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# Silica sulfuric acid catalyzed an efficient and green protocol for the synthesis of 2-amino-5-aryl-1, 3, 4-thiadiazole

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**Abstract**
This study has been undertaken to investigate an efficient and green protocol for the cyclocondensation of substituted aromatic carboxylic acids 1a-i and thiosemicarbazide 2 under solvent-free conditions using silica sulfuric acid (SSA) as a catalyst. Mild reaction conditions with high yield, fast rate of reaction, avoidance of toxic acids, Reusability of catalysts are significant advantages which make this method safe, convenient, economical and environmentally friendly for synthesis of 2-amino-5-aryl-1, 3, 4-thiadiazole 3a-i. The structures of the compounds have been confirmed by $^{1}$H-NMR, $^{13}$C-NMR & FT-IR spectroscopic techniques.

**Keywords:** Carboxylic acid, silica sulfuric acid, Solvent-free, 1, 3, 4-thiadiazole, thiosemicarbazide

## Introduction
Thiadiazole is a versatile compound that shows a wide spectrum of biological activities. 1, 3, 4-Thiadiazole nuclei are known to exhibit antimicrobial [1], anti-inflammatory [2], anticancer [3], anticonvulsant [4], antioxidant [5], antihypertensive [6], antinociceptive [7] and antifungal [8] activities. Therefore, it has been considered beneficial to either synthesize new 1, 3, 4-thiadiazole derivatives or develop new, simple, and environmentally friendly routes for the synthesis of thiadiazole compounds. Typically, 2-amino, 5-aryl thiadiazole have been prepared by reacting benzoic acid with semithiocarbazide in the presence of strong acids such as phosphorus oxychloride [9] or conc. $H_2SO_4$ [9].
Recently, silica sulfuric acid ($SiO_2$-$OSO_3H$, SSA) has been used as a versatile catalyst in organic synthesis due to its environmental, economic and industrial aspects [10]. It is due to its reusability, environmental compatibility, low cost, non-toxicity, ease of handling and the simple reaction work up in most cases. SSA works readily in various protic acid catalyzed conventional reactions by replacing homogeneous catalysts. These include protection reactions/preservation reactions [11], multicomponent synthesis [12], condensation reactions [13], etc. Further, SSA is also used as dehydrating agent to accelerate the intra/inter molecular cyclization [14]. Many heterocyclic rings have been prepared using silica sulfuric acid such as flavones [15], oxazolines and imidazolines [16], benzimidazoles [17], pyrroles [18], etc. Silica sulfuric acid is prepared at room temperature easily by the reaction of silica gel with chlorosulfonic acid [19].
In search of a green methodology for the synthesis of 2-amino-5-aryl-1, 3, 4-thiadiazoles, herein we wish to report a facile, green and environmentally-friendly protocol using silica sulfuric acid as a solid-supported acid catalyst under solvent-free conditions (Fig.1).

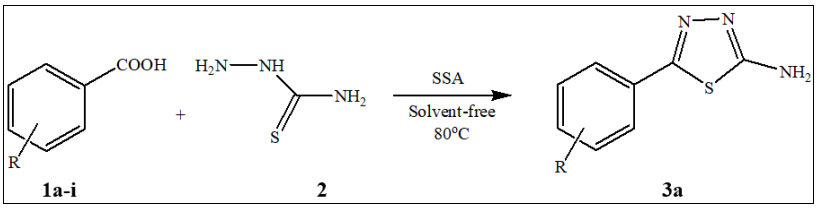


**Fig 1:** Synthesis of 2-Amino-5-phenyl-1, 3, 4-thiadiazole (3a)

## Materials and Methods

All the chemicals were obtained from Aldrich Chemical Co. and were used without further purification. Melting points determined in open capillaries using Toshnwal melting point apparatus and were uncorrected. IR spectra were recorded on an FT-IR-Alpha Bruker IR spectrometer in KBr pellets. The $^{1}$H-and $^{13}$C-NMR spectra were recorded on 500 MHz using AV500- High Resolution Multinuclear FT-NMR Spectrometer in $CDCl_3$ using tetramethylsilane as internal standard.

