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Synthesis of a SO_3H-bearing carbonaceous solid catalyst, PEG–SAC: application for the easy access to a diversified library of pyran derivatives†

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Sanjay Paul,[a] Sirshendu Ghosh,[b] Pranabes Bhattacharyya[a] and Asish R. Das*[a]

A SO_3H-bearing carbonaceous solid catalyst (PEG–SAC) has been synthesized through sulfonation followed by a hydrothermal carbonization method from renewable resources like polyethylene glycol. The biodegradable catalyst was characterized by XRD, TEM, FT-IR and EDX. The surface area and pore diameter of the catalyst were determined from a nitrogen adsorption–desorption isotherm experiment. A highly convergent, efficient and practical PEG–SAC catalyzed heteroannulation protocol for the synthesis of a library of diversified pyran fused heterocyclic scaffolds has been demonstrated. This synthesis was established to follow the group-assistant-purification (GAP) chemistry process, which can avoid traditional chromatography. A recrystallization purification appeared to be a very good alternative to the traditional classical methods, demonstrating that a carbon-based catalyst is very effective in producing pyran fused heterocyclic molecules. The aqueous reaction medium, easy recovery of the catalyst and high yield of the products make the protocol attractive, sustainable and economic.

Introduction

A wide variety of homogeneous Brønsted acids (H_2SO_4, *p*-toluenesulfonic acid, HCl and H_3PO_4) have been used for the synthesis of important chemicals, including pharmaceuticals, agrochemicals, and fragrances.[1–3] These acidic catalysts are economical and efficient, but have serious drawbacks associated with product isolation, equipment corrosion, solvent recycling, and reusability of the catalyst. Heterogeneous acid catalysts like zeolites, transition-metal ions, and strong acid cation exchange resins have also been used to serve this purpose.[4–6] Although these catalysts are reusable and offer a simplified separation process, their use prolongs the reaction time due to their very low activity.[7]

At the present, mesoporous materials have attracted a great deal of attention in organic synthesis owing to their high surface-to-volume ratio leading to a large number of active sites. Mesoporous carbon materials consisting of small polycyclic aromatic carbon sheets with a high density of sulfonic acid sites are promising solid acid catalysts.[8,9] Solid acids have many advantages such as ease of handling, fewer reactor and plant corrosion problems, and environmentally safe disposal.[10] Besides, a major emerging and challenging area of heterogeneous catalysis is that of environmental pollution control, with tightening legislation on the release of waste and toxic emissions having serious implications for the chemical industry. In addition, there is a lot of current research and general interest in heterogeneous systems because of their importance in industry and in technology development.[11] These SO_3H-bearing amorphous carbon materials can be readily prepared by partial carbonization of organic compounds (glucose, starch, and cellulose), followed by sulfonation in fuming H_2SO_4.[12]

Herein, we have demonstrated a two step synthesis of SO_3H-bearing carbonaceous solids by hydrothermal carbonization using polyethylene glycol as the carbon precursor, in a reversed mode from previously reported methods. In this protocol, the SO_3H groups are first introduced into the carbon precursor polyethylene glycol using chlorosulphonic acid (Fig. 1, A). The mesoporous carbonaceous solid acid was then obtained through the incomplete carbonization of the SO_3H functionalized polyethylene glycol (Fig. 1, B) at a high temperature.

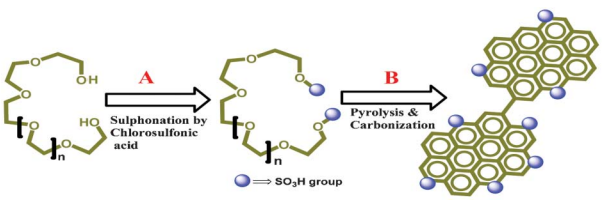

Fig. 1 Synthesis of the solid acid catalyst PEG–SAC.

[a]*Department of Chemistry, University of Calcutta, Kolkata-700009, India. E-mail: ardchem@caluniv.ac.in; ardas66@rediffmail.com; Fax: +913323519754; Tel: +913323501014 Tel: +919433120265*

[b]*Department of Materials Science, Indian Association for the Cultivation of Science, Kolkata, 700032, India*

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It is well known that pyrans are important core units in a number of natural products[13] and photochromic materials.[14] These pyran derivatives show antihyperglycemic and antidyslipidemic,[15] cytotoxic,[16] molluscicidal,[17] antiinflammatory,[18] and antifungal activities.[19] These compounds also exhibit a wide spectrum of biological activities,[20] including anticancer[21] and antimalarial,[22] and are also widely employed in cosmetics, pigments,[23] and potential biodegradable agrochemicals.[24] Various catalytic systems such as hexadecyltrimethyl ammonium bromide (HMTAB),[25a] triethylbenzylammonium chloride (TEBA),[25b] rare earth perfluorooctanoate ($RE(PFO)_3$),[25c] (*S*)-proline,[25d] amino functionalized ionic liquids,[25e] MgO,[25f] SiO_2 nanoparticles,[25g] silica bonded *n*-propyl-4-aza-1-azoniabicyclo[2.2.2]octane chloride (SB-DABCO),[25h] $H_{14}[NaP_5W_{30}O_{110}]$,[26a] Na_2HPO_4,[26b] [bmim]OH,[26c] CAN[26d] and Na_2CO_3[26e] have been used for the synthesis of 4*H*-pyrans so far. But most of the reported procedures for the synthesis of pyran derivatives suffer from drawbacks such as low yields of the products, long reaction times, the use of hazardous and often expensive catalysts, the use of volatile and hazardous organic solvents, harsh reaction conditions, tedious work-ups, and no compliance with green chemistry protocols. Consequently, the development of efficient, inexpensive and environmentally benign methods for the synthesis of this heterocyclic scaffold is still in demand.

