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Pd-catalyzed C–N coupling of vinylbromides and sulfonimidamides: a facile synthesis of *N*′-vinylsulfonimidamides†

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N′-Vinyl sulfonimidamides have been synthesized through a Pd-catalyzed C–N cross coupling between the *N*′-(imine nitrogen) of *N*′-deprotected sulfonimidamides and vinyl bromides. The hitherto unreported products were obtained in moderate to excellent yield, and the C–C double bond geometry of the vinylic substrates were retained during the course of reaction. Single crystal X-ray crystallographic analysis confirmed the product structure. Furthermore, we demonstrate that the formed *N*′-vinyl sulfonimidamides could undergo hydrogenation with Pd–C/H_2 to provide *N*′-alkyl sulfonimidamides.

Introduction

As part of our ongoing research project on sulfonimidamides and acyl sulfonimidamides as bioisosteres in medicinal chemistry,[1] we recently disclosed new synthetic protocols for preparation and modification of this functional group. In our first report,[2a] we used a Pd-catalyzed Buchwald-Hartwig[2f,g] C–N coupling procedure for the arylation of the *N*′-(imine nitrogen) of sulfonimidamides. Subsequently, we reported the synthesis of *N*-acylated sulfonimidamides *via* Pd-catalyzed amidocarbonylation of vinyl/aryl halides and triflates.[2b,c] We have also reported *N*′-arylation *via* Cu-mediated Chan–Lam–Evans coupling,[2d] and *N*-alkynylation through a Cu-catalyzed dual N–H/C–H activation protocol.[2e] Herein, we explore the Pd-catalyzed C–N coupling of various vinyl bromides to the *N*′-(imine nitrogen) of unprotected sulfonimidamides.

Although Levchenko *et al.*,[3] reported the synthesis of sulfonimidamides already in 1960, the interest in this functional group has remained low until quite recently. However, during the last decade, attention on this functional group has increased tremendously, both in the area of synthetic methodology and for applications in medicinal chemistry and agrochemistry. Some research groups applied sulfonimidamides as a reagent in organic synthesis, mainly as a 'N'-source for metal-catalyzed nitrene transfer reactions, for imination of sulfides, aziridination of olefins, and C–H aminations of hydrocarbons.[4] Additionally, sulfonimidamides have been used as organocatalysts and as chiral ligands in asymmetric synthesis; more recently they have been used in the iridium-catalyzed asymmetric hydrogenation of cyclic enamides.[5] Sulfonimidamide functional groups have also been used as analogues of oncolytic sulfonylureas, sodium channel antagonists, pesticidal agents, and as transition state analogue inhibitors of aspartic acid metalloproteases.[6] Even more recently, other groups, in addition to ours, have reported the synthetic methodology for sulfonimidamide functionalization and preparation.[7] Given the growing bio- and synthetic importance of sulfonimidamides, we became interested in attempting to prepare *N*-vinyl sulfonimidamides following the Pd-catalyzed Buchwald–Hartwig[8] C–N coupling procedure. To the best of our knowledge, there is no report on the synthesis of *N*-vinyl sulfonimidamides through any methodology.

The *N*-alkenyl functional group represent a very versatile class of olefinic compounds as the electron releasing ability of the nitrogen lone pair strongly polarizes the double bond; thereby offering high levels of reactivity in combination with strong differentiation of the two sp^2 carbon atoms. In fact, this reactivity of *N*-alkenyls is the basis for enamine activation in the very fruitful research area of organocatalysis[9–11] – another area of interest in our research group. Consequently, *N*-alkenyl functional groups are widely used as synthetic intermediates in the preparation of heterocycles[12] and in asymmetric synthesis of amides and amino acids.[13] In addition, *N*-alkenyl functional groups can be found in many natural products, that include

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anti-anthelmintic chondriamides,[14] cytotoxic tripeptide caspergillamides,[15] protease inhibitors TMC-95-A-D,[16] antibiotic CJ-15801,[17] anti-inflammatory frangufoline,[18] as well as anti-tumor lobatomide A–F,[19] salicylihalamide A and related compounds.[20]

Results and discussion

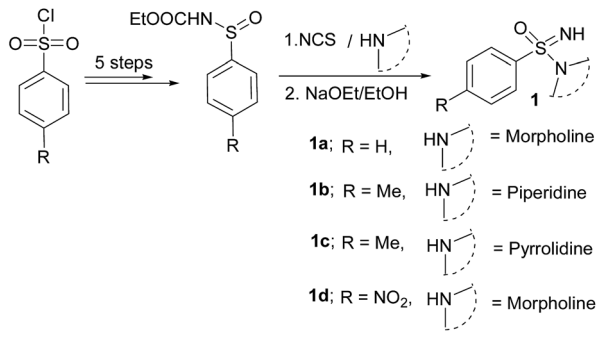
The starting sulfonimidamides were not commercially accessible, and hence prepared according to literature procedures (Scheme 1).[2a,21]