General Procedure for the synthesis of 5-Phenyl-1,3,4-thiadiazol-2-amine (3a). A mixture of benzoic acid 1a (0.1 mol), thiosemicarbazide 2 (0.1 mol) and silica sulfuric acid (0.1 gm) was heated in solvent-free condition for the appropriate time according to Table 2. After completion of reaction (monitored by TLC), the reaction mixture was cooled to room temperature and absolute ethanol (20 mL) was added. The solid catalyst was filtered by simple filtration and the product was isolated from filtrate by removal of ethanol under vacuum. The pure product 3a was obtained by recrystalization from ethanol. IR [(KBr) λmax/cm$^{-1}$]: 3354 and 3256 (-$NH_2$), 3087 (C–H, Ar), 1632 (C=N); $^{1}$H-NMR ($CDCl_3$, δ ppm): 7.2–7.4 (m, 5H), 7.2 (s, 2H); $^{13}$C-NMR ($CDCl_3$, δ ppm): 175.2 (1C, thiadiazole-$C_5$), 161.3 (1C, thiadiazole- $C_2$), 131.2 (1C), 127.4 (1C), 125.7 (1C), 124.2 (1C), 123.7 (1C), 122.1 (1C); ESI-MS (*m/z*): 177.4 ($M^+$); Anal. calcd. (%) for $C_8H_7N_3S$: C, 54.22; H, 3.98; N, 23.71, S, 18.09; found (%): C, 54.09; H, 3.99; N, 23.67; S, 18.01.

### 5-(4-nitrophenyl)-1,3,4-thiadiazol-2-amine (3b)

IR [(KBr) λmax/cm$^{-1}$]: 3366 and 3261 ($NH_2$ str), 3072 (C-H, Ar), 1627 (C=N str), 1603 and 1448 ($NO_2$ str); $^{1}$H-NMR ($CDCl_3$, δ ppm): 7.74 (s, 2H), 8.03 (d, 2H), 8.32 (d, 2H); $^{13}$C-NMR ($CDCl_3$, δ ppm): 170.8 (1C, thiadiazole-$C_5$), 154.1 (1C, thiadiazole- $C_2$), 148.2 (1C, Ar-$C_4$), 136.9 (1C, Ar-$C_1$), 127.5 (2C, Ar-$C_3$, $C_5$), 125.2 (2C, Ar-$C_2$, $C_6$); ESI-MS (*m/z*): 223.3 (M+**1**)$^+$; Anal. Calcd. (%) for $C_8H_6N_4O_2S$: C, 43.24; H, 2.72; N, 25.21; O, 14.40; S, 14.43; found (%): C, 43.16; H, 2.64; N, 25.14; O, 14.37; S, 14.35.

### (4-Bromophenyl)-1, 3, 4-thiadiazol-2-amine (3c)

IR [(KBr) λmax/cm$^{-1}$]: 3386 and 3279 ($NH_2$ str), 3066 (C-H, Ar), 1635 (C=N str), 887 (C-S-C str), 689 (C-Br str); $^{1}$H-NMR ($CDCl_3$, δ ppm): 7.48 (s, 2H), 7.65-7.67 (m, 2H), 7.71-7.73 (m, 2H); $^{13}$C-NMR ($CDCl_3$, δ ppm): 173.3 (1C, thiadiazole-$C_5$), 162.6 (1C, thiadiazole- $C_2$), 133.1 (1C, Ar-$C_1$), 131.8 (2C, Ar-$C_3$, $C_5$), 129.1 (2C, Ar- $C_2$, $C_6$), 123.0 (1C, Ar- $C_4$); ESI-MS (*m/z*): 255.03 ($M^+$); Anal. calcd. (%) for $C_8H_6BrN_3S$: C, 37.52; H, 2.36; Br, 31.20; N, 16.41; S, 12.52; found (%): C, 37.46; H, 2.32; Br, 31.17; N, 16.40; S, 12.48.

