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REVIEW PAPER

Value Added Products from Lignocellulosic Agricultural Residues: An Overview

Sanjeev Kumar Soni[1*], Om Parkash[2], Ritika Manhas[1], Rupinder Tewari[2] and Raman Soni[3]

[1]Department of Microbiology, Punjab University, Chandigarh, India
[2]Department of Microbial Biotechnology, Punjab University, Chandigarh, India
[3]Department of Biotechnology, D.A.V. College, Chandigarh, India

*Corresponding author: sonisk@pu.ac.in

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ABSTRACT

Cellulose is the most abundant biopolymer found on earth present in the form of agricultural, agro-industrial and food waste residues which also have hemicellulose and lignin associated with them. This is also known as lignocellulosic biomass and its disposal is a major global concern as most of it is presently subjected to burning or buried in soil thus leading to environmental pollution and global warming. Some residues are traditionally used as animal fodder, substrate for mushroom cultivation, pulp and paper making, composting, amalgamation and mulching in soil, fuel for domestic and industrial applications etc. It has the potential to act as a renewable and near zero cost substrate for the economical production of high value compounds. They can act as sustainable alternative sources of bioenergy to replace fossil fuels and the production of value added products including industrial enzymes, organic acids, microbial polysaccharides, biofertilizers and fine chemicals is likely to promote bioeconomy by valourisation of lignocellulosic biomass. This piece of work discusses the traditional ways of management that are employed for making use of the agricultural residues. The potential of lignocellulosic resources for bioconversion into high value compounds emphasizing on its economic importance for production of fuels and chemicals by simultaneously minimizing the contribution to environmental pollution because of burning and land filling has also been reviewed.

Keywords: Lignocellulosic biomass, agro-industrial waste, biomass conversion, fermentation, value added products

Rapid depletion rates of fossil fuels coupled with energy crisis and other environmental concerns are the major factors stressing upon an urgent need for development of sustainable sources of energy. Indiscriminate use of the fossil fuels have numerous disadvantages including environmental pollution, high cost, non-uniform distribution and negative impact on economy. Biofuels have potential to replace them. First generation biofuels are derived from edible part of the plant biomass with high starch content, which can be converted to glucose to be utilized for fermentation. But the use of high starch plant biomass, which is intended primarily for human consumption, gives rise to food security concerns (Singhania *et al.* 2014). On the other hand, non-edible part of the plant biomass derived in the form of agricultural waste including wheat straw, rice straw, bagasse, corn stover, husk and grasses, etc can also be used for production of second generation biofuels (Avci *et al.* 2013). They have

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the clear advantage of being low cost substrates as are produced in large quantities and considerable amount has been found as waste (Lynd *et al.* 2002). Major component of this biomass is lignocellulose, which is composed of cellulose, hemicellulose and lignin. Cellulose comprises the largest fraction (30-50%) of total biomass and thus makes this biomass as an attractive resource for microbial transformations to generate value added products. Fractions of hemicelluloses and lignin in lignocelluloses are variable. Use of this energy rich source is restricted by complex composition of lignocellulose and crystalline nature of cellulose which makes it difficult to hydrolyze.

A huge amount of agricultural and agro-industrial residues are produced annually through processing of food crops including wheat, rice, corn, barley, sugar cane, sugar beet, apple, carrot, orange, date, grape, peach and potato etc. In general, most of these residues have no economic value despite their richness in cellulose, hemicellulose, soluble sugars, and soluble fibers which can potentially be exploited as feedstocks for biofuel industry (Panahi *et al.* 2020).

LIGNOCELLULOSIC BIOMASS: A RESOURCE FOR VALUE ADDED PRODUCTS

Lignocellulosic biomass is a heterogeneous complex of polysaccharides and lignin (a complex polymer of phenylpropanoid units). It is considered as the major resource left on earth for the production of value-added chemicals, enzymes, and energy (Guldhe *et al.* 2017; Pandey *et al.* 2000). Annually 1.81×10^{11} tons of biomass is generated making this biopolymer most abundant on earth (Paul and Dutta, 2018). It is generated by photosynthesis consuming atmospheric CO_2, water and sunlight. A large portion of this biomass is generated as waste in agricultural activities (Pérez *et al.* 2002) and has the potential act as the feedstock for conversion to high-value compounds after enzymatic hydrolysis.

COMPOSITION OF LIGNOCELLULOSIC BIOMASS

The main components of lignocellulosic biomass include cellulose, hemicellulose, and lignin generally in a 4:3:3 ratio but the actual proportion varies depending on the source (Bajpai, 2016). Most agricultural residues have 40-50% cellulose, 15-25% hemicellulose and 20-25% lignin (Zing *et al.* 2017). Table 1 summarizes the approximate compositions of various lignocellulosic feedstocks and the general structural composition of its various components is summarized in Table 2.

Table 1: Composition of various lignocellulosic feedstocks

Lignocellulosic residues	**Composition (% dry wt)**		
	Cellulose	**Hemicellulose**	**Lignin**
Agricultural byproducts			
Rice straw	29.2–39	15–25.9	10–19
Wheat straw	33–39	22–30	12–25.5
Sugarcane bagasse	25–45	25–32	12.2–25
Corn stover	35.1–39.5	19.1–24.6	11–19.1
Rapeseed stover	27.6	20.2	18.3
Oilseed rape	27.3	20.5	14.2
Oat straw	27–35	20–37	10–19
Corn cob	32.3–45.6	35–39.8	6.7–15
Rice husk	24–36.1	12–29.3	11–20
Wheat bran	10.5–14.8	35.5–39.2	8.3–12.5
Sorghum straw	32–35	24–27	15–21
Cotton stalk	31	11	30
Cotton seed hairs	80–95	5–20	0
Nut shells	25–30	22–30	30–40
Bamboo	49–50	18–20	23
Rye straw	33–35	27–30	16–19
Jute fibers	45–53	18–21	21–26
Barley straw	31–43	24–33	6.3–15
Switch grass	25–45	22–31.4	12–20
Alfalfa	21.8	12.4	9.7
Waste woody biomass			
Loblolly pine	35	16.8	29
Lodgepole pine	44.9	22.6	26.8
Monterey pine	41.7	20.5	25.9
Douglas fir	44.6	19.4	31.5
Hybrid poplar	40	22	24
Willow	49.3	14.1	20
Hardwood stems	40–55	24–40	18–25
Softwood stems	45–50	25–35	25–35
Eucalyptus	45–51	11–18	29

Municipal solid waste			
Swine waste	6	28	NA
Cattle manure- Solid	1.6–4.7	1.4–3.3	2.7–5.7
Waste paper- chemical pulp	60–70	10–20	5–10
Waste water solids- Primary	8–15	NA	24–29
Banana waste	13.2	14.8	14

ECONOMICS IMPORTANCE OF LIGNOCELLULOSIC BIOMASS

Lignocellulosic mass possesses an immense potential to be used as the substrate with several applications in addition to the production of high-value compounds and products. It is considered as a sustainable organic carbon source for fuel and chemical production with net zero carbon emission and thus considered as a suitable candidate to compete with crude oil and reduce environmental pollution. Lignocellulosic biomass is basically a byproduct recovered from forestry, agricultural and agro-industries and its disposal is a great challenge. It has an added advantage of being a nearly zero value resource as a considerable amount of this it is discarded as waste in the form of agricultural residues, sugarcane bagasse, straws, grasses etc. (Abu Yazid *et al.* 2017). These residues can be directly used as the raw materials with several applications and generation of useful products or may be used as substrates for the growth of suitable microorganisms for transformation into value added products. Hence, using these waste byproducts as the substrates for transformation into value-added products signifies the economic importance of lignocellulosic biomass. The range of the value added products which can be obtained by conversion of lignocellulosic biomass at industrial scale and its employing in the field of agriculutre again by using traditional methods is depicted in Fig. 1.

