

Proceeding

Microwave-assisted embedding of *bis*-vanillin and *bis*-eugenol into SBA-15: Synthesis of chemosensors precursors for the detection of metal cations

Vanina A. Guntero ^{1,2}, Dailenys Espinoza-Martinez ¹, Cristián A. Ferreti^{1,3}, Pedro M.E. Mancini¹ and María N. Kneeteman ^{1,*}

¹ IQAL (UNL-CONICET), Laboratorio Fester – QUÍMICA ORGANICA (FIQ)

² Universidad Tecnológica Nacional – Facultad Regional San Francisco

³ INCAPE (UNL-CONICET)

* Correspondence: mkneeteman@fiq.unl.edu.ar; Tel.: +543424571164

Abstract: In this work we evaluate the necessary experimental conditions to carry out the embedding of *bis*-vanillin and *bis*-eugenol, two potential precursors of chemosensors, in the porous structure of the mesoporous silica SBA-15 through a microwave assisted process. The physicochemical characterization of the developed *bis*-vanillin-SBA-15 and *bis*-eugenol-SBA-15 materials confirmed the successful immobilization of these molecules in the mesoporous composite. The most important characteristic of these systems is the possibility of activating the release of the organic molecules embedding into SBA-15, depending on the liquid medium in which these composites are suspended.

Keywords: chemosensors precursors; microwave-assisted synthesis; embedding.

1. Introduction

Supramolecular chemistry has been progressively growing, incorporating novel areas of investigation. Among all these areas one of the most attractive fields of research is that of programmed systems in which the recognition process is further coupled to a specific action [1]. In this sense, we have reported the design and synthesis of new chemosensors for the determination of trivalent metal cations, such as Fe³⁺, Cr³⁺ and Al³⁺ [2]. These sensors exhibit a rapid change in their fluorescent properties, which makes them interesting for applications in chemistry, medicine, biotechnology fields [3,4,5]. The fluorogenic methods are characterized by their rapid performance, being non-destructive and highly sensitive [6]. As a consequence of this research, the need to evaluate the possibility of embedding the materials in matrices appeared.

Considering that the more rigid structure of a chemosensor tends to generate changes in fluorescence, silica was used as a matrix to embed the compounds in order to maintain their properties as sensors. Mesoporous silica, such as SBA-15, is a suitable inorganic support due to its uniform wide channels that can immobilize organic chemical sensors. Its stability leads to better dispersion, biocompatibility and subsequent functionalization [7].

This work focuses on evaluating embedding conditions of precursors of chemical sensors on SBA-15 through a microwave-assisted process. The preparation and use conditions were established to be able to evaluate the application on the synthesis of chemosensors embedded on SBA-15 in future research.

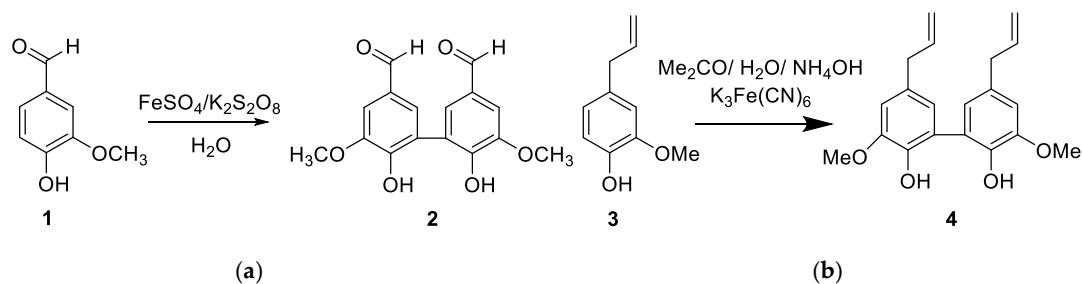
2. Experimental

2.1. Synthesis of chemosensors precursors

The precursors of chemosensors, *bis*-vanillin (BVA) [8] and *bis*-eugenol (BEG) [9], were prepared following the synthetic pathway depicted in Scheme 1.

The *bis*-vanillin (2) was prepared from the oxidative coupling of vanillin with sodium persulphate and iron sulphate. Vanillin (1) (3.55 g, 23.33 mmol) and ferrous sulfate (0.135 g, 0.89 mmol) were dissolved in distilled water (240 ml) under stirred for 10 minutes. Then, potassium persulfate (3.38 g, 12.51 mmol) was added and the reaction mixture was maintained for 5 days at 50 °C. The solid was filtered and dried.

