Heteroatom Chemistry
Volume 24, Number 1, 2013

Silica Boron Sulfuric Acid Nanoparticles: As an Efficient and Reusable Catalyst for the Large-Scale Synthesis of α-Amino Nitriles Using the Strecker Reaction

Ali Khalafi-Nezhad, Habib Ollah Foroughi, and Farhad Panahi

Department of Chemistry, Shiraz University, Shiraz 71454, Islamic Republic of Iran

Received 23 November 2011; revised 13 August 2012

ABSTRACT: *A highly efficient and green procedure for the large-scale synthesis of α-amino nitriles using three-component condensation of carbonyl compounds, amines, and trimethylsilylcyanide has been developed. Silica boron sulfuric acid nanoparticles (SBSANs) are found as an efficient heterogeneous catalyst for the promotion of this process at room temperature under solvent-free conditions. This protocol offers an effective and scale-up procedure for the synthesis of various α-amino nitriles using a wide range of amines and carbonyl compounds in relatively short reaction time with the excellent isolated yields. In addition, the SBSAN catalyst is easily separated from the reaction mixture by simple filtration and can be reused several times.* © 2012 Wiley Periodicals, Inc. Heteroatom Chem 24:1–8, 2013; View this article online at wileyonlinelibrary.com. DOI 10.1002/hc.21052

INTRODUCTION

Nowadays, some modifications to already existing synthetic methodologies, considering the environmental consciousness in both industrial and academic studies, have received great attention [1]. In industries, the green chemistry approaches such as using recyclable catalysts and less toxic materials as solvents and reagents have been considered [2]. The development of heterogeneous catalysts and the use of green conditions for excellent synthesis of materials are two important strategies in academic studies [3]. Solid acids as efficient heterogeneous catalysts have been extensively used in organic reactions, because they have several unique characteristics [4]. Generally, by the use of these catalysts, acid catalyst–based processes have been accomplished in more environmentally sensible conditions [5]. Among various supports for the preparation of solid acids, silica occupies one of the most important positions, because it is more stable, abundantly available, and can be simply functionalized [6]. Furthermore, when support is selected in the nanometer scale [7], the dispersible capability of a catalyst in solution is improved so that it acts as a pseudohomogeneous catalyst. Consequently, the diffusion rate of reactants to catalyst sites is increased and thus the reaction rate is enhanced dramatically [8].

Recently, we have developed a new solid acid based on the nanometer-scale silica support with two Lewis and protic acidic sites as a silica boron sulfuric acid nanoparticle (SBSAN) catalyst [9]. This new nanocatalyst has two Lewis and protic acidic sites and can provide efficient and green conditions for excellent performance of acid-based organic reactions. The catalytic performance of the SBSAN catalyst was evaluated in the Ritter reaction as an acid-catalyzed process, and very excellent results have been obtained [9]. In the current study, we present another important application of SBSAN as an efficient heterogeneous catalyst

Correspondence to: Ali Khalafi-Nezhad; e-mail: khalafi@chem.susc.ac.ir. Farhad Panahi; e-mail: panahi@shirazu.ac.ir.

for the preparation of α-amino nitriles under mild conditions.

Alpha-amino nitriles are classified as a main category of compounds, because of their beneficial synthetic applications in medicinal chemistry and natural products [10]. The synthesis of α-amino acids and nitrogen-containing heterocycles (such as imidazoles and thiadiazoles) is too significant in organic synthesis [11]. The Strecker reaction is one of the most important synthetic strategies for the preparation of α-amino nitriles [12]. Moreover, α-amino nitriles can be synthesized from the catalytic cyanation of imines [13]. In modern organic synthetic reactions, they have been synthesized using the one-pot three-component reaction of amines, carbonyl compounds, and trimethylsilylcyanide (TMSCN) in the presence of an acid catalyst [14]. So far, this reaction has been studied with different homogeneous, heterogeneous, and Lewis acid catalysts. Although these methods are suitable for this process, but some of them have one or more deficiencies such as low yield, prolonged reaction time, tedious workup processes, hazardous reaction conditions, and lack of scalability [15–18]. Herein, we report that the SBSAN catalyst is efficient in mild conditions with a safe and clean procedure for the large-scale synthesis of α-amino nitriles.

RESULTS AND DISCUSSION

Silica Boron Sulfuric Acid Nanoparticles

Silica boron sulfuric acid nanoparticles were prepared in a two-steps process (Scheme 1). First, silica boron acid nanoparticles (SBANs) were synthesized during the modification of the silica support by boric acid [$B(OH)_3$] using the chemical vapor deposition (CVD) process. Then SBAN was reacted with chlorosulfonic acid ($ClSO_3H$) to obtain the SBSAN catalyst.

This catalyst has been fully characterized using some different microscopic and spectroscopic techniques [9]. Our studies show that activity of the SBSAN catalyst is decreased in donor solvents. As a result, the boron atoms should have a key role in the reactivity of this catalyst. On the other hand, we know that the boron atom can be only considered as a Lewis acid if it is tricoordinated. According to this point of view, we considered all of the possible structures that are predictable for the SBSAN catalyst and we have shown all of these possible structures in Fig. 1.