Table 2: General composition of cellulose, hemicellulose, and lignin in lignocellulosic biomass

	Cellulose	**Hemicellulose**	**Lignin**
Subunits	D-Pyran glucose	D-Xylose, L-Arabinose, Glucose, Mannose Galactose, glucuronic, and galacturonic acids	Guaiacyl propane (G), Syringyl propane (S), p-Hydroxyphenyl propane (H)
Bonds between the subunits	β-1,4-Glycosidic bonds	β-1,4-Glycosidic bonds in main chains; β-1.2-, β-1.3-, β-1.6-Glycosidic bonds in side chains	Various ether bonds and carbon-carbon bonds, mainly β-O-4 ether bond
Degree of polymerization	Several hundred to tens of thousands	Less than 200	4,000
Type of polymers	**β-Glucan**	Polyxylose, Polyarabinose, Polymannose, Polygalactan, Galactoglucomannan, Galactomannan, Glucomannan	G lignin, GS lignin, GSH lignin
Composition	Three-dimensional linear molecular composed of the crystalline and amorphous regions	Three-dimensional inhomogeneous molecular with a small crystalline region	Amorphous, Inhomogeneous, Nonlinear three-dimensional polymer
Bonds between three components	Without chemical bond	Contains chemical bond with lignin	Contain chemical bond with hemicellulose

Cited from Chen, 2014.

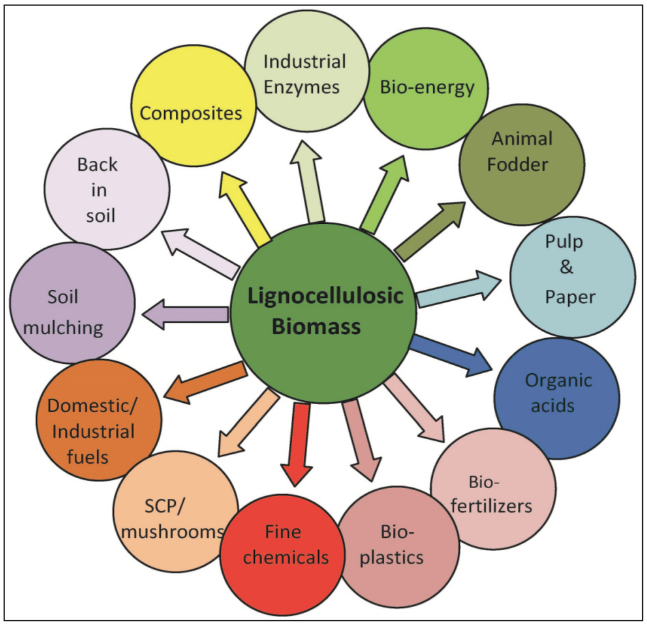

Fig. 1: Range of the applications and high-value products that can be obtained from lignocellulosic biomass

USE OF LIGNOCELLULOSIC BIOMASS IN AGRICULTURE AND ANIMAL WELFARE

The main applications of agricultural residues where they are used directly are discussed hereafter:

Mushroom farming

Paddy straw is the main substrate for the cultivation of temperate mushrooms (paddy mushroom) in Punjab (Choudhary *et al.* 2009). However, wheat straw is used for the cultivation of button ad oyster mushrooms. For the production of button mushroom, wheat straw is first subjected to composting while the oyster mushrooms are cultivated directly on properly cut and moistened wheat straw.

Incorporation back in soil

Addition of agricultural residues back in soil increases the organic carbon content by 14–29% (Singh *et al.* 1996), but at least 3 weeks must be given for in-situ decomposition before the sowing of the next crop (Singh *et al.* 1992). This decomposes the residues to some nutrients and also enhances the pH value, organic carbon, infiltration rate, and water holding capacity of the soil (Gupta *et al.* 2004). This practice is especially important considering the carbon deficiency levels observed in the soils due to continuous cultivation of crops year after year.

Mulching of soil for improving soil health

Mulching of soil with agricultural residues especially rice straw is used to conserve and maintain the moisture levels of the soil. It may be used for the crops like wheat, maize, sugarcane, sunflower, soybean, potato, and chilli production since these crops require wetland (Arora *et al.* 2011; Kumar and Singh, 2020). It also maintains the minimum soil temperature essential for crops in the winter and gives a shading effect in the summer.

Composting

Composting is the decomposition of rice straw to enable recovery of portions of its nutrients and organic components if the feedstock materials have a high nitrogen content to obtain a better carbon-to-nitrogen ratio. Rice straw takes a longer time to decompose it may take a year. Scientists have already developed a rapid composting technique to convert huge piles of rice straw into the organic-rich soil. Generally, it takes about 45 days to prepare this rice straw compost (Kumar and Singh, 2020).

Animal fodder and shed preparation

Most of the agricultural residues may be used as animal fodder, and for the preparation of shed of cattle. The paddy straw is normally not used as fodder for cattle due to the presence of high silica and lignocellulosic content which is not easily digestible except straw of basmati rice and wheat straw (Jain, 2016). Wheat and basmati rice straws are frequently used as cattle fodder. The paddy straw is frequently used for making shed for the cattle in the winter, which protects the cattle from extreme cold and prevents the chances of injury (Kumar *et al.* 2015).

USE OF AGRICULTURAL RESIDUES IN HOUSEHOLD AND INDUSTRY

Discussed below are uses of agricultural residues as raw material, fuel etc in the various industries and household:

Domestic fuel

The people of the rural areas are still dependent on fuel wood and agricultural residues (combustion with dung cake/ wood/ coal) for cooking (Jain *et al.* 2014; Kumar *et al.* 2015).

Fuel for power plants

Several thermal power plants are using rice straw as fuel for power production. Fly ash and bottom ash as the by-products of fuel combustion in power plant may be used in the cement and brick manufacturing industry. The paddy straw may be used in the form of bales directly in the furnace or in the form of shredded straw with pulverized coal. The handling and storage of straw in the form bales become easy (Kumar and Singh, 2020).

Pellets for use as refuse derived fuel (RDF)

The crop residue may be used as a fuel in the pellet form. The pellet mill is used to crush, press, compact and form the straw, peanut shell, cob, cotton bar, soybean rod, weeds branches, leaves, sawdust, bark, and other solid wastes to prepare the pellets. This kind of fuel has high efficiency and is easy to store. It can also be used as main fuel for the industrial boilers (Verma 2014; Kumar and Singh, 2020).

Paper and pulp industry

A pulping technology eliminates agricultural waste by converting into paper. The best method extracts cellulose from the straw to make paper and natural phenolic materials (Kumar and Singh, 2020).

Mixing with plastics

The paddy straw can also be used as reinforcing the material in plastics. The paddy straw is shredded into small pieces of 1.5–2 mm size and mixed with polypropylene. The mixture is then extruded into granules using a twin screw extruder (Verma 2014). Studies are being conducted to assess the lignin reinforced matrices and lignnocellulosic matrices for their application in bioplastics (Yang *et al.* 2019).

Composite materials

In India, rice husk, jute, stalk, and coconut fibre are produced in large amount. All these natural fibres have excellent physical and mechanical properties and can be utilized more effectively in the development of composite materials for various applications like hard board (Pandey and Sujatha 2011).

VALUE-ADDED PRODUCTS FROM LIGNOCELLULOSIC BIOMASS

Use of lignocellulosic biomass as a feedstock for the growth of microorganisms is a sustainable approach which is cost effective as well as eco friendly for the production of a wide range of value added products (Kumar *et al.* 2016). Potential uses of lignocellulosic biomass are in composting, manufacturing paper, production of biofuel and animal feed. Bio-transformation may be used for production of ethanol, acetone, butanol, bio-hydrogen, bio-methane, bio-fertilizers, acetic acid, citric acid, fumaric acid, lactic acid, sugar alcohols (xylitol, arabitol, etc.), hydroxymethyl furfurals, phenol, vanillin, etc. The range of various value added products which can be obtained upon the bioconversion of lignocellulosic biomass is illustrated in Fig. 2 and some of these are discussed hereafter.

