Yerba Mate as a Co-Precursor in the Synthesis of Silica Through the Sol-Gel Technique

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Abstract

The sol-gel method opened a new synthesis route at room temperature, since it allows controlling the properties of a material obtained from very pure liquid precursors, so that it meets the necessary characteristics to be used as a selective membrane. In the present work, solids are developed whose active phase is formed by silicon oxides in conjunction with bio-molecules present in the plant matrices used as a source of biomass, specifically from yerba mate. The evaluation through photographic monitoring of the yerba mate stages made it possible to establish when a plant material could be considered discarded due to its appearance or organoleptic character. Likewise, photographic monitoring made it possible to monitor the degree of solidification suffered by the silica obtained in the presence of the bio-waste used. Furthermore, the contribution in the use of spectral techniques such as FTIR provides a specific overview of the properties of the material obtained.

Introduction

The scarcity of resources on our planet, due to the indiscriminate use of mineral or agricultural sources for the manufacture of various products and the obtaining of materials, has contributed to an increase in the generation of polluting waste with a wide and varied range of effects on health and a significant risk to the environment. The industrial sector, hand in hand with chemical science, has faced the difficult challenge of implementing a new corporate philosophy called the Circular Economy, integrating environmentally friendly alternatives where technological innovation plays a central role, focusing on reducing pollution to a minimum level. Waste generation, recirculation or reuse of waste, and, of course, saving on energy costs or raw materials, creating quality jobs as profitable businesses. Based on data from the last census, 41 million Argentines consume an average of 6.4 kg of yerba mate per inhabitant per year. According to market research carried out throughout Argentina, yerba mate is present in more than 90% of Argentine homes [1]. This work seeks the introduction of the sol-gel synthesis of siliceous matrices with yerba mate bio-waste to obtain a support that contains properties that imply the reduction of the use of an active phase or a pore former of commercial origin. This incorporation will allow contributions to be made in the areas of materials, environmentally friendly synthesis, and the interaction between a silica precursor, a bio-waste, and the different synthesis variables for use as a support in eco-catalysts where properties that act together for different reactions are sought.

Experimental

A quantity of 150 g of commercial yerba mate was weighed and then introduced into a 100 ml separating funnel and filtered with 200 ml of ultrapure water (H_2O) (at 70°C), extracting the infusion obtained with the yerba mate. A homogeneous dark green liquid was obtained, which did not contain leaves, sticks, or other solids. Said liquid extract was packaged and preserved in a 500 ml caramel-colored bottle. The synthesis procedure was carried out inside a chamber with a controlled nitrogen atmosphere (Atmosbag glove bag®) at room temperature. First, a portion of the solvent (absolute ethanol, 30 ml) was placed in a beaker, along with 2.9 g of yerba mate extract (SYM). TEOS (34 ml) was then added. The last portion of the solvent (13.5 ml) was added, and an aliquot of H_2O (10 ml) was added. Subsequently, the reaction mixture was removed from the chamber, and work continued under a fume hood under ambient conditions, including a stage with magnetic stirring for 2 h at 500 rpm. Finally, the wet gel was allowed to age in the same medium at room temperature and atmospheric pressure until dry silica particles were obtained (Figure 1). It was calcined at 150°C for 1 h and placed in a caramel-colored bottle for storage. Different physical-chemical and electronic characterizations were carried out on the gel obtained (calcined and uncalcined) and on SYMc and SYM, respectively.