SCHEME 1 Synthetic routes for the preparation of SBANs and SBSAN catalyst.

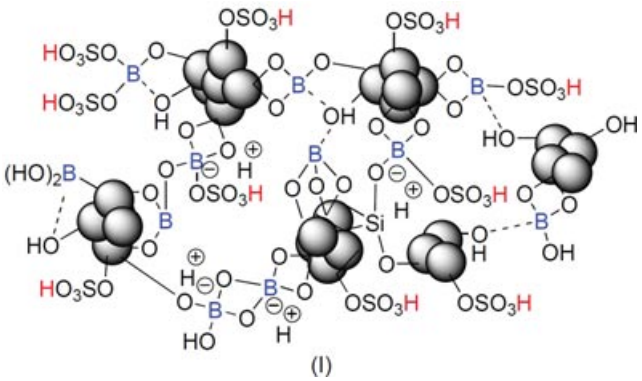


FIGURE 1 Proposed chemical structure for SBSAN.

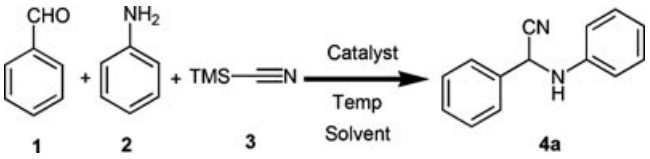
In accordance with Fig. 1, a number of possibilities of the structure of the SBSAN catalyst as a result of, during the generation of SBAN, boric acid can be connected to the silica surface with different modes. In addition, the boron atoms having the empty orbital (as Lewis acid) can interact with hydroxy groups on the substrate (silica and boric acid), and this resulted in additional complexities in the structure of the SBSAN catalyst. Furthermore, the sulfonation of some of the silica hydroxyl groups with $ClSO_3H$ should also be considered. Based on the proposed structure for the SBSAN catalyst, the Lewis acidity in the catalyst is resulted from the tricoordinated boron atoms. Perhaps this is the reason why the SBSAN catalyst is effectively catalyzed the reactions under solvent-free conditions. Overall, in the structure of the SBSAN catalyst two acidic catalytic sites including the proton of sulfuric groups (protic acid) and boron atoms (Lewis acid) are located on a silica nanostructure support. It seems that these two acidic catalytic sites have a synergistic effect, so that they can provide an efficient catalytic activity for reactions to accomplish under mild conditions.

Synthesis of α-Amino Nitriles Using the SBSAN Catalyst

The reaction between benzaldehyde (**1**), aniline (**2**), and TMSCN (**3**) was selected as a simple model to find optimum conditions for the preparation of the α-amino nitrile derivatives using the SBSAN catalyst. The results of optimization study are presented in Table 1.

According to Table 1, the reactivity of the SBSAN catalyst is decreased in donor solvents to some extent. The yield of products under both room

TABLE 1 Optimization of Reaction Condition between Benzaldehyde, Aniline and TMSCN for Preparation of the α-Amino Nitrile Derivatives Using SBSAN Catalyst[a]



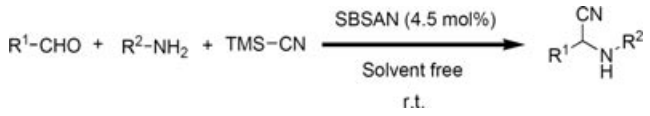
Entry	*Catalyst*	*Catalyst Loading*	*Solvent*	*Temperature (°C)*	*Time (min)*	*Yield (%)[b]*
1	SBSAN	4.5 (mol%)	DCM	r.t.	30	84
				Reflux	30	88
2	SBSAN	4.5 (mol%)	EtOH	r.t.	30	71
				Reflux	30	76
3	SBSAN	4.5 (mol%)	None	r.t.	5	96
4	SBSAN	6.75 (mol%)	None	r.t.	5	97
5	SBSAN	2.25 (mol%)	None	r.t.	30	75
6	SBAN	0.1 g	None	r.t.	120	53
				80	120	68
7	Silica	0.1 g	None	r.t.	5	0
					120	Trace
8	$B(OH)_3$	50 (mol%)	None	r.t.	5	0
					720	24
9	Silica/ $B(OH)_3$	(0.1/0.1) g	None	r.t.	5	0
					720	29
10	SSA	0.1 g	None	r.t.	5	38
					360	79
11	None	None	None	r.t.	720	0
12	None	None	None	80	720	Trace

Abbreviations: DCM, dichloromethane; r.t., room temperature; SBAN, silica boron acid nanoparticle; SBSAN, silica boron sulfuric acid nanoparticle; SSA, silica sulfuric acid.
[a]Amount of reagents in all reactions: aniline (1 mmol), benzaldehyde (1 mmol), and TMSCN (1.1 mmol).
[b]Isolated yield.

