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Short communication

Cellulosic fraction from agricultural biomass as a viable alternative for plastics and plastic products

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ABSTRACT

Plastics are versatile and cost-effective materials with a variety of functionalities. Their non-biodegradability, accumulation in landfills and natural habitats, physical problems for wildlife resulting from ingestion or entanglement in debris, leaching of chemicals and transfer to humans are concerns of greater magnitude, however. In this regard, plastic replacing materials are warranted. A possible respite is seen in agriculture that feeds the world but a significant portion of crops exists as biomass or the parts that can't be used as food by humans. Agriculture biomass such as corn stalk, wheat straw, rice straw and soy stalk offers a viable source of cellulose that has excellent potential to replace plastics. Herein, the benefits of agriculture biomass and its prospects for cellulose-based biodegradable products are highlighted. The use of agriculture biomass further offers a unique value-added proposition to the agriculture industry and farmers to capitalize on their byproducts to increase the profitability of their operations. The Earth, and its current and future generations, will benefit immensely with this cost-effective and environmentally sustainable solution to curb the ills associated with plastics.

1. Plastics – a global burden

Since plastics introduction, during the 1950 s, their development has expanded exponentially. Plastics are durable, inexpensive, lightweight and easy to prepare and consequent benefits are undeniable. These intrinsic traits, indeed, have catalyzed plastics production significantly and their applications have grown substantially in construction, food, clothing, medicine, transportation, electronics and household goods, and a cumulative total of 8.3 billion metric tons of plastics produced as of 2017 (Lusher et al., 2017). The growth is continuously rising and could double by 2025 and triple by 2050. Such an increase accounts for up to 20% of the world's total oil consumption by 2050 as plastics production is heavily dependent on non-renewable resources such as fossil hydrocarbons (Fossils, Plastics, & Petrochemical Feedstocks).

Plastics are synthetic polymers such as polyethylene, polyethylene terephthalate, polypropylene, polyvinyl chloride and polyurethane that can be grouped into two types: thermoplastics and thermoset. Thermoplastics – deformed by heat and hardened upon cooling – are used in the production of bags, food packaging films, ice cream containers, bottles for water and beverages, to name a few. On the other hand, thermosets – undergone permanent chemical changes with heat – are employed for insulated food packaging, microwave dishes, ice cream tubes and bottle caps. A major portion of plastics, 36%, is being used in the packaging sector followed by construction and textiles. Disposable plastics, also known as "Single-use" plastics, are for products in the packaging sector to be used once or recyclable. Grocery bags, food packaging, bottles, straws, containers and cups fall in this category. They contribute more than 150 million tons of annual plastic waste that needs to be recycled or incinerated. However, only 9% is being recycled and 12% incinerated but the rest 79% is floating around in landfills, dumps and the environment. It has been estimated that the plastic waste generated could reach 25,000 million tons by the year 2050 (Geyer et al., 2017). In this regard, designing and developing ecologically-conscious approaches to manage such mammoth plastic waste is quite challenging but needs to be pursued and scientifically established to manage the global plastic waste crisis. Chemical recycling of plastic waste toward producing new materials could be envisioned. However, the efficiency of catalysts, associated costs and industrial-scale operations are far from sufficient (Lee and Liew, 2021; Rahimi and Garcia, 2017). Biodegradation through microbial enzymes is another

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possibility. However, large-scale implementation through a complete biocatalytic degradation of plastics has yet to emerge (Asaindu et al., 2021; Gricajeva et al., 2022; Wei and Zimmermann, 2017). Interestingly, plastic waste possesses high energy and its use as fuel in incineration would be advantageous (Estahbanati et al., 2021). However, recycling appears to be viable toward generating valuable energy. Nonetheless, the inapt combustion of plastic waste contributes to severe environmental pollution through the release of large amounts of hazardous gases and dioxins. For example, burning one kilogram of plastic releases around 2.8 kg of CO_2 (Thakur et al., 2018a, 2018b). Inappropriate disposal of plastics coupled with unwanted and end-of-life plastics is littering our communities, oceans and waterways; all contribute to health issues in humans and animals (Fig. 1). If the current plastic consumption patterns and waste management practices are not revised, improved and strictly exercised, by 2050 our landfills and the environment would be swamped with about 12 billion tons of plastic litter (UNEP, 2018): a painful repercussion of plastic packaging and production.