SO_3H-bearing amorphous carbon materials can function as stable and highly active solid acid catalyst for various acid-catalyzed reactions with hydrophilic reactants, such as esterification, transesterification, and hydrolysis reactions.[8,9,12] In continuation of our research program dedicated to the design and synthesis of novel heterocyclic systems,[27] here we wish to disclose a PEG derived SO_3H-bearing amorphous carbon material catalyst in a general, rapid, high yielding, green synthetic protocol for a variety of pyran derivatives.

Results and discussions

The carbon based solid acid was prepared by the hydrothermal treatment of PEG–OSO_3H. The mesoporous carbonaceous PEG derived solid acid catalyst was denoted as PEG–SAC. Fig. 2 shows the XRD pattern of the PEG–SAC catalyst. The XRD pattern exhibits a broad C(002) diffraction peak (2θ = 10–30°) attributable to amorphous carbon and it also consists of a weak diffraction peak C(101) at 2θ = 35–50° due to the axis of the graphite structure of the carbonaceous material. Hence, the XRD pattern indicates amorphous carbon composed of aromatic carbon sheets oriented in a random manner (Fig. 1). The FT-IR spectrum of the PEG–SAC catalyst is shown in Fig. 3. The strong peak at around 1710 cm^{-1} and the weak peak at around 1117 cm^{-1} can be typically assigned to the stretching modes of the SO_3H groups, which are regarded as the "active sites" of this catalyst.[28]

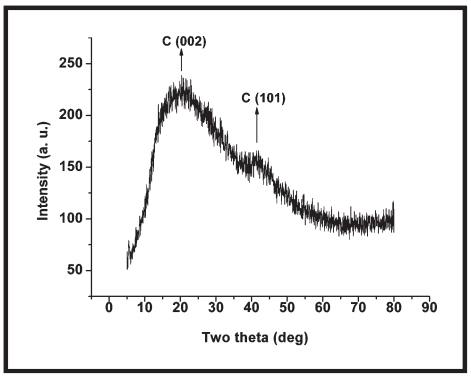


Fig. 2 XRD pattern of solid acid catalyst PEG–SAC.

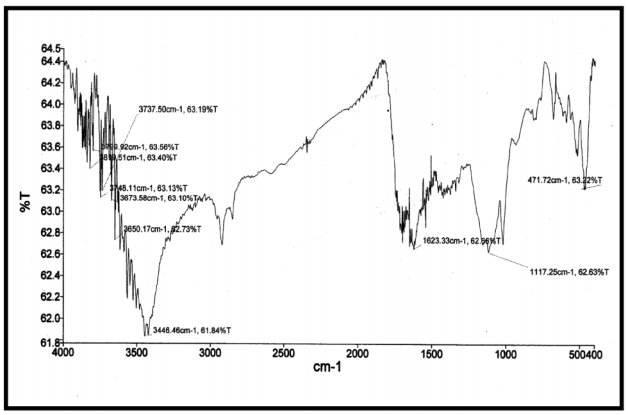


Fig. 3 FT-IR spectrum of the catalyst.

HR-TEM microscopy (Fig. 4) was used to study the morphology of the surface of the solid acid catalyst PEG–SAC synthesized from PEG-6000 by the hydrothermal method. The HR-TEM images show amorphous carbon and that the carbonaceous material PEG–SAC has a sponge-like morphology.

Three independent methods – EDX, acid–base back titration, and elemental analysis – for the quantification of the acid content in the catalyst have been applied giving similar results. Elemental analysis of the as-synthesized PEG–SAC catalyst was performed by energy dispersive X-ray analysis (EDX) equipped onto TEM. The quantitative EDX analysis in Fig. 5 and Table S1 (ESI†) clearly show that C, O and S are the main elemental components of the catalyst. The acid–base titration of the prepared catalyst was performed using a 0.03 M NaOH solution with a 50 ml dispersed solution of the catalyst in water (50 ml water was stirred with 1 g of the catalyst for 30 min at rt). From the acid–base back titration it was observed that the acid density (–SO_3H) was 1.52 mmol g^{-1} while the elemental analysis (EDX) revealed that the S content of the catalyst was 1.48 mmol g^{-1}.

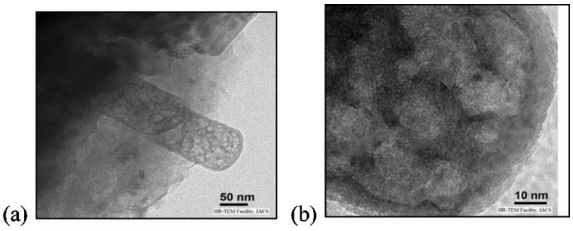


Fig. 4 HR-TEM images (a and b) of the catalyst.

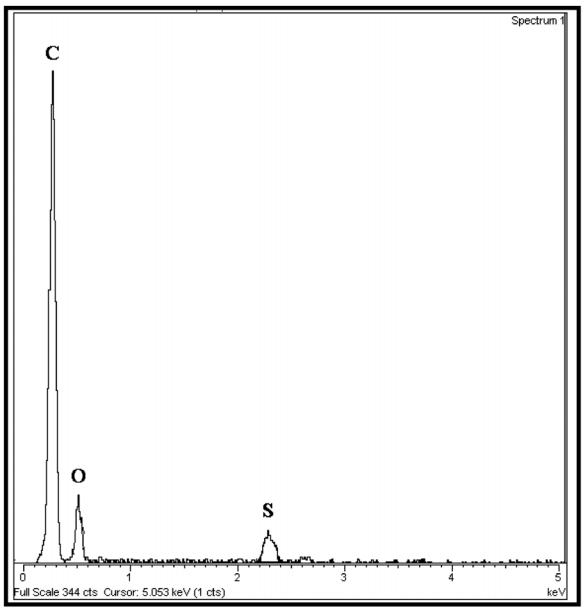


Fig. 5 Energy dispersive X-ray analysis (EDX) of the catalyst.