On the other hand, the *bis*-eugenol (2) was synthesized by oxidative coupling of eugenol. Eugenol (1) (3 g, 18.27 mmol) was dissolved in acetone (60 ml) and distilled water (30 ml), then ammonium hydroxide 28% (40 ml) was added. The mixture was stirred until a yellow color developed. Next, a saturated solution of potassium ferricyanide was added dropwise for 5 hours. The mixture was then stirred for 12 hours, previous addition of ammonium hydroxide 28% (40 ml). The reaction was neutralized with diluted hydrochloric acid. The solid was filtered and recrystallized with ethanol absolute.



Scheme 1. Synthetic pathways used for the preparation of chemosensors precursors a) *bis*-vanillin. b) *bis*-eugenol.

2.3. Synthesis of SBA-15

Mesoporous silica SBA-15 was prepared by using Pluronic P123 triblock copolymer surfactant as a template in acid media according to the bibliography [10]. First, Pluronic P123 (4 g) was dissolved at room temperature in a 3.1 M aqueous HCl solution (350 mL). Then, Polyetilenglicol 400 (10 g) was added and the resulting solution was slowly stirred at 35 °C until the solution became clear. Tetraethyl orthosilicate (TEOS, 22.5 mL) was then added to the solution and the resulting mixture was vigorously stirred at 40 °C for 24 h. Subsequently, the container was transferred to a microwave oven and kept at 100 °C for 24 h under static conditions. The resultant product was filtered, washed with water, and dried at 80 °C overnight. Finally, the surfactant template was removed by calcination at 550 °C for 5 h in air.

2.4. BVA and BEG embedding into SBA-15

The preparations of BVA-SBA and BEG-SBA were performed using an Anton Paar Monowave 300. The BVA or BEG precursor (0.15 g) was put in the vial, and SBA-15 (1.5 g) was added. Then, a solution of ethanol:water (50:50, v/v) (18 mL) was added to the mixture. The mixture was placed in a microwave oven. The reaction was carried out at 70 °C (with a controllable power system), 1200 rpm, 20 min. After a slow cooling of the mixture, the resulting material was dried at 80 °C for 5 h.

2.5. Characterization of precursors and materials

^1H and ^{13}C NMR spectra were recorded using a Bruker DPX-300 (300 MHz) spectrometer. Nitrogen adsorption-desorption isotherms were measured at $-196\text{ }^\circ\text{C}$ on a NOVA-1000 Quantachrome. The samples were treated at $100\text{ }^\circ\text{C}$ in the degassing port of the adsorption analyzer prior testing. Specific surface areas were evaluated using the Brunauer, Emmett and Teller (BET) method, while pore size distributions were calculated using the Barret-Joyner-Halenda (BJH) algorithm on the adsorption branches of the isotherms.

FTIR tests were performed on a Shimadzu FTIR Prestige-21 spectrophotometer in the region from 4000 to 1000 cm^{-1} . The samples were mixed with KBr (1% wt) and then pressed. The UV absorption measurements were carried out on an Perkin Elmer Lambda 20 spectrophotometer. Fluorescence studies were performed on a Perkin Elmer F7000 spectrofluorometer. All spectrophotometric spectra were performed from a suspension of the sample in ethanol/water (50:50, v/v) and then brought into a quartz cell for measurement.

BVA and BEG release tests were carried out to determine the amount of the compounds released from BVA-SBA and BEG-SBA composite using different liquid mediums with a composite:medium ratio (1/100 g/mL). The liquid mediums selected for BVA-SBA were water, ethanol/water (50:50, v/v), DMSO/water (1:99, v/v) and DMSO, while for BEG-SBA were water, ethanol/water (50:50, v/v), acetone/water (1:99, v/v) and acetone. The amount of BVA and BEG released from the composites at $25\text{ }^\circ\text{C}$ was determined by UV spectrophotometry using calibration curves obtained from standard solutions of BVA ($\lambda = 308\text{ nm}$) and BEG ($\lambda = 282\text{ nm}$).

