Nicotinic acid functionalized organomodified silica as an efficient heterogeneous catalyst for the synthesis of benzoyl fumarate

Rana Sanjay Kumar Singh, Bishwapran Kashyap, Prodeep Phukan

PII: S0040-4039(13)01611-0
DOI: http://dx.doi.org/10.1016/j.tetlet.2013.09.057
Reference: TETL 43557

To appear in: *Tetrahedron Letters*

Received Date: 8 August 2013
Revised Date: 10 September 2013
Accepted Date: 13 September 2013

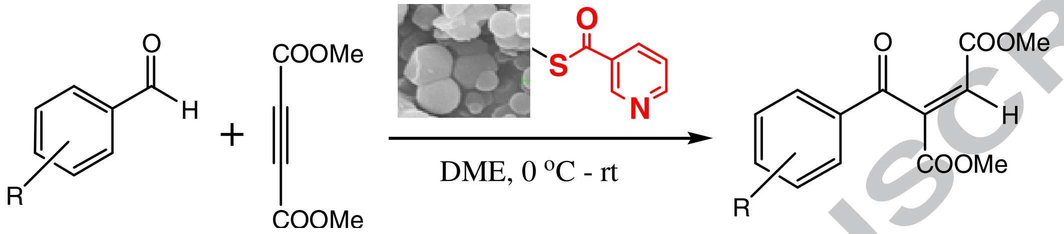
Please cite this article as: Singh, R.S.K., Kashyap, B., Phukan, P., Nicotinic acid functionalized organomodified silica as an efficient heterogeneous catalyst for the synthesis of benzoyl fumarate, *Tetrahedron Letters* (2013), doi: http://dx.doi.org/10.1016/j.tetlet.2013.09.057

Graphical Abstract

Nicotinic acid functionalized organomodified silica as an efficient heterogeneous catalyst for the synthesis of benzoyl fumarate

Rana Sanjay Kumar Singh, Bishwapran Kashyap and Prodeep Phukan

Leave this area blank for abstract info.



Tetrahedron Letters
journal homepage: www.elsevier.com

Nicotinic acid functionalized organomodified silica as an efficient heterogeneous catalyst for the synthesis of benzoyl fumarate

Rana Sanjay Kumar Singh, Bishwapran Kashyap[a], Prodeep Phukan [a]*

[a] *Department of Chemistry, Gauhati University, Guwahati -781014, Assam, India; E-mail: pphukan@yahoo.com*

ARTICLE INFO

Article history:
Received
Received in revised form
Accepted
Available online

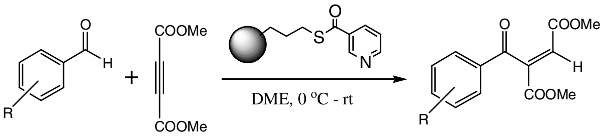
Keywords:
Organomodified silica,
Heterogeneous catalyst,
Benzoylfumarate,
DMAD,
Aldehydes

ABSTRACT

A new hybrid catalyst has been developed by incorporating nicotinic acid onto an organomodified silica. The catalyst was applied as a heterogeneous catalyst for the synthesis of benzoylfumarate. The reactions work well in presence of 20 wt% of the catalyst at room temperature to produce the desired products in high yield. The catalyst could be recovered and reused without appreciable change in activity.

The modification of silica and related materials by attachment of organic functionalities onto their surfaces is an important area of research in heterogeneous catalysis directed toward achieving green chemistry goals.[1] Surface functionalization of mesoporous silica has been widely practiced in recent years for generating active sites necessary for heterogeneous catalytic activity. Numerous strategies have been described for immobilizing inorganic and/or organic active species on or within the silica matrices.[1a] Functionalization of mesoporous silica surface via tethering of an active group generally can be done in two different ways: through the so-called "post-synthesis" method,[2] which involves grafting an organotrialkoxysilane onto the pore surfaces after mesoporous material synthesis, and through the "direct synthesis" method,[3] in which the functional groups are introduced during the synthesis of the mesoporous material. The pore functionalization is achieved through the co-condensation reaction occurring between the organotrialkoxysilane and the silica source in the presence of a structure-directing agent. The direct synthesis method is considered more predictable and hence valuable, because it can avoid several shortcomings of the post-grafting method, such as reduction in pore size, pore blocking at the aperture and difficulties in controlling the loadings as well as the distribution of active sites.[4]