The surface area and pore diameter of the catalyst were determined by nitrogen adsorption. Fig. 6 shows the N_2 adsorption–desorption isotherms by plotting the adsorbed volume as a function of the gas pressure (P) normalized by the adsorptive saturation pressure at 77 K (P_o). The measured BET (Brunauer, Emmett and Teller) surface area and NLDFT (Non-Local Density Functional Theory) pore diameter of the PEG–SAC catalyst were 480 $m^2\ g^{-1}$ and 6.1 nm respectively. According to the International Union of Pure and Applied Chemistry (IUPAC), the hysteresis loop in Fig. 6 indicates the existence of mesoporous structures in the PEG–SAC catalyst. The carbonaceous material PEG–SAC is insoluble in most of the organic solvents (ethanol, DMF, methanol, toluene, DCM, DMSO) including water. Hence, the synthesized carbonaceous material can be used as a heterogeneous catalyst in a wide range of solvents.

Pyranochromenes and their derivatives have engrossed considerable attention from synthetic and medicinal chemists

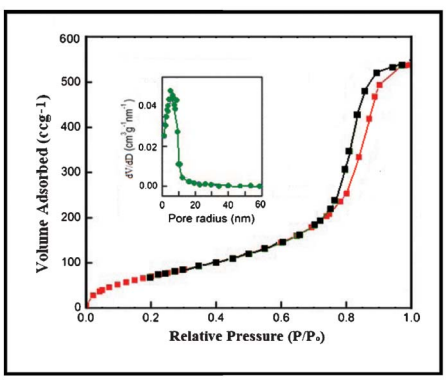
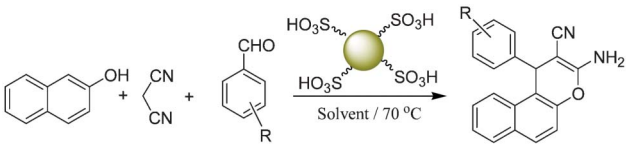


Fig. 6 Nitrogen adsorption–desorption isotherms and the pore size distribution (inset) of the as-prepared PEG–SAC catalyst.



Scheme 1 Synthesis of benzo[*f*]chromene derivatives.

because of their broad spectrum of biological and pharmaceutical activities. Chromene derivatives containing coumarin nuclei are components of numerous natural products[28] and, in view of the immense importance of the chromene derivatives, in recent years efforts have been made in developing new methodologies for the synthesis of these compounds. A number of methods have been reported for the synthesis of benzo[*f*]chromene and dihydropyrano[3,2-*c*]chromene. However, there are only two reports in the literature for the synthesis of dihydropyrano[2,3-*c*]chromene derivatives from 3-hydroxycoumarin and the condensed product of malononitrile and aldehyde. Notably, no reports are available in the literature for the application of this type of carbon based solid acid catalysts in the synthesis of organic molecules to date. We advocated the use of the carbon based solid acid catalyst for the synthesis of a diversified library of pyran derivatives and, gratifyingly, the catalyst efficiently catalyzed the three-component coupling reaction for the synthesis of all chromene derivatives.

Pyran derivatives are generally synthesized *via* the one-pot three-component condensation reaction between a carbonyl compound, a carbonyl compound possessing a reactive α-methylene group and an alkylmalonate. Our initial study focused on the development of the optimal reaction conditions for this transformation, which included solvent screening and the influence of the catalyst weight. Initially, the reaction between 3-nitrobenzaldehyde, β-naphthol and malononitrile (Scheme 1) was investigated in different solvents at 70 °C in the presence of 80 mg PEG–SAC. Various solvents like toluene, acetonitrile, DMF, DMSO, ethanol, and water were screened to test the efficiency of the catalyst and the results are summarized in Table 1. The results clearly indicated the superiority of water over the other solvents. This phenomenon can be attributed to the high ionization of the sulphonic acid group functionalized catalyst to provide H^+ ions in the aqueous medium.

To find the optimized amount of solid acid catalyst, as shown in (Fig. 7), the reaction was carried out by varying the amount of

Table 1 Influence of solvent on the synthesis of the benzo[*f*]chromene derivative

Entry	Solvent	Time	Yield (%)[a]
1	Toluene	1 h	49
2	Acetonitrile	1 h	52
3	DMF	1 h	67
4	DMSO	1 h	69
5	Ethanol	30 min	70
6	H_2O	16 min	92

[a] Isolated yield of the pure product.

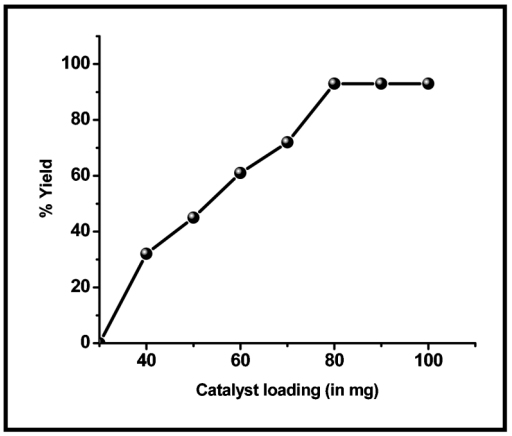


Fig. 7 Weight effect of the catalyst in the three-component coupling of 3-nitrobenzaldehyde, malononitrile and 1-naphthol.

the catalyst on the model reaction. The conversion of the benzo[*f*]chromene derivative increased linearly with the catalyst weight up to 80 mg and became almost steady when the amount of catalyst was further increased beyond this. Therefore, 80 mg of the catalyst (0.13 equivalent protons) is sufficient to catalyze the reaction leading to the expected heterocyclic molecules in excellent yield.