3. Results and discussion

3.1. Precursors Characterization

BVA: Yield: 75%. ^1H NMR (DMSO- d_6 , 300 MHz): 3.83 (s, 6H, OCH_3); 7.36 (d, 2H, CAr-H); 7.32 (d, 2H, CAr-H) 9.71 (s, 2H, CHO). ^{13}C NMR (DMSO- d_6 , 300 MHz): 192 (CHO); 148 (C-4); 129 (C-6); 128 (C-1); 125 (C-5); 110 (C-2). IR (KBr, cm^{-1}): 3264.2 (OH); 1674.2 (C=O); 1587.4 (C=C Arom.).

BEG: Yield: 80%. ^1H RMN (Acetone- d , 300 MHz) d (ppm): 6,82 (s, 2H, HAR); 6,72 (s, 2H, HAR); 6,01 (m, 2H, HC); 5,11 (d, 2H, HC=C); 5,02 (d, 2H, HC=C); 3,87 (s, 6H, CH_3); 3,35 (d, 4H, CH_2). IR (KBr) máx. (cm^{-1}): 3530 (OH); 2885 (=CH); 2880 ($-\text{CH}_2-$); 2850 ($-\text{OCH}_3$); 1665 (C=C); 1620 (C=CAr); 1470 (C=CAr); 1370 (C=CAr).

Geometry optimizations of BVA and BEG molecules were performed with Gaussian 09 software, using DFT level of theory with the gradient corrected by Becke's three parameters hybrid exchange in combination with the correlation of Lee, Yang and Parr (B3LYP) and 6-31G(d,p) set of base functions. The optimized geometrical structures of BVA and BEG are shown in **Figure 1**. From these geometries, the values of the molecular diameter (MD) were obtained. The values obtained were 11

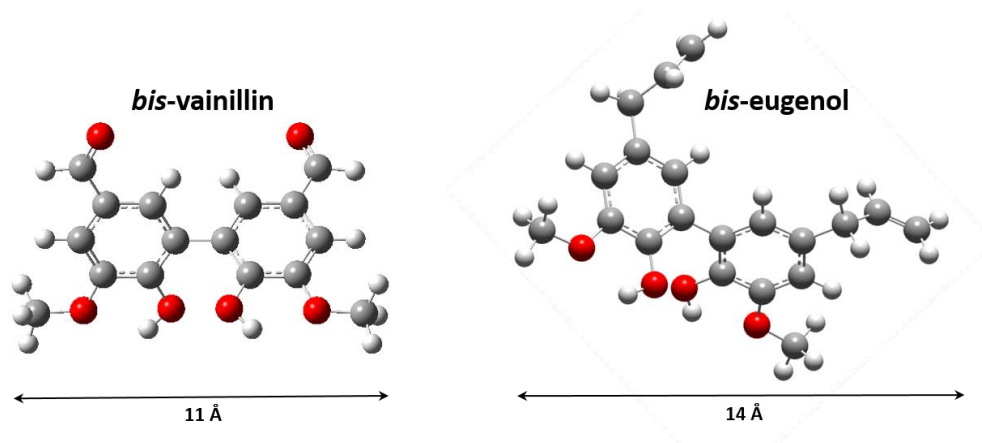


Figure 1. Optimized geometries of *bis-vanillin* and *bis-eugenol*.

Å and 14 Å for BVA and BEG, respectively. These results demonstrate that the molecule of BEG is slightly larger than the BVA molecule.

3.2. SBA-15 and composites characterizations

N₂ adsorption/desorption isotherms at -196 °C of SBA-15, BVA-SBA and BEG-SBA were determined in order to study their textural properties. Results are reported and summarized in **Figure 2** and **Table 1**, respectively. All samples show N₂ adsorption/desorption curves corresponding to type IV isotherms. The embedding of BVA and BEG into SBA-15 caused a reduction of specific surface area and a slight increase of average pore diameter while the pore volume is almost unchanged. Considering the molecular diameters of BVA and BEG previously calculated by DFT, it is possible to understand that these molecules can be easily located within the pores of the SBA-15. Then, the changes of textural parameters can be interpreted as that BVA and BEG molecules within the cannel of the mesoporous silica hinder the adsorption of nitrogen.

Table 1. Textural properties of SBA-15 and composites.