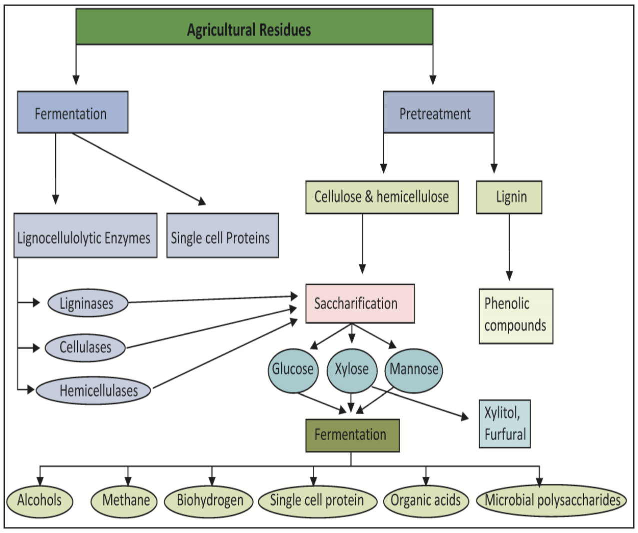

Fig. 2: Value added products from agricultural biomass conversion

INDUSTRIAL ENZYMES

As the enzyme cost is the most important factor in determining the commercial viability of a process using the rice straw as the feedstock, it is desirable to develop the low-cost processes for the enzyme production using the abundantly available agricultural residues. Since, the industrial demand for cellulases, xylanases, lignases and pectinases is extremely high, lignocellulosic biomass derived from agro-industrial residues are appropriate substrates for production of these enzymes on a large scale. Of the various fermentation technologies available for bulk enzyme production, solid-state fermentation appears to be most promising as it can use the lignocellulosic residues for supporting the growth of the microorganisms because of high carbohydrate content. This also establishes a better contact of the microorganism with the substrate for inducing higher titers of enzymes (Bansal *et al.* 2012; Chugh *et al.* 2016). Since, the industrial demand for cellulases, xylanases, lignases, pectinases and proteases is extremely high, lignocellulosic biomass derived from agro-industrial residues are appropriate substrates for production of these enzymes on a large scale. Several attempts have been made during the last few years to produce the cellulases and hemicellulases by solid-state fermentation of agricultural residues including wheat bran (Chakraborty *et al.* 2016; Hemansi *et al.* 2018), rice bran (Chugh *et al.* 2016), kitchen waste (Janveja *et al.* 2013), brewer's spent grain (Rana *et al.* 2013), rice straw (Aggarwal *et al.* 2017; Kaur *et al.* 2020), a combination of rice straw and wheat bran (Sandhu *et al.* 2013), sweet sorghum bagasse (Bagewadi *et al.* 2018), and banana peels (Rehman *et al.* 2014). Rastogi *et al.* (2016) reported the co-production of laccase, xylanase and mannanase by a natural variant of *Pyrenophora phaeocomes* on various agricultural residues. Solid state fermentation of rice straw induced the highest productivities corresponding to 10,859.51 ± 46.74, 22.01 ± 1.00 and 10.45 ± 0.128 IU gds^{-1} for laccase, xylanase and mannanase respectively after 4 days.

BIO-ENERGY

Bio fuels produced from renewable sources may replace the dependence on fossil fuels in the near future, hence, the production of bioethanol, biobutanol, biomethane and biohydrogen from lignocellulosic biomass is a sustainable alternative (Fatma *et al.* 2018).

Bioethanol: The conventional fossil fuels are detrimental in terms of future security, pollution, geopolitical instability and thus derive the need for alternative fuels. Bioethanol can be used as blend with gasoline or directly as fuel. Use of starchy food crops in first generation of biofuels is in direct conflict to the food needs of population. Second generation biofuel uses lignocellulosic biomass which is full of possibilities even upto level of replacement of fossil fuels. Market share for ethanol is largest due to its use as chemical feed stock coupled with fuel use (Gamage *et al.* 2010).

Many of such residues like wheat straw (Qui *et al.* 2017), sugarcane bagasse (Pitarelo *et al.* 2016), corn stover (Chen *et al.* 2016), corn cob (Zerva *et al.* 2014), brewers spent grain (Zerva *et al.* 2014), rice straw (Molaverdi *et al.* 2019a,b), kitchen waste (Janveja *et al.* 2013b, Karimi and Karimi, 2018), have been worked upon by various research groups for ethanol production using different pretreatment strategies, varying doses cellulases and different consortia of pentose and hexose fermenting yeasts revealing different degrees of success. Chandel *et al.* (2009) studied the fermentation of acid hydrolyzed deoiled rice bran by *Pichia stipitis* NCIM3499 and reported the release of 38.50 g/l of reducing sugars. The same, when subjected to fermentation, yielded 12.47 g/l of ethanol after 72h with fermentation efficiency of 81.74%. Rana *et al.* (2014) observed ethanol concentration of 15.6 g/L from wet exploded corn stover after enzymatic hydrolysis by cellulases from *Trichoderma reesei* RUT C30 and *Aspergillus saccharolyticus* at an enzyme dose of 15FPU/g at 5% solid concentration after 72h of hydrolysis. Singhania *et al.* (2014) carried out SHF of 2.5% H_2SO_4 pretreated wheat straw by in-house produced cellulases from *P. janthinellum* EMS-UV-8 and observed ethanol concentration and yield corresponding to 12.0 g/l and 30.2% respectively. Yu *et al.* (2016) resulted 160 g/kg of ethanol productivity from corn stover pretreated with magnesium bisulfate after enzymatic hydrolysis with two commercial enzyme preparations (Celluclast 1.5 L and Novozyme 188) at enzyme dose of 15 FPU/g after 48 h of hydrolysis. Nghiem *et al.* (2016) observed ethanol conc. of 39.5 g/L from low moisture anhydrous ammonia (LMAA) pretreated corn stover by using CTec2 and HTec2 at 7.5 % solid loading after 72 h of hydrolysis. Zhao *et al.* (2018) reported ethanol yield of 21.7 g/l and Molevardi *et al.* (2019b) obtained 83.9 g/l ethanol with Na_2CO_3 pretreated rice straw. Ethanol concentration of 6.47 g/l was also reported by simultaneous delignification, sachharification and fermentation of rice straw (Bhardwaj *et al.* 2019). Prasad *et al.* (2020) reported ethanol yield of 25.3 g/l using *P. stiptis* NCIM 3186 from 2% NaOH pretreated rice straw. Bhardwaj *et al.* (2020) and Jin *et al.* (2020) observed ethanol yield of 11.9g/l and 9.45 g/l from KCl-H_3PO_4 and NaOH pretreated rice straw respectively. Chohan *et al.* (2020) optimized bioethanol production from potato peel wastes on inputs of temperature, pH and solid loading using simultaneous saccharification and fermentation. Subsequently, the kinetics of yeast growth and bioethanol formation under the optimized conditions were assessed using the logistic and modified Gompertz models, respectively. Maximum bioethanol concentration (22.54 g/L) and yield (0.32 g/g) were observed under optimal process conditions of 40 °C (temperature), 5.78 (pH) and 12.25% w/v (solid loading). Kaur et al (2020) in a recent study saccharified 0.25N NaOH pretreated rice straw using inhouse produced cellulase-hemicellulase consortium from *A. niger* P-19 releasing 70 g/l of reducing sugars with 10% solid loading and the fermentation of C6 sugars resulted in an ethanol yield of 15.6 g/l .

Biobutanol: Biobutanol has potential to replace even gasoline in future. Its salient features include high energy density and miscibility with gasoline in all ratios. It is less corrosive and has low vapor pressure allowing transportation by existing structure. It is has lesser solubility in water reducing ground water contamination risk (Rajagopalan *et al*. 2016). Lignocellulosic biomass has been used for biobutanol production (Mahapatra & Kumar, 2017). The main drawback with the use of biobutanol is its low production rate at industrial level (Jin *et al.* 2011). Usually, the production under fermentation processes is carried out by bacteria, such as *Clostridium* spp (Gottumukkala *et al.* 2013; Grassi *et al.* 2018) which may use lignocellulosic biomass (Phanchan *et al.* 2017). Magalhães *et al.* (2018) reported the improved n-butanol production from lignocellulosic hydrolysate by *Clostridium* strain and culture-medium optimization.