We commenced our studies with the reaction of sulfonimidamide **1a** and 1-(1-bromovinyl)-4-chlorobenzene as model substrates for optimization and the results have been depicted in Table 1. First, we attempted our previously reported reaction condition[2a] (Table 1, entry 1) for *N*-arylation of sulfonimidamide [*i.e.* catalyst Pd(PhCH$_2$CH$_2$NH$_2$)(Cl) (RuPhos) and NaO^{t}Bu base in THF under MW irradiation at 100 °C]; surprisingly, this did not lead to any detectable *N*′-vinylated product. Next, we attempted the model reaction with the catalyst Pd$_2$(dba)$_3$ (1 mol%), ligand BINAP (1.5 mol%), base NaO^{t}Bu (1.5 equiv.) in toluene at 100 °C for 12 h; gratifyingly, these reaction conditions gave 78% of the expected product with some unreacted starting materials (Table 1, entry 2). A longer reaction time did not improve the yield of the reaction, but performing the reaction at 110 °C, provided 92% of isolated product within 4 h (Table 1, entry 3). Pd(OAc)$_2$ was found to be similarly effective as Pd$_2$(dba)$_3$ and afforded 89% of the product (Table 1, entry 4). Interestingly, under MW irradiation the reaction completed within 1.5 h but provided only 82% of product (Table 1, entry 5). We were also able to demonstrate that the reaction could be performed under another Buchwald's procedure[22] for *N*-vinylation, *i.e.*, stoichiometric CuI/*N*,*N*′-dimethylethylenediamine (DMEDA) mediation, rather than catalytic Pd-/BINAP conditions, albeit with longer reactions times and lower yield (79%) of product (Table 1, entry 6).

With the optimized reaction conditions (Table 1, entry 3) at hand; we next investigated the substrate scope of this *N*′-vinylation reaction by varying vinyl halides and sulfonimidamides. Representative results are shown in Chart 1. Various aryl vinylbromides were successfully employed for this transformation. Both unsubstituted- and –Cl/–OMe substituted aryl (*trans*-) vinyl bromides provided the corresponding *N*′-vinyl sulfonimidamides (**3a–c**, **3h–j**, **3o**, **p**) in good to excellent yields. The phenylvinyl bromide with *cis*-orientation also gave satisfactory results whilst retaining the double-bond geometry (**3e**, **3l**, **3n**). Vinylbromides with heteroaryl groups were equally effective for this transformation (**3d**, **3k**).

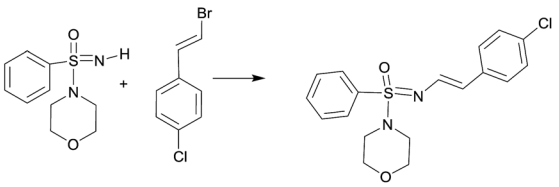
Although the cyclic aliphatic vinyl bromide afforded the corresponding product (**3g**) in moderate yield, both acyclic aliphatic vinyl bromides 2-bromo-1-propene and 1-bromo-1-propene resulted a complex reaction mixture. Even α-bromo styrene worked well for this transformation and provided very good yields of terminal alkenes (**3f**, **3m**). Modification of the sulfonimidamide moiety was tolerated satisfactorily as shown by replacing the morpholine functionality with piperidine/pyrrolidine to offer the products (**3n**, **3o**) in very good yields.

The structures of all the newly synthesized compounds were deduced from full spectroscopic characterization and unequivocally established by X-ray single crystal diffraction analysis of one representative compound (**3c**, Fig. 1).[23]



Scheme 1 Synthesis of sulfonimidamides.

Table 1 Optimization of reaction conditions for the *N*′-vinylation of sulfonimidamides[a]



Entry	Condition	Yield[b] (%)
1	Pd(PhCH$_2$CH$_2$NH$_2$)(Cl)(RuPhos) (3.0 mol%), NaO^{t}Bu (1.2 equiv.), THF, 100 °C, MW, 2.5 h	—
2	Pd$_2$(dba)$_3$ (1 mol%), BINAP (1.5 mol%), NaO^{t}Bu (1.5 equiv.), toluene, 100 °C, 12 h	78[c]
3	Pd$_2$(dba)$_3$ (1 mol%), BINAP (1.5 mol%), NaO^{t}Bu (1.5 equiv.), toluene, 110 °C, 4 h	92
4	Pd(OAc)$_2$ (1 mol%), BINAP (1.5 mol%), NaO^{t}Bu (1.5 equiv.), toluene, 110 °C, 5 h	89
5	Pd$_2$(dba)$_3$ (1 mol%), BINAP (1.5 mol%), NaO^{t}Bu (1.5 equiv.), toluene, 150 °C, MW, 1.5 h	82
6	CuI (1.0 equiv.), DMEDA (2.0 equiv.), K$_2$CO$_3$(2.0 equiv.), toluene, 110 °C, 7 h	79

[a] Sulfonimidamide and vinyl bromide were used 1.0 equiv. each. [b] Isolated yield. [c] Some starting materials were unreacted.

