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Fluoroboric acid adsorbed on silica-gel (HBF_4–SiO_2) as a new, highly efficient and reusable heterogeneous catalyst for thia-Michael addition to α,β-unsaturated carbonyl compounds

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ABSTRACT

Fluoroboric acid adsorbed on silica-gel (HBF_4–SiO_2) has been found to be a new and highly efficient heterogeneous catalyst for thia-Michael addition to α,β-unsaturated carbonyl compounds under solvent-free conditions. In the case of 1,3-diaryl-2-propenones, the reactions are best carried out in MeOH. The rate of thia-Michael addition was dependent on the steric hindrance at the β-carbon of the α,β-unsaturated carbonyl substrate as well as surrounding the thiol moiety and was exploited for selective thia-Michael addition during intermolecular competition between two enones with a common thiol and between two aryl/alkyl thiols for a common enone. The methodology finds application for one-pot syntheses of 2,3-dihydro-1,5-benzothiazepines.

Thia-Michael addition to α,β-unsaturated carbonyl compounds is an important transformation. It is a key step in biosynthesis[1] and in the synthesis of bioactive compounds[2] and provides a means to protect the olefinic double bond of α,β-unsaturated carbonyl groups.[2b] The resultant 2-sulfido carbonyl compounds undergo copper(I)-induced[3] or oxidative thermolytic[2b] elimination of the sulfur moiety for easy regeneration of the α,β-unsaturated carbonyl groups. The β-sulfido carbonyl compounds serve as starting materials for β-acylvinyl cation[4] and homoenolate[5] equivalents. Thus, there have been significant efforts towards the development of methodologies for thia-Michael addition.[6]

In continuation of our efforts[7] to develop newer and better methodologies for thia-Michael addition reactions, we were influenced by the tight legislation on maintenance of greenness in synthetic pathways and processes, that is, to prevent generation of waste, avoid use of auxiliary substances (e.g., solvents, additional reagents) and minimise energy requirements.[8] Catalysis plays a critical role in the design, development and implementation of green chemistry[9] and solid acids are leading contenders as environmentally friendly catalysts.[10]

We have been engaged recently in developing heterogeneous catalysts derived from clays, silica and silica-supported protic acids for various organic transformations.[11] In this investigation, we present HBF_4–SiO_2[12] as a new, highly efficient and reusable heterogeneous catalyst for thia-Michael addition reactions to α,β-unsaturated carbonyl compounds (Table 1).

Excellent results were obtained in each case. The rate of the thia-Michael addition was influenced by the electronic and steric factors associated with the thiols and the α,β-unsaturated carbonyl compounds. The reactions with aryl thiols were, in general, faster compared to those of aryl alkyl and alkyl thiols. Comparison of the reactions of **1a** with **1b**, and those of **1d** with **1e–g** reveals that the introduction of an alkyl/aryl substituent at the β-carbon of the α,β-unsaturated carbonyl compounds decreases the rate of the reaction. An excellent result was obtained during the reaction of an α,β-unsaturated carboxylic acid (entry 33) that is susceptible to polymerisation in the presence of an acid catalyst. There has been only one previous report of thia-Michael addition of such substrates.[13] Reactions of β-substituted α,β-unsaturated acid/ester **1j–l** with **2a** afforded 87%, 77% and 74% yields, respectively (Table 1, entries 35–37). The catalyst can be recovered and reused after reactivation without loss of the catalytic activity.

The difference in the reaction rates encouraged us to test the efficiency of this catalyst for a few representative intermolecular competition studies (Scheme 1). A 75:25 (GCMS) selectivity was observed during the reaction of an equimolar mixture of **1a** and **1b** with **2a** and exemplified the control of selectivity by the steric

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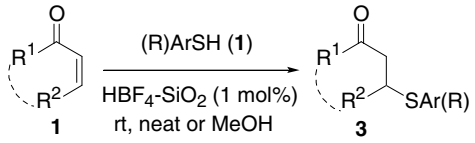
Table 1
HBF_4–SiO_2-catalysed thia-Michael addition to α,β-unsaturated carbonyl compounds[a]