Biomethane: Biogas generation has been used for meeting thermal and electrical needs at local level. It is a mixture of methane and carbon dioxide. Lignocellulosic biomass comprising fallen leaves, stover, straws etc has been used for production of biomethane (Kumar *et al*. 2016; Petersson *et al*. 2007). Few recent studies have also explored the potential of potato peels as feedstock for the production of biogas. Achinas *et al.* (2019) examined the performance of anaerobic digestion of potato peels in different inoculum-to-substrate ratios without and with dilute sulphuric acid pretreatment. In addition, the impact of combined treatment with cow manure and pretreatment of potato peels was examined. Comparing the co-digestion to mono-digestion of potato peels, co-digestion in PPW/CM ratio of 60:40 increased the methane yield by 10%. In addition, grinding and acid hydrolysis applied to potato peels were positively effective in increasing the methane amount. Compared to untreated potato peels, pretreatment led to an elevation of the methane amount by 9% and 17% respectively and alleviated the kinetics of biogas production.

Bio-Hydrogen: Hydrogen as a fuel has advantage that it has very high energy density and the only byproduct is water (Dada *et al.* 2013). Wheat bran/straw, corn cob/stalk, potato peels have been used for hydrogen production(Cheng *et al*. 2011; Soares *et al.* 2020) with the productivities ranging from 12 to 7019 mL H_2/L. This wide variation is due to the source of lignocellulosic, its pretreatment method and the operational conditions of fermentation.

BIOFERTILIZERS

Lignocellulosics can be subjected to hydrolysis for the release of sugars that can be readily utilized for the production of plant growth promoting rhizobacteria (PGPR). Many bacteria and fungi have been known to produce extracellular hydrolytic enzymes that can efficiently hydrolyse lignocellulosic biomass. In a study the effectiveness of poultry manure (PM) and banana waste (BW) as carriers for biofertilizer consortium of *Azospirillum*, *Azotobacter* and P-solubiliser was carried out. The plant's physical and soil's physical and microbiological properties were studied for six months and the biofertilizer prepared on BW was found to be better than the PM but the benefits appeared to be restricted to moderate doses of application (≤3%) (Riveracruz *et al*. 2008). *Aspergillus niger* P-19 strain has been studied for production of hydrolytic enzymes to hydrolyse rice straw, municipal solid wastes, etc which can be used as compost or as carrier for adsorption of PGPRs for the production of a carrier based biofertilizer (Kajal, 2020; Manhas, 2020; Dhiman, 2020).

ORGANIC ACIDS

A significant effort is being made to find bioconversion methods to utilize the bulk lignocellulosics being generated for the production of organic chemicals. Organic acids are used for synthesis of value added chemicals. A range of acids have been produced using lignocellulosic biomass (Prado *et al*. 2005).

Citric Acid: After ethanol, the 2nd largest fermentation product is citric acid. It is used for medicinal purposes, heavy metal bioremediation and nanotechnology. Production of citric acid using lignocellulosic biomass including cotton waste, pomace, cobs, husk etc. has been reported (Kumar *et al.* 2016).

Succinic Acid: It is used in agriculture and pharma industries as well as for production of methyl ethyl ketone, adipic acid, 1,3-butadiene, ethylene diaminedisuccinate and 1,4-butanediol. It is conventionally produced by petro based chemicals but with poor efficiency (Cheng *et al*. 2012). *Actinobacillus succinogenes* 130Z, readily converted 29.2 g/L of cellulosic glucose to 17.8 g/L of succinic acid using pre-treated sweet sorghum bagasse as the substrate (Dogaris *et al.* 2020).

Lactic Acid: It has uses in chemical, food, textile and pharmaceutical industries. Its demand is expected to rise as it is used in poly-lactic acid and lactate solvents. Poly lactic acid is environmentally safe polymer which can be used as alternative to plastics (Cui *et al*. 2011). Various lignocellulosic biomass sources have been used for lactic acid production. Currently lactic acid is produced by microbial route as it has better environmental impact (Cubas-Cano *et al*. 2018).

Acetic Acid: It is famously known as vinegar which is used as a preservative in the food industry, has anti-septic usage in the field of medicine and has found pivotal roles in many industrial processes. A study using *Moorella thermoacetica* (strain ATCC 39073) was conducted for bioconversion of sugars obtained from steam pre-treated lignocellulosic biomass into acetic acid a yield of 17 g/L acetic acid from 24 g/L total sugars was obtained (Ehsanipour *et al.* 2016). Another organism *Acetobacterium woodii* was examined for growth on lignocellulosic substrates for the production of acetic acid, with an initial 10 g/L glucose concentration a yield of 0.76g acetic acid per g glucose was recorded from 6.919 g/L acetate production (Karekar *et al*. 2019).

Levulinic Acid: It has extensive use in the fragrance and perfume industry and is used in multiple other industries as it is a precursor for numerous compounds of industrial relevance in pharmaceutical products, as herbicide, as plasticizer, etc. Levulinic acid can be produced from agricultural wastes subjected to acid hydrolysis under high pressure using the carbohydrates that are released. Sugarcane bagasse was bioconverted into levulinic acid using acid catalysed hydrolysis by determining optimum conditions and 194 Kg of levulinic acid was obtained from 1 tonne of dry sugarcane bagasse. The kinetic model thus used can predict the levulinic acid yield under different temperature and acid concentrations (Girisuta *et al.* 2013). Another study recorded a yield of up to 47.52% levulinic acid at 100 °C in 60 mins from bamboo biomass (Khan *et al.* 2018). Lately instead of acid hydrolysis use of organic solvents as the medium of reaction are being studied for the production of levulinic acid (Li *et al.* 2019).

Formic Acid: It has found its use as a preservative, anti-bacterial agent and decalcifying agent in several leather tanning industries, textile dyeing industries, etc. Due to its high demand the conventional production of formic acid as a byproduct of the acetic acid production has proven insufficient. Therefore, exploring other potential substrates for the production of formic acid is required. Lignocellulosics have been used as a substrate for the production of formic acid as a byproduct of levulinic acid from cellulose although in a study conducted the yield of formic acid was found to be highest from glucose followed by cellulose after a hydrothermal treatment (Yun *et al*. 2010). Another study used a Lindqvist type catalyst $K_5V_3W_3O_{19}$ successfully converted all the hemicellulose and lignin model compounds into formic acid but the yields were very low (Albert, 2017). A latest study a crude formic acid (CF) solution was produced having formic acid yield of 17.62 g/L using a mild reaction of combined hydrolysis/oxidation of lignocellulosic feedstock (Park *et al.* 2019).

HYDROXYMETHYL FURFURAL (HMF)

It is the primary product formed from the hydrolysis of lignocellulosics and has been vastly in use as a platform chemical as it acts as the intermediate in the production of multiple chemicals of interest for the industry. It is primarily used on the food industry as a food additive. The hexose sugars released from the lignocellulosics under acidic dehydration conditions lead to the production of HMF. With a combined acid/base treatment followed by catalytic conversion a maximum HMF yield from biomass is 79 mol% was achieved (Nguyen *et al.* 2016). Various minerals and organic solvents have been used as catalysts to increase the yield (Zhang *et al.* 2017).

Sugar Alcohols

Another class of organic compounds that are produced directly from lignocellulosic biomass is a variety of sugar alcohols. They occur naturally and are produced industrially by hydrogenation of sugar molecules, this process of hydrogenation can be hastened by employing metal catalysts in presence of acids. To list a few xylitol, maltitol, arabitol and mannitol are all sugar alcohols. Xylitol is an artificial sweetener equivalent to sucrose and used among diabetic patients and considered among top twelve value-added chemicals produced from plant biomass (Martin *et al.* 2009). Xylitol is produced by costly process resulting in low yields. Xylose present in biomass can be converted to xylitol using *Candida* spp., (Damião Xavier *et al.* 2018; Zhang *et al.* 2014). Metal catalysts such as Pt, Pd and Ru have been studied and conversion of 60% sugars was observed in an hour (Palkovits *et al.* 2010). In a study using zirconium phosphate the highest sugar alcohol yield of 70% was recorded utilizing the cellulosic and hemicellulosic fractions of raw lignocellulosic biomass (Liu *et al.* 2017).

