

Short communication

HClO₄–SiO₂ as a novel and recyclable catalyst for the one-pot synthesis of homoallylic amines

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Abstract

A facile and efficient one-pot synthesis of homoallylic amines using a variety of aromatic, heteroaromatic, aliphatic aldehydes, aromatic amines and allyltributylstannane in the presence of solid-supported perchloric acid (HClO₄–SiO₂) as a heterogeneous catalyst at room temperature. The present methodology offers several advantages such as excellent yields, simple procedure, shorter reaction times (2.5–3.0 h), milder conditions and the catalyst exhibited remarkable reusable activity.

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1. Introduction


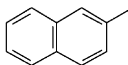


The stereoselective addition of allylmetal reagents to aldehydes and imines is one of the most important carbon–carbon bond formation reactions in organic synthesis [1]. There is significant current interest in amine synthesis, because of the growing importance of chiral amines as bases in asymmetric synthesis [2a] and as components of P–N ligand architectures [2b]. Generally, homoallylic amines are prepared either by the addition of organometallic reagents to imines [3] or by the nucleophilic addition of allylsilane or allyltin or allylborane or allylgermane reagents to imines in the presence of acid catalysts [4]. Lewis acids such as TiCl₄, BF₃·OEt₂, and PdCl₂(Ph₃P)₂ or PtCl₂(Ph₃P)₂ have been employed for this transformation [4,5]. However, many of these reagents are expensive, hygroscopic and difficult to handle especially on large scale. Furthermore, most of these reagents are deactivated or decomposed during aqueous workup and hence they cannot be recovered and recycled in subsequent runs. In order to circumvent some of these problems recently one-pot procedures have also been developed for this transformation [6–9]. During the course of our studies directed towards the development of practical, and environmentally friendly procedures for some important trans-

formations [10], we developed for the first time the applicability of a novel recyclable heterogeneous solid-supported perchloric acid (HClO₄–SiO₂) for efficient, convenient and facile synthesis of homoallylic amines by a one-pot reaction of various aldehydes, amines and allyltributylstannane at room temperature (Scheme 1). In addition, to the best of our knowledge, there are no reports on the use of solid-supported perchloric acid as a heterogeneous catalyst for this conversion. This fact has prompted us to investigate HClO₄–SiO₂ for the synthesis of homoallylic amines in a facile and practical manner.

Recently, HClO₄–SiO₂ have emerged as a powerful catalyst in various organic transformations, including acylation of alcohols [11], acylation of aldehydes [12], the Ferrier rearrangement [13], cleavage of benzylidene acetals [14], the Hantzsch condensation [15] and electrophilic substitution of indole with various aldehydes and ketones [16], also reported that perchlorates can give rise to explosive reactions when heated at high temperatures in the presence of combustible compounds [17]. Therefore, the potential hazard connected with their manufacture and use has prevented their extensive application in industrial processes [18], especially when large amounts of these compounds are involved. However, recently reported methods [19–23] indicate that low catalyst loading of HClO₄–SiO₂ can effectively brings about the organic transformations and can be operated even at 90 °C [19]. In view of its inherent properties like environmental compatibility, reusability, greater selectivity, operational simplicity,

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Table 1
HClO₄·SiO₂-catalyzed synthesis of homoallylic amines