temperature and reflux conditions in dichloromethane as a noncoordinating solvent is more than in ethanol as a donor solvent (Table 1, entries 1 and 2). It is noteworthy that, in solvent-free conditions, the SBSAN catalyst shows high activity, and the expected product was obtained in a high isolated yield (96%) after a very short reaction time (Table 1, entry 3). These results also confirm that the boron atoms as Lewis acid play an important role in the catalytic activity of the SBSAN catalyst. With a decrease in the catalyst loading to 2.25 mol%, the yield of the product significantly decreased, but its increase to 6.75 mol% did not have any effect on the reaction yield. To clarify the synergistic effect between the SBSAN catalytic sites, SBAN, silica, and boric acid were applied separately under the same reaction conditions. The SBAN showed a good reactivity for this reaction in solvent-free conditions at 80°C (Table 1, entry 6), whereas a low isolated yield for the corresponding product was obtained in the presence of silica and boric acid (Table 1, entries 7 and 8). Moreover, in the presence of a mixture of silica and boric acid the yield of product did not changed even after a more reaction time (Table 1, entry 9). This experiment provides strong evidence that the catalytic sites of SBAN are different from the silica and boric acid. This catalytic activity can result from the nanostructure nature of silica boric acid nanoparticles. Silica sulfuric acid [19] did not show activity similar to SBSAN in this multicomponent reaction. This test confirmed that the catalytic activity of SBSAN is not resulted from only—SO_3H groups (Table 1, entry 10). At the end of our optimizing studies, we also carried out the blind-probe experiments and the results show that, for the promotion of this protocol at room temperature and heat conditions, the existence of a catalyst is unavoidable and the SBSAN catalyst has a significant effect on the progress of this reaction (Table 1, entries 11 and 12). As shown in Table 1, the best results for this protocol were obtained with catalyst loading of 4.5 mol% of SBSAN at room temperature and under solvent-free conditions.

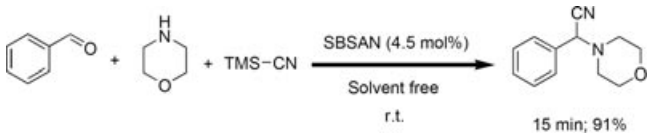
To determine the scope of the designed protocol for the preparation of α-amino nitrile derivatives, a number of commercially available aldehydes and amines were reacted with TMSCN under optimized reaction conditions and the results are summarized in Table 2.

TABLE 2 Three Components Reaction between Different Amines and Aldehydes with TMSCN in the Presence of SBSAN Catalyst[a]



Entry	R^1	R^2	*Time (min)*	*Yield (%)*[b]
1	Ph	Ph	5	96
2	4-SMe-Ph	4-Br-Ph	10	95
3	Ph	4-Br-Ph	10	93
4	2,4-Cl-Ph	Ph	10	97
5	4-Cl-Ph	4-Me-Ph	5	96
6	4-OMe-Ph	Ph	10	95
7	4-F-Ph	4-Me-Ph	5	94
8	3-NO_2-Ph	Ph	10	95
9	Thiophenyl	Ph	15	90
10	Ph	3,4-Me-Ph	10	93
11	C_4H_9	Ph	20	91

[a]Amount of reagents in all reactions: aniline (1 mmol), aldehyde (1 mmol), TMSCN (1.1 mmol), and catalyst (0.05 g, 4.5 mol%).
[b]Isolated yield.



SCHEME 2 The Strecker reaction between morpholine (as secondary amine) and benzaldehyde in the presence of the SBSAN catalyst. Reaction conditions: benzaldehyde (1 mmol), morpholine (1 mmol), and TMSCN (1.1 mmol).

We applied optimized conditions for the synthesis of α-amino nitriles by a reaction between some of the commercial aldehydes, amines, and TMSCN, and a range of α-amino nitriles were synthesized. As clearly shown in Table 2, both aromatic and aliphatic (entry 11) aldehydes reacted with amines and TMSCN in the presence of the SBSAN catalyst and the excellent yields of corresponding α-amino nitriles were obtained. Another important feature of this method is the use of sensitive acid aldehyde such as thiophene-2-carbaldehyde to generate the corresponding α-amino nitrile derivatives in the excellent isolated yield (Table 2, entry 9).

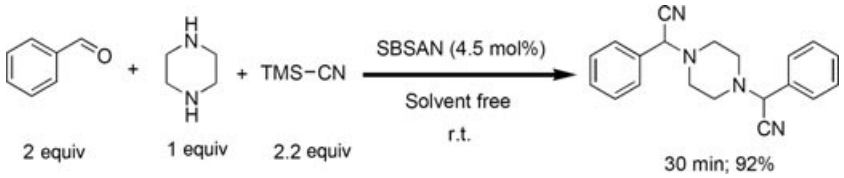
Moreover, the SBSAN-catalyzed Strecker reaction between morpholine as a secondary amine and benzaldehyde led to the formation of the 2-morpholino-2-phenylacetonitrile product in 91% yield after only 15 min (Scheme 2).

The synthetic efficiency of this reaction was highlighted by the reaction of piperazine with benzaldehyde and TMSCN to give a structurally complex α-amino nitrile derivative (Scheme 3).