Sample	Specific Surface Area (m ² /g)	Pore Volume (cm ³ /g)	Average Pore Diameter (Å)
SBA-15	420	0.77	83
BVA-SBA	387	0.78	89
BEG-SBA	264	0.61	100

The FTIR spectra of SBA-15, the precursors BVA and BEG, and composites BVA-SBA and BEG-SBA are reported in **Figure 3**. The characteristic bands reported in precursor characterization BVA and BEG were obtained from spectra b and c, respectively. In the spectrum of SBA-15 (spectrum a), a peak near 1635 cm⁻¹ is observed, mainly resulting from the bending vibration of absorbed H₂O. The typical Si-O-Si bands appear in OH bending region as three peaks: one broad and strong peak centered at 1084 cm⁻¹; two narrow and relatively weak peaks near 850 and 465 cm⁻¹, associated with the condensed silica network. Silanol groups of SBA-15 give the characteristic band at 964 cm⁻¹, but the embedding with BVA and BEG made all peaks to disappear (spectra d and e), indicating the strong interaction between silanol groups of mesoporous silica with molecules of BVA and BEG present into SBA-15 pores.

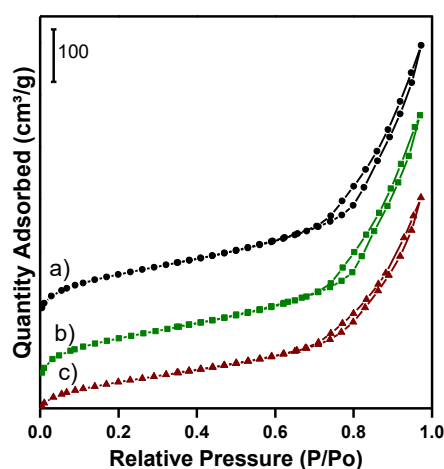


Figure 1. Nitrogen adsorption-desorption isotherms of a) SBA-15, b) BVA-SBA and c) BEG-SBA.

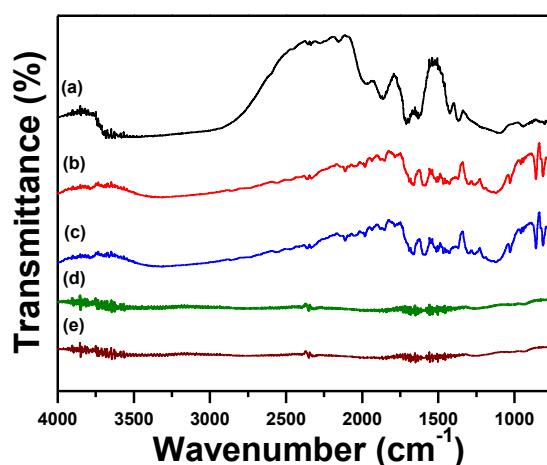


Figure 2. IR spectra of a) SBA-15, b) BVA, c) BEG, d) BVA-SBA and e) BEG-SBA.

To explore SBA composites as precursors of fluorescence sensores, a study of fluorescence spectroscopy was carried out. The fluorescence spectra of SBA-15 systems with BVA and BEG are shown in **Figure 3**. Mesoporous silica SBA-15 itself showed no fluorescence, whereas BVA showed an excitation band at 601 nm (under emission wavelength at 400 nm) and BEG presented an excitation band at 595 nm (under emission wavelength at 420 nm). The luminance phenomena of BVA and BEG are caused by the π electron conjugate system present in these molecules. The composites of BVA-SBA and BEG-SBA gave a sensitive fluorescence response, to the same wavelength as the free precursors. In these cases, the fluorescence of composites appears at a definite excitation length owing to the fluorescent of *bis*-vanillin and *bis*-eugenol molecules embedding in the mesoporous silica. However, the fluorescence intensity of hybrid material of BSA decreases due to the lower amount of BVA and BEG present in the suspension in the sample. Similar results were obtained when the same sample was analyzed by UV spectroscopy.

In conclusion, results suggest weak interactions of electrostatic nature (hydrogen bond) that connect BVA and BEG molecules with Si-OH groups present on the wall of SBA-15. These interactions do not cause chemical changes in the precursors BVA and BEG.

