NaHSO₄-SiO₂ as an efficient and chemoselective catalyst, for the synthesis of acylal from aldehydes under, solvent-free conditions

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Abstract

Background: Structurally diverse aldehydes are successfully converted into acylals (1,1-diacetates) with acetic anhydride using NaHSO₄-SiO₂ as a mild, convenient and inexpensive catalyst under solvent-free conditions. The noteworthy features of the present system are shorter reaction times, and mild and solvent-free conditions. Furthermore, it offers chemoselective protection of aldehydes.

Results: Both aromatic and aliphatic aldehydes reacts smoothly with acetic anhydride in presence of silica supported sodium hydrogen sulphate to afford the corresponding 1,1-diacetates in good to excellent yields. We studied competitive reactions for the acylation of aldehydes in the presence of ketones using silica supported sodium hydrogen sulphate as a catalyst. Using this catalytic system, the highly selective conversion of an aldehyde in the presence of ketone was observed.

Conclusions: NaHSO₄-SiO₂ is a chemoselective and highly efficient catalyst for acylal formation from aldehydes. The advantages of this methodology over the reported methods is the availability of the starting materials, simplicity of acylation procedure, a clean work-up, a short reaction time, high yields and reusability.

Keywords: Acylals, Aldehydes, Solvent-free conditions, Reusable catalyst, NaHSO₄-SiO₂

Introduction

The concept of green chemistry has been playing an important role in recent years for meeting the fundamental scientific challenges of protecting the living environment. One of the thrust areas for achieving this target is to explore alternative reaction conditions and reaction media to accomplish the desired chemical transformation with almost negligible by products and waste generation as well as elimination of the use of volatile and toxic organic solvents. It is therefore of utmost importance to evolve a simple and effective methodology for the different organic transformations that cover the concept of green chemistry.

During the multi-step synthesis, the protection of the carbonyl group is widely achieved by the formation of acylal (1,1-diacetate) [1]. These substrates are important because of their application as precursors for the synthesis of 1-acetoxy dienes, valuable synthetic intermediates for Diels-Alder cycloaddition reactions [2]. The relative acid stability of acylal is another interesting feature in the field of protection and deprotection chemistry. General, acylals are prepared by treating aldehydes with acetic anhydride in the presence of protonic acids [3], Lewis acids [4], heteropoly acids, or clays [5]. Some examples of the reagents and catalysts that have been developed for this purpose include LiOTf [6], ceric ammonium nitrate [7], InCl₃ [8], H₂NSO₃H [9], LiBF₄ [10], H₂SO₄ [11], PCl₃ [12], NBS [13], I₂ [14], TMSCl-NaI [15], FeCl₃ [16], Fe₂(SO₄)₃·xH₂O [17], Zn(BF₄)₂ [18], Cu(BF₄)₂·xH₂O [19], H₂SO₄-SiO₂ [20], Silica sulphate [21]. Although some of these methods have convenient protocols with good to high yields, the majority of these methods suffer at least from one of the following disadvantages: reaction under oxidizing conditions, prolonged reaction time, high temperatures, use of moisture-sensitive and expensive catalysts, use of solvents, strong conditions, difficulty in scaling up, etc. Therefore, development of catalysts working under mild reaction conditions is desirable.
In recent years, Heterogeneous catalysts have gained importance in several organic transformations due to their interesting reactivity as well as for economic and environmental reasons. In continuation of our research work to develop new methodologies for organic transformations, [22-25] we observed that silica supported sodium hydrogen sulphate is a highly efficient catalyst for the synthesis of 1,1-diacetates (acylals) from the reaction of aldehydes with acetic anhydride under solvent-free conditions. The catalyst NaHSO₄·SiO₂ can easily be prepared [26] from the readily available NaHSO₄ and silica gel (230–400 mesh) and these are inexpensive and nontoxic as the reaction is heterogeneous in nature, so the catalyst can easily removed by simple filtration.

Results and discussions
Herein we wish to report an extremely convenient, mild, and highly chemoselective procedure for the conversion of aldehydes to the corresponding acylals in the presence of acetic anhydride and catalytic amount of NaHSO₄·SiO₂ under solvent-free conditions (Scheme 1).

Initially we attempted the acylation reaction of benzaldehyde with acetic anhydride in the absence of NaHSO₄·SiO₂. The reaction was sluggish and no corresponding 1,1-diacetate was formed even after 24 h. However in the presence of NaHSO₄·SiO₂ (25%/wt) the reaction progressed smoothly with benzaldehyde at room temperature to afforded the corresponding 1,1-diacetate with excellent yield. Therefore, we employed the above conditions for the conversion of various aldehydes to the corresponding acylals under solvent-free conditions (Table 1).