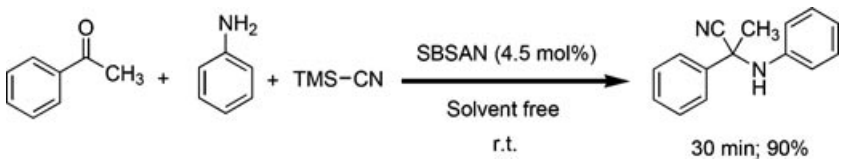
In addition, acetophenone as a ketone was converted into the corresponding α-amino nitriles with the excellent isolated yields (Scheme 4). As we know, few methods for the Strecker reaction of ketones are reported in the literature [17b] therefore our convenient procedure for the synthesis of this class of compounds may have synthetic significance.

According to Table 2 and aforementioned reactions, the SBSAN catalyst can provide a suitable condition for the three-component coupling reaction between aldehydes/ketones, amine, and TMSCN to accomplish in solvent-free conditions at room temperature. Hence, SBSAN was introduced as an efficient and green catalyst for the facile synthesis of α-amino nitriles under mild conditions.

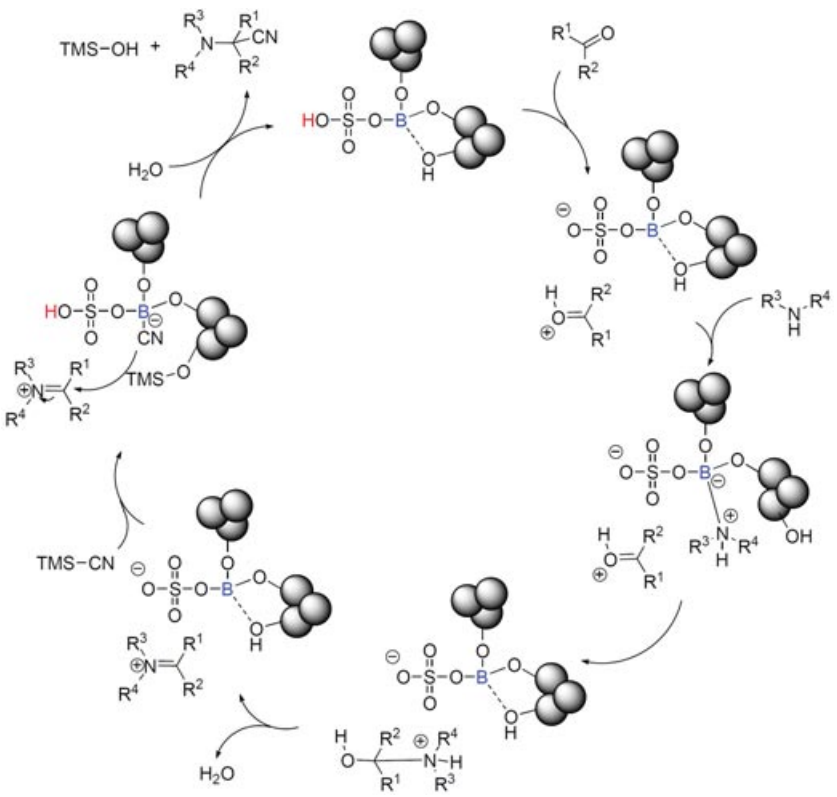
We also propose the following mechanism for this reaction in the presence of the SBSAN catalyst (Scheme 5). In the proposed mechanism, we tried to show that both active sites of the SBSAN catalyst are engaged in the Strecker reaction. As shown in Scheme 5, the aldehyde can be protonated to become active for the reaction with an amine component, producing the imine intermediate. Then, the intermediate subsequently reacts with a trapped



SCHEME 3 SBSAN-catalyzed Strecker reaction between piperazine (as bifunctionalized amine) and benzaldehyde.



SCHEME 4 SBSAN-catalyzed Strecker reaction between acetophenone and aniline. Reaction conditions: acetophenone (1 mmol), aniline (1 mmol), and TMSCN (1.1 mmol).



SCHEME 5 Proposed mechanism for the Strecker reaction of aldehydes/ketones, amines, and TMSCN for the synthesis of α-amino nitriles in the presence of the SBSAN catalyst.

CN anion to produce the corresponding product. It seems that the Lewis and protic acidic sites of the SBSAN catalyst are fully involved in the reactive substrate and intermediates for the progress of the reaction.

For practical applications of heterogeneous catalysts in the industrial scale, the level of reusability and scale-up of the reaction catalyst are very important factors.

Scalability of the Strecker Reaction in the Presence of the SBSAN Catalyst

The reaction between benzaldehyde, aniline, and TMSCN was evaluated using some different amounts of the SBSAN catalyst to optimize the catalyst loading for the scale-up procedure. The obtained results have shown that the optimum catalyst loading for this process can be 2.0 g of the SBSAN catalyst (Table 3).

In comparison to the small-scale experiment (Table 2, entry 1), approximately 1 additional h was required to achieve the desired isolated yield of product using the SBSAN catalyst. The slight decrease in the efficiency and an unimportant increase in the time could be due to the fact that the orbital shaking is less efficient when the reaction is performed with a higher volume of vessel [20].