Benzoyl fumarates and its corresponding acids are known to be important precursor for the synthesis of many agrochemicals,[5] drugs[6] and organic transformations.[7] Nair *et al.* and latter Shi *et al.* have prepared benzoyl fumarates by one pot reaction between dimethylacetylenediacetate (DMAD) and aldehyde in presence of Lewis base as homogeneous catalyst.[8] Bayat *et al.* have prepared this benzoyl fumarate by multicomponent reaction between DMAD, aldehyde and PPh_3.[9] We have also developed a ferrocene based pyridine catalyst for benzoyl furmarate synthesis under homogeneous condition.[10] In addition, there are a few more examples for the synthesis of benzoyl fumarates from aldehyde and DMAD.[11] However, till date, heterogeneous approach has not been applied for this transformation. We have developed a new nicotinic acid functionalized organomodified mesoporous silica catalyst, for the first time, which acts as heterogeneous catalyst for the synthesis of benzoyl fumarates (Scheme 1). It has been observed that the organomodified silica, which has been characterized by various methods including spectroscopy and electron microscopy, is suitable as heterogeneous catalysts for the preparation of benzoyl fumarates from aldehydes and DMAD.



Scheme 1: Synthesis of benzoyl fumarates

To realize our goal, we have developed a new organomodified mesoporous silica by incorporating nicotinic acid to the thiol group of mercaptopropyl silica (MPMS). Initially, MPMS was prepared by mixing tetraethylorthosilicate and mercaptopropyl (triethoxy) silane with a solution of n-dodecylamine in aqueous ethanol.[3a,b] The MPMS was characterized by powder X ray diffraction, IR spectra, TGA, SEM and EDX. The appearance of low-angle broad XRD peaks at 2Θ = 0.5- 2 degree is the characteristic of mesoporous nature of MPMS (Figure 1). The observed pattern does not show well resolved diffraction peaks. The broad peaks seen for this material suggest the lack of long-range order in the structure. In the IR spectrum (Figure S1 of SI), the presence of bands at 2950, 2560 cm^{-1} and a broad peak at around 3300-3400 cm^{-1} confirms the presence of propyl, thiol(-S-H stretching) and Si-OH groups in the MPMS. The TGA (Figure S3 of SI) study indicates that loss in weight up to 100 °C is due to loss of water molecule from the surface and one main weight loss in the range 340-680 °C is due to loss of organic group from the surface. Morphology of MPMS was also analyzed by using SEM (Figure 2) and it is obvious from the picture that the major portion of the material is made up of aggregates of smaller roughly spherical particles. A second type of structure consists of single particles, again roughly spherical, but of much larger size. Some of these are aggregated into groups of two or three, but not into larger aggregates. The spherical structures present are often seen in a range of mesostructured materials. EDX data (Figure S2 of SI) confirms the presence of thiol moiety in the MPMS.

