Study shows how waste can be converted into materials for advanced industries

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A paper by a research group including Brazilian scientists and international collaborators shows that low-cost waste biomass can be upcycled to make bioplastic, electronic devices, equipment for power generation, storage and transmission, and other high added-value products. Credit: Researchers' archive

Between 118 and 138 million tons of organic waste are generated annually worldwide, with waste from the food production and distribution chain accounting for 100 million tons of the total. Only about 25% of all this biowaste is collected and recycled. The other 75% is simply thrown away, representing a huge loss of potential resources and major damage to the environment.

These numbers are from a report published in 2018 by the European Environment Agency. Its statistics are the most recent available and are probably underestimated because they are based on data for 2011.

Converting waste into resources (or "turning trash into cash," in the latest jargon) is one of the drivers of a circular economy. When the waste comes from biomass, it is part of a circular bioeconomy. The topic is explored in a recent article published in *Advanced Materials*.

"In our group, we have seen waste and residues of various kinds as raw materials for over a decade. We conducted a critical review of the literature and repositioned the state of the art in strategies to convert agri-food losses and waste into bioplastic and advanced materials. We looked for arguments not to do this but could find none. It's a win-win," said Caio Gomide Otoni, first author of the article. Otoni is a professor in the Department of Materials Engineering at the Federal University of São Carlos (DEMA-UFSCar), in the state of São Paulo, Brazil, and creator of a group called maTREErials.

As an alternative to the more rustic and environmentally harmful recycling of agro-industrial waste as cattle feed, for example, the study shows that the biomass that is habitually thrown away or underused can serve as low-cost raw material for bioplastics and advanced materials usable in a wide array of high added-value devices.

The applications range from multifunctional packaging with anti-viral, anti-microbial and anti-oxidant properties to flexible electronic equipment, biomedical devices, power generation, storage and transmission gear, sensors, thermal and acoustic insulation, and cosmetics, among many others.

"The food-materials-energy nexus is highly relevant to the circular bioeconomy. We set out to present the most advanced strategies for deconstructing agri-food waste, converting the result into monomeric, polymeric and colloidal building blocks, and synthesizing advanced materials on that basis," said Daniel Souza Corrêa, penultimate author of the article. Correa is a researcher at the National Laboratory of Nanotechnology for Agribusiness (LNNA), an arm of the Brazilian Agricultural Research Corporation (EMBRAPA) in São Carlos, and a professor of chemistry and biotechnology at UFSCar.

Conversion of food losses and waste into advanced industrial "green materials" is an emerging policy option in the most developed countries, as exemplified by the European Green Deal. "The circular bioeconomy maximizes the use of side and residual streams from agriculture, food processing and forest-based industries, thus reducing the amount of waste sent to landfills," states the official European Commission website on the program.

The article by Otoni et al. argues that if the stratosphere is considered a boundary, there is no such thing as "throwing away." Converting waste into useful resources is the rational alternative to covering the planet with trash.

"The complex and heterogeneous composition of biomass derived from food losses and waste poses technological and economic challenges," Otoni said. "We have to address what can be called the 'recalcitrance of biomass to deconstruction.' Another adverse factor is the seasonality of agroindustrial production. Certain kinds of waste are abundant at certain times of year and scarce at others. Even when they're available, their composition is usually variable. But the main obstacle to large-scale upcycling [creatively recycling materials into new products with more environmental value] is political in nature. The hope is that startups and highly innovative firms can surmount these barriers and move the process forward."

The technological routes to do so exist, as the article shows. Its authors have already mastered them on a laboratory scale, or depending on the case, on a semi-pilot or pilot scale. "Several examples can be cited, including production of materials from mango, banana, wheat and cashew waste, among many others," said Henriette Monteiro Cordeiro de Azeredo, also a co-author and researcher at LNNA-EMBRAPA.

In the images at the top of this page, materials resulting from minimum processing of carrots on a semi-pilot scale at LNNA exemplify the potential for conversion of food waste to bioplastic.

The researchers have also produced anti-microbial foam from sugarcane bagasse, packaging containing chitin extracted from crustacean and insect exoskeletons, and emulsion-stabilizing particles with potential applications in the manufacturing of pharmaceuticals, cosmetics and paints.

As can be seen, this research displays strong affinities with the economy of a country such as Brazil, the world's largest producer of sugar cane and oranges, and a leading producer of many other food crops. It is also worth recalling that a highly significant source of food losses and waste is associated with fruit and vegetables: About a third of the total amount produced is lost from one end of the chain to the other.

"A large proportion of food losses and waste contains high levels of vitamins, minerals, fiber and protein, all of which could ideally be converted back into food," Otoni said. "However, most of it is classed as unsuitable and rejected on the basis of microbiological and sensory standards. Hence the alternative of converting waste into chemical platforms and useful materials with potential applications in high added-value devices. Given the large and growing volume of food waste, food producers are genuinely interested in valorizing these flows."

An example is the edible bioplastic developed by Luiz Henrique Capparelli Mattoso, one of the leaders of this research line at LNNA-

EMBRAPA. The research is conducted in a network, with contributions from dozens of researchers in this specific field. The other co-authors of the article are Bruno Mattos, a researcher at Aalto University in Finland; Marco Beaumont, a researcher at the University of Natural Resources and Life Sciences (BOKU) in Vienna, Austria; and Orlando Rojas, Director of the Bioproducts Institute at the University of British Columbia in Canada.

According to Mattos, "the quality of building blocks obtained from waste biomass is the same as that of purer, less processed sources, such as cotton or paper pulp. However, wastes contain several other residual molecules, such as pectin and lignin, offering a larger palette of properties that can be explored for the introduction of functionality into bioplastics."

More information: Caio G. Otoni et al, The Food–Materials Nexus: Next Generation Bioplastics and Advanced Materials from Agri-Food Residues, *Advanced Materials* (2021). DOI: 10.1002/adma.202102520

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