Plastics do not corrode or biodegrade, and on average 700 years are needed for a single bottle to start decomposing. They also photodegrade and result in small fragments known as microplastics. Weathering, cracking, weakening and fragmentation of large plastic items to microplastics and nanoplastics occur on land and ocean. Cosmic UV irradiation and abrasion of waves at beaches generate microplastics naturally. Manmade microplastics also exist, as they have been purposefully manufactured for industrial and domestic purposes such as cosmetic and healthcare products and toothpaste (Fig. 1). Synthetic microfibers that account 14% of the global plastic products generate microfibers through plastics fragmentation and degradation (Gavigan et al., 2020) and washing process of synthetic textile industries (De Falco et al., 2019). These tiny plastics invisible to the naked eyes do not decompose but leach out to soil, water bodies and the ocean. They have been found in aquatic habitats of inland water, open-ocean and enclosed seas, beaches and surface water (Lenaker et al., 2019, 2021; Mason et al., 2020; Minor et al., 2020; Cox et al., 2021) as well as beet, tap water and sea salt (Kosuth et al., 2018). They migrate across larger distances, due to smaller size, and accumulate in natural habitats with adverse impact on biota. A few of the environmental impacts are habitat damage, entanglement and ingestion of marine litter by biota, and the introduction of non-native species such as microorganisms, seaweeds and invertebrates through rafting on floating litter (Kühn et al., 2015). These plastic particles are also detrimental to terrestrial ecosystems and are found to stunt the growth of earthworms with their weight loss (Lamb et al., 2018; Boots et al., 2019).

Study on the Great Pacific Garbage Patch (GPGP) - eastern part of the North Pacific Subtropical Gyre - suggests 80 thousand tons of floating plastic debris with around 1.8 trillion microplastics (Lebreton et al., 2018). The Secretariat of the Convention on Biological Diversity and the Scientific and Technical Advisory Panel reports that 800 species of wildlife have been affected through entanglement and ingestion of marine litter (Harding, 2016). There are an estimated 270 thousand tons of plastic waste floating in oceans and projected to exterminate 100,000 sea creatures each year. Furthermore, plastic particles ingested by marine species get stashed in their digestive tract and could end up in the human food chain (Barboza et al., 2018). These findings not only accentuate the curbing need for plastics flow into the oceans but also to the environment.

It is estimated that around 10 million plastic bags are being used worldwide every minute with a total of 5 trillion bags per year (TheWorldCounts, 2022). When tied together, mankind uses enough bags to go around the Earth seven times every hour. The toxic monomers and oligomers such as phthalates, alkylphenols and bisphenol A that these plastic bags contain get delivered to food which in-turn poison food, leading to ill effects on nervous, respiratory and reproductive systems as well as kidneys and liver (Waring et al., 2018). Styrene from food containers causes the proliferation of human breast tumor cells (Ohyama