Under the optimized reaction conditions, various aromatic aldehydes and carbonyl compounds possessing a reactive α-methylene group (4-hydroxycoumarin, β-naphthol, 3-hydroxycoumarin, dimedone and cyclohexane-1,3-dione) were screened. Indeed, there is no difference in reactivity between 4-hydroxycoumarin, β-naphthol, dimedone or cyclohexane-1,3-dione, and the corresponding pyran (Table 2) derivatives were formed within very short reaction times (10–20 min), although 3-hydroxycoumarin took longer times (1.5–2 h) for the formation of the dihydropyrano[2,3-*c*]chromene derivative (Table 2, entries 1–12).

Since 4-hydroxycoumarin is the enol tautomer of a 1,3-dicarbonyl compound, in the presence of an acid or base it can act as a nucleophile and easily form chromene[3,2-*c*] derivatives. But 3-hydroxycoumarin may be considered as the enol tautomer of a 1,2-dicarbonyl compound (Fig. 8). During the formation of the pyran derivative, 3-hydroxycoumarin passes through this very unstable cyclic 1,2-dicarbonyl intermediate (Michael reaction step) and hence it is a very poor Michael donor under acidic or basic conditions, the formation of chromene[2,3-*c*] derivatives from it is rather difficult and therefore the rate of the reaction is relatively sluggish. Following these results, as summarized in Table 2, a variety of aromatic aldehydes with electron-donating and electron-withdrawing substituents were converted to 4*H*-pyrans in excellent yields. Besides, our methodology has been applied successfully in acid and base sensitive materials such as heteroaromatic aldehydes, and the corresponding 4*H*-pyrans were obtained in excellent yields without any by-product. In our previous work,[27a] we have reported nano crystalline ZnO as an efficient catalyst for the synthesis of dihydropyrano[2,3-*c*]chromene derivatives in water, but PEG–SAC is a more effective catalyst compared to ZnO for this synthesis. As PEG–SAC is a Brønsted acid, it shows a much higher catalytic activity in aqueous media than the amphoteric nano ZnO. Table 2 (entries 1–12) clearly shows the superior catalytic activity of the PEG–SAC catalyst. The products were isolated, purified by recrystallization and characterized by their melting point, ^{1}H and ^{13}C NMR, IR spectroscopy and HR-MS. The X-ray crystal structure of **2c**, shown in Fig. 9, further confirmed the product identity. The results obtained with various substrates are summarized in Table 2.

A mechanistic rationale for the reaction applying our carbon based solid acid catalyst, portraying the probable sequence of events, is given in Scheme 2. The reaction presumably proceeds in three steps: a Knoevenagel condensation, a Michael addition, and then an intramolecular cyclization as presented in Scheme 2. The Knoevenagel adduct formed from the acid catalyzed condensation of aldehydes and malononitrile subsequently undergoes the solid acid catalyzed Michael reaction with carbonyl compounds possessing a reactive α-methylene group (4-hydroxycoumarin, β-naphthol, 3-hydroxycoumarin, dimedone and cyclohexane-1,3-dione) that after cyclization affords the pyran annulated heterocyclic systems. The high surface area of the catalyst not only reduces the reaction time but also enhances the yield of the chromene derivative due to its very large number of reaction sites. The catalyst shows the most remarkable activity during the formation of the pyrano[2,3-*c*]chromene derivative, as it stabilizes the 1,2-dicarbonyl intermediate efficiently.

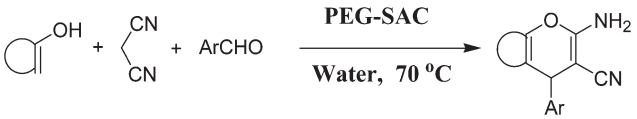
To assess the capability and efficiency of our catalyst with respect to the reported catalysts for the preparation of benzo[*f*]-chromene, the results have been tabulated in Table 3. In comparison with other catalysts employed for the synthesis of benzo[*f*]chromene from 4-methoxybenzaldehyde, 2-naphthol and malononitrile, PEG–SAC shows a much higher catalytic activity in terms of very short reaction times and mild conditions (Table 3).

A heterogeneous catalyst is more interesting when it can be easily recovered and re-used. For this purpose, the reusability of the catalyst was tested for the reaction of 3-nitrobenzaldehdye, malononitrile and β-naphthol at 70 °C. After completion of the reaction, water was removed under reduced pressure from the reaction mixture and acetone was added to it for the dissolution of the crude product. The catalyst was filtered, washed with acetone and dried under vacuum at 100 °C for 12 h. As shown in Fig. 10, the catalyst was recovered in excellent yield (90–95%) after each new reaction. This recycled catalyst was used for the synthesis of pyran derivatives applying the developed protocol. The catalyst was found to be reusable for at least 5 cycles without considerable loss of activity (run 1: 95% yield; run 5: 92% yield of the product). Furthermore, the loading amount of the five times used catalyst was determined by elemental analysis, and it was found that 1.31 mmol g^{-1} of SO_3H was still grafted onto the surface of the catalyst compared to 1.48 mmol g^{-1} for the fresh catalyst. These results indicate that the catalyst is very stable and can endure these reaction conditions.