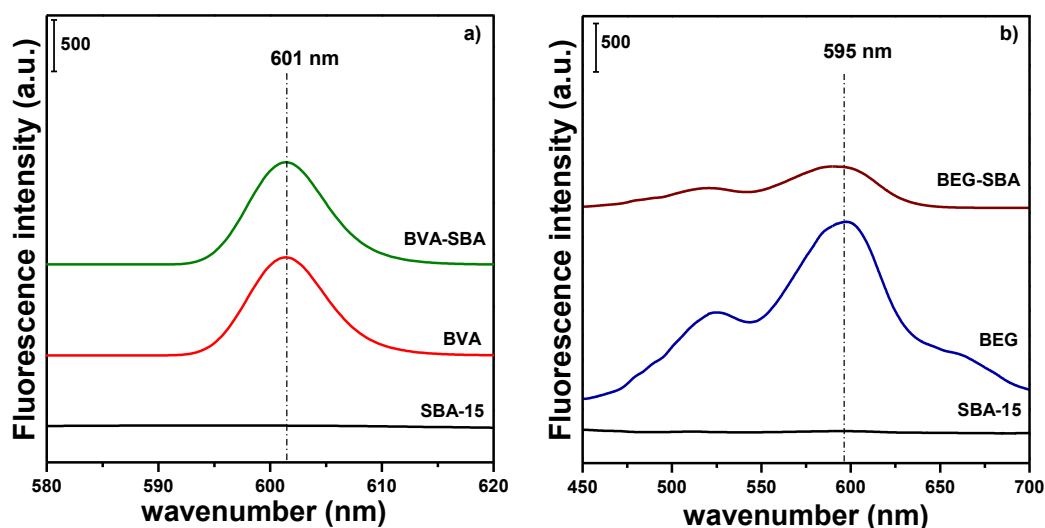


Figure 3. Fluorescence spectrum of SBA-15, precursor and composite by systems with: a) BVA, b) BEG.

3.3. Release test of composites BVA-SBA and BEG-SBA

Release tests of precursors BVA and BEG were performed in order to investigate the effect of embedding these molecules into SBA-15. Depending on the future application, in some cases it could be interesting that chemosensors derivatives of BVA and BEG remain attached to SBA-15 pores, while in others it could be interesting the release of them. In **Figure 4** are shown the results of release of BVA and BEG in different medium in relation of the total content present in the composites at 0.5 h and 2.5 h. These results show that a medium with a high percentage of organic solvents favors the release of precursors, while aqueous solvents do not favor their release from the SBA matrix.

There are no important changes in the release of the precursors in aqueous media at different test times, while there is a substantial difference when the tests were performed in media rich in organic solvents. The higher release of SBA and BEG from SBA which was observed in these liquid media would not only be attributed to the solubilization of the precursors in the organic solvents tested, but also to the ease of the diffusion from the silica matrix to medium.

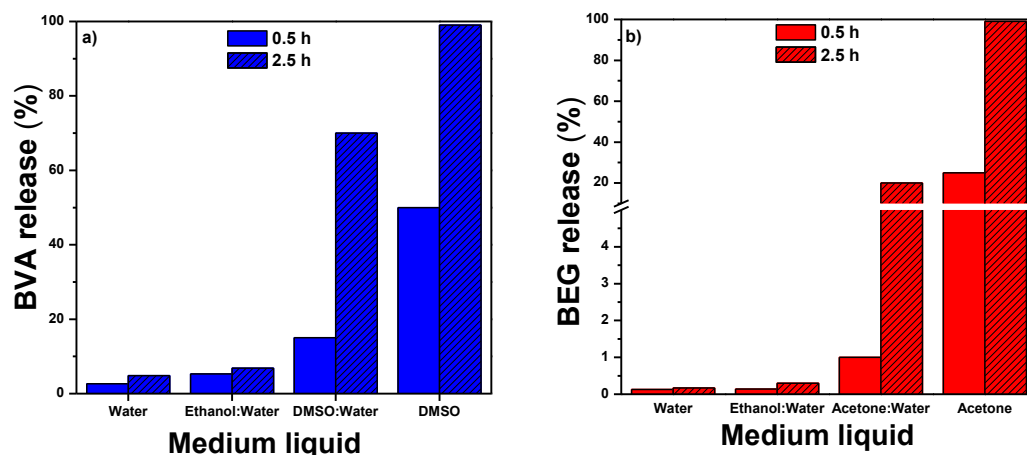


Figure 4. Release of precursors in different liquid medium from: a) BVA-SBA, b) BEG-SBA.