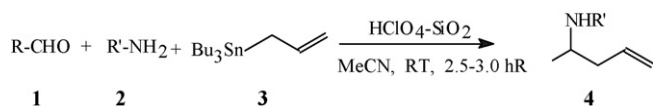
Entry	Aldehyde R-CHO ^a	Amine R'-NH ₂ ^b	Product R-CH(NHR')-CH ₂ -CH=CH ₂ ^c	Time (h)	Yield (%) ^d
a	Ph	Ph	4a	3.0	89
b	Ph	4-ClC ₆ H ₄	4b	2.5	90
c	Ph	4-FC ₆ H ₄	4c	2.5	87
d	Ph	4-MeC ₆ H ₄	4d	3.0	85
e	Ph	4-OMeC ₆ H ₄	4e	3.0	86
f	2-ClC ₆ H ₄	Ph	4f	2.5	88
g	4-ClC ₆ H ₄	Ph	4g	2.5	90
h	4-NO ₂ C ₆ H ₄	Ph	4h	3.0	90
i	4-NO ₂ C ₆ H ₄	4-OMeC ₆ H ₄	4i	3.0	78
j		Ph	4j	3.0	82
k	2-HOC ₆ H ₄	4-MeC ₆ H ₄	4k	3.0	81
l		Ph	4l	3.0	86
m	PhCH=CH	Ph	4m	3.0	84
n		Ph	4n	3.0	82
o		Ph	4o	3.0	83

^a Values of R.

^b Values of R'.

^c All products were characterized by ¹H NMR, ¹³C NMR, IR and mass spectroscopy.

^d Isolated and unoptimized yields.



Scheme 1.

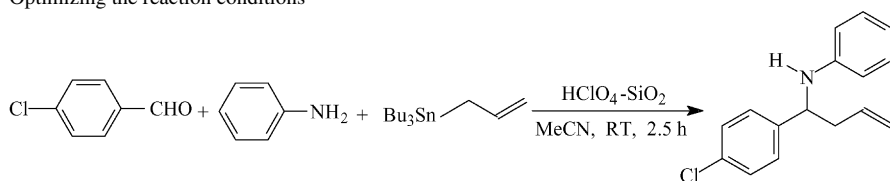
non corrosiveness, low cost and ease of isolation, we wish to describe our results on HClO₄-SiO₂ catalyzed three-component reactions of various aldehydes, amines and allyltributylstannane (Scheme 1).

2. Results and discussion

During the course of our study on the one-pot reaction of a variety of aryl or hetero or aliphatic aldehydes and amines (for

in situ formation of imines) and allyltributylstannane were used to produce a series of homoallylic amines (Table 1). The products were formed with in 2.5–3.0 h and in high yields. Aromatic, heteroaromatic and aliphatic aldehydes underwent the conversion smoothly. Upon screening with *p*-chlorobenzaldehyde, it was found that HClO₄ supported on silica gel with low loading (0.01 mmol) is an efficient catalyst to bring about this transformation at room temperature. Blank experiments have shown that the silica gel alone cannot bring about this transformation. In addition, only 0.01 mmol of HClO₄ is sufficient for the synthesis of homoallyl amines from the reaction of various aldehydes, amines and allyltributylstannane. In absence of this catalyst only a trace of amount of homoallylic amines could be detected even after 4 h.

Table 2
Optimizing the reaction conditions^a



Entry	Catalyst (mmol%)	Time (h)	Yield (%) ^b
1	HClO ₄ -SiO ₂ (0.05)	2.5	96
2	HClO ₄ -SiO ₂ (0.04)	2.5	93
3	HClO ₄ -SiO ₂ (0.02)	3.0	96
4	HClO ₄ -SiO ₂ (0.01)	2.5	90

^a *p*-Chloro benzaldehyde/aniline/allyltributylstannane/HClO₄·SiO₂-2:2:2.4:0.01.

^b Isolated yields.

Table 3
Reuse of the catalyst for synthesis of 4 g (entry g, Table 1)

Entry	Time (h)	Yield (%) ^a
0	2.5	90
1	2.5	90
2	2.5	87
3	3.0	89
4	3.5	86
5	4.0	82

^a Isolated yields.

Encouraged by the results obtained for *p*-chlorobenzaldehyde with aniline and allyltributylstannane, we investigated a number of other aldehydes and various amines to probe their behaviour under the current catalytic conditions. The aromatic aldehydes containing both electron-donating and electron-withdrawing groups in the aromatic ring worked well. However, ketones did not form any product under similar reaction conditions. Homoallylic alcohols (adducts between aldehydes and allyltributylstannane) were also not formed. This is due to the rapid formation and activation of imines under the influence of the catalyst (Table 2).