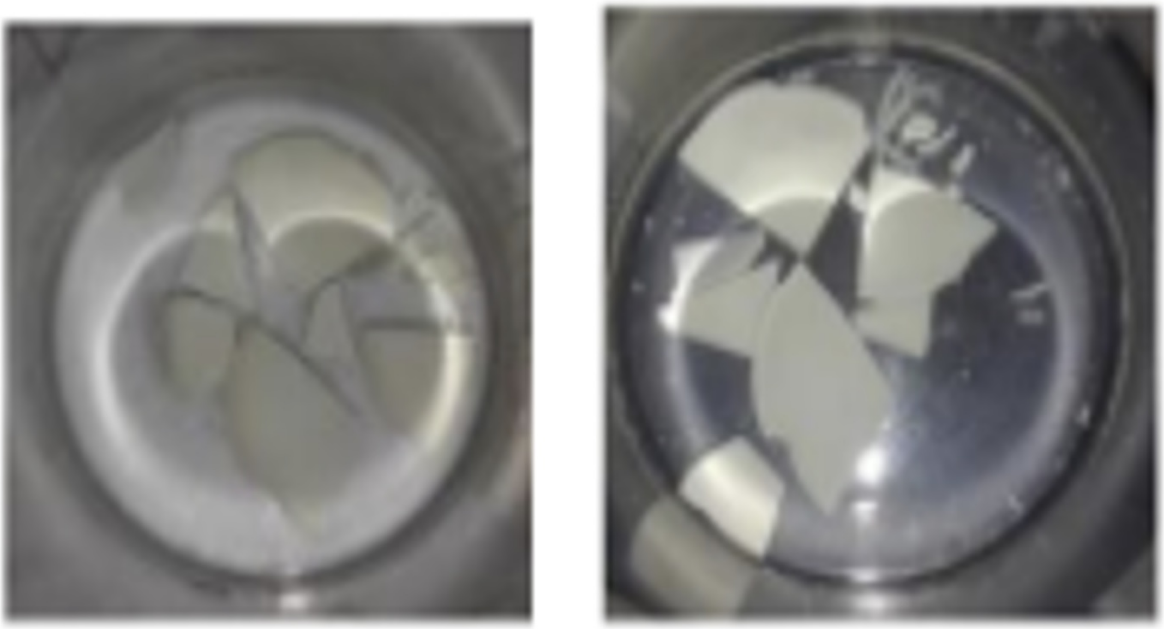

Figure 1. Dry gel with silica crystals forming

Results and discussion

Fourier Transform Infrared Spectroscopy (FTIR) is one of the most common spectroscopic techniques used to determine the chemical functional groups of a solid sample. This technique has been widely used in the characterization of sol-gel materials, allowing extensive knowledge of the relationships between the FT-IR spectrum, material properties, and structure at the atomic level [2]. Figure 2 shows the characteristic peaks within the range studied for YM silica (calcined and uncalcined).