PHENOL

Lignin present as a major fraction in the lignocellulosics biomass available is known to be converted into phenol and phenolic compounds that are used in the production of various chemicals. This is attributable to its complex structure. To convert lignin into value added products processes such as hydrogenolysis, pyrolysis, oxidation and depolymerization have been found to be very promising. Kraft lignin pyrolysis assisted with formates gives monophenols and polyphenols as the main components. Using alkylated lignin for the production of phenolics by exploring supercritical conditions of methanol or ethanol to obtain cathecol is also a very promising method (Tang and Zhou, 2015). Amongst formates the nickel formates have shown high selectivity for polyphenols 21.95% (w/w) was recorded and 23.7% (w/w) guaiacol was obtained from pure lignin (Wang *et al.* 2019). In a catalytic transfer hydrogenolysis process using isopropanol as H-donor solvent 98.1% highest activity was achieved giving phenolic compounds as major products making it a promising strategy for valourisation of lignin (Guan *et al.* 2020).

VANILLIN

It is widely used in the food, cosmetics and perfume, and pharmaceutical industry as a flavouring agent. Vanillin forms a major fraction of the phenol aldehydes obtained from lignin especially from the guaiacyl and syringyl units (Luo *et al.* 2016). The linkages present in the lignin used for the production of vanillin play a vital role in determining the yield of vanillin. The lignin high in content of β-*O*-4 linkages showed higher vannilin yield (Wang *et al.* 2018).

MICROBIAL POLYSACCHARIDES

Bio based polymers are used in different industries like chemical, food, petroleum, health, and bionanotechnology due to diverse functionality, rheological and physicochemical properties (Özcan & Öner, 2015). Fermentation is used for production of polysaccharides like schizophyllan, xanthan, dextran, pullulan, curdlan etc. Microbial species belonging to *Xanthomonas, Leuconostoc, Sphingomonas,* and *Alcaligenes* are used industrially for production of xanthan, dextran, gellan, and curdlan. Hyaluronan is used in cosmetics and in regenerative medicine as it has high immune compatibility, water binding ability and retention properties. Alginate has a wide spread use as thickener, stabilizer and as gelifying thickening, stabilizing, and gelifying agent (Özcan & Öner, 2015). Municipal solid waste (MSW) including sugarcane bagasse (Hilares *et al.* 2017), kitchen waste (Rishi *et al.* 2020), sugar cane baggase (Hilares *et al.* 2017; 2019), Asian palm kernel (Sugumaran *et al.* 2013), cassava bagasse (Sugumaran *et al.* 2014) have been exploited as cheap sources of carbon for production of pullulan by *A. pullulans* after the enzymatic hydrolysis. A study conducted using spent/damaged wheat grains as source of sugars for growth of *Aureobasidium pullulans* 3B2 obtained highest yield of polysaccharide production of 44.4 mg/gds. It can further be used for film casting and 2.5% and 5% conc of eps gave good and properly peelable film that can be used as bioplastics (Armaan, 2018).

Single-Cell Proteins

Single cell proteins are extracts or whole microbes used as a dietry supplement or ingredient rich in proteins. They are used for human and animal feed. They have advantage over agricultural practices as they have low water consumption, lesser use of land, low greenhouse gas production and an all-weather production (Ivanovs *et al.* 2018). Lignocellulosic biomass can be used for single cell protein production due to their low cost. A study using lignocellulosic hydrolysates for production of single cell protein by *Candida intermedia* FL023 reported high protein content (Ivanovs *et al.* 2018). Rice straw pulp has been used as substrate for single cell protein production using *Trichoderma reesei* by solid state fermentation (Ivanovs *et al.* 2018). Also, *Chaetomium* spp. are well recognised among the group of cellulolytic fungi for their potential to produce single cell protein (SCP) (Darwish *et al.* 2019).

CONCLUSION

The entire concept of lignocellulosic biomass conversion has been described with an attempt to formulate the idea of valorization of biomass residues into value-added products. In this regard, a detailed analysis on the economical significance of lignocellulosic biomass has been carried out displaying it as a near zero cost substrate. The traditional and conventional ways already in place for the use of the lignocellulosic residues have also been discussed. An effort has also been made to specify the various effective processes to produce various value-added products from lignocellulosic feedstock. The important steps in the bioconversions are the pretreatment and enzymatic hydrolysis making use of a consortium of cellulases and hemicellulases which are produced commercially and marketed by several industries globally, but these are very expensive and the cost of these is another crucial factor in making the bioprocesses using agricultural residues a reality. The conversion of lignocellulosic biomass by on-site production of cellulases employing suitable micro-organisms is a potential, sustainable and economically viable approach to develop novel bioprocesses using cellulosic residues. Further, cellulase research has been concentrated mostly in fungi, though many bacterial cellulases have also been isolated but they are reported to have lower yields as compared to fungi so there is also a need to genetically engineer such bacterial isolates for high productivities or cellulase genes from efficient fungi need to be cloned and expressed in fast growing bacteria. Further advanced biotechnologies are crucial for discovery and characterization of new enzymes, and production in homologous or heterologous systems which will ultimately lead to low-cost conversion of lignocellulosic biomasses into bio-fuels and bio-chemicals.

REFERENCES

Abu Yazid, N., Barrena, R., Komilis, D., and Sánchez, A. 2017. Solid-state fermentation as a novel paradigm for organic waste valorization: a review. *Sustainability*, **9**: 224-224.

Achinas, S., Li, Y., Achinas, V. and Euverink, G.J.W. 2019. Biogas Potential from the Anaerobic Digestion of Potato Peels: Process Performance and Kinetics Evaluation. *Energies*, **12**: 2311.

Aggarwal, N.K., Goyal, V., Saini, A., Yadav, A. and Gupta, R. 2017. Enzymatic saccharification of pretreated rice straw by cellulases from *Aspergillus niger* BK01. 3 *Biotech*, **7**: 158.

Albert, J. 2017. Selective oxidation of lignocellulosic biomass to formic acid and high-grade cellulose using tailor-made polyoxometalate catalysts. *Faraday Discussions*, **202**: 99–109.

Arora, V.K., Singh, C.B., Sidhu, A.S. and Thind, S.S. 2011. Irrigation, tillage and mulching effects on soybean yield and water productivity in relation to soil texture. *Agric. Water Manage*., **98***:* 563–568.

Avci, A., Saha, B.C., Dien, B.S., Kennedy, G.J. and Cotta, M. A. 2013. Response surface optimization of corn stover pretreatment using dilute phosphoric acid for enzymatic hydrolysis and ethanol production. *Bioresour. Technol.,* **130**: 603-612.

Bagewadi, Z.K., Sikandar, I.M. and Harichandra. Z.N. 2018. Optimization of endoglucanase production from *Trichoderma harzianum* strain HZN11 by central composite design under response surface methodology. *Biomass Convers. Bior.,* **8**: 305-316.

Bajpai, P. 2016. Structure of lignocellulosic biomass. *Springer,* pp. 7-12.

Bansal, N., Tewari, R., Soni, R. and Soni, S.K., 2012. Production of cellulases from *Aspergillus niger* NS-2 in solid state fermentation on agricultural and kitchen waste residues. *Waste Manag.,* **3**: 1341-1346.

Bhardwaj, N., Kumar, B., Agrawal, K. and Verma, P. 2019. Bioconversion of rice straw by synergistic effect of in-house produced ligno-hemicellulolytic enzymes for enhanced bioethanol production. *Bioresour. Technol. Rep.,* 2019. 100352.

Bhardwaj, N., Kumar, B. and Verma, P. 2020. Microwave-assisted pretreatment using alkali metal salt in combination with orthophosphoric acid for generation of enhanced sugar and bioethanol. *Biomass Conv. Bioref.,* 2020. 1-8.

Chandel, A.K., Narasu, M.L., Rudravaram, R., Pogaku, R., Rao, L.V. 2009. Bioconversion of de-oiled rice bran (DORB) hemicellulosic hydrolysate into ethanol by *Pichia stipitis* NCM3499 under optimized conditions. *Int. J. Food Eng*., **5**.

Chen, H. 2014. Chemical composition and structure of natural lignocellulose. *Springer*, pp. 25-71. *In:* Biotechnology of Lignocellulose. Springer, Dordrecht, pp. 25-71.