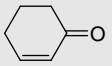
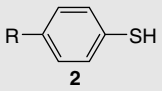
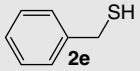
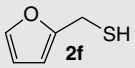
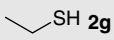
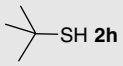
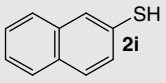
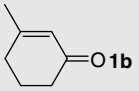
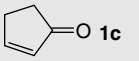
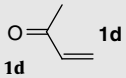
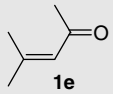
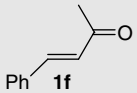
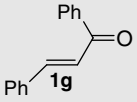
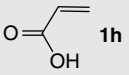
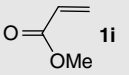
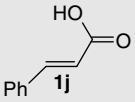
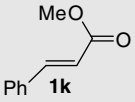
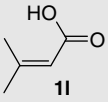
Entry	Enone	Thiol	Time (min)	Yield **3**[b,c,d] (%)
	 **1a**	 **2**		
1	**1a**	**a**: R = H	5	90
2	**1a**	**b**: R = Me	10	90
3	**1a**	**c**: R = NO_2	5	95
4	**1a**	**d**: R = F	10	90
5	**1a**	 **2e**	15	88
6	**1a**	 **2f**	15	89
7	**1a**	 **2g**	20	85
8	**1a**	 **2h**	180	78
9	**1a**	 **2i**	60	77
10	 **1b**	**2a**	240	70[e]
	 **1c**			
11	**1c**	**2a**	5	95
12	**1c**	**2b**	5	90
13	**1c**	**2c**	5	95
14	**1c**	**2e**	10	90
15	**1c**	**2f**	10	90
16	**1c**	**2g**	10	86
	 **1d**			
17	**1d**	**2a**	5	85
18	**1d**	**2b**	5	79
19	**1d**	**2e**	10	81
20	**1d**	**2f**	10	82
21	**1d**	**2g**	10	78
	 **1e**			
22	**1e**	**2a**	25	90
23	**1e**	**2b**	35	88
24	**1e**	**2e**	60	84
	 **1f**			
25	**1f**	**2a**	240	90[e]
26	**1f**	**2b**	300	85[e]
27	**1f**	**2e**	360	82[e]
	 **1g**			

Table 1 (*continued*)

Entry	Enone	Thiol	Time (min)	Yield **3**[b,c,d] (%)
28	**1g**	**2a**	45	85[f]
29	**1g**	**2b**	60	82[f]
30	**1g**	**2c**	45	88[f]
31	**1g**	**2e**	60	88[f]
32	**1g**	**2i**	180	77[f]
33	 **1h**	**2a**	15	82
34	 **1i**	**2a**	10	78[g]
35	 **1j**	**2a**	240	87[h]
36	 **1k**	**2a**	240	77
37	 **1l**	**2a**	240	78[h]

[a] The α,β-unsaturated carbonyl compound (2.5 mmol) was treated with the thiol (2.75 mmol, 1.1 equiv) in the presence of HBF_4–SiO_2 (1 mol %) at room temperature (~25 °C, except for entries 10, 25–27, 34, 35 and 37) under neat conditions (except for entries 28–32).
[b] Isolated yield of the corresponding thia-Michael adduct obtained after chromatographic purification.
[c] All the products were characterised by analysis of the spectral data (IR, ^1H and ^{13}C NMR and MS).
[d] All new compounds gave satisfactory elemental analysis.
[e] The reaction was carried out at 80 °C.
[f] The reaction was carried out in methanol.
[g] The reaction was carried out at 0 °C.
[h] The reaction was carried out at 50 °C.