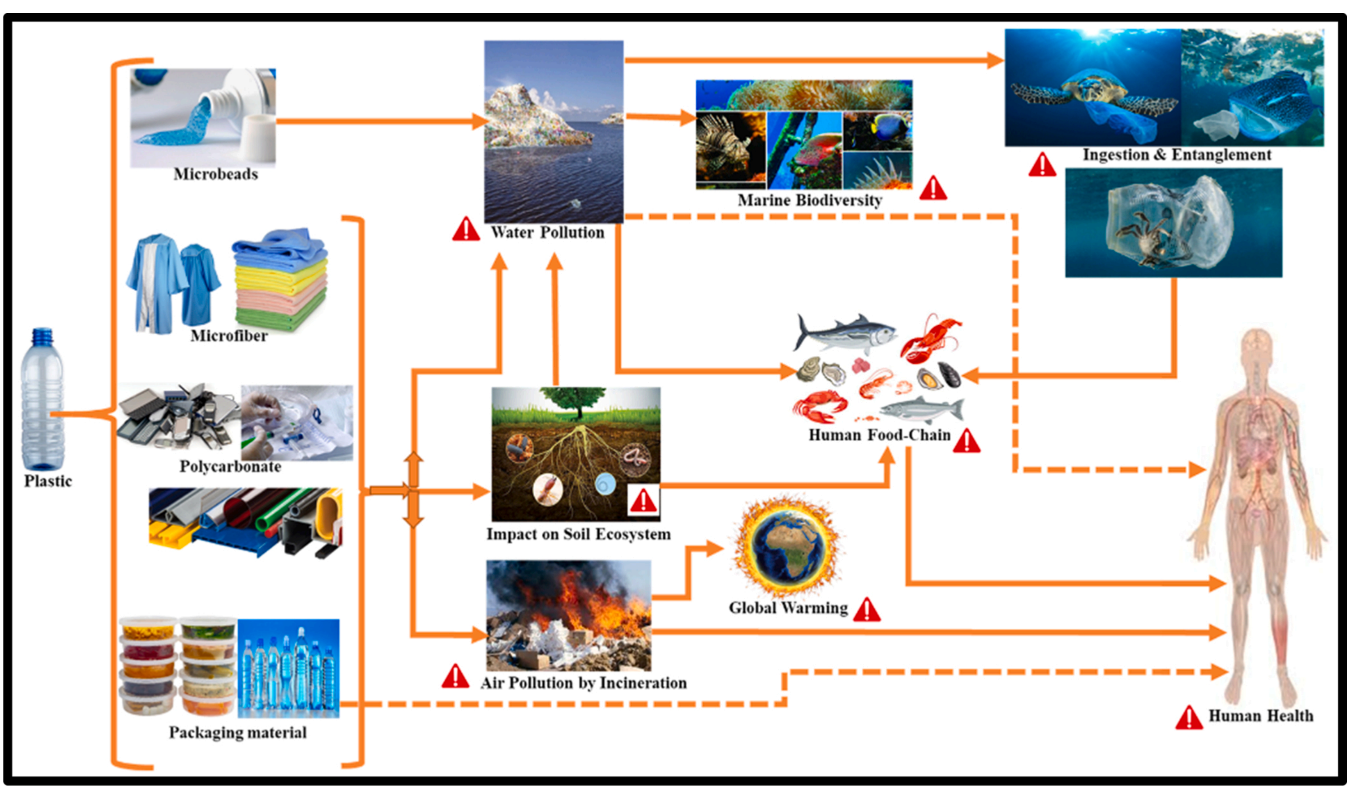

Fig. 1. Plastics, used in different applications, non-biodegradability pollutes waterways, oceans and air, and impacts marine biota, wildlife and soil ecosystem. Consumption by wildlife leads to ingestion, choking and entanglement hazards, and potentially to their extinction and in-turn contaminates food chain toward negatively impacting human health (images are from internet).

et al., 2001). Similarly, styrene migration from the polystyrene-containing packaging foods has been reported in instant foods (Kawamura et al., 1998), yogurt (Nerín et al., 1998) and milk (Tawfik and Huyghebaert, 1998). The water-repellent, stain-resistant and non-stick fluorinated compounds, linked to kidney and testicular cancer, elevated cholesterol, decreased fertility and thyroid problems as well as adverse developmental effects and decreased immune response in children, are found in fast-food packaging (Schaider et al., 2017). Their prevalence would lead to dietary exposure as well as environmental contamination during production and disposal. The water contamination in plastic bottles further emphasizes the concerns for human health due to plastic use (Mason et al., 2018).

In the US alone, around 2 billion plastic straws and 50 billion single-use plastic bottles are used every year (Earthday, 2018). While the statistics are not available for worldwide usage, the number of straws and plastic bottles used and thrown away could be chillingly astronomical, and about 111 million tons of plastic waste is projected to be disposed of by 2030 (Brooks et al., 2018). The situation poses a bigger challenge to address not only the food and beverage products but also packaging and other relevant industries.

Overall, though plastics are versatile and cost-effective for a wide variety of functionalities they are painfully problematic. The accumulation of plastic waste in landfills and natural habitats results in health issues, mainly due to the leaching of chemicals from plastic products. The leached chemicals not only drift to humans by ending up on dinner plates but also are hazardous to wildlife through plastic ingestion and entanglement. Plastics lack of biodegradability and associated detrimental impacts warrant alternative biodegradable materials, and cellulose, a plant-based material, that is renewable and inexpensive stands out as a viable option (Dey et al., 2021).