### 5-(4-Fluorophenyl)-1,3,4-thiadiazol-2-amine (3d)

IR [(KBr) λmax/cm$^{-1}$]: 3359 and 3267 ($NH_2$ str), 3049 (C-H, Ar), 1627 (C=N str), 1051 (C-F str), 869 (C-S-C str, thiadiazole); $^{1}$H-NMR ($CDCl_3$, δ ppm): 7.31-7.33 (m, 2H), 7.45 (s, 2H), 7.79-7.81 (m, 2H); $^{13}$C-NMR ($CDCl_3$, δ ppm): 175.2 (1C, thiadiazole-$C_5$), 163.1 (1C, Ar- $C_4$) 162.2 (1C, thiadiazole- $C_2$), 130.3 (2C, Ar- $C_2$, $C_6$), 129.8 (1C, Ar-$C_1$), 117.1 (2C, Ar-$C_3$, $C_5$); ESI-MS (*m/z*): 195.3 ($M^+$); Anal. calcd. (%) for $C_8H_6FN_3S$: C, 49.22; H, 3.10; N, 21.52; S, 16.43; found (%): C, 49.12; H, 3.08; N, 21.45; S, 16.39.

### 5-(4-Chlorophenyl)-1, 3, 4-thiadiazol-2-amine (3e)

IR [(KBr) λmax/cm$^{-1}$]: 3369 and 3258 ($NH_2$ str), 3069 (C-H, Ar), 1624 (C=N str), 882 (C-S-C str), 759 (C-Cl str); $^{1}$H-NMR ($CDCl_3$, δ ppm): 7.47 (s, 2H), 7.53-7.56 (d, 2H), 7.73-7.76 (d, 2H); $^{13}$C-NMR ($CDCl_3$, δ ppm): 174.6 (1C, thiadiazole-$C_5$), 162.1 (1C, thiadiazole-$C_2$), 134.9 (1C, Ar-$C_4$), 131.8 (1C, Ar-$C_1$), 129.7 (2C, Ar-$C_3$, $C_5$), 127.8 (2C, Ar-$C_2$, $C_6$); ESI-MS (*m/z*): 211.06 ($M^+$); Anal. calcd. (%) for $C_8H_6ClN_3S$: C, 45.39; H, 2.86; Cl, 16.75; N, 19.85; S, 15.15; found (%): C, 45.31; H, 2.80; Cl, 16.69; N, 19.78; S, 15.11.

### 5-(3- Chlorophenyl)-1, 3, 4-thiadiazol-2-amine (3f)

IR [(KBr) λmax/cm$^{-1}$]: 3349 and 3251 ($NH_2$ str), 3072 (C-H, Ar), 1627 (C=N str), 885 (C-S-C str), 764 (C-Cl str); $^{1}$H-NMR ($CDCl_3$, δ ppm): 7.43 (s, 2H), 7.51-7.54 (m, 3H), 7.69-7.72 (m, 1H); $^{13}$C-NMR ($CDCl_3$, δ ppm): 175.3 (1C, thiadiazole-$C_5$), 161.9 (1C, thiadiazole-$C_2$), 134.6 (1C), 133.8 (1C), 130.6 (1C), 129.8 (1C), 127.5 (1C), 125.2 (1C); ESI-MS (*m/z*): 211.13 ($M^+$); Anal. calcd. (%) for $C_8H_6ClN_3S$: C, 45.39; H, 2.86; Cl, 16.75; N, 19.85; S, 15.15; found (%): C, 45.30; H, 2.82; Cl, 16.67; N, 19.80; S, 15.12.

### 5-(4-Hydroxyphenyl)-1, 3, 4-thiadiazol-2-amine (3g)

IR [(KBr) λmax/cm$^{-1}$]: 3442 (O-H str, bs), 3362 and 3144 ($NH_2$ str), 1642 (C=N str), 1074 (C-O str), 888 (C-S-C str, thiadiazole); $^{1}$H NMR ($CDCl_3$, δ ppm) 2.52 (s, 3H), 7.2 (d, 2H), 7.31 (s, 2H), 7.56-7.58 (d, 2H); $^{13}$C-NMR ($CDCl_3$, δ ppm): 173.7 (1C, thiadiazole-$C_5$), 161.5 (1C, thiadiazole-$C_2$), 158.0 (1C, Ar-$C_4$), 128.2 (2C, Ar-$C_2$, $C_6$), 125.4 (1C, Ar-$C_1$), 116.1 (2C, Ar-$C_3$, $C_5$); ESI-MS (*m/z*): 193.2 ($M^+$); Anal. Calcd. (%) for $C_8H_7N_3OS$: C, 49.73; H, 3.65; N, 21.75; S, 16.60; found (%): C, 49.66; H, 3.62; N, 21.72; S, 16.59.