Chen, X., Kuhn, E., Jennings, E.W., Nelson, R., Tao, L., Zhang, M. and Tucker, M.P. 2016. DMR (deacetylation and mechanical refining) processing of corn stover achieves high monomeric sugar concentrations (230 g/l) during enzymatic hydrolysis and high ethanol concentrations (>10% v/v) during fermentation without hydrolysate purification or concentration**.** *Energy Environ. Sci.,* **9**: 1237-1245.

Cheng, C.-L., Lo, Y.-C., Lee, K.-S., Lee, D.-J., Lin, C.-Y., and Chang, J.-S. 2011. Biohydrogen production from lignocellulosic feedstock. *Bioresource Technology,* **102**(18), 8514–8523.

Cheng, K.K., Zhao, X.B., Zeng, J. and Zhang, J.A. 2012. Biotechnological production of succinic acid: current state and perspectives. *Biofuel. Bioprod. Bior.*, **6**: 302-318.

Chohan, N.A., Aruwajoye, G.S., Sewsynker-Sukai, Y. and Kana, E.B.G. 2020. Valorisation of potato peel wastes for bioethanol production using simultaneous saccharification and fermentation: Process optimization and kinetic assessment. *Renew. Energ*., **146**: 1031-1040.

Choudhary, M., Dhanda, S., Kapoor, S., and Soni, G. 2009. Lignocellulolytic enzyme activities and sub-strate degradation by *Volvariella volvacea*, The paddy straw mushroom/Chinese mushroom. *Indian J. Agricl Res*., **43**: 223–226.

Chugh, P., Soni, R. and Soni, S.K. 2016. Deoiled rice bran: a substrate for co-production of a consortium of hydrolytic enzymes by *Aspergillus niger* P-19. *Waste Biomass Valori.*, **7***:* 513-525.

Cubas-Cano, E., González-Fernández, C., Ballesteros, M. and Tomás-Pejó, E. 2018. Biotechnological advances in lactic acid production by lactic acid bacteria: lignocellulose as novel substrate. *Biofuel Bioprod. Bior.*, **12**: 290-303.

Cui, F., Li, Y. and Wan, C. 2011. Lactic acid production from corn stover using mixed cultures of *Lactobacillus rhamnosus* and *Lactobacillus brevis*. *Bioresour. Technol*., **102**: 1831–1836.

Dada, O., Yusoff, W.M.W. and Kalil, M.S. 2013. Biohydrogen production from ricebran using *Clostridium saccharoperbutylacetonicum* N1-4. *Int. J. Hydrogen Energ*., **38**: 15063–15073.

Damião Xavier, F., Santos Bezerra, G., Florentino Melo Santos, S., Sousa Conrado Oliveira, L., Luiz Honorato Silva, F., Joice Oliveira Silva, A., and Maria Conceição, M. 2018. Evaluation of the Simultaneous Production of Xylitol and Ethanol from Sisal Fiber. *Biomolecules*, **8**: 2.

Darwish, A.M.G. and Abdel-Azeem, A.M. 2020. *Chaetomium* enzymes and their applications. In: Abdel-Azeem A. (eds) Recent Developments on Genus *Chaetomium*. *Fungal Biology.* Springer, Cham, pp. 241-249.

Dhiman, V. 2020. Development of a novel microbial consortium for efficient composting of kitchen waste residues. M.Sc Thesis, Panjab University, Chandigarh, India.

Dogaris I., Lo E., Brabo-Catala L., Ammar E.M. and Philippidis G.P. 2020 Biochemical conversion of sweet sorghum bagasse to succinic acid. *J. Biosci. Bioeng.*, **129**: 104-109.

Ehsanipour, M., Suko, A.V. and Bura, R. 2016. Fermentation of lignocellulosic sugars to acetic acid by *Moorella thermoacetica*. *Journal of Industrial Microbiology & Biotechnology,* **43**(6): 807–816.

Fatma, S., Hameed, A., Noman, M., Ahmed, T., Shahid, M., Tariq, M., Tabassum, R. 2018. Lignocellulosic biomass: A sustainable bioenergy source for the future. *Protein Peptide Lett.,* **25**: 148-163.

Gamage, J., Lam, H. and Zhang, Z. 2010. Bioethanol production from lignocellulosic biomass, a review. *J. Biobased Mater. Bioener.,* **4**: 3-11.

Girisuta, B., Dussan, K., Haverty, D., Leahy, J.J. & Hayes, M. H.B. 2013. A kinetic study of acid catalysed hydrolysis of sugar cane bagasse to levulinic acid. *Chemical Eng. J.,* **217**: 61–70.

Gottumukkala D., Parameswaran B., Valappil S.K., Mathiyazhakan K., Pandey A. and Sukumaran R.K. 2013. Biobutanol production from rice straw by a non-acetone producing *Clostridium sporogenes* BE01. *Bioresour. Technol*., **145**: 182-187

Grassi, M.C.B., Carazzolle, M.F., Nakagawa, B.T., Ferrari, A., Nagamatsu, S., Murakami, M.T., Pirolla, R.A.S. and Pereira, G.A.G. 2018. New contributions for industrial n-butanol fermentation: An optimized *Clostridium* strain and the use of xylooligosaccharides as a fermentation additive. *Biomass Bioenerg*., **119**: 304-313

Guan, W., Chen, X., Zhang, J., Hu, H. and Liang, C. 2020. Catalytic transfer hydrogenolysis of lignin α-O-4 model compound 4-(benzyloxy)phenol and lignin over Pt/HNbWO6/CNTs catalyst. *Renew. Energ.*, **156**: 249–259.

Guldhe, A., Singh, B., Renuka, N., Singh, P., Misra, R. and Bux, F. 2017 Bioenergy: a sustainable approach for cleaner environment. *In:* Bauddh K, Singh B, Korstad J (eds) Phytoremediation potential of bioenergy plants. Springer, Singapore, pp. 47–62.

Gupta, P.K., Sahai, S., Singh, N., Dixit, C.K., Singh, D.P. and Sharma, C. 2004. Residue burning in rice–wheat cropping system: Causes and implications. *Current Science India,* **87**: 1713–1715.

Hemansi, Gupta R., Kuhad R.C. and Saini J.K. 2018. Cost effective production of complete cellulose system by newly isolated *Aspergillus niger* RCKH-3 for efficient enzymatic saccharification: Medium engineering by overall evaluation criteria approach (OEC). *Biochem. Eng. J.,* **132**: 182-190.

Hilares, R.T., Orsi, C.A., Ahmed, M.A., Marcelino, P.F., Menegatti, C.R., da Silva, S.S. and dos Santos, J.C. 2017. Low-melanin containing pullulan production from sugarcane bagasse hydrolysate by *Aureobasidium pullulans* in fermentations assisted by light-emitting diode. *Bioresour. Technol*., **230**: 76–81.

Hilares, R.T., Resende, J., Orsi, C.A., Ahmed, M.A., Lacerda, T.M., da Silva, S.S. and Santos, J.C. 2019. Exopolysaccharide (pullulan) production from sugarcane bagasse hydrolysate aiming to favor the development of biorefineries. *Int. J. Biol. Macromol*., **127**: 169–177.

Iqbal, H.M.N., Kyazze, G. and Keshavarz, T. 2013. Advances in the valorization of lignocellulosic materials by biotechnology: An overview. *BioResources*, **8:** 3157-3176.

Ivanovs, K., Spalvins, K., and Blumberga, D. 2018. Single cell protein production from waste biomass: review of various agricultural by-products. *Agron. Res.*, **16**: 1493-1508.

Jain, A.K. 2016. Residue crop (Paddy Straw) burning shrouds NCR. In Proceedings of the 2nd inter- national seminar on utilizationof non-conventional energy sources for sustainable development of rural areas, ISNCESR. Parthivi College of Engineering &Management, C.S.V.T. University, Bhilai, Chhattisgarh, India. 16, 17th and 18th March 2016.

Jain, N., Pathak, H. and Bhatia, A. 2014. Sustainable management of crop residues in India. *Curr. Adv. Agric. Sci.*, **6***: 1–9.*

Janveja, C., Rana, S.S. and Soni, S.K. 2013a. Environmentally acceptable management of kitchen waste residues by using them as substrates for the co-production of a cocktail of fungal carbohydrases. *IJCEES,* **4**: 20–29.