Recyclability of the SBSAN Catalyst in the Strecker Reaction

The possibility of recycling of the catalyst was examined using the reaction of benzaldehyde and aniline with TMSCN under optimized reaction conditions. When the reaction was complete, the reaction mixture was washed with hot EtOH and catalyst was separated by simple filtration, and the recycled catalyst was saved for the next operation. The recycled

TABLE 3 Optimization of Catalyst Loading for the Large-Scale Synthesis of α-Amino Nitriles Using SBSAN Catalyst[a]

Entry	*Catalyst Loading (g)*	*Time (h)*	*Yield (%)[b]*
1	5	1	92
2	3	1	91
3	2.5	1	91
4	2	1	91
5	1.5	5	78
		12	79

[a]Reaction condition: benzaldehyde (0.1 mol), aniline (0.1 mol), TMSCN (0.11 mol), r.t., and solvent-free condition.
[b]Isolated yield.

TABLE 4 Reusability of the SBSAN Catalyst in the Reaction between Benzaldehyde, Aniline, and TMSCN[a]

Entry	*Yield of Product (%)*	*Recovery of SBSAN (%)*
Fresh	96	>99
1	96	99
2	95	98
3	94	98
4	94	98
5	93	97

[a]Reaction conditions: SBSAN (0.05 g, 4.5 mol%), aniline (1.0 mmol), benzaldehyde (1.0 mmol), and TMSCN (1.1 mmol). Reaction time is 5 min.

catalyst could be reused more than five times without any treatment (Table 4).

To confirm this point, the catalyst activity of SBSAN did not change remarkably during the reaction process, we checked the sulfur content of the SBSAN catalyst using elemental analysis after six times of reusability and the results have shown that only 0.7% of sulfur was lost. These results are in good agreement with catalyst activity of the SBSAN catalyst after each recovery and we did not observed any appreciable loss in the catalytic activity of the SBSAN catalyst.

CONCLUSIONS

In summary, SBSANs as a dual Lewis/protic solid acid catalyst are introduced for the large-scale synthesis of α-amino nitriles under green conditions using the Strecker reaction. The one-pot three-component condensation of aldehydes/ketones, amines, and TMSCN is catalyzed by SBSAN at room temperature under solvent-free conditions. This new approach was preceded by the excellent isolated yields, and the target products were obtained in short reaction time. Reusability and easy workup were two other advantages of the SBSAN catalyst for this process.

EXPERIMENTAL

Chemicals were purchased from Fluka (Neu-Ulm, Germany) and Aldrich (Gillingham, UK). ^{1}H NMR and ^{13}C NMR were run on a Brucker Avance DRX (300 and 400 MHz) in a pure deuterated $CDCl_3$ solvent with tetramethylsilane (TMS) as internal standards. Melting points were determined in open capillary tubes in a Barnstead Electrothermal 9100 BZ circulating oil melting point apparatus. The reaction monitoring was accomplished by thin layer chromatography (TLC) on silica gel Poly Gram SILG/UV254 plates.

Preparation of SBSANs

The SBSAN catalyst was synthesized on the basis of the previous procedure [9]. According to this procedure, first SBANs were prepared and then this material was reacted with chlorosulfonic acid to produce the SBSAN catalyst. For the preparation of SBANs, the CVD process was applied for doping of boron species on a silica support. In this way, a mixture of Ar, O_2, and the aerosols of the aqueous solution of boric acid (2.0 g mL^{-1}) was injected into the solid silica supports positioned inside a quartz tube located in a tubing furnace at 600°C. Then, SBANs were transferred into a flask and chlorosulfonic acid was added to it dropwise at room temperature. After completion of acid addition, the mixture was stirred for 30 min under vacuum pressure. Therefore, the SBSAN catalyst was obtained as a white solid.

A representative example of the large-scale preparation of α-amino nitriles using the SBSAN catalyst is 2-phenyl-2-(phenylamino)acetonitrile (Table 2, entry 1). Into a canonical flask (500 mL), a mixture of benzaldehyde (0.1 mol), aniline (0.1 mol), TMSCN (0.11 mol), and SBSAN (2.0 g) was stirred at room temperature for 1 h. Then, the reaction mixture was washed with hot ethanol (100 mL) and the SBSAN catalyst was separated by simple filtration. The α-amino product was precipitated following the cooling of ethanol, and pure 2-phenyl-2-(phenylamino)acetonitrile was obtained by its recrystallization in ethanol (18.9 g, 91%). White solid; mp 80–81°C; ^{1}H NMR (300 MHz, DCl_3/TMS): δ = 4.04 (brs, 1H, NH), 5.46 (s, 1H), 6.79–6.93 (m, 3H), 7.28–7.65 (m, 7H); ^{13}C NMR (75 MHz, $CDCl_3$/TMS): δ = 50.3, 114.2, 118.2, 120.4, 127.3, 129.4, 129.6, 131.3, 34.0, 144.7; Anal. Calcd for $C_{14}H_{12}N_2$ (208.2): C, 80.74; H, 5.81; N, 13.45. Found: C, 80.65; H, 5.78; N, 13.37. The recovered SBSAN catalyst was washed with water (2 × 20 mL) and ethanol (2 × 20 mL), dried at 100°C in an oven (for 5 h), and reused catalyst was saved for the next operation without any treatment.