### 5-(4-Methoxyphenyl)-1, 3, 4-thiadiazol-2-amine (3h)

IR [(KBr) λmax/cm$^{-1}$]: 3386 and 3172 ($NH_2$ str), 3081 (C-H str, Ar), 2952 (C-H str, aliphatic), 1641 (C=N str), 1072 (C-O, str), 887 (C-S-C str, thiadiazole); $^{1}$H NMR ($CDCl_3$, δ ppm) 3.81 (s, 3H), 7.01-7.04 (m, 2H), 7.28 (s, 2H), 7.67-7.69 (m, 2H); $^{13}$C-NMR ($CDCl_3$, δ ppm): 174.7 (1C, thiadiazole-$C_5$), 162.2 (1C, thiadiazole-$C_2$), 158.0 (1C, Ar-$C_4$), 127.3 (2C, Ar-$C_2$, $C_6$), 125.0 (1C, Ar-$C_1$), 114.1 (2C, Ar-$C_3$, $C_5$); 56.2 (O-$CH_3$); ESI-MS (*m/z*): 207.3 ($M^+$); Anal. calcd. (%) for $C_9H_9N_3OS$: C, 52.16; H, 4.38; N, 20.75; S, 15.47; found (%): C, 52.09; H, 2.34; N, 20.71; S, 15.44.

### 5-(4-Methylphenyl)-1, 3, 4-thiadiazol-2-amine (3i)

IR [(KBr) λmax/cm$^{-1}$]: 3381 and 3177 ($NH_2$ str), 3069 (C-H str, Ar), 2937 (C-H str, aliphatic), 1638 (C=N str), 892 (C-S-C str, thiadiazole); $^{1}$H NMR ($CDCl_3$, δ ppm): 2.34 (s, 3H), 7.28 (d, 2H), 7.37 (s, 2H), 7.67 (d, 2H); $^{13}$C NMR ($CDCl_3$, δ ppm): 173.4 (1C, thiadiazole-$C_5$), 162.9 (1C, thiadiazole-$C_2$), 131.2 (1C, Ar-$C_4$), 130.4 (1C, Ar-$C_1$), 128.3 (2C, Ar-$C_3$, $C_5$); 126.1 (2C, Ar-$C_2$, $C_6$), 22.0 (-$CH_3$); ESI-MS (*m/z*): 191.5 (M+); Anal. calcd. (%) for $C_9H_9N_3S$: C, 56.52; H, 4.74; N, 21.97; S, 16.77; found (%): C, 56.44; H, 4.72; N, 21.93; S, 16.75.

## Results and Discussion

An efficient and green protocol for the cyclocondensation of substituted aromatic carboxylic acids and

thiosemicarbazides under solvent-free conditions using silica sulfuric acid (SSA) as a catalyst is described. The optimization of reaction was carried out by reacting benzoic acid 1a with thiosemicarbazide 2 to find out the effect of various parameters such as reaction solvent, amount of catalyst and temperature (Table 1).

**Table 1:** Optimization of the reaction conditions for the silica sulfuric acid catalyzed reaction of benzoic acid (1a) with thiosemicarbazide (2).

| Entry | SSA (gm) | Solvant | Temp. (ºC) | Time (hrs) | Yield (%)[a] |
|---|---|---|---|---|---|
| 1 | 0.1 | Ethanol | Reflux | 12 | 12 |
| 2 | 0.1 | Acetone | Reflux | 12 | 16 |
| 3 | 0.1 | Acetonitrile | Reflux | 16 | 20 |
| 4 | 0.1 | Solvent-free | 80 | 4 | 88 |
| 5 | 0.1 | Solvent-free | 60 | 6 | 53[b] |
| 6 | 0.15 | Solvent-free | 80 | 4 | 86 |
| 7 | 0.2 | Solvent-free | 60 | 6 | 61[b] |
| 8 | 0.2 | Solvent-free | RT | 8 | 34[b] |

[a] Isolated yield.
[b] No further progress was found even after 24 hrs.

The effect of solvents like ethanol, acetone and acetonitrile was observed along with solvent-free condition and it was found that solvent-free condition gave the best results as shown in Table 1 (Entry 5). The optimal temperature of reaction was 80 °C (Entry 4), while the reaction was incomplete at lower temperatures even at higher reaction times (Entry 5, 7). Further, increasing the amount of catalyst had no effect on the product yield, but decreasing the amount decreased the yield.