Conclusions

In summary, we have developed a green, sustainable and economic protocol for the one-pot three-component synthesis of

Table 2 Scope of hydroxy compounds and aldehydes for pyran derivative synthesis



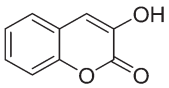
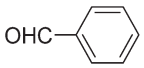
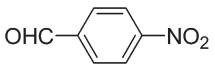
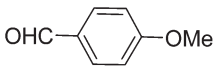
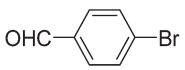
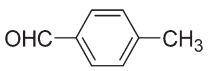
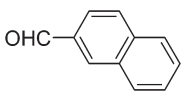
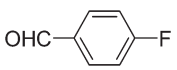
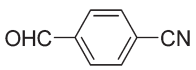
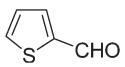
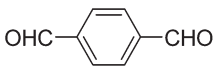
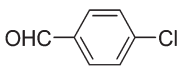
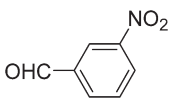
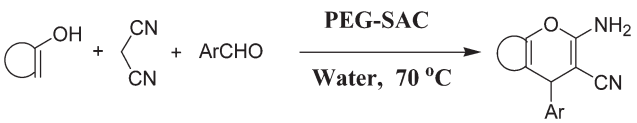
Entry	Hydroxy compound	Ar–CHO	Time	Product[a]	Yield (%)[b]	Reference
1			2.0 h	**2a**	90	27*a*
2			2.0 h	**2b**	87	27*a*
3			1.5 h	**2c**	95	27*a*
4			1.5 h	**2d**	93	27*a*
5			1.5 h	**2e**	92	27*a*
6			1.5 h	**2f**	94	27*a*
7			2.0 h	**2g**	90	27*a*
8			1.5 h	**2h**	92	27*a*
9			2.0 h	**2i**	90	27*a*
10			2.0 h	**2j**	83	27*a*
11			1.5 h	**2k**	91	—
12			2.0 h	**2l**	85	—

Table 2 (*Continued*)



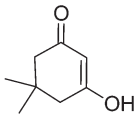
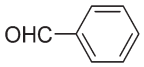
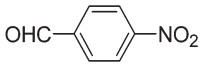
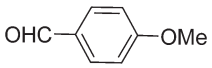
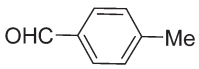
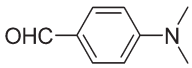
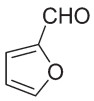
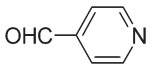
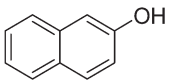
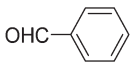
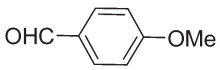
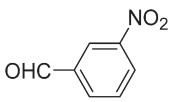
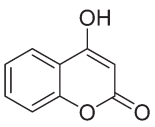
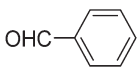
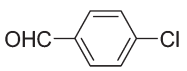
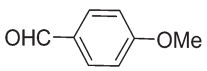
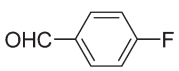
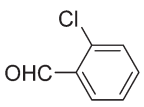
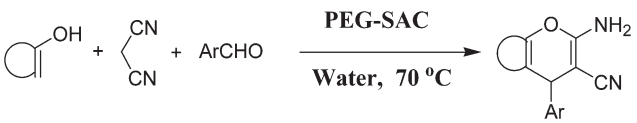
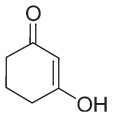
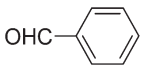
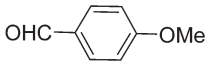
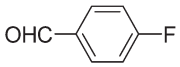
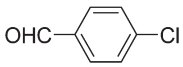
Entry	Hydroxy compound	Ar–CHO	Time	Product[a]	Yield (%)[b]	Reference
13			15 min	**3a**	91	27*e*
14			10 min	**3b**	95	27*e*
15			15 min	**3c**	89	27*e*
16			14 min	**3d**	88	27*e*
17			14 min	**3e**	85	27*e*
18			14 min	**3f**	86	27*e*
19			15 min	**3g**	84	27*e*
20			16 min	**4a**	90	26*a*
21			16 min	**4b**	92	26*a*
22			12 min	**4c**	95	26*a*
23			15 min	**5a**	93	26*f*
24			10 min	**5b**	89	26*f*
25			15 min	**5c**	96	26*f*
26			12 min	**5d**	95	26*f*
27			12 min	**5e**	95	26*f*

Table 2 (*Continued*)



Entry	Hydroxy compound	Ar–CHO	Time	Product[a]	Yield (%)[b]	Reference
28			16 min	**6a**	92	26*f*
29			16 min	**6b**	90	26*f*
30			14 min	**6c**	95	26*f*
31			14 min	**6d**	95	26*f*

[a] Products were characterized by ^{1}H NMR, ^{13}C NMR, IR, and HR-MS data. [b] Isolated yield of the pure product.

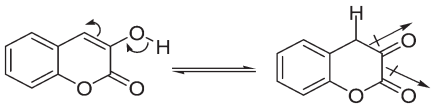


Fig. 8 3-Hydroxycoumarin and the 1,2-dicarbonyl intermediate.

a combinatorial library of diversified pyran fused heterocyclic molecules with the aid of a SO_3H-bearing carbonaceous solid catalyst (PEG–SAC) developed by us for the first time. The highly active, stable solid acid catalyst was prepared by carbonization of PEG–SO_3H at 200 °C. The catalysts are composed of polycyclic aromatic carbons with SO_3H groups. The very high surface area and acid density of the catalyst will surely grab the attention of the biological and pharmaceutical industries as a very good replacement for the homogeneous acid catalysts used in the synthesis of organic molecules in the future.