4. Conclusions

In summary, two novel hybrid mesoporous materials *bis*-vanillin-SBA and *bis*-eugenol-SBA have been prepared by a process assisted by microwave. The physicochemical characterization of these materials confirmed the successful immobilization of this compound into the mesoporous silica by weak interactions such as hydrogen bonds that connect the BVA and BEG molecules with the wall of SBA-15 without producing chemical changes.

The spectroscopic properties of this material evidenced by UV adsorption and fluorimetry, allow them to be used as precursors of chemosensors. The most important characteristic of these systems is the possibility of activating the release of the organic molecules embedding into SBA-15, depending on the liquid medium in which this composite is suspended. These findings give an important insight into these hybrid systems in the development of chemical sensors for the detection of metallic cations in different medium.

Acknowledgments

This research was supported by the Agencia Nacional de Ciencia y Tecnología (ANCyT) of Argentina -PICT 2014 No. 1587 and by CAI+D 2017 (PEN 3042150100036 LI) of the Universidad Nacional del Litoral, Santa Fe, Argentina.

References

- [1] Ochando, E.; Dome, A.; Jose, M.; Costero, A. M.; and Jose, M. "Cation and anion fluorescent and electrochemical sensors derived from 4 , 4' -substituted biphenyl". *Tetrahedron Lett.* **2005**, vol. 61, pp. 10309–10320. DOI:10.1016/j.tet.2005.08.010.
- [2] Costero, A. M.; Gil, S.; Parra, M.; Mancini, P. M. E.; Kneeteman, M. N.; and Quindt, M. I. "5 , 5' -Bis-vanillin derivatives as discriminating sensors for trivalent cations". *Tetrahedron Lett.* **2015**, vol. 56, no. 26, pp. 3988–3991. DOI:10.1016/j.tetlet.2015.04.120.
- [3] Ghorpade, T. K.; Patri, M.; and Mishra, S. P. "Highly Sensitive Colorimetric and Fluorometric Anion

- Sensors Based on Mono and Di-Calix[4]pyrrole Substituted Diketopyrrolopyrroles". *Sensors Actuators B. Chem.* **2015**, vol. 225, pp. 428–435.
- [4] Brigo, L.; Pistore, A.; Ba, L.; Arduini, M.; Mancin, F.; and Brusatin, G. "Natively porous films as halide anion fluorescence optical sensors". *Thin Solid Films.* **2016**, vol. 600, pp. 53–58.
- [5] Miyawaki, A.; Llopis, J.; Heim, R.; Mccaffery, J. M.; Adams, J. A.; Ikura, M.; and Tsien, R. Y. "Fluorescent indicators for Ca²⁺ based on green fluorescent proteins and calmodulin". *Nature.* **1997**, vol. 388, pp. 882–887. DOI: 10.1038/42264.
- [6] Chen, X.; Pradhan, T.; Wang, F.; Kim, J. S.; and Yoon, J. "Fluorescent Chemosensors Based on Spiroring-Opening of Xanthenes and Related Derivatives". *Chem. Rev.* **2012**, vol. 112, pp. 1910–1956. DOI:10.1021/cr200201z.
- [7] Akhter, H.; Murshed, J.; Rashed, M. A.; Oshima, Y.; Nagao, Y.; Rahman, M. M.; Asiri, A. M.; Hasnat, M. A.; Uddin, M. N.; and Siddiquey, I. A. "Fabrication of hydrazine sensor based on silica-coated Fe₂O₃ magnetic nanoparticles prepared by a rapid microwave irradiation method". *J. Alloys Compd.* **2017**, vol. 698, pp. 921–929. DOI:10.1016/j.jallcom.2016.12.266.
- [8] Quindt, M. I.; Gutiérrez, L.; Kneeteman, M. N.; Mancini, P. M. E.; Parra, M.; Gil, S.; and Costero, A. M. "A new highly selective chromogenic and fluorogenic chemosensor for Copper (II)". *Tetrahedron Lett.*, **2017**.
- [9] Farias Dias, A. "An improved high yield synthesis of dehydrodieugenol". *Phytochem. Lett.* **1988**, vol. 27, no. 9, pp. 3008–3009.
- [10] Wang, A.; Ji, Y.; Yin, H.; and Liu, S. "Synthesis of different-sized SBA-15 nanoparticles and their fluoride release performances from poly(methyl methacrylate) dental restorative resin". *New J. Chem.* **2016**, vol. 40, pp. 9781–9787.