General Procedure for the Preparation of α-Amino Nitriles Using the SBSAN Catalyst on a 1 mmol Scale

Into a canonical flask (50 mL), a mixture of aldehyde/ketone (1.0 mmol), amine (1.0 mmol), TMSCN (1.1 mmol), and SBSAN (0.05 g) was stirred at room temperature for an appropriate time, as specified in Table 2. After completion of the reaction, as indicated by TLC, the reaction mixture was washed with hot ethanol (10 mL) and catalyst separated by simple filtration. After cooling of ethanol, the α-amino

product was precipitated and pure product was obtained by its recrystallization in ethanol.

2-Morpholino-2-phenylacetonitrile. Yield; 91%; white solid; mp 68–70°C; ^{1}H NMR (300 MHz, $CDCl_3$/TMS): $\delta = 2.61$ (t, $J = 4.7$ Hz, 4H), 3.69–3.81 (m, 4H), 4.85 (s, 1H), 7.41–7.57 (m, 5H); ^{13}C NMR (75 MHz, $CDCl_3$/TMS): $\delta = 50$, 62.5, 66.7, 115.2, 128.0, 128.9, 129.1, 132.5; Anal. Calcd for $C_{12}H_{14}N_2O$ (202.2): C, 71.26; H, 6.98; N, 13.85. Found: C, 71.19; H, 6.91; N, 13.78.

2-(2,4-Dichlorophenyl)-2-(phenylamino) acetonitrile (Table 2, entry 4). Yield: 97%; pale yellow solid; mp 116–118°C; ^{1}H NMR (300 MHz, $CDCl_3$/TMS): $\delta =$ 4.05 (brs, 1H, NH), 5.7 (s, 1H), 6.77–7.71 (m, 8H); ^{13}C NMR (75 MHz, $CDCl_3$/TMS): $\delta = 47.7$, 114.4, 117.4, 120.8, 128.1, 129.7, 129.9, 130.4, 134.3, 136.5; Anal. Calcd for $C_{14}H_{10}Cl_2N_2$ (277.1): C, 60.67; H, 3.64; N, 10.11. Found: C, 60.61; H, 3.59; N, 10.05.

2-(p-Tolylamino)-2-(4-chlorophenyl)acetonitrile (Table 2, entry 5). Yield: 96%, yellow solid; mp 86–88°C; ^{1}H NMR (300 MHz, $CDCl_3$/TMS): $\delta =$ 2.31 (s, 3H), 3.97 (brs, 1H, NH), 5.4 (s, 1H), 6.7 (d, $J = 8.0$ Hz, 2H), 7.11 (d, $J = 8.0$ Hz, 2H), 7.44 (d, $J = 8.6$ Hz, 2H), 7.56 (d, $J = 8.3$ Hz, 2H); ^{13}C NMR (75 MHz, $CDCl_3$/TMS): $\delta = 20.6$, 50.2, 114.7, 118.0, 128.6, 129.5, 130.1, 132.7, 142.1; Anal. Calcd for $C_{15}H_{13}ClN_2$ (256.7): C, 70.18; H, 5.10; N, 10.91. Found: C, 70.11; H, 5.02; N, 10.86.

2-(4-Methoxyphenyl)-2-(phenylamino) acetonitrile (Table 2, entry 6). Yield: 95%; pale yellow solid; mp 96–97°C; ^{1}H NMR (300 MHz, $CDCl_3$/TMS): δ = 3.85 (s, 3H), 4.01 (brs, 1H, NH), 5.38 (s, 1H), 6.8 (d, $J = 8.0$ Hz, 2H), 6.90–7.00 (m, 3H), 7.27–7.33 (m, 2H), 7.53 (d, $J = 8.0$ Hz, 2H); ^{13}C NMR (75 MHz, $CDCl_3$/TMS): $\delta = 49.7$, 55.5, 114.2, 114.7, 118.4, 120.2, 126.0, 128.6, 129.6, 144.8, 160.5; Anal. Calcd for $C_{14}H_{10}Cl_2N_2$ (238.3): C, 75.61; H, 5.92; N, 11.76. Found: C, 75.55; H, 5.84; N, 11.71.

2-(p-Tolylamino)-2-(4-fluorophenyl)acetonitrile (Table 2, entry 7). Yield: 94%; white solid; mp 100–102°C; ^{1}H NMR (300 MHz, $CDCl_3$/TMS): $\delta =$ 2.20 (s, 3H), 3.82 (brs, 1H, NH), 5.30 (s, 1H), 6.61 (d, $J = 8.4$ Hz, 2H), 6.9–7.09 (m, 4H), 7.48–7.53 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$/TMS): $\delta = 20.5$, 50.1, 114.7, 116.2, 116.5, 118.2, 129.1, 126.0, 130.1, 142.2, 161.6; Anal. Calcd for $C_{15}H_{13}FN_2$ (240.3): C, 74.98; H, 5.45; N, 11.66. Found: C, 74.91; H, 5.41; N, 11.60.