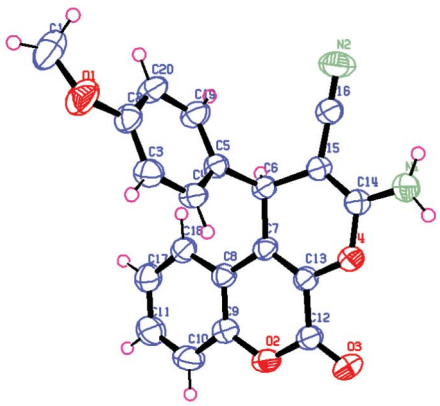
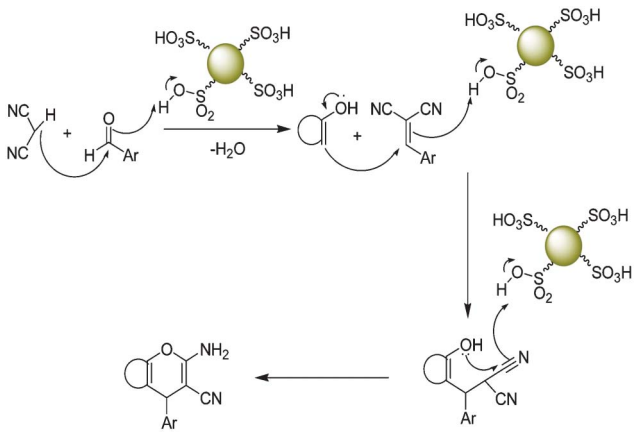


Fig. 9 X-ray crystal structure of **2c** (CCDC 818608).



Scheme 2 A plausible mechanism for the PEG–SAC catalyzed three-component coupling reaction for the synthesis of pyran derivatives.

Table 3 Comparison of different catalysts for the one-pot three-component reaction of 4-methoxy-benzaldehyde, 2-naphthol and malononitrile

Entry	Catalyst	*T*/°C	Time	Yield (%)	Reference
1	$H_{14}[NaP_5W_{30}O_{110}]$	100	3 h	92	26*a*
2	Na_2HPO_4	120	1 h	88	26*b*
3	[bmim]OH	100	100 min	80	26*c*
4	CAN	120	30 min	89	26*d*
5	PEG–SAC	70	20 min	90	This work

Experimental

Preparation of the solid acid catalyst from polyethylene glycol

At 0 °C, chlorosulfonic acid (10 mmol) was added to a solution of PEG-6000 (1 mmol) in CH_2Cl_2 (10 ml), and the resulting solution

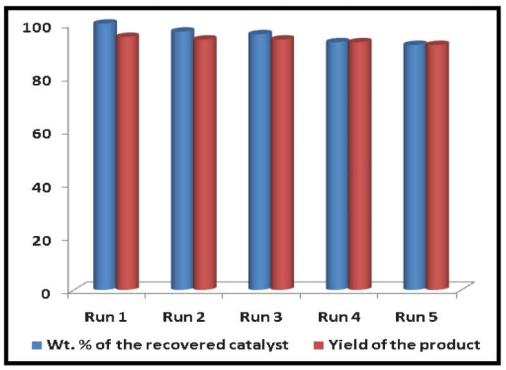


Fig. 10 Reusability study and recovery of the catalyst.

was stirred at room temperature overnight. Then, the solution was concentrated under vacuum, and ether was added to it. The resulting precipitate was filtered and washed with ether three times to afford PEG–OSO_3H as a gummy solid.

The carbon based solid acid was prepared by hydrothermal treatment of PEG–OSO_3H. Carbon and SO_3H precursor PEG–OSO_3H (6 g) were heated at 200 °C in a 100 ml Teflon hydrothermal reactor, the conditions were maintained for 6 h at the autogenous pressure and then, on cooling to room temperature, a black amorphous solid was formed. The mesoporous carbonaceous PEG derived solid acid catalyst was denoted as PEG–SAC.

General procedure for the synthesis of 4*H*-pyran derivatives

A mixture of an aldehyde (1.1 mmol), malononitrile (1.1 mmol), a carbonyl compound possessing a reactive α-methylene group (1.0 mmol), and PEG–SAC (0.080 g) in water (5 ml) was stirred at 70 °C for a required period of time (TLC). After completion of the reaction, water was removed under reduced pressure from the reaction mixture and acetone was added to it for the dissolution of the crude product. The acetone solution was filtered to remove the catalyst. A solid was obtained upon concentration of the acetone solution of the crude product extract. The product thus was collected by filtration, washed with chilled aqueous ethanol and finally recrystallized from ethanol to get the pure product.

Selected spectral data

3-Amino-1-(4-chloro-phenyl)-5-oxo-1,5-dihydro-pyrano[2,3-*c*]chromene-2-carbonitrile (2k)

Characteristics: Yellow crystalline solid; mp: 218 °C; IR (KBr): 2191, 1729, 1650, 1594 cm^{-1}; ^1H NMR (300 MHz, DMSO-d_6; Me_4Si): δ 4.84 (s, 1H, CH), 6.68 (s, 2H, NH_2) 7.05–7.65 (m, 8H, Ar); ^{13}C NMR (75 MHz, DMSO-d_6): δ 37.6, 57.2, 116.2, 116.4, 118.8, 124.4, 125.9, 128.8, 130.0, 132.7, 133.9, 140.6, 150.1, 153.8, 158.7; HR-MS calcd. for $C_{19}H_{11}ClN_2O_3$ ($[M + H]^+$): 350.0458; found: 350.0451.

3-Amino-1-(3-nitro-phenyl)-5-oxo-1,5-dihydro-pyrano[2,3-c]chromene-2-carbonitrile (2l)

Characteristics: Yellow crystalline solid; mp: 237 °C; IR (KBr): 2190, 1720, 1658, 1592, 1401 cm^{-1}.