2. Cellulose – a favorable solution to plastics

Cellulose is a low-density biomaterial with a strong and stiff structure, and certainly meets the desirable qualities of plastics. It is abundant and manifests good biocompatibility, biodegradability and low toxicity. Chemically, cellulose is a linear polysaccharide composed of β-1–4-linked D-glucopyranosyl units. The ribbon-like polysaccharide chains exist in a tight network structure stabilized through strong intra (O3H···O5) and inter-chain (O3H···O6 and O2H···O6) hydrogen bonds (Nishiyama et al., 2002) that bestow magnificent strength, chemical resilience and water insolubility (Fig. 2).

Hydroxyl groups of cellulose facilitate chemical modification toward generating microcrystalline cellulose, carboxymethyl cellulose, methylcellulose, cellulose acetate and nanocrystalline cellulose for food, pharmaceutical and biomedical applications. To solubilize and mold cellulose to tailored modification, several protocols involving chemicals such as ammonium, lithium chloride/1,3-dimethyl-2-imidazolidinone (LiCl/DMI), lithium chloride/N,N-dimethylacetamide N-methyl morpholine N-oxide (NMMO), ammonia/ammonium salt, phosphoric acid, ionic liquids, NaOH, urea and thiourea as well as $ZnCl_2$ are being explored (Nie et al., 2021; Xu et al., 2016; Medronho and Lindman, 2015; Xiong et al., 2014; Wang et al., 2012; Zhang et al., 2010; Perepelkin, 2007; Jin et al., 2007; Heinze and Koschella, 2005; Heinze and Liebert, 2001). A few examples of cellulose solubilizing solvent systems are summarized in Table 1. Each of them has some advantages and also shortcomings related to toxicity, environmental threat, higher power consumption, complicated solvent recovery and higher production costs. However, dissolving cellulose in $ZnCl_2$ solution stands out as promising, green and sustainable in which Zn^{2+} ions competitively bind to O3H atoms of cellulose chains and break the canonical O3H···O5 hydrogen bonds leading to chain flexibility and water solubility (Xu et al., 2016). Such solubilized cellulose chains could then be crosslinked