2-(3-Nitrophenyl)-2-(phenylamino)acetonitrile (Table 2, entry 8). Yield: 95%; pale yellow solid; mp 90–92°C; ^{1}H NMR (300 MHz, $CDCl_3$/TMS): $\delta = 4.19$ (brs, 1H, NH), 5.6 (s, 1H), 6.8 (d, $J = 8.0$ Hz, 2H), 6.97 (t, $J = 8.0$ Hz, 1H), 7.31 (d, $J = 10.0$ Hz, 2H), 7.7 (t, $J = 8.0$ Hz, 1H), 8 (d, $J = 7.1$ Hz, 1H), 8.33 (d, $J = 8.0$ Hz, 1H), 8.5 (s, 1H); ^{13}C NMR (75 MHz, $CDCl_3$/TMS): $\delta = 49.7$, 114.7, 121.2, 122.4, 124.5, 129.7, 129.8, 130.5, 133.0, 136.2, 143.9; Anal. Calcd for $C_{14}H_{11}N_3O_2$ (253.2): C, 66.40; H, 4.38; N, 16.59. Found: C, 66.38; H, 4.34; N, 16.52.

ACKNOWLEDGMENT

We acknowledge Shiraz University for partial support of this work.

REFERENCES

[1] Horváth, I. T.; Anastas, P. T. Chem Rev 2007, 107, 2169.
[2] Ran, N.; Zhao, L.; Chen, Z.; Tao, J. Green Chem 2008, 10, 361.
[3] Polshettiwar, V.; Varma, R. S. Green Chem 2010, 12, 743.
[4] (a) Melero, J. A.; Grieken, R. V.; Morales, G. Chem Rev 2006, 106, 3790; (b) Kitano, M.; Nakajima, K.; Kondo, J. N.; Hayashi, S.; Hara, M. J Am Chem Soc 2010, 132, 6622; (c) Karimi, B.; Khalkhali, M. J Mol Catal A Chem 2005, 232, 113; (d) Chakraborti, A. K.; Singh, B.; Chankeshwara, S. V.; Patel, A. R. J Org Chem 2009, 74, 5967; (e) Kumar, A.; Gupta, G.; Srivastava, S. J Comb Chem 2010, 12, 458; (f) Pariente, S.; Tanchoux, N.; Fajula, F. Green Chem 2009, 11, 1256.
[5] (a) Yadav, G. D.; Murkute, A. D. Langmuir 2004, 20, 11607; (b) Srilatha, K.; Kumar, C. R.; Devi, B. L. A. P.; Prasad, R. B. N.; Prasad, P. S. S.; Lingaiah, N. Catal Sci Technol 2011, 1, 662; (c) Tian, X.; Su, F.; Zhao, X. S. Green Chem 2008, 10, 951; (d) Getty, E. E.; Drago, R. S. Inorg Chem 1990, 29, 1186; (e) Luque, R.; Budarin, V.; Clark, J. H.; Macquarrie, D. J. Green Chem 2009, 11, 459.
[6] (a) Hicks, J. C.; Mullis, B. A.; Jones, C. W. J Am Chem Soc 2007, 129, 8426; (b) Quinn, C. R.; Clark, J. H.; Tavener, S. J.; Wilson, K. Green Chem 2003, 5, 602; (c) Keana, J. F. W.; Shimizu, M.; Jernstedt, K. K. J Org Chem 1986, 51, 1641; (d) Karam, A.; Gu, Y.; Jérôme, F.; Douliez, J. P.; Barrault, J. Chem Commun 2007, 2222; (e) Motokura, K.; Itagaki, S.; Iwasawa, Y.; Miyaji, A.; Baba, T. Green Chem 2009, 11, 1876; (f) Price, P. M.; Clark, J. H.; Martin, K.; Macquarrie, D. J.; Bastock, T. W. Org Process Res Dev 1998, 2, 221.
[7] Fan, J.; Chen, S.; Gao, Y. Colloids Surf, B 2003, 28, 199.
[8] (a) Kell, A. J.; Stringle, D. L. B.; Workentin, M. S. Org Lett 2000, 2, 3381; (b) Wang, J.; Sugawara-Narutaki, A.; Fukao, M.; Yokoi, T.; Shimojima, A.; Okubo, T. ACS Appl Mater Interfaces 2011, 3, 1538.
[9] Khalafi-Nezhad, A.; Foroughi, H. O.; Doroodmand, M. M.; Panahi, F. J Mater Chem 2011, 21, 12842.
[10] (a) Chakraborty, T. K.; Reddy, G. V.; Hussain, K. A. Tetrahedron Lett 1991, 32, 7597; (b) Leblanc, J.; Gibson, H. W. Tetrahedron Lett 1992, 33, 6295; (c) Zhong, Y. L.; Lee, J.; Reamer, R. A.; Askin, D. Org Lett 2004, 6, 929; (d) Enders, D.; Shilvock, J. P. Chem Soc Rev 2000, 29, 359; (e) Failla, S.; Finocchiaro, P.; Consiglio, G. A. Heteroatom Chem 2000, 11, 493.
[11] (a) Dyker, G. Angew Chem, Int Ed Engl 1997, 36, 1700; (b) Bergner, I.; Wiebe, C.; Meyer, N.; Opatz,