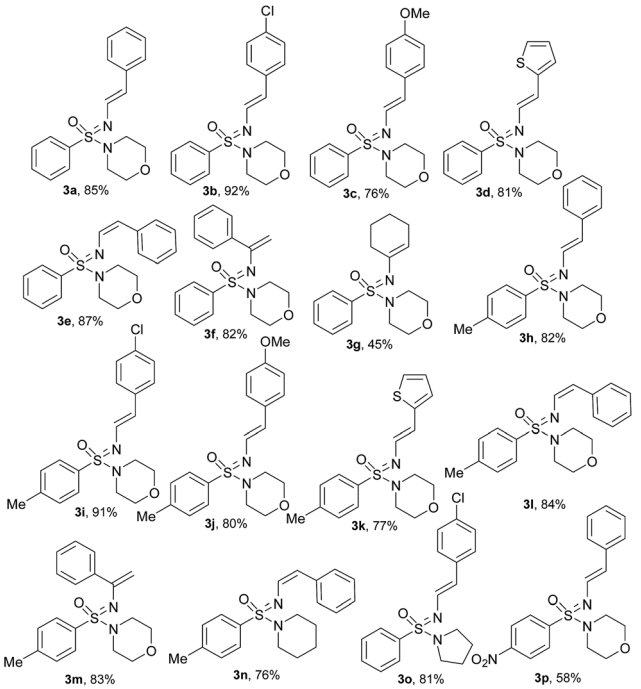


Chart 1 Substrate scope for the *N*′-vinylation of the sulfonimidamides under optimized reaction conditions.

According to a search performed using the Cambridge Structural Database, this structure is the first of its kind to be reported. Comparable sulfonimidamide and sulfonimidate structures displayed a fairly trigonal pyramidal shape with respect to the groups bonded to sulphur atom; bond angles S1–O3–C13 109°, S1–O3–N1 104°, while S1–O3–N2 122° (deviation). In addition, the X-ray structure of **3c** displayed a slightly longer S1–N1 bond length of 1.6 Å as compared to analogous structures that displayed approximately 1.5 Å. The S1=N2 double bond length in the structure of **3c** is 1.51 Å, which is also slightly longer than other reported structures (1.4–1.52 Å). Similar to other enamine systems, the C=C bond displays (*E*)-configuration, and the conformation of the bond between the *N*′-atom and the C3 is *trans*-, so that the styryl group points away from the bulky substituents of the sulfone group and the conjugated π-system that includes the *N*′-atom, the C=C bond, and the phenyl ring, is perfectly planar.

The *N*′-alkenyl compounds reported here are expected to be very sensitive towards acid. Not too surprising, the *N*-vinyl

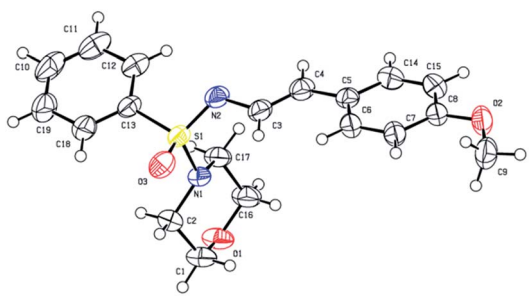
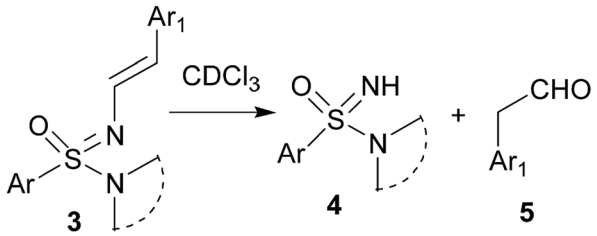
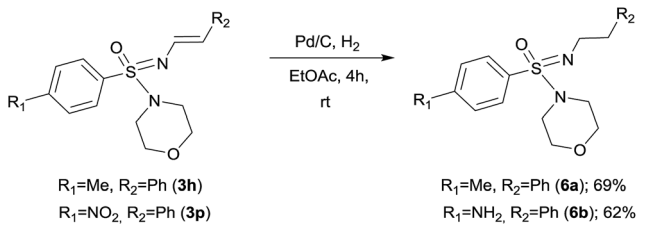


Fig. 1 ORTEP diagram of **3c**.



Scheme 2 Decomposition of *N*′-vinyl sulfonimidamides in $CDCl_3$.



Scheme 3 Pd–C catalyzed hydrogenation of *N*′-vinyl sulfonimidamides.

sulfonimidamides **3** decomposed to starting sulfonimidamide **4** and aryl acetaldehyde **5** (Scheme 2) when $CDCl_3$ was used as solvent for recording the NMR spectra. Hence, we replaced $CDCl_3$ by CD_3CN as solvent for NMR spectroscopic characterization of the products. For authentication, in a separate experiment, sulfonimidamide **4** and phenyl acetaldehyde (1 : 1) were mixed in $CDCl_3$ in an NMR tube; the resulting NMR spectra matched that obtained from the reaction product **3a** in $CDCl_3$, thus independently verifying the decomposition of **3** to **4** and **5** under slightly acidic conditions. To verify the reversibility of the process, sulfonimidamide **4** and phenyl acetaldehyde **5** (1 : 1) were refluxed in toluene in the presence of catalytic *p*-toluenesulfonic acid (PTSA); LCMS analysis of the reaction mixture confirmed the formation of **3** albeit in trace amount.