^1H NMR (300 MHz, DMSO-d_6; Me_4Si): δ 5.34 (s, 1H, CH), 7.18–8.29 (m, 10H, Ar, NH_2); ^{13}C NMR (75 MHz, DMSO-d_6; Me_4Si): δ 37.1, 56.1, 116.3, 119.0, 122.1, 124.7, 125.3, 130.3, 133.9, 134.6, 144.9, 148.1, 150.2, 153.9, 159.2; HRMS calcd. for $C_{19}H_{11}N_3O_5$ ($[M + H]^+$): 361.0699; found: 361.0692.

Acknowledgements

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References

1 Y. R. Leshkov, J. N. Chheda and J. A. Dumesic, *Science*, 2006, **312**, 1933.
2 (*a*) M. Bicker, J. Hirth and H. Vogel, *Green Chem.*, 2003, **5**, 280; (*b*) Y. R. Leshkov, C. J. Barrett, Z. Y. Liu and J. A. Dumesic, *Nature*, 2007, **447**, 982.
3 J. N. Chheda, Y. Roman-Leshkov and J. A. Dumesic, *Green Chem.*, 2007, **9**, 342.
4 V. V. Ordomsky, J. van der Schaaf, J. C. Schouten and T. A. Nijhuis, *J. Catal.*, 2012, **287**, 68.
5 (*a*) Z. H. Zhang, B. Liu and Z. B. Zhao, *Carbohydr. Polym.*, 2012, **88**, 891; (*b*) Y. Yang, C. W. Hu and M. M. Abu-Omar, *Green Chem.*, 2012, **14**, 509; (*c*) B. R. Caes and R. T. Raines, *ChemSusChem*, 2011, **4**, 353; (*d*) B. Kim, J. Jeong, D. Lee, S. Kim, H. J. Yoon, Y. S. Lee and J. K. Cho, *Green Chem.*, 2011, **13**, 1503.
6 X. H. Qi, M. Watanabe, T. M. Aida and R. L. Smith, *Green Chem.*, 2008, **10**, 799.
7 (*a*) C. Carlini, M. Giuttari, A. M. R. Galletti, G. Sbrana, T. Armaroli and G. Busca, *Appl. Catal., A*, 1999, **183**, 295; (*b*) C. Carlini, P. Patrono, A. M. R. Galletti and G. Sbrana, *Appl. Catal., A*, 2004, **275**, 111.
8 M. Hara, T. Yoshida, A. Takagaki, T. Takata, J. N. Kondo, K. Domen and S. Hayashi, *Angew. Chem., Int. Ed.*, 2004, **43**, 2955.
9 M. Toda, A. Takagaki, M. Okamura, J. N. Kondo, K. Domen, S. Hayashi and M. Hara, *Nature*, 2005, **438**, 178.
10 (*a*) A. Corma, *Curr. Opin. Solid State Mater. Sci.*, 1997, **2**, 63; (*b*) G. Busca, *Catal. Today*, 1998, **41**, 191; (*c*) A. Corma and H. Garcia, *Catal. Today*, 1997, **38**, 257; (*d*) S. K. Sikdar and S. G. Howell, *J. Clean. Prod.*, 1998, **6**, 253.
11 (*a*) R. A. Sheldon and R. S. Downing, *Appl. Catal., A*, 1999, **189**, 163; (*b*) Ch. Ramesh, J. Banerjee, R. Pal and B. Das, *Adv. Synth. Catal.*, 2003, **345**, 557.
12 (*a*) M. Okamura, A. Takagaki, M. Toda, J. N. Kondo, T. Tatsumi, K. Domen, M. Hara and S. Hayashi, *Chem. Mater.*, 2006, **18**, 3039; (*b*) K. Fukuhara, K. Nakajima, M. Kitano, H. Kato, S. Hayashi and M. Hara, *Chem-SusChem*, 2011, **4**, 778; (*c*) M. Hara, *ChemSusChem*, 2009, **2**, 129.
13 (*a*) Y. Tang, J. Oppenheimer, Z. Song, L. You, X. Zhang and R. P. Hsung, *Tetrahedron*, 2006, **62**, 10785; (*b*) T. C. McKee, R. W. Fuller, C. D. Covington, J. H. Cardellina, R. J. Gulakowski, B. L. Krepps, J. B. McMahon and M. R. Boyd, *J. Nat. Prod.*, 1996, **59**, 754; (*c*) T. C. McKee, C. D. Covington, R. W. Fuller, H. R. Bokesch, S. Young, J. H. Cardellina, M. R. Kadushin, D. D. Soejarto, P. F. Stevens, G. M. Cragg and M. R. Boyd, *J. Nat. Prod.*, 1998, **61**, 1252; (*d*) E. J. Jung, B. H. Park and Y. R. Lee, *Green Chem.*, 2010, **12**, 2003.

14 (*a*) S. Kumar, D. Hernandez, B. Hoa, Y. Lee, J. S. Yang and A. McCurdy, *Org. Lett.*, 2008, **10**, 3761; (*b*) M. Rawat, V. Prutyanov and W. D. Wulff, *J. Am. Chem. Soc.*, 2006, **128**, 11044; (*c*) O. A. Fedorova, F. Maure, A. V. Chebunkova, Y. P. Strokach, T. M. Valova, L. G. Kuzmina, J. A. K. Howard, M. Wenzel, K. Gloe, V. Lokshin and A. Samat, *J. Phys. Org. Chem.*, 2007, **20**, 469; (*d*) S. Delbaer, J.-C. Micheau and G. Vermeersch, *J. Org. Chem.*, 2003, **68**, 8968.

15 A. Kumar, R. A. Maurya, S. A. Sharma, P. Ahmad, A. B. Singh, G. Bhatia and A. K. Srivastava, *Bioorg. Med. Chem. Lett.*, 2009, **19**, 6447.