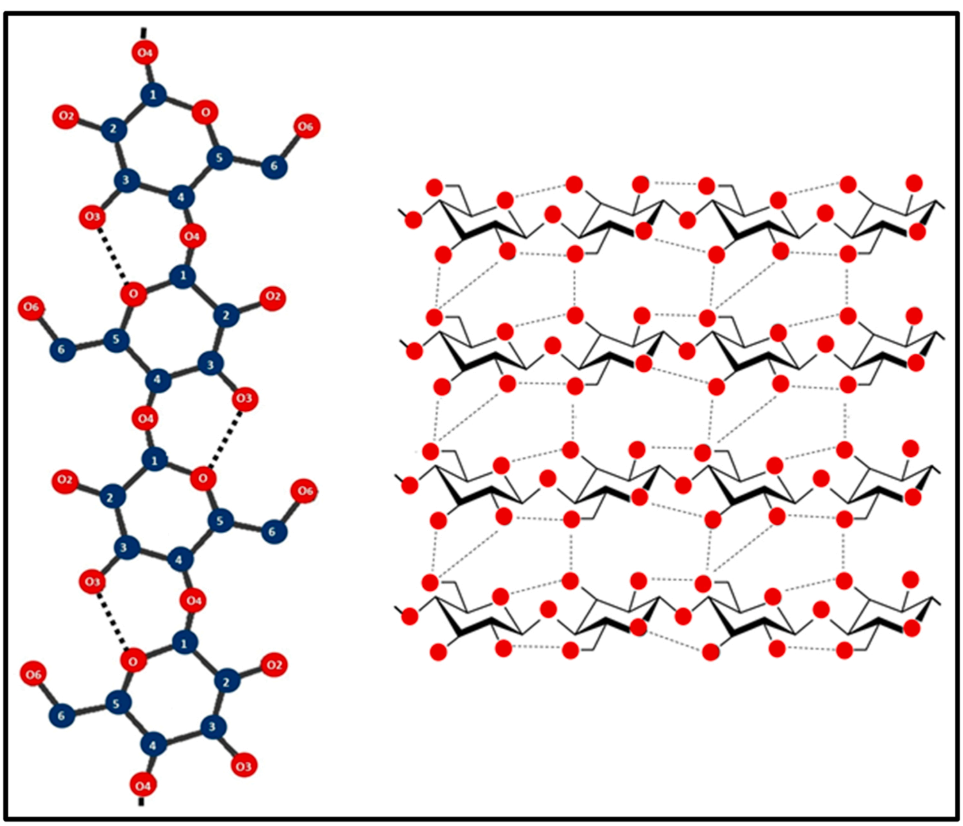

Fig. 2. Robust molecular structure (left) and network structure (right) stabilized through strong intra- and inter-chain hydrogen bonds confer water insolubility and resilient mechanical properties to cellulose.

Table 1
A few examples of cellulose solubilizing solvents.

Solvent system	Reference
Ammonia/Ammonium salt	Chundawat et al. (2020)
Ethylenediamine	Xiao and Frey (2009)
Ethylenediamine and potassium thiocyanate	Frey et al. (2006)
H_3PO_4	Conte et al. (2009)
Ionic liquids	Wang et al. (2012)
$LiClO_4.3\ H_2O$	Leipner et al. (2000)
LiCl and Dimethyl imidazolidinone	Yanagisawa et al. (2004)
LiOH	Yamashiki et al. (1988)
NaOH and CS_2	El Khadem (2003)
NaOH and Polyethylene glycol	Yan and Gao (2008)
NaOH and urea	Huber et al. (2016);Xiong et al. (2014)
NaOH, urea and thiourea	Zhai et al. (2016);Zhang et al. (2010); Jin et al. (2007)
N-methyl morpholine N-oxide	Krysztof et al. (2018);Perepelkin (2007)
N,N-dimethylacetamide and LiCl	McCormick and Lichatowich (1979); Zhang et al. (2014)
SO_2/Diethylamine/dimethyl sulfoxide	Isogai et al. (1987)
Tetrabutylammonium fluoride and dimethyl sulfoxide	Ostlund et al. (2009)
$ZnCl_2$	Xu et al. (2016);Nie et al. (2021)

to generate biodegradable functional products, e.g., high tensile strength films (Xu et al., 2016) and hydrogel beads (Nie et al., 2021). Overall, cellulose is a low-density biomaterial with a robust molecular and packing structure and certainly meets the desirable qualities of plastics. Consequently, cellulose has the potential to stand out as a suitable and desirable alternative for plastics. Widespread applications of cellulose toward making hydrogels for absorbents, aerogels for insulation, membranes for fillers, packaging films and fibers for textiles and reinforcement have already been established (Wang et al., 2021). On average, around 700 billion tons of cellulose are produced every year, predominantly generated from forest resources. However, forests and their tree products aid immensely to lessen the climate change impacts. In this regard, cellulose from renewable agricultural residues and agriculture processing by-products stands out as a suitable and favorable alternative, which certainly will benefit bioplastics that mostly rely on starch, polylactic acid (PLA) and polyhydroxyalcanoates (PHA) (Ibrahim et al., 2021).

3. Agricultural biomass – a sustainable source of cellulose

Biomass is abundant and recyclable and is predominantly generated from plants (agriculture, forestry, manufacturing process, etc.), animals (animal husbandry and fishery production, food processing, rural living garbage, etc.) and microbial wastes (plant and animal wastes). On a global scale, 140 billion tons of biomass is generated annually from agriculture alone (Fig. 3). The 2011 Billion-Ton Update estimates that around 205 million dry tons of primary crop residues are produced annually in the US (Perlack et al., 2011). Among them, three-fourths are corn stover followed by wheat straw, sorghum straw, barley straw and oats straw. By the year 2030, these primary residues are projected to reach 320 million dry tons, due to continued growth in crop yields and higher amounts of land in reduced-tillage and no-till cultivation. They constitute a valuable resource of cellulose (Table 2) along with hemicellulose and lignin as well as minor components such as phenolics, lipids, pectin and protein (Kaur et al., 2021; Edwards, 2020; Qiu et al., 2020, 2017; Smithers, 2019; Stoklosa et al., 2019; Yadav and Hicks, 2018; Yadav et al., 2017, 2016; Zhang et al., 2021). For example, corn stover is composed of 45% cellulose, 30% hemicellulose and 25% lignin. The isolation and marketing of cellulose fraction would be useful to address the plastic concerns and is also practical to design and develop functional materials across a wide range of industries including packaging, food, biofuels, cosmetics, medicine, construction and animal feed sectors.