In order to demonstrate the reactivity and utility of the newly prepared *N*-vinyl sulfonimidamides, we decided to reduce the *N*-alkenyl group to the corresponding *N*-alkane derivative. An attempt to reduce the double bond following our previously reported $BH_3 \cdot DMS$ mediated reduction[2e] proved unsuccessful. However, for these substrates Pd–C catalyzed hydrogenation provided the expected *N*′-alkyl sulfonimidamides **6** in good yield (Scheme 3). Under the same conditions, compound **3p** gave the corresponding amine **6b** through a one-pot reduction of both the olefin and the nitro functionality, thus making an interesting building block for further transformations.

Conclusions

In summary, we have described a Pd-catalyzed C–N coupling reaction of *N*′-deprotected sulfonimidamides and vinyl bromides for the synthesis of *N*′-vinyl sulfonimidamides. A variety of α/β-vinyl bromides and cyclic vinyl bromides were successfully coupled to different *N*′-deprotected sulfonimidamides. The coupling took place with retained stereochemistry around the vinylic double bond. The structure of the *N*′-vinyl

sulfonimidamide product was indisputably proven by single crystal X-ray diffraction. In addition, we demonstrated the reactivity of the newly formed *N*′-alkenyl group through hydrogenation of *N*′-vinyl sulfonimidamides to *N*′-alkyl sulfonimidamides. The preliminary observation of the dynamic nature of these *N*-vinyl sulfonimidamides suggest that they can be used as precursors for many other synthetic transformations and further studies along these lines are currently underway in our laboratory.

Experimental

General

The starting material sulfonimidamides were synthesized in the laboratory following the reported method.[2a,21] Vinyl bromide [(*E*)-2-bromoethenyl]benzene and 1-[(*E*)-2-bromoethenyl]-4-methoxybenzene,[24] 1-[(*E*)-2-bromoethenyl]-4-chlorobenzene,[25] 2-[(*E*)-2-bromoethenyl]thiophene,[26] [(*Z*)-2-bromoethenyl]benzene,[27] 1-bromocyclohex-1-ene[28] were synthesized using reported procedures. (1-Bromoethenyl)benzene and Pd-catalysts, ligands were purchased from various suppliers and used as received. ^{1}H and ^{13}C NMR spectra were recorded on Bruker Avance III spectrometer operating at 400 and 100 MHz, respectively. CD_3CN and $CDCl_3$ were purchased from Merck and used as received. IR spectra were recorded on BRUKER-ALPHA spectrophotometer. HRMS were recorded on BRUKER micrOTOF-Q-II spectrometer. Melting points were uncorrected.

General procedure for the reaction of sulfonimidamides and vinyl halides for the synthesis of *N*′-vinyl sulfonimidamides (3a–p). A Schlenk tube under nitrogen atmosphere was charged with sulfonimidamide (1.0 equiv.), vinyl bromide (1.0 equiv.), $Pd_2(dba)_3$ (1 mol%), (±)-BINAP (1.5 mol%), NaO*t*-Bu (1.5 equiv.), and 2 mL of dry toluene. The reaction was stirred at 110 °C for 4–6 h and then allowed to cool to room temperature. The reaction mixture was filtered through Celite and the filtrate was purified through neutral alumina column chromatography using 5–10% ethyl acetate in hexane as eluent to obtain the pure *N*′-vinyl sulfonimidamides.

General procedure for the Pd–C catalyzed hydrogenation of *N*′-vinyl sulfonimidamides (6a, b). To a N_2 flushed round bottom flask, vinyl sulfonimidamides (0.3 mmol, 1.0 equiv.) in EtOAc (2 mL) and Pd/C 10% wt (0.5 equiv.) were taken and stirred under H_2 atmosphere for 4–6 h. The reaction mixture was filtered through Celite, washed with EtOAc (2 × 5 mL) and purified by column chromatography using 25–50% ethyl acetate in hexane as eluent to obtain the pure *N*′-alkyl sulfonimidamides.

4-[*S*-Phenyl-*N*′-(phenylvinyl)sulfonimidoyl]morpholine (3a). White solid, R_f = 0.30 (15% ethyl acetate/hexane), mp 126–127 °C. IR (ATR): ν = 3061, 2870, 2850, 1630, 1446, 1446, 1257, 1171, 1108, 921 cm^{-1}. ^{1}H NMR (400 MHz, CD_3CN): δ = 7.91 (d, J = 7.4 Hz, 2H), 7.71 (t, J = 7.2 Hz, 1H), 7.6 (t, J = 7.8 Hz, 2H), 7.33 (d, J = 7.5 Hz, 2H), 7.27–7.24 (m, 3H), 7.12 (t, J = 7.2 Hz, 1H), 6.23 (d, J = 13.6 Hz, 1H), 3.65 (t, J = 4.7 Hz, 4H), 2.95–2.91 (m, 4H). ^{13}C NMR (100 MHz, CD_3CN): δ = 139.0, 135.1, 134.1, 130.2, 129.5, 129.3, 128.9, 126.6, 125.9, 119.4, 66.8, 47.7. HRMS (ESI) calcd for $C_{18}H_{20}N_2O_2S$ $[M + H]^+$ 329.1318, found 329.1324.