3. Reusability of catalyst

Next, we investigated the reusability and recycling of HClO₄–SiO₂. At first, we put *p*-chloro benzaldehyde (2.0 mmol), aniline (2.0 mmol), allyltributylstannane (2.4 mmol) and 0.01 mmol% of HClO₄–SiO₂ in acetonitrile (5 mL) together, and then the mixture was stirred at room temperature. When the reaction was completed, the catalyst was separated by simple filtration by diluting with excess acetonitrile and recovered HClO₄–SiO₂ was reused in subsequent reactions without significant decrease in activity even after five runs (Table 3).

4. Conclusion

In conclusion, this paper describes a convenient and efficient process for the synthesis of homoallyl amines through a three-components coupling of various aldehydes, amines, allyltributylstannane in the presence of solid supported HClO₄–SiO₂ as a heterogeneous catalyst at room temperature. Present methodology offers very attractive features such as shorter reaction times, higher yields and will have wide scope in organic synthesis. This simple procedure combined with easy of recovery and reuse of the catalyst makes this method economic, benign, and a waste-free chemical process for the synthesis of homoallyl amines. We believe that this procedure is convenient, economic, and a user-friendly process for the synthesis of homoallyl amines.

5. Experimental

All of the products were characterized by a comparison of their spectral and physical data with those of authentic samples [8]. All yields refer to isolated products. NMR spectra were recorded on a Varian 200 MHz or Bruker 300 MHz. IR spectra

were run on a Perkin-Elmer bio-spectrometer. Mass spectra were recorded on VG micromass 7070 H or a Finnigan Met 1020B at 70 eV. The purity of the substances and the progress of the reactions were monitored by TLC on silica gel. The catalyst (HClO₄–SiO₂) was prepared by an established procedure [19].

5.1. Preparation of the catalyst

HClO₄ (1.25 g, 12.5 mmol, as a 70% aqueous solution) was added to the suspension of silica gel (23.75 g, 230–400 mesh) in diethyl ether (75 mL). The mixture was concentrated and the residue dried under vacuum at 100 °C for 72 h to afford HClO₄–SiO₂ (0.5 mmol g⁻¹) as a free flowing powder.

5.2. Typical procedure

To a mixture of aldehyde (2.0 mmol), aniline (2.0 mmol) and allyltributylstannane (2.4 mmol) in acetonitrile (5.0 mL) HClO₄–SiO₂ (0.01 mmol) were added. The reaction mixture was stirred at room temperature and the reaction was monitored by TLC. After completion the mixture was filtered (to remove the catalyst). The filtrate was concentrated and the gummy residue was purified by column chromatography over silica gel using hexane as eluent to obtain pure homoallylic amine.

5.3. Representative spectral data

5.3.1. Compound 4a

Pale yellow liquid, IR (neat): 3412, 3055, 3024, 2923, 1600, 1503, 1314, 751, 695 cm⁻¹; ¹H NMR (200 MHz, CDCl₃): δ 2.41–2.66 (m, 2H, –CH₂–), 4.09 (br s, 1H, –NH), 4.35 (dd, 1H, *J* = 7.8 and 5.3 Hz, –CH=), 5.10–5.25 (dd, 2H, =CH), 5.65–5.89 (m, 1H, –CH–), 6.40 (d, 2H, *J* = 8.2 Hz, Ar–H), 6.60 (t, 1H, *J* = 7.8 Hz, Ar–H), 7.00 (t, 2H, *J* = 8.6 Hz, Ar–H), 7.20–7.40 (m, 3H, Ar–H). ¹³C NMR (CDCl₃, 75 MHz): δ 43.1, 57.0, 113.9, 117.6, 118.2, 127.0, 128.3, 129.9, 134.3, 143.4, 147.6. ESI MS: *m/z* = 224 [M+H].