Janveja, C., Rana, S.S., Soni, S.K., 2013b. Kitchen waste residues as potential renewable biomass resources for the production of multiple fungal carbohydrases and second generation bioethanol. *J. Technol. Innov. Renew. Energy,* **2**: 186-200.

Jin, C., Yao, M., Liuc, H., Fon, C., Lee, F. and Ji, J. 2011. Progress in the production and application of n-butanol as a biofuel. *Renew. Sustain. Energy Rev*., **15**: 4080–4106.

Jin, X., Song, J. and Liu, G.Q. 2020. Bioethanol production from rice straw through an enzymatic route mediated by enzymes developed in-house from *Aspergillus fumigatus*. *Energy*, **190**: 116395.

Kajal. 2020. Valorisation of rice straw by converting it into a compost and carrier-based biofertilizer. M.Sc Thesis, Panjab University, Chandigarh, India.

Karekar, S.C., Srinivas, K. and Ahring, B.K. 2019. Kinetic study on heterotrophic growth of *Acetobacterium woodii* on lignocellulosic substrates for acetic acid production. *Fermentation*, **5**: 17.

Karimi, S. and Karimi, K. 2018. Efficient ethanol production from kitchen and garden wastes and biogas from the residues. *J. Clean. Prod*., **187**: 37-45.

Kaur J., Chugh, P., Soni, R. and Soni, S.K. 2020. A low-cost approach for the generation of enhanced sugars and ethanol from rice straw using in-house produced cellulase-hemicellulase consortium from *A. niger* P-19. *Bioresour. Technol. Reports*., **11**: https://doi.org/10.1016/j.biteb.2020.100469

Khan, A.S., Man, Z., Bustam, M.A., Nasrullah, A., Ullah, Z., Sarwono, A., Shah, F.U. and Muhammad, N. 2018. Efficient conversion of lignocellulosic biomass to levulinic acid using acidic ionic liquids. *Carbohydrate Polymers*, **181**: 208–214.

Kumar, A., Gautam, A. and Dutt, D. 2016. Biotechnological transformation of lignocellulosic biomass in to industrial products: An overview. *Adv. Biosci. Biotechnol*., **7:** 149-168.

Kumar, A.K., Parikh, B.S. and Pravakar, M. 2016. Natural deep eutectic solvent mediated pretreatment of rice straw: bioanalytical characterization of lignin extract and enzymatic hydrolysis of pretreated biomass residue. *Environ. Sci. Pollut. Res.*, **23**: 9265–9275.

Kumar, P., Kumar, S., and Joshi, L. 2015. Socioeconomic and environmental implications of agricultural residue burning: A case study of Punjab, India, p. 144. Springer Open.

Kumar, P., and· Singh, R.K. 2020. Selection of sustainable solutions for crop residue burning: an environmental issue in northwestern states of India. *Environ. Dev. Sustain.* https://doi.org/10.1007/s10668-020-00741-x

Li, X., Xu, R., Yang, J., Nie, S., Liu, D., Liu, Y. and Si, C. 2019. Production of 5-hydroxymethylfurfural and levulinic acid from lignocellulosic biomass and catalytic upgradation. *Ind. Crops Prod*., **130**: 184–197.

Liu, Q., Zhang, T., Liao, Y., Cai, C., Tan, J., Wang, T., Qiu, S., He, M., and Ma, L. 2017. Production of C5/C6 sugar alcohols by hydrolytic hydrogenation of raw lignocellulosic biomass over Zr based solid acids combined with Ru/C. *ACS Sust. Chem. Eng*., **5**: 5940–5950.

Luo, J., Melissa, P., Zhao, W., Wang, Z., and Zhu, Y. 2016. Selective lignin oxidation towards vanillin in phenol media. *Chemistry Select*., **1**: 4596–4601.

Lynd, L.R., Weimer, P.J., Van Zyl, W.H. and Pretorius, I.S. 2002. Microbial cellulose utilization: fundamentals and biotechnology. *Microbiol. Mol. Biol. Rev.*, **66**: 506-577.

Magalhães B.L. , Grassi M.C.B., Pereira G.A.G. and Brocchi M. 2018. Improved n-butanol production from lignocellulosic hydrolysate by *Clostridium* strain and culture-medium optimization. *Biomass Bioenerg.*, **108**: 157-166

Mahapatra, M.K. and Kumar, A. 2017. A short review on biobutanol, a second generation biofuel production from lignocellulosic biomass. *J. Clean Energy Technol*., **5**: 27-30.

Manhas, R. (2020). Value addition of biodegradable municipal solid waste by converting it into liquid and carrier based biofertilizers. M.Sc Thesis, Panjab University, Chandigarh, India.

Martin, A.R., Martins, M.A., Mattoso, L.H. and Silva, O.R. 2009. Caracterização química e estrutural de fibra de sisal da variedade Agave sisalana. *Polímeros,* **19**: 40-46.

Molaverdi, M., Karimi, K., Mirmohamadsadeghi, S., Galbe, M., 2019a. High titer ethanol production from rice straw via solid-state simultaneous saccharification and fermentation by *Mucor indicus* at low enzyme loading. *Energy Convers. Manag*., **182**: 520-529

Molaverdi, M., Karimi, K. and Mirmohamadsadeghi, S., 2019b. Improvement of dry simultaneous saccharification and fermentation of rice straw to high concentration ethanol by sodium carbonate pretreatment. *Energy,* **167**: 654-660.

Nghiem, N.P., Senske, G.E. and Kim, T.H. 2016. Pretreatment of corn stover by low moisture anhydrous ammonia (LMAA) in a pilot-scale reactor and bioconversion to fuel ethanol and industrial chemicals. *Appl. Biochem. Biotechnol*., **14**: 1-5.

Nguyen, C.V., Lewis, D., Chen, W.H., Huang, H.W., ALOthman, Z.A., Yamauchi, Y. and Wu, K.C.W. 2016. Combined treatments for producing 5-hydroxymethylfurfural (HMF) from lignocellulosic biomass. *Catalysis Today*, **278**: 344–349.

Özcan, E. and Öner, E.T. 2015. Microbial production of extracellular polysaccharides from biomass sources. Polysaccharides. *In:* Bioactivity and Biotechnology, Ed. Ramawat, K.G. and Mérillon, J.M. Springer International Publishing Switzerland, pp. 161-184.

Palkovits, R., Tajvidi, K., Procelewska, J., Rinaldi, R., and Ruppert, A. 2010. Hydrogenolysis of cellulose combining mineral acids and hydrogenation catalysts. *Green Chem*., **12:** 972–978.

Panahi S.H.K, Dehhaghi M., Aghbashlo M., Karimi K., and Tabatabaei, M. 2020. Conversion of residues from agro-food industry into bioethanol in Iran: An under-valued biofuel additive to phase out MTBE in gasoline. *Renew. Energ.,* **145**: 699-710.

Pandey, A., Soccol, C.R., Nigam, P. and Soccol, V.T. 2000 Biotechnological potential of agro industrial residues. I: Sugarcane Bagasse. *Bioresour. Technol.,* **74**: 69–80

Pandey, C.H. and Sujatha, D. 2011. *Crop residues, the alternate raw materials of tomorrow for the preparation of composite board*.

Indian Plywood Industries Research & Training Institute. https:// innovate.mygov.in/wp-content/uploads/2018/07/mygov1532797148376098.pdf

Park, J.H., Jin, M.H., Lee, D.W., Lee, Y.J., Song, G.S., Park, S.J., Namkung, H., Song, K.H. and Choi, Y.-C. 2019. Sustainable Low-Temperature Hydrogen Production from Lignocellulosic Biomass Passing through Formic Acid: Combination of Biomass Hydrolysis/Oxidation and Formic Acid Dehydrogenation. Environ. Sci. Technol., **53**: 14041–14053.

Paul, S. and Dutta, A. 2018. Challenges and opportunities of lignocellulosic biomass for anaerobic digestion. *Resour. Conserv. Recycl.*, **130**: 164-174.

Pérez, J., Muñoz-Dorado, J., de la Rubia, T. and Martínez, J. 2002. Biodegradation and biological treatments of cellulose, hemicellulose and lignin: an overview. *Int. Microbiol.*, **5:** 53-63.