Significantly, there could be an enormous impact on the packaging industry. The future of global packaging suggests that the requirement will reach $1.05 trillion in 2024 (Smithers, 2019). Especially, the food packaging market that was $303 billion in 2019 is projected to grow at a CAGR of 5.2%. The market is predominantly driven by a surge in demand for packaged, ready-to-eat and ready-to-cook foods, requirements

Fig. 3. A few examples of agriculture biomass from corn, cassava, sweetpotato, banana, sugarcane, rice, soybean, wheat and oat (clockwise from left top corner).

Table 2
The percentage amount of cellulose, hemicellulose and lignin in selected biomass.

Agricultural biomass	Cellulose	Hemicellulose	Lignin	Reference
Bagasse	32–48	19–24	23–32	Reddy and Yang (2005);Martins et al. (2021)
Bamboo	26–43	15–26	21–31	Jahirul et al. (2012)
Barley hull	34	36	14–19	Isikgor and Becer (2015)
Barley straw	31–45	27–38	14–19	Reddy and Yang (2005); Bratishko et al. (2021)
Coastal Bermuda grass	25	36	6	Jahirul et al. (2012)
Corn cob	70	22	8	Ruan et al. (2019)
Corn stalks	39–47	26–31	3–5	Rocha-Meneses et al. (2017)
Corn stover	45	30	25	Wiselogel et al. (2018)
Forage sorghum	34	17	16	Ndibewu and Tchieta (2017)
Groundnut husk	36	20	25	Salihu et al. (2015)
Miscanthus	24	44	17	Jahirul et al. (2012)
Napier grass straw	41	30	7	Amnuaycheewa et al. (2017)
Oat straw	31-35	20-26	10-15	Passoth and Sandgren (2019)
Olive husk	24	23	48	Jahirul et al. (2012)
Ray straw	36–47	19–24	10–24	Isikgor and Becer (2015)
Rice husks	29–36	12–29	15–20	Isikgor and Becer (2015)
Rice straw	28–36	23–28	12–14	Saini et al. (2015)
Sorghum straw	32	24	13	Rocha-Meneses et al. (2017)
Sorghum stalk	27	25	11	Gressel and Zilberstein (2003); Pimentel et al. (2021)
Soybean hulls	35	16	4	Salihu et al. (2015)
Sugarcane bagasse	25–45	28–32	15–25	Isikgor and Becer (2015)
Sweet sorghum bagasse	34–45	18–28	14–22	Saini et al. (2015)
Switchgrass	32–45	21–31	12–28	Wang et al. (2020)
Wheat straw	33–52	26–40	5–30	Rowell and Rowell (1996);Yasin et al. (2010);Rio et al. (2012);Mohammed et al. (2021)

for improved shelf-life, easy transportation as well as hectic lifestyles of today's world, along with the increasing urban population. Such a growing need renders long-term market for packaging films, and cellulose extract from agricultural residues and agriculture processing by-products has the potential to offer unparalleled advantages to address the current and future plastics concerns.