16 T. Raj, R. K. Bhatia, A. Kapur, M. Sharma, A. K. Saxena and M. P. S. Ishar, *Eur. J. Med. Chem.*, 2010, **45**, 790.

17 F. M. Abdelrazek, P. Metz and E. K. Farrag, *Arch. Pharm.*, 2004, **337**, 482.

18 T. Symeonidis, K. C. Fylaktakidou, D. J. Hadjipavlou-Litina and K. E. Litinas, *Eur. J. Med. Chem.*, 2009, **44**, 5012.

19 T. Raj, R. K. Bhatia, R. K. Sharma, V. Gupta, D. Sharma and M. P. S. Ishara, *Eur. J. Med. Chem.*, 2009, **44**, 3209.

20 (*a*) M. M. Khafagy, A. H. F. A. El-Wahas, F. A. Eid and A. M. El-Agrody, *Farmaco*, 2002, **57**, 715; (*b*) W. P. Smith, L. S. Sollis, D. P. Howes, C. P. Cherry, D. I. Starkey and N. K. Cobley, *J. Med. Chem.*, 1998, **41**, 787; (*c*) A. G. Martinez and L. J. Marco, *Bioorg. Med. Chem. Lett.*, 1997, **7**, 3165; (*d*) K. Hiramoto, A. Nasuhara, K. Michiloshi, T. Kato and K. Kikugawa, *Mutat. Res., Genet. Toxicol. Environ. Mutagen.*, 1997, **395**, 47.

21 (*a*) C. J. Li and Y. L. Li, *U.S. Patent Appl. Publ. U.S. 2005222246 A1 20*, 051, 006, 2005; (*b*) M. Ough, A. Lewis, E. A. Bey, J. Gao, J. M. Ritchie, W. Bornmann, D. A. Boothman, L. W. Oberley and J. J. Cullen, *Cancer Biol. Ther.*, 2005, **4**, 95.

22 (*a*) V. F. De Andrade-Neto, M. O. F. Goulart, J. F. Da Silva Filho, M. J. Da Silva, M. D. C. F. R. Pinto, A. V. Pinto, M. G. Zalis, L. H. Carvalho and A. U. Krettli, *Bioorg. Med. Chem. Lett.*, 2004, **14**, 1145; (*b*) P. S. Elisa, E. B. Ana, A. G. Ravelo, D. J. Yapu and A. G. Turba, *Chem. Biodiversity*, 2005, **2**, 264.

23 G. P. Ellis, A. Weissberger and E. C. Taylor, John Wiley: New York, NY, 1977, 11, Chapter 11.

24 E. A. Hafez, M. H. Elnagdi, A. G. A. Elagemey and F. M. A. A. El-Taweel, *Heterocycles*, 1987, **26**, 903.

25 (*a*) T. S. Jin, A. Q. Wang, X. Wang, J. S. Zhang and T. S. Li, *Synlett*, 2004, 871; (*b*) D. Q. Shi, S. Zhang, Q. Y. Zhuang, S. J. Tu and H. W. Hu, *Chin. J. Org. Chem.*, 2003, **23**, 877; (*c*) L. M. Wang, J. H. Shao, H. Tian, Y. H. Wang and B. Liu, *J. Fluorine Chem.*, 2006, **127**, 97; (*d*) S. Balalaie, M. Bararjanian, A. M. Amani and B. Movassagh, *Synlett*, 2006, 263; (*e*) Y. Peng and G. Song, *Catal. Commun.*, 2007, **8**, 111; (*f*) D. Kumar, V. B. Reddy, Sh. Sharadb, U. Dube and S. Kapur, *Eur. J. Med. Chem.*, 2009, **44**, 3805; (*g*) S. Banerjee, A. Horn, H. Khatri and G. Sered, *Tetrahedron Lett.*, 2011, **52**, 1878; (*h*) A. Hasaninejada, M. Shekouhy, N. Golzar, A. Zare and M. M. Doroodmand, *Appl. Catal., A*, 2011, **402**, 11.

26 (*a*) M. M. Heravi, K. Bakhtiari, V. Zadsirjan, F. F. Bamoharramb and O. M. Heravi, *Bioorg. Med. Chem. Lett.*, 2007, **17**, 4262; (*b*) X.-Y. Meng, H.-J. Wang, C.-P. Wang and Z.-H. Zhang, *Synth. Commun.*, 2011, **41**, 3477; (*c*) K. Gong, H.-L. Wang, D. Fang and Z.-L. Liu, *Catal. Commun.*, 2008, **9**, 650; (*d*) A.-Q. Zhang, M. Zhang, H.-H. Chen, J. Chen and H.-Y. Chen, *Synth. Commun.*, 2007, **37**, 231; (*e*) A. Kumar, S. Sharma, R. A. Maurya and J. Sarkar, *J. Comb. Chem.*, 2010, **12**, 20; (*f*) G. Zhang, Y. Zhang, J. Yan, R. Chen, S. Wang, Y. Ma and R. Wang, *J. Org. Chem.*, 2012, **77**, 878.

27 (*a*) S. Paul, P. Bhattacharyya and A. R. Das, *Tetrahedron Lett.*, 2011, **52**, 4636; (*b*) S. Paul and A. R. Das, *Tetrahedron Lett.*, 2012, **53**, 2206; (*c*) S. Paul and A. R. Das, *Catal. Sci. Technol.*, 2012, **2**, 1130; (*d*) P. P. Ghosh, G. Pal, S. Paul and A. R. Das, *Green Chem.*, 2012, **14**, 2691; (*e*) P. P. Ghosh and A. R. Das, *J. Org. Chem.*, 2013, **78**, 6170.

28 M. Rueping, E. Sugiono and E. Merino, *Chem. Eur. J.*, 2008, **14**, 6329.