**Table 2:** Physical properties of 2-Amino-5-phenyl-1, 3, 4-thiadiazoles 3a-h

| Compound | R | Molecular Formula | Molecular Weight | M P (ºC) | Yield (%)[a] |
|---|---|---|---|---|---|
| 3a | H | $C_8H_7N_3S$ | 177 | 221-222 | 88 |
| 3b | 4-$NO_2$ | $C_8H_6N_4O_2S$ | 222 | 248-249 | 79 |
| 3c | 4-Br | $C_8H_6BrN_3S$ | 256 | 229-230 | 94 |
| 3d | 4-F | $C_8H_6FN_3S$ | 195 | 233-234 | 91 |
| 3e | 4-Cl | $C_8H_6ClN_3S$ | 211 | 226-227 | 92 |
| 3f | 3-Cl | $C_8H_6ClN_3S$ | 211 | 207-208 | 82 |
| 3g | 2-OH | $C_8H_7N_3OS$ | 193 | 175-177 | 83 |
| 3h | 4-$OCH_3$ | $C_9H_9N_3OS$ | 207 | 211-213 | 81 |
| 3i | 4-$CH_3$ | $C_9H_9N_3S$ | 191 | 197-198 | 89 |

[a] Isolated yield.

The nature of the substitution of the aromatic carboxylic acid has a significant effect on the product yield and reaction time (Table 2). Carboxylic acids with electron-withdrawing groups give the desired product in high yields with short reaction times, while an aromatic ring with electron-donating groups such as hydroxy and ethoxy groups gives low yields with high reaction times. The yield and melting point of the synthesized compounds 3a-h was observed and given in Table 2.

The synthesized compounds 3a-h were characterized by infrared, $^1$H and $^{13}$C-NMR, and mass spectroscopic techniques. The infrared spectra of all the compounds clearly showed a strong and broad band at the region of 3150-3200 $cm^{-1}$ which confirm the presence of $–NH_2$ group and a strong C=N stretching band around 1610-1620 $cm^{-1}$. An absorption band around 680 $cm^{-1}$ for C-S-C linkage indicates the formation of 1, 3, 4-thiadiazole ring. The 1H-NMR spectra of compounds 3a-h showed a broad singlet for two protons of $–NH_2$ group. $^{13}$C-NMR signals of carbon atoms also confirms the formation of 1, 3, 4-thiadiazole ring.

## Conclusion

In conclusion, we have developed an efficient and green protocol for the cyclocondensation of substituted aromatic carboxylic acids and thiosemicarbazides under solvent-free conditions using silica sulfuric acid (SSA) as a catalyst. Mild reaction conditions with high yield, fast rate of reaction, avoidance of toxic acids, reusability of catalysts are significant advantages which make this method safe, convenient, economical and environmentally friendly for synthesis of 2-amino-5-aryl-1,3,4-thiadiazole.