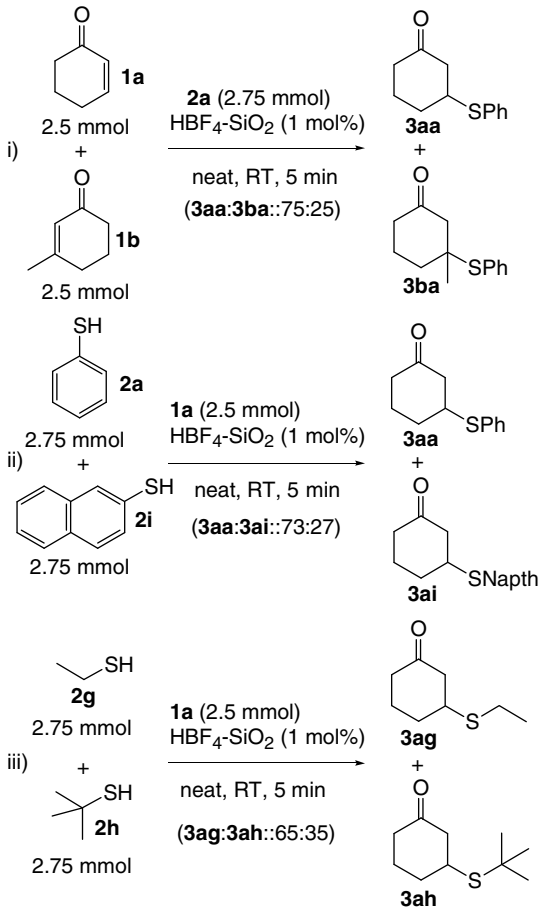
influence of the substituent at the β-position of the α,β-unsaturated carbonyl compound. The different steric factors of the thiol moiety in controlling the selectivity were demonstrated during the reaction of **1a** with equimolar mixtures of **2a** and **2i** (73:27 selectivity in favour of **2a**) and **2g** and **2h** (65:35 selectivity in favour of **2g**), respectively.

We next planned to elaborate the applicability of this methodology in the selectivity of thia- versus aza-Michael addition reactions. Thus, various chalcones were treated with 2-aminothiophenol (**2j**) and 4-aminothiophenol (**2k**) in the presence of HBF_4–SiO_2 (Table 2). In each case, selective thia-Michael addition to the α,β-unsaturated carbonyl moiety took place to form the corresponding adduct **4**. In addition, no competitive imine formation was observed.[14]

The chemoselective formation of the thia-Michael adducts in excellent yields during the reactions of 1,3-diaryl-2-propenones with **2j** gave us impetus to extend this protocol for the synthesis of benzothiazepines (Scheme 2).[15]

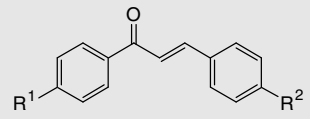
We were delighted to observe that the cyclodehydration of the intermediate thia-Michael adducts **4** occured efficiently leading to the corresponding 2,3-dihydro-1,5-benzothiazepines **5** in high yields in a one-pot reaction under reflux in MeOH (Table 3).

In conclusion, we have reported HBF_4–SiO_2 as a highly efficient heterogeneous reusable catalyst for chemoselective thia-Michael



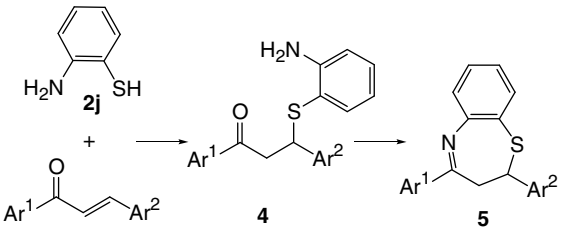
Scheme 1. Selective thia-Michael addition reaction during intermolecular competition studies.

Table 2
HBF_4–SiO_2-catalysed thia-Michael addition of **2j** and **2k** to 1,3-diaryl-2-propenone[a]

Entry	1,3-Diaryl-2-propenones	Thiol	Time (min)	Yield **4**[b,c] (%)
				
1	$R^1 = R^2 = H$	**2j**	45	83
2	$R^1 = H$; $R^2 = Cl$	**2j**	45	88
3	$R^1 = Cl$; $R^2 = H$	**2j**	40	86
4	$R^1 = H$; $R^2 = NO_2$	**2j**	45	90
5	$R^1 = H$; $R^2 = OMe$	**2j**	75	81
6	$R^1 = OMe$; $R^2 = H$	**2j**	75	87
7	$R^1 = R^2 = H$	**2k**	60	82
8	$R^1 = H$; $R^2 = NO_2$	**2k**	45	84
9	$R^1 = Cl$; $R^2 = H$	**2k**	45	87
10	$R^1 = H$; $R^2 = OMe$	**2k**	60	80
11	$R^1 = OMe$; $R^2 = H$	**2k**	60	81

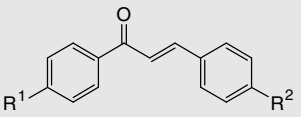
[a] The 1,3-diaryl-2-propenone (2.5 mmol) was treated with the thiol (2.75 mmol, 1.1 equiv) in the presence of HBF_4–SiO_2 (1 mol %) at room temperature (~25 °C) in MeOH (3 mL).
[b] Isolated yield of the corresponding thia-Michael adduct **4** obtained after chromatographic purification.
[c] All the products were characterised by analysis of spectral data (IR, ^1H and ^{13}C NMR and MS).

addition to α,β-unsaturated carbonyl compounds.[16] The methodology finds application in a one-pot synthesis of 2,3-dihydro-1,5-benzothiazepines.