In addition to cellulose, agriculture biomass is also a good source of hemicellulose and lignin (Table 2), and their use further adds value to the agriculture biomass. Hemicellulose displays distinct applications such as adsorbent, paper coating, adhesive, biodegradable bioplastic, hydrogel and packaging material. Hemicellulose-based byproducts are explored in food, toothpaste, cosmetics, papermaking and pharmaceutical industries (Chen et al., 2016; Farhat et al., 2017; Huang et al., 2021; Lian et al., 2018; Xiang et al., 2022). In addition, value-added chemicals for biorefinery could be envisioned through selective degradation of hemicellulose (Gao et al., 2022). Hemicellulose inclusion in diet, as a beneficial dietary fiber, could also offer health benefits. Adequate intake of dietary fiber reduces the risks of health ailments such as heart disease, stroke, high blood pressure, diabetes, obesity and cancer. Similarly, lignin would be useful to generate high-value products such as phenolic compounds, oxidized products, hydrocarbons, carbon fiber and syngas, to name a few (Bajwa et al., 2019a; Collins et al., 2019; Sun et al., 2018; Thakur et al., 2014; Tian et al., 2022; Upton and Kasko, 2016; Zhong et al., 2021). Lignin is also explored as a green filler due to its low-cost, non-toxic, biodegradable and thermal stability properties (Gillet et al., 2017). The lignin functionality could be further improved by preparing nanoparticles (Luo et al., 2021, 2022) and hydrogels (Li et al., 2022) toward improving water quality and related applications. Overall, agriculture feeds people with nutritious food. The parts of biomass that cannot be consumed by humans can also impact and improve human health. The three primary constituents of biomass namely cellulose, hemicellulose and lignin have a great potential to distinctly address an array of human and societal problems in a cost-effective and environment-friendly manner, which certainly adds an undeniable additional value to the agriculture biomass.

4. Additional value

The use of agricultural biomass to extract cellulose for preventing current and future plastics problems matches the "Zero-Waste" ideology of systematically managing agricultural products and processes and avoiding and eliminating waste and also conserving and recovering resources without burning or burying. Farmers will not only get the grains from their crops but could also derive income from stock to be discarded. On average, if one ton of corn stover per acre is produced, a farmer with 1000 acres will have a projected agriculture residue income of $83,000 per year, assuming the cattle feed value of corn stover is $83 per ton (Edwards, 2020). If 30% of biomass goes as livestock feed and 30% is left in the field to improve soil health, roughly $33,000 of extra income a year could be envisioned, which certainly improves the economic status of the farmer.

5. Economic feasibility

The growing global attention towards sustainability, steep increase in oil price, environmental pollution and concerns for non-renewable fossil fuel exhaustion are demanding alternatives for petroleum-based products. Furthermore, as plastic materials are being produced from fossil fuels especially from natural gas or oil, depletion of non-renewable fossil sources is a serious concern. The global economy is also facing lower supplies of oil, and thus utilization of fossil fuel for plastic products will become an expensive proposition shortly (Hammond, 2012). In addition, as petroleum prices are rising, the cost of plastic production is set to rise. Synthetic plastic materials not only use non-renewable resources as raw ingredients but also cause global warming. The littering impact of plastics on the economy includes overall sanitation and valuation of properties that in-turn influence the tourism sector as well. Removal of plastic debris demands significant investment, which could otherwise be used for development. For example, the North Carolina Department of Transportation spent more than $15 billion US dollars to remove 7.5 million pounds of roadside litter during the year 2015 (NCDPS, 2020); on a global scale, the amount would be significantly high. In this regard, the use of agricultural biomass will save much more than 150 million tons of oil equivalent worldwide by 2050 (Guillard et al., 2018). The cellulose extract from agriculture biomass for plastics-replacing-products could serve as a promising alternative for plastics with added environmental benefits and significantly assist to solve the negative impact on the environment. More importantly, cellulose extraction and processing toward product development wouldn't be an expensive process thereby allowing value-addition with minimal cost to the otherwise discarded or low-valued biomass. Thus, substituting current petroleum-based platforms with renewable-based technologies would be beneficial as: (a) Compared to petroleum-based products, bio-based materials will substantially promote the environmental profile and sustainability in the production chain, (b) Use of cellulose as raw material could advance the economic diversification in rural areas, and (c) Cellulose-based products reduce the dependency on the petroleum resources and, in the long term, enhance the national and international energy security.

6. Long-term sustainability

It is not possible to remove all the plastics from society but alternatives could help to significantly reduce the current and future dependence on plastics. The substitutes should encompass long lasting production patterns, particularly for packaging and single-use items, with the redesign, reduction and recycle principles. The idea to replace petroleum-based materials with lignocellulose from agriculture biomass would certainly lead to sustainable development with reduced economic and environmental concerns. The use of cellulose from agriculture biomass not only contributes to the production of environmentally friendly products that could easily biodegrade but also displays advantages to create lightweight durable products with low manufacturing costs. Consequently, the ecological-economic concerns associated with petroleum-based products will be reduced significantly, which for good lessens the emissions of greenhouse gases and other environmental pollution in the long run. Several high-value and high-quality non-plastic-containing functional products could be envisioned that in-turn improve the economic viability of the food, fiber, bioenergy and industries. Incidentally, cellulose is one of the byproducts of biochemical processes that generate biofuels such as butanol and ethanol from biomass; turning a discarded material into one of the useful and profitable products would not only solve the current and future burning issues (e.g. plastics concerns) but also creates new employment opportunities.

