# Yerba mate residue: an example of food waste utilization in the improvement of the properties of recycled plastics

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## Introduction

Poly(lactic acid) (PLA) is one of the most important bioplastics in the market due to its acceptable optical and mechanical properties, biocompatibility and good processability with the available processing technologies. However, the increasing use of PLA could lead to the accumulation of wastes and littering because the PLA used in food packaging and other demanding applications is only compostable in industrial conditions (Beltrán et al., 2019). Among the different valorization alternatives for PLA, mechanical recycling stands out because it allows to reduce the consumption of raw materials and energy (Rossi et al., 2015), thus complying with a circular economy approach.

Despite of the environmental advantages provided by mechanical recycling, it has been reported that this process leads to the degradation of PLA, and ultimately to a decrease of some key properties of the plastic (Beltrán et al., 2018). There are several methods to improve the properties of the recycled plastics, and thus its recyclability, such as thermal treatments, utilization of additives and addition of inorganic and organic fillers (Badia and Ribes-Greus, 2016). In this sense, the possibility of the utilization of organic fillers, especially those coming from food wastes, is generating a fair amount of interest since it would allow to obtain greener materials with improved properties, while reducing the accumulation of wastes and the consumption of raw materials (Cecchi et al., 2019).

In this work, lignocellulosic nanoparticles (NM) were extracted from yerba mate (*Ilex paraguariensis*) residue in an environmentally sound process and used as reinforcement in mechanically recycled PLA. Yerba mate (Ilex paraguariensis) tea is a traditional South American beverage, especially in Argentina, where over 6 kg per capita of yerba mate waste is produced every year (Arrieta et al., 2018). The extract of yerba mate can act as a plasticizing agent and, furthermore, provides antimicrobial and antioxidant capacity due to the presence of polyphenols and xanthines in their chemical composition (Medina Jaramillo et al., 2016). The main aim of this work is to evaluate the effects of lignocellulosic nanoparticles, extracted from the mate residue, on the structure and key properties of recycled PLA (PLAR), with special emphasis in food packaging applications. Taking this application into account, the use of PLAR-NM nanocomposites in multilayers with good barrier properties has also been studied.

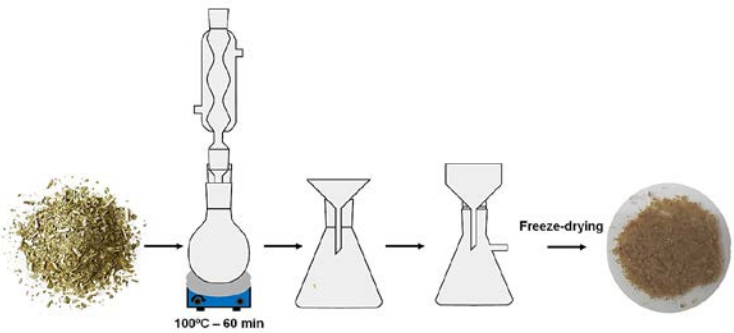


**Figure 1.** Schematic representation of mate nanoparticles extraction procedure.

## Methodology

The NM nanoparticles were obtained as represented in Fig. 1 (Arrieta et al., 2018). In brief, yerba mate residue obtained after its consumption was dried in an oven at 60 ºC for 24 h. Then, 3 g of residue were heated under reflux in 100 mL of distilled water at 100 ºC during 60 min., with vigorous magnetic stirring. The obtained mate extract solution was filtered off and subjected to a freeze-drying process to obtain the nanoparticles in powder form.

Mechanically recycled PLA was obtained according to the procedure presented in previous studies (Beltrán et al., 2018). Neat PLA was extruded and compression molded into 210 μm films, which were subjected to an accelerated ageing, including 40 h of photochemical degradation, 468 h of thermal degradation at 50 ºC and 250 h of hydrolytic degradation at 25 ºC. The aged samples were washed at 85 ºC in a solution of NaOH and a surfactant. Finally, the washed PLA was reprocessed by extrusion and compression molding, thus obtaining the recycled plastic, PLAR. During this second processing step different amounts of NM were added to PLA in order to obtained PLAR-based nanocomposites. The resulting materials were characterized by means of Fourier transform infrared spectroscopy (FTIR), gas permeability measurements, UV-Visible spectroscopy (UV-Vis), differential scanning calorimetry (DSC), thermogravimetric analysis (TGA), nanoindentation tests and intrinsic viscosity measurements.

**Results and discussion**

Figure 1 shows the FTIR-ATR spectra of NM, PLAR and PLAR with 3% NM. The spectrum that corresponds to PLAR-3NM shows a broad band at 3320 cm$^{-1}$ ($\upsilon_{OH}$) and a shoulder at 2920 cm$^{-1}$ ($\upsilon_{C\text{-}H}$), which confirm the presence of the yerba mate nanoparticles in the material (Arrieta et al., 2018).

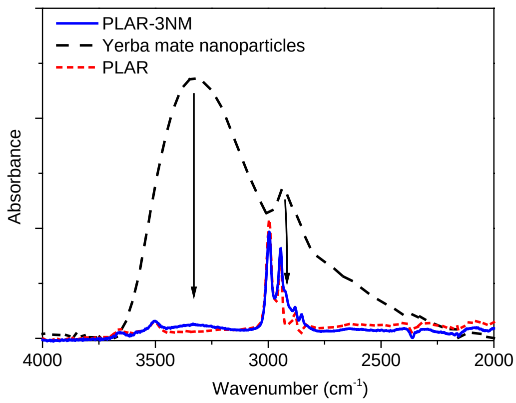


**Figure 2.** FTIR-ATR spectra of nanoparticles, PLAR and PLAR-3NM.

Regarding the key properties of these materials, it is worth to note that the addition of 1% NM led to a decrease of the diffusion coefficient of $O_2$ (from $1.7\cdot10^{-12}$ to $6.1\cdot10^{-13}$ m$^2$/s), due to the good dispersion of the nanoparticles in the polymer matrix. This result shows that the addition of the yerba mate nanoparticles leads to an improvement of the gas barrier properties of recycled PLA, which are crucial in food packaging applications. Further improvements in barrier properties can be achieved by using the nanocomposites in suitably selected multilayer structures. In this work, migration in food simulants, another key issue in materials used for food packaging, has also been studied.

Summarizing, the obtained results show that yerba mate nanoparticles were effectively added to a recycled PLA matrix, resulting in an improvement of the gas barrier properties of recycled PLA. The use of nanoparticles extracted from yerba mate residues for improving the properties of a recycled plastic represents a potential method for the valorization of this food waste.

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