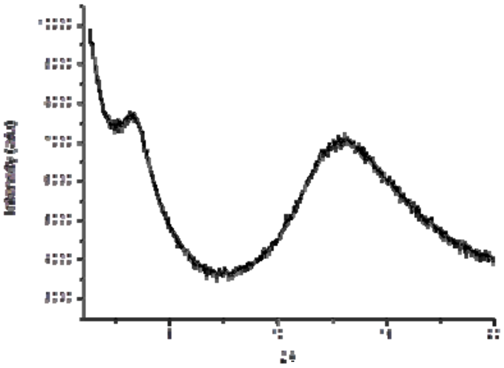


Figure 1: XRD pattern of MPMS

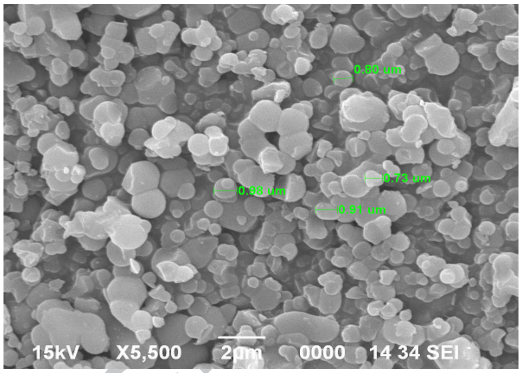
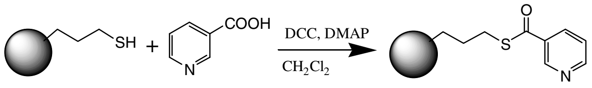


Figure 2: SEM image of MPMS

Nicotinic acid functionalized MPMS was prepared by simple esterification between MPMS and nicotinic acid in DCM (Scheme 2). Functionalization was carried out by stirring a mixture of MPMS, nicotinic acid, dicyclohexylcarbodiamide and DMAP in dry DCM under N_2 atmosphere at room temperature for 48 h. The resulting white solid was separated by filtration, washed several times with DCM and dried in vacuum.



Scheme 2: Synthesis of Nicotinic acid functionalized MPMS

The X-Ray diffraction patterns (Figure 3) were also measured for nicotinic acid functionalized MPMS and as expected, these materials do not display the degree of long range order associated with the MCM-41 class of silicates. Unlike MPMS, it shows a sharp peak at around 2Θ = 7°. The IR spectra of nicotinic acid functionalized MPMS shows bands at around 1360-1310 cm^{-1} and 1725-1700 cm^{-1} which indicates the presence of aromatic C-N vibration of pyridine ring and carbonyl group respectively. The SEM picture (Figure 4) indicates no significant change in morphology after functionalization of MPMS with nicotinic acid.

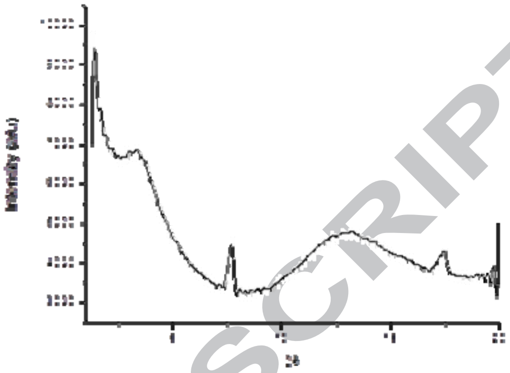


Figure 3. XRD pattern of nicotinic acid functionalized MPMS

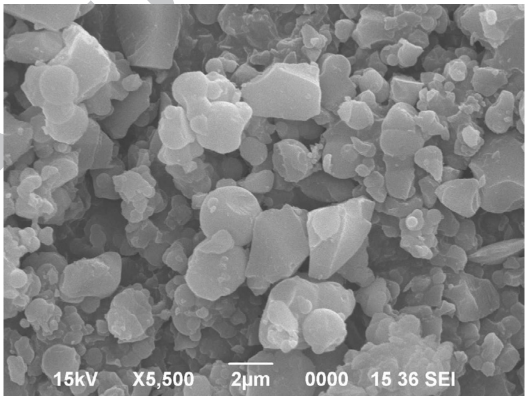
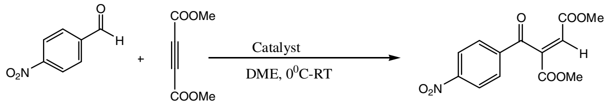


Figure 4: SEM image of nicotinic acid functionalized MPMS

Pore size distributions and surface areas were measured by N_2 adsorption studies for both the MPMS and nicotinic acid functionalized MPMS (Figure S7-S10, SI). In both cases the materials displayed isotherms characteristic hysteresis loop of type IV (according to the scheme of classification recommended by IUPAC) of HMS materials with small pores and high surface areas. The isotherms of MPMS and nicotinic acid functionalized MPMS are of similar shape indicating that porous structure has been retained after functionalization. Pore size distribution is quite narrow with BJH adsorption pore average diameter between 2.17487 - 4.1727 nm. It has been observed that on functionalization of thiol group with nicotinic acid, there is a drop in surface area as well as in average pore size.