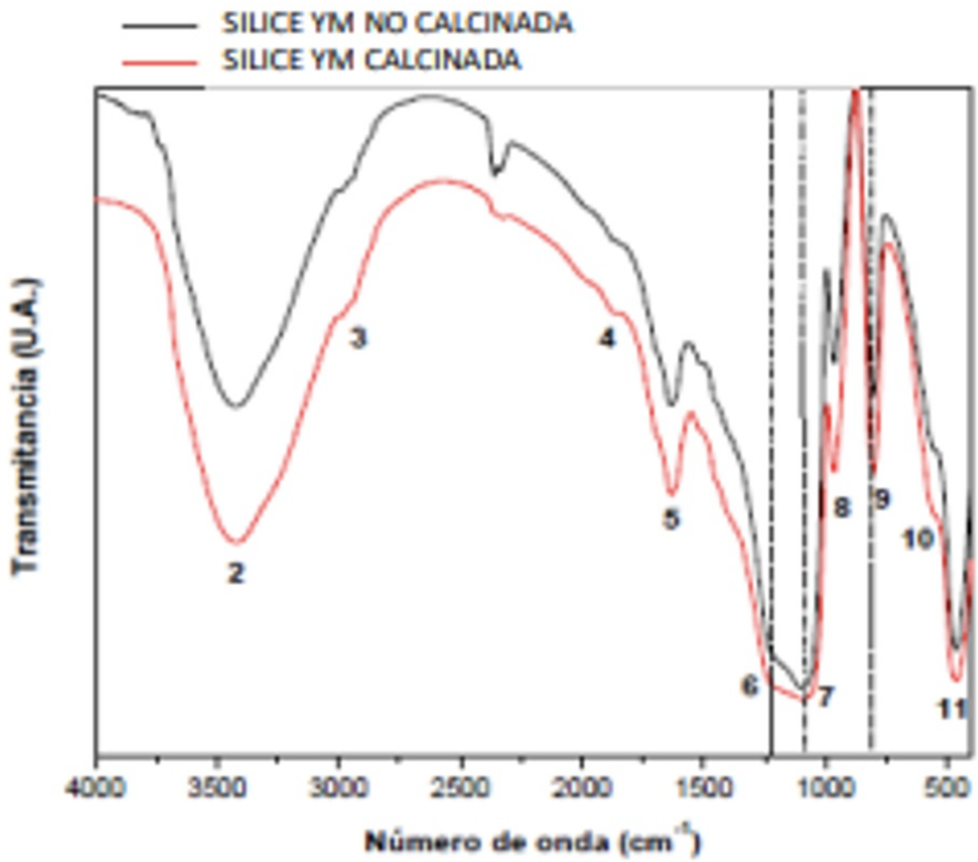

Figure 2. FT-IR spectrum of silica obtained with yerba mate extract

For sol-gel silica, it is possible to see four bands located at 460 (number 11), 800 (number 9), 1080 (number 7), and 1200 (number 6) cm^{-1}, which correspond to vibrations of silicon-oxygen bonds and can be classified by the type of movement of the oxygen atom with respect to the silicon atoms in rocking, bending, and stretching. The band near 2250 cm^{-1} corresponds to the background spectrum of the FT-IR measurement. The bands at 1200 and 1080 cm^{-1} are assigned to the asymmetric stretching modes of the Si-O-Si bond, and the vibration at 800 cm^{-1} is associated with the symmetric stretching of the Si-O-Si bond. At smaller wavenumber values, the band located around 560 cm^{-1} is attributed to the deformation of four-membered siloxane rings (cyclotetrasiloxanes), which may constitute a large fraction of the oligomeric species present in the TEOS-derived systems. Three additional characteristic bands of silica xerogel are observed in the ranges 4000-3000 cm^{-1} (3778 is number 1 -not shown-, and the others assigned to numbers 2 and 3) and are assigned to the stretching vibrations of the water molecules with hydrogen bonds and silanol groups on the surface of silica (OH and SiO-H). The band at 1640 cm^{-1} is assigned to the deformation of molecular water and results from the angular deformations of O-H in H_2O. This band is associated with the adsorption of water on the surface of the synthesized sample. There is also a contribution near 1650 cm^{-1}, which may be due to residual ethanol. In turn, Figure 2 shows the characteristic bands of a lignocellulosic material. The broad band observed in the region of 3700 to 3000 cm^{-1} can be attributed to the stretching vibration of OH-groups present in compounds such as lignin and cellulose. The two bands at 2986 and 2936 cm^{-1} can be attributed to the stretching vibration of -CH, $-CH_2$, and $-CH_3$ groups in aliphatic moieties of cellulose, lignin, and hemicellulose. The bands between 1800 and 1540 cm^{-1} are due to carbonyl stretching in esters, amides, acids, and other compounds such as xanthines and saponins.

Conclusions

The present work is focused on the development of new materials with the aim of minimizing the generation of industrial and urban waste. Likewise, the high costs of waste disposal, which must be assumed by the generating companies in the case of agricultural industries, make them not only an environmental but also an economic problem. Particularly, the use of yerba mate to obtain silica is a mitigation alternative to the generation of agricultural/domestic waste, giving them a very significant benefit. Therefore, the use of this type of waste becomes an appropriate environmental and economic strategy for the management of byproducts. In the presented case of yerba mate waste, encouraging results are observed for the silicas obtained, due to the homogeneity of the synthesized solids and their rapid solidification. In addition, the different uses of silica in different products as catalytic supports, catalysts, and in pharmaceutical and cosmetic supplies, among others.

References

1. ^*Fuente: INYM (Informe del Sector Yerbatero): (1) Voices & Research 2017*
2. ^*Romina Arreche (2016): Doctoral Thesis: Inclusion of Ag in materials based on silica and zirconia, synthesized by the sol-gel method, for their application as antimicrobial additives in paints.*