T. J Org Chem 2009, 74, 8243; (c) Duthaler, R. O. Tetrahedron 1994, 50, 1539; (d) Matier, W. L.; Owens, D. A.; Comer, W. T.; Deitchman, D.; Ferguson, H. C.; Seidehamel, R. J.; Young, J. R. J Med Chem 1973, 16, 897.

[12] (a) Strecker, A. Ann Chem Pharm 1850, 75, 27; (b) Kaur, P.; Wever, W.; Pindi, S.; Milles, R.; Gu, P.; Shi, M.; Li, G. Green Chem 2011, 3, 1288–1292.

[13] (a) Hatano, M.; Hattori, Y.; Furuya, Y.; Ishihara, K. Org Lett 2009, 11, 2321; (b) Goodman, M. J Am. Chem. Soc. 2009, 131, 4070; (c) Surendra, K.; Srilakshmi Krishnaveni, N.; Mahesh, A.; Rao, K. R. J Org Chem 2006, 71 2532.

[14] (a) Groger, H. Chem Rev 2003, 103, 2795; (b) Karimi, B.; Maleki, A. Chem Commun 2009, 5180; (c) Yet, L. Angew Chem, Int Ed 2001, 40, 871.

[15] (a) Ranu, B. C.; Dey, S. S.; Hajra, S. Tetrahedron 2002, 58, 2529; (b) De, S. K.; Gibbs, R. A. Tetrahedron Lett 2004, 45, 7407; (c) Yadav, J. S.; Reddy, B. V. S.; Eswaraiah, B.; Srinivas, M. Tetrahedron 2004, 60, 1767; (d) Reddy, B. M.; Thirupathi, B.; Patil, M. K. J Mol Catal A: Chem 2009, 307, 154; (e) Khan, N. H.; Agrawal, S.; Kureshy, R. I.; Abdi, S. H. R.; Singh, S.; Suresh, E.; Jasra, R. V. Tetrahedron Lett 2008, 49, 640; (f) Shen, Z. L.; Ji, S. J.; Loh, T. P. Tetrahedron 2008, 64, 8159.

[16] (a) Mojtahedi, M. M.; Abaee, S.; Alishiri, T. Tetrahedron Lett 2009, 50, 2322; (b) Rajabi, F.; Ghiassian, S.; Saidi, M. R. Green Chem 2010, 12, 1343; (c) Zhang, G. W; Zheng, D. H; Nie, J.; Wang, T.; Ma, J. A. Org Biomol Chem 2010, 8, 1399; (d) Heydari, A.; Arefi, A.; Khaksar, S.; Shiroodi, R. K. J Mol Catal A: Chem. 2007, 271, 142; (e) Shaabani, A.; Maleki, A.; Soudi, M. R.; Mofakham, H. Catal Commun 2009, 10, 945; (f) Yadav, J. S.; Reddy, B. V. S.; Eshwaraiah, B.; Srinivas, M.; Vishnumurthy, P. New J Chem 2003, 27, 462; (g) Jarusiewicz, J.; Choe, Y.; Yoo, K. S.; Park, C. P.; Jung, K. W. J Org Chem 2009, 74, 2873.

[17] (a) Narasimhulu, M.; Reddy, T. S.; Mahesh, K. C.; Reddy, S. M.; Reddy, A. V.; Venkateswarlu, Y. J Mol Catal A: Chem 2007, 264, 288; (b) Karimi, B.; Zareyee, D. J Mater Chem 2009, 19, 8665; (c) Acosta, F. C.; Expósito, A. S.; Armas, P. D.; Tellado, F. G. Chem Commun 2009, 6839; (d) Niknam, K.; Saberi, D.; Sefat, M. N. Tetrahedron Lett 2010, 51, 2959.

[18] (a) Heydari, A.; Khaksar, S.; Pourayoubi, M.; Mahjoub, A. R. Tetrahedron Lett 2007, 48, 4059; (b) Shaabani, A.; Maleki, A. Appl Catal A: Gen 2007, 331, 149; (c) Chen, W. Y.; Lu, J. Synlett 2005, 2293; (d) Kumar, M. A.; Babu, M. F. S.; Srinivasulu, K.; Kiran, Y. B.; Reddy, C. S. J Mol Catal: A Chem 2007, 265, 268; (e) Surendra, K.; Krishnaveni, N. S.; Mahesh, A.; Rao, K. R. J Org Chem 2006, 71, 2532.

[19] Zolfigol, M. A. Tetrahedron 2001, 57, 9509.

[20] Busto, E.; Gotor-Fernandez, V.; Gotor, V. Org Process Res Dev 2011, 15, 236.