After the confirmation of the structure and morphology of the prepared nicotinic acid functionalized MPMS we intend to test its efficiency as heterogeneous catalysts for the preparation of benzoyl fumarates from aldehydes and dimethylacetylene-diacetate (DMAD). Initially, the reaction between 4-nitrobenzaldehyde and DMAD was selected as a model reaction to investigate the best reaction condition (Table 1). In a typical reaction, 10 wt% of the catalyst was added to a mixture of 4-nitrobenzaldehyde (1 mmol) and DMAD (1 mmol) in DME (5 ml) at 0 °C under N_2 atmosphere. The reaction was continued at room temperature for appropriate time and it was found that 12 h of stirring gives the maximum yield. After usual work-up, the crude product was purified using column chromatography to get the pure product. It was observed that 20 wt% of the catalyst and 12 h of reaction time give the best result. Further reaction using 25 wt% of catalyst did not improve the reaction yield. The reaction in other solvents such as THF and acetonitrile produced lower yield. The reaction in DCM did not proceed at all. Finally, 20 wt% of catalyst was found to be the optimum amount for the best yield.

Table 1 Reaction of *p*-nitrobenzaldehyde with DMAD catalyzed by nicotinic acid functionalized MPMS catalyst in different solvent.[a]

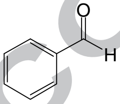
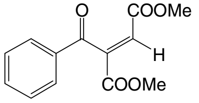
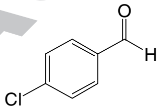
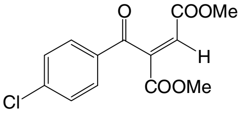
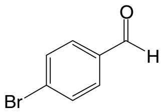
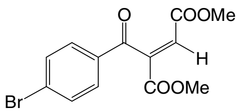
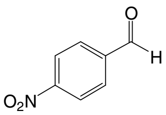
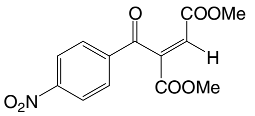
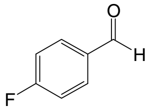
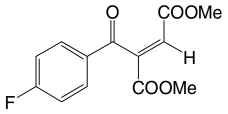
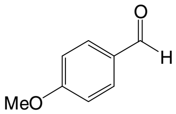
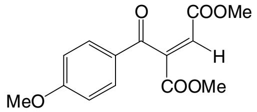
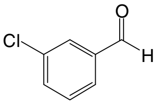
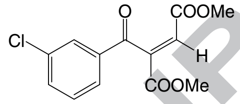
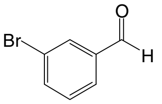
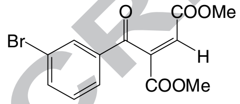
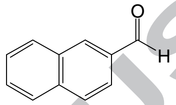
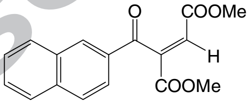
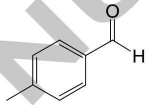
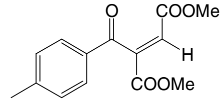
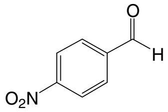
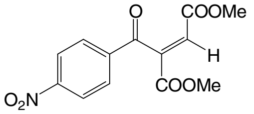
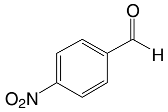
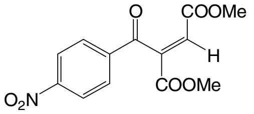
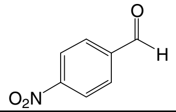
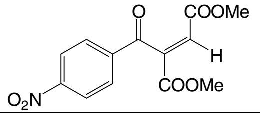