Scheme 2. One-pot synthesis of 2,3-dihydro-1,5-benzothiazepines **5**.

Table 3
HBF_4–SiO_2-catalysed one-pot synthesis of 2,3-dihydro-1,5-benzathiazepines by reaction of 1,3-diaryl-2-propenones with **2j**[a]

Entry	1,3-Diaryl-2-propenone	Time (h)	Yield **5**[b,c] (%)
			
1	$R^1 = R^2 = H$	4	81
2	$R^1 = H$; $R^2 = Cl$	5	89
3	$R^1 = Cl$; $R^2 = H$	4	82
4	$R^1 = H$; $R^2 = NO_2$	5	88
5	$R^1 = H$; $R^2 = OMe$	6	89
6	$R^1 = OMe$; $R^2 = H$	6	87

[a] The 1,3-diaryl-2-propenone (2.5 mmol) in MeOH (3 mL) was treated with **2j** (2.75 mmol, 1.1 equiv) in the presence of HBF_4–SiO_2 (1 mol %) under reflux.
[b] Isolated yield of the corresponding 2,3-dihydro-1,5-benzothiazepine **5** obtained after chromatographic purification.
[c] All of products were characterised by analysis of spectral data (IR, ^1H and ^{13}C NMR and MS).

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References and notes

1. Fujita, E.; Nagao, Y. *Bioorg. Chem.* **1977**, *6*, 287–309.
2. (a) Fluharty, A. L. In *The Chemistry of the Thiol Group, Part 2*; Patai, S., Ed.; Wiley Interscience: New York, 1974; p 589; (b) Trost, B. M.; Keeley, D. E. *J. Org. Chem.* **1975**, *40*, 2013; (c) Kumar, A.; Salunkhe, R. V.; Rane, R. A.; Dike, S. Y. *J. Chem. Soc., Chem. Commun.* **1991**, 485–486.
3. Cohen, T.; Mura, A. J., Jr.; Shull, D. W.; Fogel, E. R.; Ruffner, R. J.; Falck, J. R. *J. Org. Chem.* **1976**, *41*, 3218–3219.
4. Bakuzia, P.; Bakuzis, M. L. F. *J. Org. Chem.* **1981**, *46*, 235–239.
5. Cherkauskas, J. P.; Cohen, T. *J. Org. Chem.* **1992**, *57*, 6–8.
6. Recent examples: (a) Chu, C.-M.; Gao, S.; Sastry, M. N. V.; Kuo, C.-W.; Lu, C.; Liu, J.-T.; Yao, C.-F. *Tetrahedron* **2007**, *63*, 1863–1871; (b) Hussain, S.; Bharadwaj, S. K.; Chaudhuri, M. K.; Kalita, H. *Eur. J. Org. Chem.* **2007**, 374–378; (c) Chu, C.-M.; Huang, W.-J.; Lu, C.; Wu, P.; Liu, J.-T.; Yao, C.-F. *Tetrahedron Lett.* **2006**, *47*, 7375–7380; (d) Karodia, N.; Liu, X.; Ludley, P.; Pletsas, D.; Stevenson, G. *Tetrahedron* **2006**, *62*, 11039–11043; (e) Maria, M.; Stefan, T. *Lett. Org. Chem.* **2006**, *3*, 794–797; (f) Kumarraja, M.; Pitchumani, K. *J. Mol. Catal. A: Chem.* **2006**, *256*, 138–142; (g) Pore, D. M.; Saodagar, M. S.; Desai, U. V.; Thopate, T. S.; Wadagaonkar, P. P. *Tetrahedron Lett.* **2006**, *47*, 9325–9328; (h) Khan, A. T.; Ghosh, S.; Choudhary, L. H. . *Eur. J. Org. Chem.* **2006**, 2226–2231; (i) Firouzabadi, H.; Iranpoor, N.; Jafarpour, M.; Ghaderi, A. *Tetrahedron Lett.* **2006**, *249*, 98–102; (j) Zahouily, M.; Mounir, B.; Charki, H.; Mezdar, A.; Bahlaouan, B.; Ouammou, M. *ARKIVOC* **2006**, *xiii*, 178–186; (k) Yang, L.; Xu, L.-W.; Xia, C.-G. *Tetrahedron Lett.* **2005**, *46*, 3279–3282; (l) Krishnaveni, N. K.; Surendra, K.; Rao, K. R. *Chem. Commun.* **2005**, 669–671; (m) Chu, C.-M.; Gao, S.; Sastry, M. N. V.; Yao, C.-F. *Tetrahedron Lett.* **2005**, *46*, 4971–4974; (n) Zhang, H.; Zhang, Y.; Liu, L.; Xu, H.; Wang, Y. *Synthesis* **2005**, 2129–2136; (o) Ranu, B. C.; Dey, S. S.; Samanta, S. *ARKIVOC* **2005**, *iii*, 44–50; (p) Firouzabadi, H.; Iranpoor, N.; Jafari, A. A. *Adv. Synth. Catal.* **2005**, *347*, 655–661; (q) Firouzabadi, H.; Iranpoor, N.; Jafari, A. A. *Synlett* **2005**, 299–303.
7. (a) Garg, S. K.; Kumar, R.; Chakraborti, A. K. *Tetrahedron Lett.* **2005**, *46*, 1721–1724; (b) Garg, S. K.; Kumar, R.; Chakraborti, A. K. *Synlett* **2005**, 1370–1374; (c) Khatik, G. L.; Kumar, R.; Chakraborti, A. K. *Org. Lett.* **2006**, *8*, 2433–2436; (d)

