Waste into wealth: Harvesting useful products from microbial growth

February 18 2021

Anca Delgado (left) and Aide Robles are researchers in the Biodesign Swette Center for Environmental Biotechnology. Delgado is also an assistant professor in ASU's School of Sustainable Engineering and the Built Environment. Credit: The Biodesign Institute at Arizona State university

Ancient alchemists dreamed of transforming base materials like lead into gold and other valuable commodities. While such efforts generally came to naught, researchers today are having some success in extracting a variety of useful products like aviation fuels, lubricants, solvents, food additives and plastics from organic waste.

The trick is accomplished with the aid of specialized bacteria, whose metabolic activities can convert simpler chemicals into useful products through a microbial growth process knows as chain elongation.

Anca Delgado, a researcher in the Biodesign Swette Center for Environmental Biotechnology at Arizona State University, has been exploring the phenomenon. In a new study, she describes for the first time how the chain elongation processes are carried out by microorganisms under normal conditions in soil.

The work promises to shed new light on these poorly understood processes in nature, allowing researchers to better leverage them to convert organic sources like food waste into valuable products. Such techniques offer a double benefit to society, minimizing or eliminating environmental waste/contaminants while producing biochemicals or biofuels and other important resources, through green chemistry. The work will also help researchers expand their knowledge of microbial ecology.

"We observed that different soil types sampled from 1.5 m or less below ground surface harbor a readily active potential for chain elongation of acetate and ethanol," Delgado says. " When fed acetate and ethanol, soil microcosms produced butyrate and hexanoate in just a few days and chain elongation became the main metabolism occurring in these samples."

Delgado is joined by ASU colleagues Sayalee Joshi, Aide Robles, and Samuel Aguiar.

Their research findings appear in the current issue of the *International*

Society of Microbial Ecology (ISME) journal.

Energy from waste

The idea of converting organic residual streams like food waste to fuels and useful compounds has been steadily gaining ground, driven by advancing technologies as well as the rapidly growing global need for clean energy sources and pollution reduction. Such processes can help society form so-called circular economies, in which unwanted waste streams are continually converted into energy sources and other useful commodities.

Organic waste sources hold enormous potential as an alternative resource for producing high-value fuels and chemicals because they are renewable and because they do not compete with the human food chain, (as some existing biofuels like corn ethanol do).

One source for these useful transformations is organic food waste, a staggering amount of which is produced annually. Driven by rising global populations, the accumulation of food waste has become a critical problem, due to associated health and environmental hazards.

Food waste is discharged from a variety of sources, including food processing industries, households, and the hospitality sector. According to the United Nations Food and Agriculture organization, a staggering 1.3 billion tons of food are lost to the food chain, and the amount is on a rapid rise.

Laboratory soil microcosm samples used in the research Credit: The Biodesign Institute at Arizona State university

From environmental threat to opportunity

In addition to the squandering of food and land resources, food waste contributes a hefty burden to the environment in terms of carbon footprint, increasing greenhouse gas emissions and liberating an estimated 3.3 billion tons of CO_2 into the atmosphere per year. Researchers hope to convert these waste residues into useful products and purify them in an efficient manner.

One of the most innovative and eco-friendly means of dealing with all of this organic waste is through anaerobic digestion, which also holds the promise of expanding the world's energy supply. A promising emergent technology employing anaerobic digestion is known as microbial chain elongation, a metabolic process used by anaerobic microorganisms to grow and acquire energy. They do this by combining carboxylate chemicals like acetate (C2), with more reduced compounds, such as ethanol (C2), to produce longer-chain carboxylates (typically C4-C8).

This biotechnological process converts volatile fatty acids (VFAs) and an electron donor, typically, ethanol, into more valuable medium chain fatty acids (MCFAs), which are the precursors needed to produce biofuels and other useful chemicals. Initial waste sources are processed through chain-elongation, which involves the cyclic addition of carbon units, thereby converting municipal solid waste, agriculture waste, syngas, etc., into the high-value, medium-chain carboxylates like hexanoate (C6) and octanoate (C8).

The conversion of VFAs into MCFAs with ethanol as electron donor is accomplished by chain elongating microorganisms, particularly, a bacterium known as Clostridium kluyveri. C. kluyveri (and closely related bacterial strains) accomplish their chain-elongation feats through a process known as the reverse β-oxidative pathway. As the name suggests, this pathway is the opposite of metabolic pathway organisms use to break down fatty acids derived from foods.

In recent years, researchers have explored β-oxidation pathways as well as developing the means to reverse these pathways in order to produce chemicals and polymer building blocks, using industrially relevant microorganisms.

Reactions under our feet

Chain elongation has hence proven an effective means of producing valuable chemicals in laboratory bioreactors, though the process is presumed to occur naturally in soils as well. It turns out that anaerobic soils and sediments are often rich in the same kinds of biodegradable organic compounds found in municipal or agriculture waste streams and therefore, a natural source of chain elongation.

Using soil samples from four various US locations, the current study examines the extent of natural chain elongation and how these processes vary according to the particular biogeochemical characteristics of soil composition. The research was designed to gauge the prevalence of chain elongation in anaerobic soil microorganisms and its possible role in microbial ecology.

The results demonstrate the potential for chain elongation activities involving acetate and ethanol, which are typical metabolites found in soils as a result of organic compound fermentation. The study measured high enrichment rates in microorganisms similar to C. kluyveri under chain elongating conditions, which were found to vary with soil type.

The findings shed new light on this intriguing aspect of microbial ecology and may provide helpful clues for future efforts using microorganisms to process waste streams into a range of beneficial chemicals and other products.

As Delgado notes, "on the fundamental side, results from this study are paving the way for investigations on the activity of chain elongation in situ. On the biotechnology side, this work shows that soils can be excellent sources of chain-elongating microorganisms for bioreactors focused on production of the specialty chemicals, hexanoate and octanoate."

More information: Sayalee Joshi et al, The occurrence and ecology of microbial chain elongation of carboxylates in soils, *The ISME Journal* (2021). DOI: 10.1038/s41396-021-00893-2

Provided by Arizona State University