5.3.2. Compound 4h

Pale yellow liquid, IR (neat): 3411, 3065, 2924, 2853, 1635, 1602, 1522, 1341, 990, 920, 751, 695 cm⁻¹; ¹H NMR (200 MHz, CDCl₃): δ 2.32–2.68 (m, 2H, –CH₂–), 4.10 (br s, 1H, –NH), 4.45 (dd, 1H, *J* = 7.9 and 5.5 Hz, –CH=), 5.19–5.25 (dd, 2H, =CH), 5.65–5.80 (m, 1H, –CH–), 6.35 (d, 2H, *J* = 8.0 Hz, Ar–H), 6.65 (t, 1H, *J* = 8.0 Hz, Ar–H), 7.00 (d, 2H, *J* = 8.0 Hz, Ar–H), 7.51 (d, 2H, *J* = 8.0 Hz, Ar–H), 8.19 (d, 2H, *J* = 8.0 Hz, Ar–H). ¹³C NMR (CDCl₃, 75 MHz): δ 42.5, 56.0, 113.5, 118.2, 119.2, 123.5, 127.3, 129.3, 133.3, 146.4, 146.5, 151.6. FAB MS: *m/z* = 269 [M+H].

5.3.3. Compound 4j

Pale yellow liquid, IR (neat): 3411, 3053, 3019, 2922, 1602, 1503, 1431, 1313, 1150, 1003, 919, 743, 690 cm⁻¹; ¹H NMR (300 MHz, CDCl₃): δ 2.65 (t, 2H, *J* = 5.6 Hz, –CH₂–), 3.90 (br s, 1H, –NH), 4.51 (t, 1H, *J* = 5.5 Hz, –CH=), 5.10–5.20 (dd, 2H, =CH), 5.65–5.80 (m, 1H, –CH–), 6.10 (d, 1H, *J* = 2.0 Hz, Ar–H), 6.25 (dd, 1H, *J* = 2.0 and 1.8 Hz, Ar–H), 6.55 (d, 2H,

$J=8.0$ Hz, Ar–H), 6.65 (t, 1H, $J=8.0$ Hz, Ar–H), 7.10 (t, 2H, $J=8.0$ Hz, Ar–H), 7.31 (d, 1H, $J=1.8$ Hz, Ar–H). ^{13}C NMR (CDCl_3 , 75 MHz): δ 39.1, 51.3, 106.1, 113.5, 117.8, 118.3, 129.1, 133.9, 141.4, 146.9, 115.6. MS: $m/z=213$ [M^+], 172 (100%), 121, 104, 77

5.3.4. Compound 4l

Pale yellow liquid, IR (neat): 3412, 3053, 2923, 1690, 1600, 1503, 1430, 994, 919, 860, 777, 692 cm^{-1} . ^1H NMR (300 MHz, CDCl_3): δ 2.50–2.61 (m, 1H, $-\text{CH}_A-$), 2.80–2.90 (m, 1H, $-\text{CH}_B-$), 4.20 (br s, 1H, $-\text{NH}$), 5.13–5.25 (dd, 2H, $=\text{CH}$), 5.75–5.80 (m, 1H, $-\text{CH}=\text{}$), 6.40 (d, 2H, $J=8.0$ Hz, Ar–H), 6.60 (t, 1H, $J=8.0$ Hz, Ar–H), 7.00 (t, 2H, $J=7.9$ Hz, Ar–H), 7.40 (t, 1H, $J=7.8$ Hz, Ar–H), 7.45–7.62 (m, 3H, Ar–H), 7.70 (d, 1H, $J=8.0$ Hz, Ar–H), 7.90 (d, 1H, $J=8.0$ Hz, Ar–H), 8.25 (d, 1H, $J=8.0$ Hz, Ar–H). FAB MS: $m/z=274$ [$\text{M}+\text{H}$].

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