Agricultural Residue-based Bioplastics: Potential Options for High-value Agricultural Residue Utilization

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The extensive application of petroleum-based plastics has caused serious environmental pollution and ecological problems. Now, governments in the world are urgently aiming to develop biodegradable and renewable plastic alternatives. Agricultural waste, being widely available and affordable, may provide a resource of natural polymers to replace those from fossil sources for material manufacturing. However, there are still some non-negligible issues needing more attention. Herein, we briefly discuss the issues and challenges in the conversion of agricultural waste into bioplastics to provide a possible way for its further utilization.

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Why Should Agricultural Residues be Taken Seriously?

Most agricultural wastes, such as straw, stalk, or fruit-shells, can be used as a source of natural polymers, such as polysaccharides (cellulose, hemicellulose) and polyaromatics (lignin). These polymers in the residues are not well utilized despite the fact that they have been regarded with prestige in recent literature (Koul *et al.* 2022). It is reported that the new production of agricultural waste is about 2 billion tons in the world every year (Srivastava *et al.* 2021). The main agricultural residues containing cellulosic materials include wheat straw, rice straw, barley straw, corn stalks, sorghum stalks, coconut shells, bagasse, pineapple, and banana leaves, *etc.* The residues available are dependent on the regions in the world where they grow and are affected by the climate and soil. Most of the residues are regarded favorably by investigators, but they are not accepted as valuable sources by industry, and consequently they are discarded, *e.g.* by being burned in the field. Meanwhile, in areas where forestry resources are scarce, agricultural residue may be used as a fiber source for the paper industry. Besides the paper industry, agricultural residues are more and more considered as sources for materials and energy.

There are several reasons why we should prioritize the utilization of agricultural residue:

1. **Environmental protection:** Agricultural residue contains a large amount of organic matter and nutrients. If arbitrarily disposed or buried, it would produce a large amount of harmful gas, such as greenhouse gases and ozone, which will cause serious pollution to the environment. Utilization of agricultural residue can reduce the emission of harmful gases, which is benefit to the environment.
2. **Energy conservation:** The components in agricultural residues may be converted by biological, chemical/thermal methods to biobased energy forms, including bioethanol,

biobutanol, and bio-oil, which can replace traditional fossil fuels, such as gasoline and natural resources. Such a replacement will reduce net greenhouse gas emissions.

3. **Economic benefits:** The manufacturing of energy or materials from agricultural residues may create many jobs and bring incomes for farmers so as to boost the rural economy.

The Problems in Agricultural Residue-based Bioplastics

Agricultural waste is considered as a kind of desirable source of bioplastics because there are three kinds of natural renewable polymers: cellulose, hemicellulose, and lignin in them, and they can be directly isolated with various methods. Cellulose derivatives were applied as plastic-like materials many years ago and can be processed as plastics. However, all of the agricultural residues cannot be plasticized because the native cellulose is present in crystalline form as a result of dense and regular hydrogen bonds. The cellulose in a nanofibril is also linked with hemicellulose and lignin in 3D networks and does not dissolve in water and general organic solvents. As a consequence, it may decompose before reaching the glass-transition temperature. However, as a natural polymer, cellulose is rich in hydroxyl groups in its molecular chains. These groups make it possible to form modified cellulose or surface-modified cellulose fibrils by esterification or grafting of hydrophobic groups, which may enable thermoplastic processing of lignocellulose and its components.

Opportunities and Challenges

With increasing attention to use the agricultural waste around the world, a lot of researchers have focused on the conversion of biomass into bioplastics. However, much of the bioplastics research has been focused on food crops such as starch as raw materials, which may lead to a competition with food. Currently, the main challenges for converting agricultural waste into bioplastics are related to the complexity of the processing steps (including the generation, recycling, conversion, production, and other steps of agricultural waste), lower mechanical strength compared to traditional plastics, and higher production costs. Additionally, the agricultural waste-based bioplastics industry is still in its early stages, and issues related to environmental impact, cost, and overall sustainability require extensive investigation and rigorous evaluation throughout the industrialization process. The exploration of agricultural waste conversion into bioplastics holds strategic significance for addressing the global energy crisis.

There are many challenges involved in converting agricultural waste into bioplastics, but there are also significant opportunities. The use of traditional plastics has caused serious environmental pollution, prompting many countries around the world to enact laws and regulations to restrict the use of traditional plastics. This has created a growing market for biodegradable plastics. However, the treatment of agricultural waste, which currently includes incineration, landfilling, and composting, produces negative environmental impacts such as carbon dioxide and harmful gas emissions. By using agricultural waste as a raw material for bioplastics, we can reduce the consumption of food resources and avoid competition with food production. In order to efficiently transform agricultural waste, we need to construct a corresponding recycling system for classification and effective recycling. An appropriate pretreatment system should also be selected to improve reaction accessibility, and chemical modification should be carried out to enhance the mechanical properties, hydrophobicity, wet mechanical strength, and other properties of bioplastics. Thus, the development and industrial production of high-performance

bioplastics based on agricultural waste can be realized. Furthermore, attention should also be paid to the recyclability of bioplastics. Three million water bottles are reportedly used every hour in the United States, and less than 30 percent of them are recycled (Williams and Rangel-Buitrago 2022). However, this number is still much less than a quarter of the global plastic production, and a large amount of plastic is discharged into the environment. Therefore, in the development of agricultural waste-based bioplastics, their recyclability should also be taken into account.

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