4-[*S*-Phenyl-*N*′-(4-chlorophenylvinyl)sulfonimidoyl]morpholine (3b). White solid, R_f = 0.35 (15% ethyl acetate/hexane), mp 120–122 °C. IR (ATR): ν = 2901, 2856, 2843, 1625, 1445, 1297, 916 cm^{-1}. ^{1}H NMR (400 MHz, CD_3CN): δ = 7.90 (d, J = 7.3 Hz, 2H), 7.71 (t, J = 7.3 Hz, 1H), 7.63 (t, J = 7.7 Hz, 2H), 7.32–7.24 (m, 5H), 6.19 (d, J = 13.6 Hz, 1H), 3.65 (t, J = 4.6 Hz, 4H), 2.97–2.89 (m, 4H). ^{13}C NMR (100 MHz, CD_3CN): δ = 137.9, 135.0, 134.2, 131.3, 130.3, 130.2, 129.4, 128.9, 127.3, 118.0, 66.8, 47.7. HRMS (ESI) calcd for $C_{18}H_{19}ClN_2O_2S$ $[M + H]^+$ 363.0928, found 363.0918.

4-[*S*-Phenyl-*N*′-(4-methoxyphenylvinyl)sulfonimidoyl]morpholine (3c). White solid, R_f = 0.25 (20% ethyl acetate/hexane) mp 110–111 °C. IR (ATR): ν = 2966, 2916, 2855, 1511, 1599, 1252, 1110 cm^{-1}. ^{1}H NMR (400 MHz, CD_3CN): δ = 7.90 (d, J = 7.4 Hz, 2H), 7.70 (t, J = 7.4 Hz, 1H), 7.63 (t, J = 7.4 Hz, 2H), 7.26 (d, J = 8.6 Hz, 2H), 7.10 (d, J = 13.6 Hz, 1H), 6.83 (d, J = 8.7 Hz, 2H), 6.18 (d, J = 13.7 Hz, 1H), 3.76 (s, 3H), 3.64 (t, J = 4.7 Hz, 4H), 2.94–2.90 (m, 4H). ^{13}C NMR (100 MHz, CD_3CN): δ = 159.0, 135.2, 134.0, 131.5, 130.1, 128.9, 127.2, 127.0, 119.2, 114.9, 66.8, 55.8, 47.7. HRMS (ESI) calcd for $C_{19}H_{22}N_2O_3S$ $[M + H]^+$ 359.1423, found 359.1428.

4-[*S*-Phenyl-*N*′-(2-thienylvinyl)sulfonimidoyl]morpholine (3d). White solid, R_f = 0.30 (20% ethyl acetate/hexane), mp 134–135 °C. IR (ATR): ν = 2961, 2862, 2840, 1631, 1457, 1275, 1103, 924 cm^{-1}. ^{1}H NMR (400 MHz, CD_3CN): δ = 7.92 (d, J = 7.4 Hz, 2H), 7.73 (t, J = 7.4 Hz, 1H), 7.65 (t, J = 7.8 Hz, 2H), 7.35–7.33 (m, 1H), 7.24 (d, J = 4.9 Hz, 1H), 7.16 (d, J = 13.6 Hz, 1H), 7.07 (m, 1H), 6.29 (d, J = 17.1 Hz, 1H) 3.67 (t, J = 4.7 Hz, 4H), 3.00–2.90 (m, 4H). ^{13}C NMR (100 MHz, CD_3CN): δ = 140.7, 135.1, 134.0, 130.1, 129.2, 128.9, 126.9, 125.6, 119.1, 114.4, 66.8, 47.7. HRMS (ESI) calcd for $C_{16}H_{18}N_2O_2S_2$ $[M + H]^+$ 335.0882, found 335.0882.

4-[*S*-Phenyl-*N*′-(phenylvinyl)sulfonimidoyl]morpholine (3e). White solid, R_f = 0.30 (15% ethyl acetate/hexane) mp 115–116 °C. IR (ATR): ν = 2966, 2915, 2854, 1621, 1445, 1254, 923 cm^{-1}. ^{1}H NMR (400 MHz, CD_3CN): δ = 7.96 (d, J = 7.1 Hz, 2H), 7.84 (d, J = 7.3 Hz, 2H), 7.72 (t, J = 7.4 Hz, 1H), 7.66 (t, J = 7.3 Hz, 2H), 7.31 (t, J = 7.6 Hz, 2H), 7.14 (t, J = 7.3 Hz, 1H), 6.68 (d, J = 8.6 Hz, 1H), 5.65 (d, J = 8.5 Hz, 1H), 3.64–3.62 (m, 4H), 2.97–2.85 (m, 4H). ^{13}C NMR (100 MHz, CD_3CN): δ = 138.7, 135.0, 134.2, 130.3, 129.3, 129.0, 128.9, 127.7, 126.4, 115.3, 66.7, 47.6. HRMS (ESI) calcd for $C_{18}H_{20}N_2O_2S$ $[M + H]^+$ 329.1318, found 329.1319.