The results listed in Table 1 show that both aromatic and aliphatic aldehydes reacts smoothly with acetic anhydride to afford the corresponding 1,1-diacetates in good to excellent yields. Aromatic aldehydes possessing electron-withdrawing substituents, halogens and electron-releasing substituents on the aromatic ring afforded the corresponding acylals in Excellent yields and in short reaction times. Nitro substituted aldehydes are also produced good yields, but the powerful electron-releasing substituent OMe slightly decreased the yield and increased the reaction time. In order to show the high selectivity of the method, we studied competitive reactions for the acylation of aldehydes in the presence of ketones using silica supported

![Scheme 1 Synthesis of 1,1 diacetates from aldehydes.](image)

Table 1 Formation of acylals using NaHSO₄·SiO₂ under solvent-free conditions at rt

| Entry | Substrate | Product | Time (min) | Yield (%) | M.p. °C (Lit) |
|-------|-----------|---------|------------|-----------|---------------|
| 1     |           |         | 15         | 94        | 45-46 (44-45) |
| 2     |           |         | 20         | 88        | 82-84 (82-83) |
| 3     |           |         | 20         | 90        | 83-85 (84)    |
| 4     |           |         | 15         | 91        | 81-83 (81-82) |
| 5     |           |         | 15         | 89        | 69-71 (68-70) |
| 6     |           |         | 25         | 84        | 64-65 (65-66) |
| 7     |           |         | 20         | 90        | 86-88 (88)    |
| 8     |           |         | 15         | 94        | 124-126 (125) |
| 9     |           |         | 20         | 85        | 50-52 (52-53) |
| 10    |           |         | 15         | 87        | Oil (27)      |

*aReaction conditions: benzaldehyde (1 mmol), Ac₂O (4 mmol) and NaHSO₄·SiO₂ (25%/wt) were stirred at RT under solvent-free conditions, b isolated yields.
sodium hydrogen sulphate as a catalyst. Using this catalytic system, the highly selective conversion of an aldehyde in the presence of ketone was observed (Scheme 2).

The recycling of the catalyst is one of the most advantages of our method. For the reaction of benzaldehyde with acetic anhydride good yield was observed when NaHSO₄-SiO₂ was reused even after three times recycling (Table 2).

**Conclusion**

In conclusion, NaHSO₄-SiO₂ is a chemoselective and highly efficient catalyst for acylal formation from aldehydes. The advantages of this methodology over the reported methods is the availability of the starting materials, simplicity of acylation procedure, a clean work-up, a short reaction time, and high yields. In addition, this reagent acts as a heterogeneous catalyst that could be removed from the reaction mixture by simple filtration and compliance with the green chemistry protocols.

**Experimental section**

All ¹H NMR spectra were recorded on 400 MHz Varian FT-NMR spectrometers. All chemical shifts are given as δ value with reference to Tetra methyl silane (TMS) as an internal standard. Melting points were taken in open capillaries. The IR spectra were recorded on a PerkinElmer 257 spectrometer using KBr discs. Products were purified by flash chromatography on 100–200 mesh silica gel. The chemicals and solvents were purchased from commercial suppliers either from Aldrich, Spectrochem and they were used without purification prior to use. The obtained products were characterized from their spectral (¹H-NMR, IR) and comparison to authentic samples.

**Table 2 The synthesis of acylal from benzaldehyde and acetic anhydride in the presence of recycled NaHSO₄-SiO₂**

| Entry | Cycle          | Time(min) | Yield(%)a |
|-------|----------------|-----------|-----------|
| 1     | 1º use         | 15        | 94        |
| 2     | 2º use         | 20        | 89        |
| 3     | 3º use         | 30        | 77        |

aIsolated yield.

Preparation of silica supported sodium hydrogen sulphate

To a solution of 4.14 g (0.03 mol) of NaHSO₄·H₂O in 20 mL of water in a 100 mL beaker containing a stir bar was added 10 g of SiO₂ (column chromatographic grade, 230–400 mesh). The mixture was stirred for 15 min and then gently heated on a hot plate, with intermittent swirling, until a free-flowing white solid was obtained. The catalyst was further dried by placing the beaker in an oven maintained at 120 °C for at least 48 h prior to use.