Sharma, G.; Kumar, R.; Chakraborti, A. K. *J. Mol. Catal. A: Chem.* **2007**, *263*, 143–148.
8. Clark, J. H. *Green Chem.* **1999**, 1–8.
9. (a) Anastas, P. T.; Bartlett, L. B.; Kirchhoff, M. M.; Williamson, T. C. *Catal. Today* **2000**, *55*, 11–22; (b) Clark, J. H. *Pure Appl. Chem.* **2001**, *73*, 103–111.
10. Wilson, K.; Clark, J. H. *Pure Appl. Chem.* **2000**, *72*, 1313–1319.
11. (a) Kumar, R.; Kumar, D.; Chakraborti, A. K. *Synthesis* **2007**, 299–303; (b) Rudrawar, S.; Besra, R. C.; Chakraborti, A. K. *Synthesis* **2006**, 2767–2771; (c) Chakraborti, A. K.; Chankeshwara, S. V. *Org. Biomol. Chem.* **2006**, *4*, 2769–2771; (d) Chankeshwara, S. V.; Chakraborti, A. K. *J. Mol. Catal. A: Chem.* **2006**, *253*, 198–202; (e) Chakraborti, A. K.; Kondaskar, A.; Rudrawar, S. *Tetrahedron* **2004**, *60*, 9085–9091; (f) Chakraborti, A. K.; Rudrawar, S.; Kondaskar, A. *Org. Biomol. Chem.* **2004**, *2*, 1277–1280; (g) Chakraborti, A. K.; Gulhane, R. *J. Chem. Soc., Chem. Commun.* **2003**, 1896–1897; (h) Chakraborti, A. K.; Gulhane, R. *Tetrahedron Lett.* **2003**, *44*, 3521–3525.
12. Fluoroboric acid adsorbed on silica-gel is not commercially available and was prepared following the procedure originally discovered by Chakraborti et al.[11h] (Chakraborti, A. K.; Gulhane, R. Indian Patent, 266/DEL/**2003** (10-3-2003)).
13. Gao, S.; Tzeng, T.; Sastry, M. N. V.; Chu, C.-M.; Liu, J.-T.; Lin, C.; Yao, C.-F. *Tetrahedron Lett.* **2006**, *47*, 1889–1893.
14. Chakraborti, A. K.; Bhagat, S.; Rudrawar, S. *Tetrahedron Lett.* **2004**, *45*, 7641–7644.
15. (a) Khatik, G. L.; Kumar, R.; Chakraborti, A. K. *Synthesis* **2007**, 541–546; (b) Khatik, G. L.; Kumar, R.; Chakraborti, A. K. *Tetrahedron* **2007**, *63*, 1200–1210.
16. *Typical experimental procedure. Preparation of HBF_4–SiO_2*:[12] A magnetically strirred suspension of silica-gel (26.7 g, 230–400 mesh, Sisco Research Laboratories Pvt. Ltd, India) in diethyl ether (75 mL) was treated with 40% aq HBF_4 (3 g) for 3 h. The mixture was concentrated and the residue dried under vacuum at 100 °C for 72 h to afford HBF_4–SiO_2 (0.5 mmol g^{-1}). *Representative experimental procedure for thia-Michael addition to an α,β-unsaturated ketone. 3-Phenylthiocyclohexanone **3aa** (Table 1, entry 1):* To a magnetically stirred mixture of 2-cyclohexen-1-one (**1a**) (0.24 g, 2.5 mmol) and thiophenol (**2a**) (0.30 g, 2.75 mmol, 1.1 equiv) was added HBF_4–SiO_2 (0.05 g, 0.025 mmol, 1 mol %) and the reaction mixture was stirred at rt (~25–30 °C) until completion of the reaction (5 min: TLC, IR). The reaction mixture was diluted with Et_2O (2 mL), filtered through a plug of cotton (to separate the catalyst), and the cotton plug was washed with Et_2O (2 × 1 mL). The combined ethereal filtrates were concentrated, adsorbed on silica gel, charged on a column of silica gel (60–120 mesh) and eluted with hexane followed by 1:10 EtOAc–hexane to afford 3-phenylthiocyclohexanone (**3aa**) (0.46 g, 90%) as a colourless oil, identical (IR, ^1H and ^{13}C NMR, and MS) with an authentic sample.