Conversion of POLYURETANE wastes into agronomic biostimulants/biofertilizers through a two-phase chemical/biological circular economy process.

J.M Orts[1*], A. Orts[1], M. Tejada[2], I. Gómez-Parrales[2], J. Parrado[1*],
[1] Departament of Biochemistry and Molecular Biology, Facultad de Farmacia, Universidad de Sevilla, C/Prof. García Gonzalez 2, 41012 Seville, Spain
[2] Environmental Soil Research Group, Department of Crystallography, Mineralogy and Agricultural Chemistry, E.T.S.I.A. Universidad de Sevilla, 41004 Seville, Spain
Corresponding author: Parrado, Juan (parrado@us.es); Orts, José María (jorts1@us.es)
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ABSTRACT

The conversion of polyurethane waste into agronomic bio-stimulants (proteins) or biofertilizers Plant Growth Promoting bacteria (PGPb) through a two-phase chemical/biological circular economy process is an innovative idea that is based on the reuse of waste to obtain value-added products, thus minimizing the environmental impact of such waste.

Polyurethanes (PU) are a type of plastic polymers used as foams in car seats, coatings, sealants, textile industry, etc., with an estimated production of around 27-30 million tons annually (Danso et al., 2019). The management of polyurethane waste poses challenges due to its non-biodegradable nature and durability. Disposing of polyurethane waste in landfills can occupy significant space and contribute to environmental issues. Therefore, various strategies are employed to manage polyurethane waste, including recycling, transforming it into raw materials for new polyurethane products (Orts et al., 2023). Chemical recycling methods can also be used to break down polyurethane into its original components for recovery and reuse. Landfill disposal is considered the least favorable option from an environmental perspective (Liu et al., 2022).

PU foams are synthesized through the reaction of diisocyanate (R-N=C=O) and polyol (R'-OH) (Fig. 1), generating organic units called urethane (Xie et al., 2019). The numerous urethane groups joined together form a polyurethane molecule (Mahajan & Gupta, 2015) that is highly resistant to both physical and biological degradation due to its chemical composition, which provides high temperature resistance, hydrophobicity, etc., thus increasing its lifespan for decades (Gaytán et al., 2020).

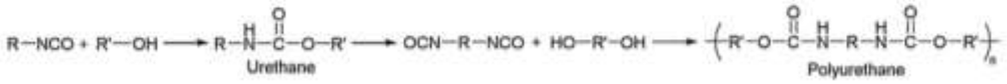

Fig. 1. Polyurethane synthesis mechanism.

The process presented in this communication is biphasic, with a first chemical phase (patent pending) that leads to complete depolymerization of PU in water, converting its long and linear molecule into small-molecular-weight molecules with high content of essential elements for life, such as Carbon and Nitrogen. The second phase is a biological phase, where these molecules are metabolized and converted into new bio-stimulant products for agriculture, such as proteins and PGPbs bacteria (Fig. 2).

Here is a general approach to how this process could be carried out:

Chemical Phase. This is carried out using chemical agents such ozone that break the bonds of polyurethane. The aim of this stage is to break down the long polymeric chains into simpler, more metabolized components. The depolymerization phase is carried out in an aqueous solution, achieving the solubilization of the polymer in water, transforming it into OLE (Organic Liquid Extract), a solution composed of small organic molecules with sizes smaller than 600 Daltons, which have been characterized by HPLC-LC-MS. The OLE mainly consists of polyols (derived from Polyethylene Glycol) and chemically modified diisocyanates.

Biological Phase This solution of molecules (OLE) is susceptible to be metabolized by environmental microorganisms. Different environmental bacteria capable of utilizing OLE as the sole source of carbon, nitrogen, and energy have been isolated and identified. These bacteria convert the chemically-based molecules into biologically-originated ones, such as proteins, and amino acids, which can improve plant growth and soil quality (biosimulants) and biomass of Plant Growth Promoting bacteria (PGPb). (biofertilizer).

This OLE-metabolizing bacteria belong to the metabolically versatile family *Bacillus*, specifically *Bacillus licheniformis* and *Bacillus siamensis*, And other bacteria has been isolated such as *Micrococcus yunannensis* and *Rhodococcus pyridinivorans* that are also capable of metabolizing OLE and have been characterized as PGPB, exhibiting various activities such as phosphate solubilization, nitrogen fixation, production of siderophores and auxins, biofilm formation, and enzymatic activities like DNAse, lipase, protease, etc. *Rhodococcus* is a genus well known for its ability to depolymerize plastic polymers such as PET using enzymes called PETases that are capable of hydrolyzing different bonds characteristic of plastic polymers, such as ester, C-C, amide bonds, among others. Among them we can find cutinase, esterase, Glutamyl-tRNA amidotransferase, FAD binding Oxidoreductase, α/β-Hydrolase, superoxide dismutase, dihydrolypoyl dehydrogenase, cytochrome P450 and multicopper oxidase which were synthesized by *R.pyridinovorans* when it was grown in OLE medium, allowing microbial growth through the biotransformation of chemical molecules present in the OLE.

Fig. 2. Scheme of the two-phase process for the recovery of Polyurethane

Conclusion

Through our biphasic process, we convert a long and hardly biodegradable molecule like PU into low-molecular-weight molecules that can be metabolized and biotransformed into biologically originated molecules using cultivation techniques with bacteria that possess PGPb capabilities and can utilize them as the sole source of carbon, nitrogen and energy. This circular economy approach not only helps mitigate the issue of polyurethane waste but also contributes to the sustainable production of agricultural inputs, closing the material life cycle in a more ecological way.

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