General experimental procedure

A mixture of aldehyde (2 mmol), freshly distilled AC₂O (8 mmol) and NaHSO₄-SiO₂ (25%/wt) was stirred at room temperature and the progress of the reaction was monitored by TLC Hexane:EtOAc (9:1) after completion of the reaction, the reaction mixture was treated by dilution with EtOAc and the catalyst was removed by filtration. Obtained filtrate was washed with saturated NaHCO₃ solution and then dried over Na₂SO₄. The solvent was evaporated under reduced pressure to get the crude product was purified by column chromatography to give pure acylal compound.

Selected spectral data of the products

**Phenylmethylene diacetate** (Table 1, Entry-1)

1H NMR (CDCl₃): 87.63 (s, 1 H), 7.53-7.50 (m, 2 H), 7.40-7.36 (m, 3 H), 2.11 (s, 6 H); IR (KBr, cm⁻¹): 3068, 1756, 1504, 1440, 1010; Anal. Calcd. For C₁₁H₁₂O₄: C, 60.50; H, 5.92. Found: C, 60.98; H, 5.66.

**4-chlorophenyl methylene diacetate** (Table 1, Entry-2)

1H NMR (CDCl₃): 87.63 (s, 1 H), 7.46 (d, J = 8.4 Hz, 2 H), 7.38 (d, J = 8.4 Hz, 2 H), 2.12 (s, 6 H); IR (KBr, cm⁻¹): 3019, 2924, 1769, 1745, 1492, 1373, 1241, 1041, 1006; Anal. Calcd. For C₁₁H₁₂ClO₄: C, 54.45; H, 4.57. Found: C, 54.36; H, 4.68.

**4-methoxyphenyl methylene diacetate** (Table 1, Entry-6)

1H NMR (CDCl₃): 87.62 (s, 1 H), 7.45 (d, J = 8.8 Hz, 2 H), 6.92 (d, J = 8.8 Hz, 2 H), 3.82 (s, 3 H), 2.11 (s, 6 H); IR (KBr, cm⁻¹): 3014, 2937, 1749, 1618, 1378, 1244, 1207, 1018, 936; Anal. Calcd. For C₁₂H₁₄O₅: C, 60.50; H, 5.92. Found: C, 60.98; H, 5.66.
Competing interests
The authors declare that they have no competing interests.

Authors’ contributions
RKK the main author completed this work under the guidance of VVSP as the corresponding author, and SRB as the coauthor. All authors read and approved the final manuscript.

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References
1. Greene TW, Wuts PGM: Protective groups in organic synthesis. 3rd edition. New York: John Wiley; 1999:306.
2. Snider BL, Armin SG: An Improved Synthesis of 1α, 3β-Dihydroxycholesta-5, 7-Diene. Synth Commun 1978, 8:117–125.
3. Tomita M, Kikutchi T, Beruko K, Hori T, Inubushi Y: Studies on Pilocerine and Related Compounds. III. Synthesis of 2, 2’, 3-Trimethylxyphenyl Ether-4’, 5- and 4’, 6-dicarboxaldehyde. Chem Pharm Bull 1963, 11:1484–1490.
4. Man EH, Sanderson JJ, Hauser CR: Boron Fluoride Catalyzed Addition of Aliphatic Anhydrides to Aldehydes. J Am Chem Soc 1950, 72:847–847.
5. Kumar R, Tiwari P, Maulik PR, Misra AKJ: HClO4-SiO2 catalyzed chemoselective conversion of aldehydes to gem diacetates. mol Catal A Chem 2006, 247:27–30.
6. Karimi B, Maleki J: Lithium Trifluoromethanesulfonate (LiOTf) as a Recyclable Catalyst for Highly Efficient Acetylation of Alcohols and Diacetylation of Aldehydes under Mild and Neutral Reaction Conditions. J Org Chem 2003, 68:4951–4954.
7. Roy SC, Baneejee S: A Mild and Efficient Method for the Chemoselective Synthesis of Acylals from aldehydes and their Deprotections Catalysed by Ceric Ammonium Nitrate. Synlett 2002, 10:1677–1678.
8. Yadav JS, Reddy BVS, Sirivinas C: Indium tri chloride catalyzed chemoselective conversion of aldehydes to gem diacetates. Synth Commun 2002, 32:149–215.
9. Jin TS, Sun G, Li YW, Li TS: An efficient and convenient procedure for the preparation of 1,1-diacetates from aldehydes catalyzed by H2SO4-H2O. Green Chem 2002, 4:255–256.
10. Sumida N, Nishioka K, Sato T: Conversion of Aldehydes into Geminal Dicarboxylates (Acylals) Catalyzed by Lithium Tetrafluoroborate. Synlett 2001, 12:1921–1922.
11. Gregory MJ: Evidence for a cyclic A6,1 mechanism in the hydrolysis of benzylidene dicetates. J Chem Soc 1970, B:2101–2107.
12. Michie JK, Miller JA: Phosphorus Trichloride as Catalyst in the Preparation of 1,1-Diacetates from Aldehydes. Synthesis 1981, 10:824–825.
13. Karimi B, Seradj H, Ebrahimian Ro: Mild and Efficient Conversion of Aldehydes to 1,1-Diacetates Catalyzed with N-Bromosuccinimide (NBS). Synlett 2000, 8:623–624.
14. Deka N, Kalita DJ, Borah R, Samta JC: Iodine as Acetylation Catalyst in the Preparation of 1,1-Diacetates from Aldehydes. Org Chem 1997, 62:1563–1564.
15. Deka N, Borah R, Kalita DJ, Samta JC: Synthesis of 1,1-Diacetates from Aldehydes using Trimethylchlorosilane and Sodium Iodide as Catalyst. J Chem Res 1998, 0:94–95.
16. Kochhar KS, Ball BS, Destjande RP, Rajahyakshma SN, Pinnick HW: Protecting groups in organic synthesis. Part 8. Conversion of aldehydes into geminal dicetates. J Org Chem 1983, 48:1765–1767.
17. Zhang X, Li L, Zhang G: An efficient and green procedure for the preparation of acylals from aldehydes catalyzed by Fe3(SO4)2·4H2O. Green Chem 2003, 5:656–648.