[7] In a large-scale batch, **1a** (5.0 g, 52 mmol) was treated with **2a** (6.3 g, 57.2 mmol, 1.1 equiv) in the presence of HBF_4–SiO_2 (1.04 g, 0.52 mmol, 1 mol %) to afford **3aa** (9.5 g, 89%) after work-up and purification. The cotton plug retaining the recovered catalyst was put on a round bottomed flask (50 mL) and dried in a rotary evaporator during which the catalyst separated out from the cotton. The catalyst was activated on heating under reduced pressure (10 mm Hg) at 80 °C for 24 h. Repetition of the reaction of **1a** (2.5 g, 26 mmol) with **2a** (3.1 g, 28.6 mmol, 1.1 equiv) in the presence of recovered HBF_4–SiO_2 (0.52 g, 0.26 mmol, 1 mol %) afforded **3aa** (4.6 g, 86%) after work-up and purification. No decrease in the catalytic activity was observed after four consecutive uses of the recovered catalyst (yield after third and fourth uses are 85% and 88%, respectively). *Representative experimental procedure for the intermolecular competition reaction (Scheme 1):* To a magnetically stirred mixture of **1a** (0.24 g, 2.5 mmol), 3-methyl-2-cyclohexen-1-one **1b** (0.27 g, 2.5 mmol) (2) and **2a** (0.30 g, 2.75 mmol, 1.1 equiv) was added HBF_4–SiO_2 (0.05 g, 0.025 mmol, 1 mol %) and the reaction mixture was stirred at rt (~25–30 °C) for 5 min. The reaction mixture was diluted with Et_2O (2 mL), filtered through a plug of cotton (to separate the catalyst), and the cotton plug was washed with Et_2O (2 × 1 mL). The combined ethereal filtrates were concentrated and the isolated reaction mixture, without further purification, was subjected to GCMS which indicated 75:25 selectivity in favour of the formation of **3aa**. *Representative experimental procedure for the intra-molecular competition of thia- vs aza-Michael addition reactions (Table 2, entry 1):* To a magnetically stirred mixture of 1,3-diphenylpropenone (**1g**) (0.21 g, 1 mmol) and 2-aminothiophenol (**2j**) (0.14 g, 1.1 mmol, 1.1 equiv) in MeOH (3 mL) was added HBF_4–SiO_2 (0.02 g, 0.01 mmol, 1 mol %) at rt (~25–30 °C). After 45 min, the reaction mixture was diluted with EtOAc (5 mL), filtered through a plug of cotton (to separate the catalyst), and the cotton plug was washed with EtOAc (2 × 1 mL). The combined filtrates were concentrated, and the solid residue crystallised (EtOH) to afford 0.27 g (83%) of 