Petersson, A., Thomsen, M.H., Hauggaard-Nielsen, H. and Thomsen, A.B. 2007. Potential bioethanol and biogas production using lignocellulosic biomass from winter rye, oilseed rape and faba bean. *Biomass Bioenerg*,, **31:** 812-819.

Phanchan N., Fiala K. and Apirakakorn J. 2017. Isolation of cellulolytic Clostridia and their performance for one-step butanol production from sugarcane bagasse. *Energy Proc.*, **138**: 163-168.

Pitarelo, A.P., Da Fonseca, C.S., Chiarello, L.M., Ramos, L.P., 2016. Ethanol production from sugarcane bagasse using phosphoric acid-catalyzed steam explosion. *J. Brazil. Chem. Soc.* **27**(10): 1889-1898.

Prado, F.C., Vandenberghe, L.P.S., Woiciechowski, A.L., Rodrígues-León, J.A. and Soccol, C.R. 2005. Citric acid production by solid-state fermentation on a semi-pilot scale using different percentages of treated cassava bagasse. *Brazilian J. Chem. Eng.*, **22**: 547–555.

Prasad, S., Kumar, S., Yadav, K.K., Choudhry, J., Kamyab, H., Bach, Q.V., Radhakrishnan, S., Kannojiya, S. and Gupta, N., 2020. Screening and evaluation of cellulytic fungal strains for saccharification and bioethanol production from rice residue. *Energy*, **190**: 116422.

Qiu, J., Ma, L., Shen, F., Yang, G., Zhang, Y., Deng, S., Zhang, J., Zeng, Y., and Hu, Y., 2017. Pretreating wheat straw by phosphoric acid plus hydrogen peroxide for enzymatic saccharification and ethanol production at high solid loading. *Bioresour. Technol*., **238**: 174-181

Rajagopalan, G., He, J. and Yang, K.L. 2016. One-pot fermentation of agricultural residues to produce butanol and hydrogen by *Clostridium* strain BOH3. *Renew. Energ*., **85**: 1127–1134.

Rana, V., Eckard, A.D. and Ahring, B.K. 2014. Comparison of SHF and SSF of wet exploded corn stover and loblolly pine using in-house enzymes produced from *T. reesei* RUT C30 and *A. saccharolyticus*. *Springerplus*, **3**: 516.

Rastogi, S., Soni, R., Kaur, J. and Soni, S.K. 2016. Unravelling the capability of Pyrenophora phaeocomes S-1 for the production of ligno-hemicellulolytic enzyme cocktail and simultaneous bio-delignification of rice straw for enhanced enzymatic saccharification. *Bioresour. Technol.*, **222**: 458-469.

Rehman, S., Aslam, H., Ahmad, A., Khan, S.A. and Sohail, M., 2014. Production of plant cell wall degrading enzymes by monoculture and co-culture of *Aspergillus niger* and Aspergillus terreus under SSF of banana peels. *Braz. J. Microbiol.*, **45**: 1485-1492.

Rishi, V., Sandhu, A.R., Kaur, A., Kaur, J., Sharma, S. and Soni, S.K. 2020. Utilization of kitchen waste for production of pullulan to develop biodegradable plastic. *Appl. Microbiol. Biotechnol.*, **104**: 1307–1317.

Riveracruz, M., Trujillonarcia, A., Cordovaballona, G., Kohler, J., Caravaca, F. and Roldan, A. 2008. Poultry manure and banana waste are effective biofertilizer carriers for promoting plant growth and soil sustainability in banana crops. *Soil Biol. Biochem*., **40**: 3092–3095.

Sandhu, A. 2018. Management of agricultural and food wastes for biosynthesis of pullulan. M.Sc Thesis, Panjab University, Chandigarh, India.

Sandhu, S.K., Oberoi, H.S., Babbar, N., Miglani, K., Chadha, B.S. and Nanda, D.K. 2013. Two-stage statistical medium optimization for augmented cellulase production via solid-state fermentation by newly isolated Aspergillus niger HN-1 and application of crude cellulase consortium in hydrolysis of rice straw. *J. Agr. Food Chem.*, **61:** 12653-12661.

Singh, S., Batra, R., Mishra, M.M., Kapoor, K.K. and Goyal, S. 1992. Decomposition of paddy straw in soil and the effect of straw incorporation in the field on the yield of wheat. *J. Plant Nutr. Soil Sci.*, **155***:* 307–311.

Singh, Y., Singh, D. and Tripathi, R.P. 1996. Crop residue management in rice–wheat cropping system. In: *Abstracts of poster sessions 2nd international crop science congress* (p. 43). New Delhi: National Academy of Agricultural Sciences, p. 26.

Singhania, R.R., Saini, J.K., Saini, R., Adsul, M., Mathur, A., Gupta, R. and Tuli, D.K. 2014. Bioethanol production from wheat straw via enzymatic route employing *Penicillium janthinellum* cellulases. *Bioresource Technology*, **169**: 490-495.

Soares, J.F., Confortin, T.C., Todero, I., Mayer, F.D. and Mazutti, M.A. 2020. Dark fermentative biohydrogen production from lignocellulosic biomass: Technological challenges and future prospects. *Renew. Sust. Energ. Rev.*, **117**.

Sugumaran, K.R., Gowthami, E., Swathi, B., Elakkiya, S., Srivastava, S.N., Ravikumar, R., Gowdhaman, D. and Ponnusami, V. 2013. Production of pullulan by *Aureobasidium pullulans* from Asian palm kernel: a novel substrate. *Carbohydr. Polym.*, **92**: 697–703.

Sugumaran, K.R., Jothi, P. and Ponnusami, V. 2014. Bioconversion of industrial solid waste—cassava bagasse for pullulan production in solid state fermentation. *Carbohydr. Polym.*,**99**: 22-30.

Tang, K., and Zhou, X.-F. 2015. The degradation of kraft lignin during hydrothermal treatment for phenolics. *Polish J. Chem. Technol.*, **17**: 24–28.

Verma, S.S. 2014. Technologies for stubble use. *J. Agric. Life Sci.,* **1***:* 106–110.

Wang, W., Wang, M., Huang, J., Zhao, X., Su, Y., Wang, Y., & Li, X. 2019. Formate-assisted analytical pyrolysis of kraft lignin to phenols. *Bioresour. Technol*., **278**: 464–467.

Wang, Y., Sun, S., Li, F., Cao, X., and Sun, R. 2018. Production of vanillin from lignin: The relationship between β-O-4 linkages and vanillin yield. *Industrial Crops and Products*, **116**: 116–121.

Yang, J., Ching, Y.C. and Chuah, C.H. 2019. Applications of Lignocellulosic Fibers and Lignin in Bioplastics: A Review. *Polymers.* **11**: 751.

Yu, H., Ren, J., Liu, L., Zheng, Z., Zhu, J., Yong, Q. and Ouyang, J. 2016. A new magnesium bisulfite pretreatment (MBSP) development for bio-ethanol production from corn stover. *Bioresour. Technol.*, **19**: 188-193.

Yun, J., Jin, F., Kishita, A., Tohji, K., and Enomoto, H. 2010. Formic acid production from carbohydrates biomass by hydrothermal reaction. *Journal of Physics: Conference Series,* **215**(1): 012126.

Zhang, J., Zhang, B., Wang, D., Gao, X. and Hong, J. 2014. Xylitol production at high temperature by engineered *Kluyveromyces marxianus. Bioresour. Technol.*, **152**: 192–201.

Zhang, L., Xi, G., Zhang, J., Yu, H., & Wang, X. 2017. Efficient catalytic system for the direct transformation of lignocellulosic biomass to furfural and 5-hydroxymethylfurfural. *Bioresour. Technol.*, **224**: 656–661.

Zhao, C., Zou, Z., Li, J., Jia, H., Liesche, J., Chen, S. and Fang, H., 2018. Efficient bioethanol production from sodium hydroxide pretreated corn stover and rice straw in the context of on-site cellulase production. *Renew. Energ*., **118**: 14-24..

Zing, Y., Himmel, M.E., Ding, S. 2017 Visualizing chemical functionality in plant cell walls. *Biotechnol. Biofuel*s., **10**: 263.