7. Future prospects

One of the desirable attributes of plastics is durability and this property combined with the human inability or unwillingness to manage end-of-life plastic effectively has resulted in plastics debris, microplastics and nanoplastics, all unfolding as a multifaceted global problem. Plastic pollution is slow, silent, omnipresent, ever-increasing and more toxic than ever. Towards this end, the abundant cellulose from renewable agricultural residues and agricultural processing by-products stands out as a feasible alternative to design and develop plastic replacing and biodegradable cellulose-based products. Many countries around the globe have started imposing restrictions on plastic bags used for commercial purposes. Options for cleaning the plastic waste in and around beaches and the sea are also underway. Several fast-food restaurants are also reducing the use of plastic straws.

Cellulose derivatives inhibit the recrystallization of drugs and increase the solubility of some recalcitrant drugs (Guan et al., 2021). Similarly, cellulose acts as a substrate to measure the hydrolytic efficiency of cellulase (Mboowa et al., 2020), metal adsorption (El-Shahawi et al., 2020), immobilizing enzymes (Ma et al., 2020) rapid of detection of DNA (Song and Gyarmati, 2020) and pesticides removal from water (Rana et al., 2021a). Furthermore, cellulose has the potential to substitute plastics in electronic devices and opens a new window of opportunities as supercapacitors, batteries, solar cells, fuel cells, electrochemical energy storage devices and biosensors toward curbing the e-waste. More interestingly, nano cellulose in combination with silver nanowires could support building flexible touch screen panels (f-TSP) as well as flexible electronic sensors (Yu et al., 2021). The mixtures of cellulosic fibers and polymeric matrices serve as a possible choice for developing novel construction materials owing to their energy savings, reduced emissions, greater recyclability and reusability (Devi et al., 2022; Thakur, 2014). They further help in the design and development of thermal insulation materials (Hayase et al., 2014), roof coverings (Christian and Billington, 2011), roof structure (Dweib et al., 2006) door frames (Singh and Gupta, 2005), porous stay-in-place bridge forms (Kalia et al., 2011), aerogels (Syeda and Yap, 2022) and water remediation systems (Rana et al., 2021b; Thakur et al., 2022). The preparation of nanocellulose (NC) contributes to value addition (Abitbol et al., 2016; Bajwa et al., 2019b; Lin and Dufresne, 2014; Nasseri et al., 2020; Rana et al., 2021c; Shu et al., 2022; Sinclair et al., 2018; Thomas et al., 2018). The high sonic velocity and low dynamic loss of NC offer unparalleled advantages to manufacture acoustic diaphragms in the electronic industry such as high sensitive fiber-optic microphones (Hayber et al., 2018) and flexible organic light-emitting diodes (FOLED) (Legnani et al., 2009). The stability and paper-like properties of NC provide high reflectivity, contrast and flexibility to electronic paper. The increased surface area and negative charge of NC aid to bind significant amounts of drug molecules toward substantial payload and precise dosage control. In addition, it could also serve as potential carriers of drugs, nutraceuticals and several health-promoting and disease-preventing molecules. Overall, the lightweight, non-abrasive, non-toxic, inexpensive and biodegradable properties of cellulose-based materials are set to be a new frontier in the food, pharmaceutical, medical, electronic, automotive and construction industries. These opportunities offer great potential for cellulose-extract from agricultural biomass and agricultural processing by-products.

CRediT authorship contribution statement

Srinivas Janaswamy: Research conception, Funding acquisition, Visualization, Writing – original draft, Writing – review & editing. **Madhav Yadav**: Writing – review & editing. **Shafaet Ahmed**: Visualization, Writing – review & editing. **Mominul Hoque**: Writing – review & editing. **Sajal Bhattarai**: Visualization, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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