3-(2-amino-phenylsulfanyl)-1,3-diphenyl-propan-1-one (**4a**) as the sole product indicating exclusive selectivity for thia-Michael addition over aza-Michael addition. *One-pot synthesis of 2,3-dihydro-2,4-diphenyl-1,5-benzothiazepine (Table 3, entry 1):* To a magnetically stirred mixture of **1g** (0.21 g, 1 mmol) and **2j** (0.14 g, 1.1 mmol, 1.1 equiv) in MeOH (3 mL) was added HBF_4–SiO_2 (0.02 g, 0.01 mmol, 1 mol %) and the reaction mixture was stirred under reflux until completion of the reaction (4 h: TLC, IR). The reaction mixture was diluted with EtOAc to dissolve the product (5 mL), filtered through a plug of cotton (to separate the catalyst), and the cotton plug was washed with EtOAc (2 × 1 mL). The combined filtrates were concentrated and purification was accomplished by column chromatography (silica gel #60-120) to afford 2,3-dihydro-2,4-diphenyl-1,5-benzothiazepine (**5a**) (0.25 g, 81%) as a yellow solid identical (mp, IR, ^1H and ^{13}C NMR, and MS) with an authentic sample.[15] *Spectral data of new compounds. 3-(4-Fluorophenylsulfanyl)-cyclohexanone (Table 1, entry 4)*: IR (neat) ν_{max} 1712, 1588, 1489 cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ: 1.70–1.76 (m, 2H), 2.12–2.14 (m, 2H), 2.30–2.38 (m, 3H), 2.61–2.66 (m, 1H), 3.32–3.33 (m, 1H), 6.99–7.05 (m, 2H), 7.41–7.45 (m, 2H). ^{13}C NMR ($CDCl_3$, 75 MHz) δ: 24.5, 31.6, 41.3, 47.3, 48.1, 116.5, 116.8, 128.4, 136.6, 161.7, 165.0, 209.1. Anal. Calcd for $C_{12}H_{13}FOS$: C, 64.26; H, 5.84; S, 14.30. Found: C, 64.30; H, 5.88; S, 14.33. *3-(Naphthalen-2-ylsulfanyl)-cyclohexanone (Table 1, entry 9)*: IR (neat) ν_{max} 1751, 1712, 1628 cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ: 1.73–1.76 (m, 2H), 2.13–2.43 (m, 5H), 2.69–2.72 (m, 1H), 3.51–3.54 (m, 1H), 7.47–7.49 (m, 2H), 7.74–7.89 (m, 5H). ^{13}C NMR ($CDCl_3$, 75 MHz) δ: 26.2, 31.8, 41.4, 46.6, 48.3, 127.1, 128.0, 128.2, 129.2, 130.5, 130.8, 132.7, 133.1, 134.1, 151.1, 209.2. MS (MALDI-TOF) m/z 256.4 (MH^+). Anal. Calcd for $C_{16}H_{16}OS$; C, 74.96; H, 6.29; S, 12.51. Found: C, 74.93; H, 6.32; S, 12.49. *3-(Naphthalen-2-ylsulfanyl)-1,3-diphenylpropan-1-one (Table 1, entry 32)*: IR (KBr) ν_{max} 1684, 1595, 1448 cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ: 3.57–3.74 (m, 2H), 5.08 (t, J = 6.9 Hz, 1H), 7.16–7.25 (m, 3H), 7.36–7.46 (m, 7H), 7.53 (t, J= 7.2 Hz, 1H), 7.68–7.78 (m, 4H), 7.87 (d, J = 7.6 Hz, 2H). ^{13}C NMR ($CDCl_3$, 75 MHz) δ: 45.2, 48.7, 122.7, 126.8, 126.9, 128.0, 128.1, 128.4, 128.6, 128.9, 129.0, 129.1, 130.4, 132.1, 132.3, 133.0, 133.8, 134.1, 141.7, 145.4, 197.5. MS (APCI) m/z 209.1, 249.2, 368.9 (MH^+). Anal. Calcd for $C_{25}H_{20}OS$: C, 81.49; H, 5.47; S, 8.70. Found: C, 81.53; H, 5.49; S, 8.68.