18. Ranu BC, Dutta J, Das A: Zinc Tetrafluoroborate-Catalyzed Efficient Conversion of Aldehydes to Geminal Diacetates and Cyanacacetates. Chem Lett 2003, 32:366–367.
19. Chakraborti AK, Thilagavathi R, Kumar R: Copper(ll) Tetrafluoroborate-Catalyzed Formation of Aldehyde-1,1-diacetates. Synthesis 2004, 6:831–833.
20. Pourmousavi SA, Zinati Z: H2SO4-silica as an efficient and chemoselective catalyst for the synthesis of acylal from aldehydes under solvent-free conditions. Turk J Chem 2009, 33:385–392.
21. Kumar RK, Satyanarayana PVW, Reddy SB: Simple and Efficient Method for Tetrahydropryanolysis of Alcohols and Phenols by Using silica supported Sodium Hydrogen Sulphate as a Catalyst. Asian J Chem 2012, 24:3767–3788.
22. Jin TS, Zhao Y, Gu SQ, Liu LB, Li TS: An efficient procedure for the synthesis of 1,1-diacetates from aldehydes with acetic anhydride catalyzed by silica sulfate. Indian J Chem 45B 2006, 4:1054–1056.
23. Kumar RK, Satyanarayana PVW, Reddy SB: Simple and Efficient Method for Deprotection of Tetrahydropryanolyl Ethers by Using silica Supported Sodium Hydrogen Sulphate. Eur J Chem 2012, 30:1189–1191.
24. Kumar RK, Satyanarayana PVW, Reddy SB: Direct and practical synthesis of 2-Arylbenzoxazoles promoted by silica supported hydrogen sulphate. Der Pharma Chemica 2012, 4(2):761–766.
25. Kumar RK, Satyanarayana PVW, Reddy SB: NaH2SO4·SiO2 promoted synthesis of Benzimidazole derivatives. Arch Appl Sci Res 2012, 4(3):1517–1521.
26. Breton GW: Selective Monocetylisation of Unsymmetrical Diols Catalysed by silica Gel-Supported Sodium Hydrogen Sulphate. J Org Chem 1997, 62:9852–9854.
27. Heravi MM, Bakhtiari K, Taheri S, Oskooie HA: KHSO4: a catalyst for the chemo-selective preparation of 1,1-diacetates from aldehydes under solvent-free conditions. Green Chem 2005, 7:867–869.
28. Hajipour AR, Khazdooz L, Rutho AE: Brønsted acidic liquid as an efficient catalyst for chemoselective synthesis of 1,1-diacetates under solvent-free conditions. Catal Commun 2008, 9:92–96.
29. Khan AT, Choudhury LH, Ghosh SJ: Silica supported per chloric acid (HClO4·SiO2): A highly efficient and reusable catalyst for geminal diacetylation of aldehydes under solvent-free conditions. Mol Catal A Chem 2006, 255:330.
30. Saini A, Kumar S, Sandhu JS: RuCl3·h2O: A New Efficient Catalyst for Facile Preparation of 1,1-Diacetates from Aldehydes. Synth Commun 2007, 38:106–113.

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