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Long-term properties and end-of-life of polymers from renewable resources

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ABSTRACT

The long-term properties and end-of-life of polymers are not antagonist issues. They actually are inherently linked by the duality between durability and degradation. The control of the service-to-disposal pathway at useful performance, along with low-impact disposal represents an added-value. Therefore, the routes of design, production, and discarding of bio-based polymers must be carefully strategized. In this sense, the combination of proper valorisation techniques, i.e. material, energetic and/or biological at the most appropriate stage should be targeted. Thus, the consideration of the end-of-life of a material for a specific application, instead of the end-of-life of a material should be the fundamental focus. This review covers the key aspects of lab-scale techniques to infer the potential of performance and valorisation of polymers from renewable resources as a key gear for sustainability.

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Abbreviations

AFM	Atomic Force Microscopy
AIDS	Acquired Immune Deficiency Syndrome
ASTM	American Society for Testing Materials
ATP	Adenosine Triphosphate
DETA	Dielectric Thermal Analysis
DMTA	Dynamic Mechanical-Thermal Analysis
DSC	Differential Scanning Calorimetry
EN	European Standards Organisation
FTIR	Fourier Transformed Infrared Spectroscopy
GC	Gas Chromatography
GPC	Gel Permeation Chromatography
HV	Hydroxyvalerate
ISO	International Standard Organisation
LCA	Life Cycle Assessments
LMWC	Low Molecular Weight Compounds
MALDI-TOF-MS	Matrix-Assisted Laser Desorption-Ionization Time-of-Flight Mass Spectrometry
MODA	Microbial Oxidative Degradation Analyser
NMR	Nuclear Magnetic Resonance
OIT	Oxidation Induction Time
PBAT	Poly(butylene adipate terephthalate)
PBF	Poly(butylene fumarate)
PBS	Poly(butylene succinate)
PCL	Polycaprolactone
PE	Polyethylene
PET	Poly(ethylene terephtalate)
PGA	Poly(glycolic acid)
PHAs	Polyhydroxyalkanoates
PHB	Polyhydroxybutirate
PHBV	Poly(hydroxybutyrate-co-valerate)
PHV	Polyhydroxyvalerate
PLA	Poly(lactic acid)
PLGA	Poly(lactic-co-glycolic acid)
PP	Poly(propylene)
PVA	Poly(vinyl alcohol)
PVC	Poly(vinyl chloride)
PS	Polystyrene
PSW	Plastic Solid Waste
SEM	Scanning Electron Microscopy
TE-EC	End-Chain Transesterifications
TE-MC	Middle-Chain Transesterifications
TEM	Transmission Electron Microscopy
TGA	Thermogravimetric Analysis
TPS	Thermoplastic Starch
UV	Ultraviolet

1. Sustainability of polymers from renewable resources

Plastics currently account for about 20% by volume of municipal solid waste. Even more, they are not only generating so much waste, but are also becoming extinct due to finite petroleum-based reserves. It is estimated that the global resources of oil, natural gas and coal are limited and the economic impact could be exhausted in a near future, as prices will rise as these resources are more limited [1]. Due to the oscillation of oil prices and the problem of the accumulation of waste, which has led to hard environmental policies, polymers from renewable resources may become a sustainable solution. Actually, this market has experienced a high expansion, being the focus of lots of research studies [2], in many sectors of application, such as food packaging, agriculture and biomedicine, among other.

Food packaging applications aim at substitute traditional polymers [3,4] by bio-based polymers such as poly(lactic acid) (PLA) [5–8] or polyhydroxyalkanoates (PHA) [9,10], along with other polymers [11–13], blends [14–16], or nanocomposites [17–31]. The focus is devoted to the combination of appropriate processability, good durability [32–34] barrier properties [35–38,24,39,40], and tuned biodegradability [33,41–46], as well as to add value with natural additives [47], the combination of coatings [48,35,36,49–58], and multilayers [37,38,59–63,31,64,65], or even the production of edible [66–70,58,71,72,57,58,73,74] or active properties [75–87]. Agricultural applications [88] consider the use of polymers from renewable resources as films for mulching and protection [88–92], drug delivery [93–103], or goods as twines, strings, filaments and clips [104]. Biomedical applications based on polymers from renewable resources [105,106], are based on their biodegradability and biocompatibility with low-impact form substance after degradation [107–109], for applications such as tissue engineering [110–121], which ensure cell proliferation [122–124,119,125–128], controlled drug delivery [129–142], wound dressing [143–159,117,160–163]. In all cases, all polymers require a tuned balance between their performance during service life, and their degradation behaviour after use, that is, between the long-term properties and their end-of-life. Nevertheless, polymers from renewable resources still involve relatively high production costs and, frequently, they show underperformed properties for each application in contrast to their petroleum-based counterparts. In addition, concerns are growing into the society about the use of long-life polymers in products in which a short-life is expected. Therefore, there is an engagement to base the research in appropriate production-service-waste management mainstreams on an equitable commitment of the three pillars of sustainability, i.e. People (social pillar), Planet (environmental pillar) and Profit (economic pillar) [164].

Specifically, the sustainability of polymers from renewable resources, i.e. bio-based polymers, is a topic which has been approached from several perspectives due to its importance and impact on wealth, environment and technological development