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## References

1. Zamani K, Faghili K, Mehranjani MS. Synthesis of some new 2,5-disubstituted 1,3,4-thiadiazoles containing isomeric pyridyl as potent antimicrobial agents. Polish Journal of Pharmacology. 2003;55:1111-1117.
2. Gazzar AE, Hegab MI. A facile regioselective synthesis of novel spiro-thioxanthene and spiro-xanthene-9',2-[1,3,4]thiadiazole derivatives as potential analgesic and anti-inflammatory agents. Bioorganic and Medicinal Chemistry Letters. 2008;18:4538-4543.
3. Dayam R, Aiello F, Deng J, Wu Y, Garofalo A, Chen X, *et al*. Discovery of small molecule integrin $\alpha_v\beta_3$ antagonists as novel anticancer agents. Journal of Medicinal Chemistry. 2006;49:4526-4534.
4. Gupta A, Mishra P, Pandeya SN, Kashaw SK, Kashaw V, Stables JP. Synthesis and anticonvulsant activity of some substituted 1, 2, 4-thiadiazoles. European Journal of Medicinal Chemistry. 2009;44:1100-1105.
5. Baldwin JJ, Engelhardt EL, Hirschmann R, Ponticella GS, Atkinson JG, Wasson BK, *et al*. Heterocyclic analogues of the antihypertensive β-adrenergic blocking agent (S)-2-[3-(tert-butylamino)-2-hydroxypropoxy]-3-cyanopyridine. Journal of Medicinal Chemistry. 1980;23:65-70.
6. Turner S, Myers M, Gadie B, Hale SA, Horsley A, Nelson AJ, *et al*. Antihypertensive thiadiazoles. 2. Vasodilator activity of some 2-aryl-5-guanidino-1,3,4-thiadiazoles. Journal of Medicinal Chemistry. 1988;31:906-913.
7. Kucukguzel SG, Kucukguzel I, Tatar E, Rollas S, Sachin F, Gulluce M, *et al*. Synthesis of some novel heterocyclic compounds derived from diflunisal hydrazide as potential anti-infective and anti-inflammatory agents. European Journal of Medicinal Chemistry. 2007;42:893-901.
8. Kumar D, Kumar NM, Chang K-H, Shah K. Synthesis and anticancer activity of 5-(3-indolyl)-1,3,4-thiadiazoles. European Journal of Medicinal Chemistry. 2010;45:4664-4668.
9. Keerthi Kumar CT, Keshavayya J, Rajesh TN, Peethambar SK, Ali ARS. Synthesis, characterization, and biological activity of 5-phenyl-1, 3, 4-thiadiazole-2-amine incorporated azo dye derivatives. Organic Chemistry International 2013; Article ID. 370626.

10. Tamagaki S, Card RJ, Neckers DC. (Poly styrylpyridine) (Tetracarbonyl) tungsten. An active, reusable heterogeneous catalyst for metathesis of internal olefins. Journal of American Chemical Society. 1978;100:6635-6639.
11. Gawande MB, Polshettiwar V, Rajender RS, Jayaram RV. An efficient and chemoselective cbz-protection of amines using silica-sulfuric acid at room temperature. Tetrahedron Letters. 2007;48:8170-8173.
12. Shaterian HR, Ghashang M, Feyzi M. Silica sulfuric acid as an efficient catalyst for the preparation of 2*H*-indazolo 2,1-b phthalazine-triones. Applied Catalysis A. 2008;345:128-133.
13. Veisi H. Silica sulfuric acid (SSA) as a solid acid heterogeneous catalyst for one-pot synthesis of substituted pyrroles under solvent-free conditions at room temperature. Tetrahedron Letters. 2010;51:2109-2114.
14. Saheli P, Dabiri M, Zolfigol MA, Baghbanzadeh M. A new approach to the facile synthesis of mono- and disubstituted quinazolin-4(3*H*)-ones under solvent-free conditions. Tetrahedron Letters. 2005;46:7051-7053.
15. Ramana MMV, Nimkar AP; Betkar RR, Ranade PB. Silica sulphuric acid: An efficient reusable, heterogeneous acidic media for synthesis of flavones (2-aryl-4*H*-chromen-4-one) by cyclocondensation of *o*-hydroxyphenyl aryl-1,3-propanediones. International Journal of Pharmaceutical Sciences and Research. 2014;25:202-204.
16. Baltork IM, Mirkhani V, Moghadam M, Tangestaninejad S, Zolfigol MA, Alibeik MA, *et al*. Silica sulfuric acid: A versatile and reusable heterogeneous catalyst for the synthesis of oxazolines and imidazolines under various reaction conditions, Catalysis Communications. 2008;9:894-901.
17. Sadeghi B, Nejad MG. Silica sulfuric acid: an ecofriendly and reusable catalyst for synthesis of benzimidazole derivatives. Journal of Chemistry. 2013;2012:1-5.
18. Azizian J, Karimi AR, Kazemizadeh Z, Mohammadi AA, Mohammadizadeh MR. Silica sulfuric acid-catalyzed reaction of 4-hydroxy proline with 11*H*-indeno 1, 2-β-quinoxalin-11-one and isatin derivatives: A novel synthesis of new pyrrole compounds. Synthesis. 2005;7:1095-1098.
19. Zolfigol MA. Silica sulfuric acid/$NaNO_2$ as a novel heterogeneous system for production of thionitrites and disulfides under mild conditions. Tetrahedron. 2001;57:9509-9511.