cleaner fuel blends.

Copra industry **:** Coconut palms (*Cocos nucifera*) are cultivated worldwide in more than 90 countries and territories that contribute to a global production that has exceeded 59 million tons as of 2018. The epicentre of coconut production is concentrated in tropical Asia, which has accounted for the major share of the world's output. Notably, the Philippines, India and Indonesia emerged as the major producers and have collectively represented over 72 % of the total coconut yield globally.

The cultivation of coconut palms requires specific environmental conditions, typically favouring tropical regions which are characterized by hot and humid climates. These conditions are essential for the growth and fruiting of coconut palms, due to their consistent need for warmth and moisture throughout the year to thrive. In arid and less hospitable climates, the establishment of coconut palms is a challenging endeavor, requiring the implementation of regular irrigation to support their growth. Furthermore, prolonged drought conditions may lead to premature fruit detachment and older fronds may exhibit signs of dehydration

Table 3. Paper mills waste and ethanol yield

Crop/Commodity	Key Processes	Efficiency Metrics	Results
Waste paper slurries (27)	Dilute acid hydrolysis and fermentation	Ethanol comparable to laboratory-grade	Demonstrated efficient conversion of waste paper slurries into ethanol
Paper mill sludge (29)	Enzymatic saccharification, PEG-4000 surfactant, fermentation	57.66% saccharification; 91.6% ethanol conversion efficiency	Demonstrated high conversion efficiency from paper mill sludge
Paper sludge with additives (30)	Subcritical water pretreatment, saccharification, fermentation	5.5× glucose yield; 11× bioethanol yield vs. untreated sludge	Achieved significant yield improvement from pretreated paper sludge
Paper sludge (high-solids waste)	High-solids fermentation using advanced S. cerevisiae strains	Ethanol concentration up to 101.8 g/L	Reduced enzyme dosage by 50% while achieving high ethanol concentrations
Paper waste (32)	Dilute sulfuric acid pretreatment, fermentation, distillation	28.3% ethanol yield at 10:1 liquid-to-solid ratio	Enhanced bioethanol blends (E5, E10, E15) with improved octane ratings

In the Indian subcontinent, certain states and regions have traditionally been prolific in coconut cultivation. The states of Kerala, Tamil Nadu, Karnataka, Puducherry, Andhra Pradesh, Goa, Maharashtra, Odisha, West Bengal and Gujarat, along with the union territories of Lakshadweep, Andaman and Nicobar, constitute the prominent coconut-growing areas in India. Nearly 90 % of the nation's total coconut production is attributed to four southern states: Tamil Nadu (33.84 %), Karnataka (25.15 %), Kerala (23.96 %) and Andhra Pradesh (7.16 %), as indicated by data from the Coconut Development Board of the Government of India for the fiscal year of 2017-18.

Other states in India, such as Goa, Maharashtra, Odisha, West Bengal, and those in the northeastern regions like Tripura and Assam, contribute to the remainder of the production. Despite Kerala having the highest density of coconut trees, Tamil Nadu outperforms all other states in terms of production per hectare. Notable production hubs in Tamil Nadu include the districts of Tiruppur and Coimbatore

The coconut industry holds the status of being an emerging agro-industry, making significant contributions to employment in both rural and urban areas. Over 70 % of the rural population and 10% of the urban population are linked to this industry (35).The industry yields a diverse array of products, such as coconut virgin oil, coconut cream and coconut milk. This industry simultaneously generates substantial waste in the form of coconut husks, coconut water and other byproducts. Notably, the wastewater from coconuts, while having a sweeter taste and being nutrient-rich, is often disposed of into the environment without proper treatment. Most notably, this matured coconut water holds the potential for biofuel generation, constituting an environmentally sustainable approach to recycling waste back into the ecosystem. Interestingly, coconut water derived directly from the fruits exhibits limited microbial growth, with the counts largely arising from external contamination sources. The low pH and elevated sugar content in high-quality coconut water foster favorable conditions for yeast growth in these beverages (36).

Conclusion

The energy sector is highly dependent on renewable sources, as the supply of fossil fuels is reaching its endpoint. The current demand in the energy sector is growing enormously due to the technological interventions in most of the industrial sectors. Energy-generation systems with fossil fuels are one of the major sources of greenhouse gas emissions and thus environmental pollution. Production of bioethanol from agro-residues is finding a new place nowadays as a large quantum of waste material is generated from agro-industries and has high nutritional value. The main advantage of these waste materials is that they are nutritionally rich and thus they can be potentially applied for the production of bioethanol. On the other hand, their disposal involves huge extra costs for the industries and hence they are aiming to produce bioethanol from these waste materials to meet the energy demand of the industry with the principle of circular economy in energy.

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Authors' contributions

All authors contributed equally to the article.

Compliance with ethical standards

Conflict of interest : The authors declare no conflict of interest.

Ethical issues: None

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