Entry	Catalyst (wt%)	Solvent	Time (h)	Yield (%)[b]
1	10	DME	7	60
2	10	DME	12	67
3	15	DME	12	72
4	15	THF	12	65
5	15	MeCN	24	30
6	15	DCM	24	trace
7	20	DME	12	78
8	25	DME	12	79
9	0	DME	24	0

[a]Reaction condition: 4-nitrobenzaldehyde (1 mmol), DMAD (1 mmol), solvent (4 mL), 0 °C-rt; [b]isolated yield

After establishing the optimum reaction condition, the scope of the reaction was examined with various aldehydes under the same reaction condition (Table 2).[12] It has been observed that various aldehydes undergo this reaction with good efficiency under the reaction condition. It was observed that, presence of electron withdrawing group in the benzene ring gives better yield (Table 2, Entry 2-8) than electron donating groups (Table 2 Entry 10).

Table 2: Synthesis of benzoyl fumarates catalyzed by nicotinic acid functionalized MPMS.[a]

Sl No	Reactant	Product	Yield (%)[b]
1	 1a	 1b	72
2	 2a	 2b	75
3	 3a	 3b	81
4	 4a	 4b	78
5	 5a	 5b	73
6	 6a	 6b	66
7	 7a	 7b	69
8	 8a	 8b	70
9	 9a	 9b	64
10	 10a	 10b	60
11			77[c]
12			76[d]
13			76[e]

[a]Reaction condition: aldehyde (1 mmol), DMAD (1 mmol), catalyst (20 wt%), DME (4 mL), 0 °C-rt. 12h; b. isolated yield; c. catalyst reused: 1st run; d. catalyst reused: 2nd run; e. catalyst reused: 3rd run.

Reusability of the catalyst was tested with 4-nitrobenzaldehyde. To reuse, the catalyst was filtered after completion of the reaction, washed with petroleum ether, dried under vacuum and then kept in a desiccator overnight before reuse. It was observed that the catalyst could be reused for three times without appreciable loss in activity (Table 2, Entry 11-13).

The mechanism of the reaction has already been discussed in detail by Shi.[8b] Accordingly, the pyridine moiety attached to the MPMS core acts as a nucleophilic promoter to form a zwitter ionic intermediate at the initial stage of the reaction.[8b] Subsequent reaction with aldehyde followed by an intramolecular proton transfer process leads to formation of the product.

In conclusion, we have effectively prepared a nicotinic acid functionalized organomodified silica catalyst from MPMS. The catalyst was characterized using XRD, SEM, IR, TGA and EDX. It was further demonstrated that the prepared functionalized silica acts as a heterogeneous catalyst for the synthesis of benzoylfumarates from aldehydes and DMAD. The catalyst is reusable with good yield

Acknowledgement: Financial support from UGC (grant No. 41-206/2012/SR) is gratefully acknowledged. RSKS thanks UGC (NERO) and BK thanks CSIR for research fellowship.

References:

1. (a) Hoffmann, F.; Cornelius, M.; Morell, J.; Fröba, M. *Angew. Chem. Int. Ed.* **2006**, *45*, 3216 – 3251. (b) Melero, J. A.; van Grieken, R.; Morales, G. *Chem. Rev.* **2006**, *106*, 3790-3812; (c) Clark, J. H.; Macquarrie, D. J. *Chem. Commun*, **1998**, 853-860.
2. (a) Cauvel, A.; Renaud,G.; D. Brunel, *J. Org. Chem.*, **1997**, *62*, 749 (b) Sutra, P.; Brunel, D. *Chem. Commun.* **1996**, 2485. (c) Subba Rao, Y. V.; de VosD. E.; Jacobs, P. A. *Angew. Chem. Int. Ed. Engl.* **1997**, *36*, 2661. (d) Subba Rao,Y. V.; de Vos,D. E.; Jacobs, P. A. *Chem. Commun.***1997**, 355; (e) Feng, X.; Fryell, G. E.; Wang, L. Q.; Kim, A. Y.; Lin J.; Kenner, K. M. *Science*, **1997**, *276*, 923.
3. (a) Macquarrie, D. J. *Chem. Commun*, **1996**, 1961-1962; (b) Macquarrie, D. J.; Jackson, D. B.; Mdoe, J. E. G.; Clark, J. H. *New J. Chem.* **1999,** *23*, 539-544; (c) Burkett, S. L.; Sims, S. D.; Mann, S. *Chem. Commun.***1996**, 1367-1368; (d) Richer, R.; Mercier, L. *Chem. Commun.* **1998**, 1775-1776; (e) Lim, M. H.; Blanford, C. F.; Stein, A. *J. Am. Chem. Soc*., **1997**, *119*, 4090; (f) Sarma, P., Chakrabarty, R., Phukan, P., Das, B. K. *J. Mol. Catal. A: Chem.* **2007**, *268*, 36–44.
4. Characterisation and Chemical Modification of the Silica Surface, ed. Vansant, E. F.; Van, P.; der Voort; Vrancken, K. C. Elsevier, Amsterdam, **1995**, p. 176.
5. (a) *Nippon Synthetic Chemical Industry Jpn. Kokai* 5838202, 1983; *Chem. Abstr.* **1983**, *99*, 1818d; (b) *Nippon Synthetic Chemical Industry Jpn. Kokai* 81127302, 1981; *Chem. Abstr.***1982**, *110*, 7866k.
6. (a) Yamada, K.; Ino, K.; Takashashi, S.; Ohashi, T.; Watanabe, K. *Eur. Pat. Appl.* EP 239062, 1987; *Chem. Abstr.* **1988**, *109*, 110904z; (b) Chosakon, Y.; Yamamoto, N. *Jpn. Kokai* 63104940, 1988; *Chem. Abstr.***1988**, *109*, 230551d; (c) Ikeda, T.; Hirano, H.; Aoki, K. *Jpn. Kokai* 63130564, 1988; *Chem. Abstr.* **1989**, *110*, 7866k.
7. (a) Reymond, S.; Cossy, J. *Chem Rev.* **2008**, *108*, 5359-5406; (b) Kagan, H. B.; Riant, O. *Chem. Rev.***1992**, *92*, 1007-1019; (c) Pindur, U.; Lutz, G.; Otto, C. *Chem. Rev*. **1993**, *93*, 741-761.
8. (a) Nair, A.; Sreekanth, A. R.; Abhilash, N.; Biju, A. T.; Devi, B. R.; Menon, R. S.; Rath, N. P.; Srinivas, R. *Synthesis* **2003**, 1895-1902; (b) Li, C-Q.;Shi, M. *Org. Lett*. **2003**, *5*, 4273-4276.
9. Bayat, M.; Imanieh H.; Hassanzadeh, F. *Tetrahedron Lett*. **2010**, *51*, 1873-1875.
10. Kashyap, B.; Phukan, P. *RSC Adv*. **2013**, *3*, 15327-15336.
11. (a) Ikeda, T.; Hirano, H.; Aoki, K. JpnKokai 63130564, 1989; *Chem. Abstr*. **1989**, *110*, 7866; (b) Takahashi, S.; Ueda, Y.; Yanagida, Y.; Namito, Y.; Ohaska T.; Watanabe, K. European Patent Appl. EP 204286, 1986; *Chem. Abstr*. **1987**, *106*, 84179.
12. **Typical procedure**: The catalyst (20 wt % based on aldehyde) was added to a mixture of aldehyde (1 mmol) and DMAD (1 mmol) in DME (4 ml) at 0 °C under N_2 atmosphere and the reaction mixture was stirred for 12h, (first two hours at 0 °C and then at room temperature). After completion of the reaction (TLC), the reaction mixture was filtered and the solvent from the filtrate was removed and the residue was purified with column chromatography using 20% ethyl acetate/petroleum ether as eluent to get the product. The recovered catalyst was washed with petroleum ether, dried under vacuum and then kept in a desiccator overnight before reuse.