4-[*S*-Phenyl-*N*′-(1-phenylvinyl)sulfonimidoyl]morpholine (3f). White solid, R_f = 0.30 (20% ethyl acetate/hexane) mp 98–99 °C. IR (ATR): ν = 3061, 2966, 2915, 2855, 1681, 1596, 1445, 1254, 1111, 927 cm^{-1}. ^{1}H NMR (400 MHz, CD_3CN): δ = 7.91 (d, J = 7.4 Hz, 2H), 7.78 (d, J = 8.4 Hz, 2H), 7.68 (t, J = 7.4 Hz, 1H), 7.61 (t, J = 7.8 Hz, 2H), 7.37–7.30 (m, 3H), 5.12 (s, 1H), 4.93 (s, 1H), 3.61 (t, J = 4.7 Hz, 4H), 2.99–2.92 (m, 4H). ^{13}C NMR (100 MHz, CD_3CN): δ = 147.0, 141.6, 137.1, 134.4, 130.7, 129.7, 129.5, 129.4, 127.2, 98.6, 67.4, 48.0. HRMS (ESI) calcd for $C_{18}H_{20}N_2O_2S$ $[M + H]^+$ 329.1318, found 329.1309.

4-[*S*-Phenyl-*N*′-(1-cyclohexenyl)sulfonimidoyl]morpholine (3g). White solid, R_f = 0.25 (20% ethyl acetate/hexane), mp 84–85 °C. IR (ATR): ν = 2918, 2852, 1619, 1443, 1253, 1109 cm^{-1}. ^{1}H NMR (400 MHz, CD_3CN): δ = 7.83 (d, J = 7.2 Hz, 2H), 7.63 (t, J = 7.2 Hz, 1H), 7.57 (t, J = 7.5 Hz, 2H), 5.27 (t, J = 3.8 Hz, 1H), 3.61 (t, J = 4.6 Hz, 4H), 2.89 (t, J = 4.6 Hz, 4H), 2.21–2.19 (m, 2H), 2.05–2.02 (m, 2H), 1.69–1.63 (m, 2H), 1.56–1.50 (m, 2H). ^{13}C NMR (100 MHz, CD_3CN): δ = 139.3, 136.9, 133.4, 129.9, 128.8, 112.6, 67.0, 47.9, 31.8, 25.6, 24.2, 23.2. HRMS (ESI) calcd for $C_{16}H_{22}N_2O_2S$ $[M + H]^+$ 307.1474. Found 307.1460.

4-[*S*-*p*-Tolyl-*N*′-(phenylvinyl)sulfonimidoyl]morpholine (3h). White solid, $R_f = 0.30$ (15% ethyl acetate/hexane), mp 98–99 °C. IR (ATR): $\nu = 2963, 2854, 1624, 1441, 1259, 1105, 920\ cm^{-1}$. ^1H NMR (400 MHz, CD_3CN): $\delta = 7.78$ (d, $J = 8.2$ Hz, 2H), 7.43 (d, $J = 8.0$ Hz, 2H), 7.32 (d, $J = 7.5$ Hz, 2H), 7.27–7.23 (m, 3H), 7.11 (t, $J = 7.3$ Hz, 1H), 6.21 (d, $J = 13.6$ Hz, 1H), 3.64 (t, $J = 4.6$ Hz, 4H), 2.93–2.89 (m, 4H), 2.44 (s, 3H). ^{13}C NMR (100 MHz, CD_3CN): $\delta = 145.2, 139.1, 132.0, 130.7, 129.5, 129.4, 129.0, 126.5, 125.8, 119.1, 66.8, 47.7, 21.5$. HRMS (ESI) calcd for $C_{19}H_{22}N_2O_2S$ $[M + H]^+$ 343.1474, found 343.1468.

4-[*S*-*p*-Tolyl-*N*′-(4-chlorophenylvinyl)sulfonimidoyl]morpholine (3i). White solid, $R_f = 0.35$ (15% ethyl acetate/hexane), mp 82–84 °C. IR (ATR): $\nu = 2962, 2917, 2850, 1624, 1255, 916\ cm^{-1}$. ^1H NMR (400 MHz, CD_3CN): $\delta = 7.77$ (d, $J = 8.3$ Hz, 2H), 7.43 (d, $J = 8.3$ Hz, 2H), 7.30–7.23 (m, 5H), 6.17 (d, $J = 13.6$ Hz, 1H), 3.64 (t, $J = 4.7$ Hz, 4H), 2.94–2.88 (m, 4H), 2.43 (s, 3H). ^{13}C NMR (100 MHz, CD_3CN): $\delta = 145.1, 137.9, 131.8, 131.0, 130.6, 130.3, 129.2, 128.9, 127.1, 117.6, 66.6, 47.5, 21.4$. HRMS (ESI) calcd for $C_{19}H_{21}ClN_2O_2S$ $[M + H]^+$ 377.1085, found 377.1089.

4-[*S*-*p*-Tolyl-*N*′-(4-methoxyphenylvinyl)sulfonimidoyl]morpholine (3j). White solid, $R_f = 0.25$ (20% ethyl acetate/hexane) mp 101–103 °C. IR (ATR): $\nu = 2964, 2913, 2856, 1515, 1601, 1250, 1108\ cm^{-1}$. ^1H NMR (400 MHz, CD_3CN): $\delta = 7.77$ (d, $J = 8.2$ Hz, 2H), 7.43 (d, $J = 8.1$ Hz, 2H), 7.25 (d, $J = 8.6$ Hz, 2H), 7.09 (d, $J = 13.7$ Hz, 1H), 6.83 (d, $J = 8.6$ Hz, 2H), 6.16 (d, $J = 13.6$ Hz, 1H), 3.76 (s, 3H), 3.63 (t, $J = 4.6$ Hz, 4H), 2.92–2.87 (m, 4H), 2.44 (s, 3H). ^{13}C NMR (100 MHz, CD_3CN): $\delta = 159.0, 145.1, 132.1, 131.6, 130.6, 129.0, 127.4, 127.0, 118.9, 114.9, 66.8, 55.8, 47.7, 21.5$. HRMS (ESI) calcd for $C_{20}H_{24}N_2O_3S$ $[M + H]^+$ 373.1580, found 373.1564.

4-[*S*-*p*-Tolyl-*N*′-(2-thienylvinyl)sulfonimidoyl]morpholine (3k). White solid, $R_f = 0.35$ (25% ethyl acetate/hexane), mp 126–128 °C. IR (ATR): $\nu = 2957, 2917, 2864, 2845, 1629, 1592, 1453, 1279, 1108, 921\ cm^{-1}$. ^1H NMR (400 MHz, CD_3CN): $\delta = 7.77$ (d, $J = 8.2$ Hz, 2H), 7.43 (d, $J = 8.0$ Hz, 2H), 7.32–7.30 (m, 1H), 7.20 (d, $J = 5.0$ Hz, 1H), 7.12 (d, $J = 13.6$ Hz, 1H), 7.03 (m, 1H), 6.24 (d, $J = 13.6$ Hz, 1H), 3.64 (t, $J = 4.7$ Hz, 4H), 2.92–2.88 (m, 4H), 2.44 (s, 3H). ^{13}C NMR (100 MHz, CD_3CN): $\delta = 145.2, 140.8, 132.1, 130.7, 129.4, 129.0, 126.9, 125.6, 119.0, 114.2, 66.8, 47.7, 21.5$. HRMS (ESI) calcd for $C_{17}H_{20}N_2O_2S_2$ $[M + H]^+$ 349.1038, found 349.1044.

4-[*S*-*p*-Tolyl-*N*′-(phenylvinyl)sulfonimidoyl]morpholine (3l). White solid, $R_f = 0.25$ (15% ethyl acetate/hexane), mp 109–110 °C. IR (ATR): $\nu = 3061, 3019, 2902, 2861, 2844, 1620, 1445, 1417, 1273, 1149, 1109, 922\ cm^{-1}$. ^1H NMR (400 MHz, CD_3CN): $\delta = 7.84–7.82$ (m, 4H), 7.47 (d, $J = 8.1$ Hz, 2H), 7.30 (t, $J = 7.6$ Hz, 2H), 7.13 (t, $J = 7.3$ Hz, 1H), 6.66 (d, $J = 8.56$ Hz, 1H), 5.63 (d, $J = 8.6$ Hz, 1H), 3.65–3.62 (m, 4H), 2.93–2.87 (m, 4H), 2.46 (s, 3H). ^{13}C NMR (100 MHz, CD_3CN): $\delta = 145.3, 138.6, 131.9, 130.7, 129.1, 128.9, 128.9, 127.8, 126.3, 115.0, 66.6, 47.5, 21.4$. HRMS (ESI) calcd for $C_{19}H_{22}N_2O_2S$ $[M + H]^+$ 343.1474, found 343.1476.

4-[*S*-*p*-Tolyl-*N*′-(1-phenylvinyl)sulfonimidoyl]morpholine (3m). White solid, $R_f = 0.30$ (20% ethyl acetate/hexane), mp 89–91 °C. IR (ATR): $\nu = 3059, 2915, 2853, 1681, 1596, 1441, 1259, 1107, 921\ cm^{-1}$. ^1H NMR (400 MHz, CD_3CN): $\delta = 7.80–7.76$ (m, 4H), 7.42 (d, $J = 8.1$ Hz, 2H), 7.37–7.30 (m, 3H), 5.09 (s, 1H), 4.91 (s, 1H), 3.61 (t, $J = 4.6$ Hz, 4H), 2.97–2.93 (m, 4H), 2.43 (s, 3H). ^{13}C NMR (100 MHz, CD_3CN): $\delta = 146.4, 144.7, 140.5, 133.3, 130.5, 128.9, 128.8, 128.7, 126.4, 97.6, 66.7, 47.3, 21.3$. HRMS (ESI) calcd for $C_{19}H_{22}N_2O_2S$ $[M + H]^+$ 343.1474, found 343.1480.

1-[*S*-*p*-Tolyl-*N*′-(phenylvinyl)sulfonimidoyl]piperidine (3n). White solid, $R_f = 0.40$ (15% ethyl acetate/hexane), mp 85–86 °C. IR (ATR): $\nu = 3061, 3026, 2936, 2850, 1625, 1596, 1446, 1248, 914\ cm^{-1}$. ^1H NMR (400 MHz, CD_3CN): $\delta = 7.83–7.81$ (m, 4H), 7.45 (d, $J = 8.0$ Hz, 2H), 7.29 (t, $J = 7.6$ Hz, 2H), 7.12 (t, $J = 7.4$ Hz, 1H), 6.64 (d, $J = 8.6$ Hz, 1H), 5.58 (d, $J = 8.5$ Hz, 1H), 2.99–2.88 (m, 4H), 2.44 (s, 3H), 1.59–1.54 (m, 4H), 1.42–1.37 (m, 2H). ^{13}C NMR (100 MHz, CD_3CN): $\delta = 144.8, 138.8, 133.1, 130.6, 129.1, 128.9, 128.7, 128.4, 126.1, 114.3, 48.2, 26.0, 24.1, 21.4$. HRMS (ESI) calcd for $C_{20}H_{24}N_2OS$ $[M + H]^+$ 341.1682, found 341.1696.

4-[*S*-Phenyl)-*N*′-(4-chlorophenylvinyl)sulfonimidoyl]pyrrolidine (3o). White solid, $R_f = 0.30$ (15% ethyl acetate/hexane), mp 78–80 °C. IR (ATR): $\nu = 2905, 2849, 1621, 1447, 1291, 918\ cm^{-1}$. ^1H NMR (400 MHz, CD_3CN): $\delta = 7.96$ (d, $J = 7.3$ Hz, 2H), 7.68 (t, $J = 7.4$ Hz, 1H), 7.61 (t, $J = 7.4$ Hz, 2H), 7.31–7.27 (m, 3H), 7.23 (d, $J = 8.5$ Hz, 2H), 6.13 (d, $J = 13.6$ Hz, 1H), 3.18 (t, $J = 6.6$ Hz, 4H), 1.71–1.67 (m, 4H). ^{13}C NMR (100 MHz, CD_3CN): $\delta = 138.3, 136.7, 133.8, 131.4, 131.0, 130.1, 129.4, 128.8, 127.1, 117.0, 49.3, 25.9$. HRMS (ESI) calcd for $C_{18}H_{19}ClN_2OS$ $[M + H]^+$ 347.0979, found 347.0985.

4-[*S*-4-Nitrophenyl-*N*′-(phenylvinyl)sulfonimidoyl]morpholine (3p). Yellow oil, $R_f = 0.30$ (20% ethyl acetate/hexane), IR (ATR): $\nu = 3100, 2919, 2857, 1573, 1349, 970, cm^{-1}$. ^1H NMR (400 MHz, CD_3CN): $\delta = 8.40$ (dt, $J = 8.8, 1.8$ Hz, 2H), 8.11 (dt, $J = 8.8, 1.8$ Hz, 2H), 7.35 (d, $J = 7.7$ Hz, 2H), 7.27 (t, $J = 7.5$ Hz, 2H), 7.22 (d, $J = 13.6$ Hz, 1H), 7.14 (t, $J = 7.2$ Hz, 1H), 6.28 (d, $J = 13.6$ Hz, 1H), 3.66 (t, $J = 4.2$ Hz, 4H), 3.06–2.96 (m, 4H). ^{13}C NMR (100 MHz, CD_3CN): $\delta = 151.4, 141.2, 138.6, 130.2, 129.4, 128.2, 126.8, 126.0, 125.3, 120.5, 66.7, 47.6$. HRMS (ESI) calcd for $C_{18}H_{19}N_3O_4S$ $[M + H]^+$ 374.1172, found 374.1169.

4-[*S*-*p*-Tolyl-*N*′-(phenylethyl)sulfonimidoyl]morpholine (6a). Pale yellow oil, $R_f = 0.30$ (20% ethyl acetate/hexane), IR (ATR): $\nu = 2954, 2924, 2852, 1459, 1281, 1256, 930\ cm^{-1}$. ^1H NMR (400 MHz, $CDCl_3$): $\delta = 7.66$ (d, $J = 8.3$ Hz, 2H), 7.30–7.27 (m, 6H), 7.22–7.17 (m, 1H), 3.58–3.56 (m, 4H), 3.55–3.50 (m, 1H), 3.33–3.26 (m, 1H), 2.99–2.87 (m, 2H), 2.81–2.76 (m, 2H), 2.60–2.55 (m, 2H), 2.41 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): $\delta = 143.0, 141.0, 132.0, 129.4, 129.2, 128.3, 128.1, 126.1, 66.4, 46.8, 44.1, 39.2, 21.5$. HRMS (ESI) calcd for $C_{19}H_{24}N_2O_2S$ $[M + H]^+$ 345.1637, found 345.1619.

4-[*S*-4-Aminophenyl-*N*′-(phenylethyl)sulfonimidoyl]morpholine (6b). Yellow oil, $R_f = 0.20$ (50% ethyl acetate/hexane) IR (ATR): $\nu = 3439, 3164, 2944, 1631, 1375, 918, 749$; ^1H NMR (400 MHz, $CDCl_3$): $\delta = 7.56$ (dt, $J = 8.7, 1.8$ Hz, 2H), 7.28 (d, $J = 4.3$ Hz, 4H), 7.21–7.17 (m, 1H), 6.66 (dt, $J = 8.7, 1.7$ Hz, 2H), 4.05 (br, 2H), 3.59–3.57 (m, 4H), 3.55–3.49 (m, 1H), 3.31–3.24 (m, 1H), 2.98–2.88 (m, 2H), 2.81–2.76 (m, 2H), 2.60–2.55 (m, 2H). ^{13}C NMR (100 MHz): $\delta = 150.5, 140.9, 130.3, 129.2, 128.3, 126.1, 114.1, 66.4, 46.8, 44.2, 39.1$. HRMS (ESI) calcd for $C_{18}H_{23}N_3O_2S$ $[M + H]^+$ 346.1568, found 346.1584.

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