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Authors: Antonio Luiz Braga, Lais T. Silva, Juliano B. Azeredo, Sumbal Saba, Jamal Rafique, and Adailton J. Bortoluzzi

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FULL PAPER

Solvent- and metal-free chalcogenation of bicyclic arenes using I_2/DMSO as non-metallic catalytic system

Lais T. Silva,[a] Juliano B. Azeredo,[b] Sumbal Saba,[a],[c] Jamal Rafique,*[a] Adailton J. Bortoluzzi,[a] and Antonio L. Braga*[a]

Abstract: In this study, we developed a greener and efficient protocol for the chalcogenylation of bicyclic arenes using the I_2/DMSO catalytic system under solvent- and metal-free conditions. This protocol allowed access to several chalcogenated bicyclic arenes through C(sp^2)-H bond functionalization, in good to excellent yields, using MW irradiation or conventional heating.

Introduction

Organochalcogen compounds are recognized for their biological activity. [1] In particular, certain enzymes containing selenium show relevant antioxidant properties. Importantly, some organochalcogen compounds present mimetic activity of these enzymes, making them attractive synthetic targets.[2] Furthermore, organoselenium compounds are widely applied in organic synthesis, as reagents, in different transformations and in material sciences.[3]

Similarly, the bicyclic arenes, especially naphthalene derivatives are present in bioactive compounds, featuring a wide range of activities such as antihypertensive,[4] anti-inflammatory,[5] antimicrobial,[6] anti-malarial[7] and anti-HIV.[8] Several commercially available drugs also have this moiety in their core structure, e.g., **propranolol**, one of the most sold antihypertensive drugs in the world, **naproxen**, a non-steroidal anti-inflammatory & the anti-malarial drug **primaquine** (Figure 1).

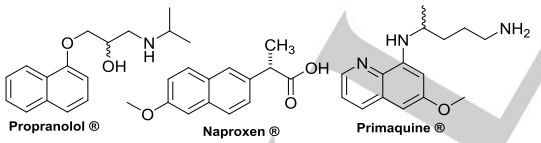
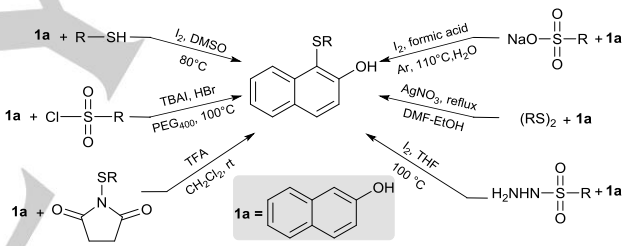


Figure 1. Naphthalene based drug compounds.

Considering the biological relevance of organochalcogen compounds and the wide spectrum of therapeutic properties of naphthalene derivatives, few synthetic methods for the construction of 1-(arylthio)naphthols have been reported in the literature.[9] Generally, one of the commen route is through C-H bond functionalization of α-position of 2-naphthols **1a** with sulfenylating agents. This functionalization may occur through the photo-induced reaction of 1-bromo-2-naphthol and 2-naphthols with thiols, via a radical pathway,[10] or through an electrophilic substitution reaction using sulfenylating agents. Among these agents, thiols,[11] sodium sulfinates,[12] sulfonyl hydrazides,[13] disulfides,[14] organosulfonyl chlorides[15] and *N*-organoylsuccinimides[16] are commonly used reagents (Scheme 1). Despite the merits of these methods, some of them have limitations, such as the use of non-green solvents, transition metal catalysis, additives, malodorous reagents, and pre-functionalized coupling partners.



Scheme 1. Reported work.

Recently, Huang and co-workers reported the functionalization of 2-naphthols and 2-naphthylamines using sulfonyl hydrazides in the presence of an equivalent amount of iodine and THF as solvent.[13a] However, to the best of our knowledge, the selenylation of these nuclei has not yet been explored.

On the other hand, the use of microwave (MW) irradiation in C−Se and C−S bond formation,[17] can provide higher yields in shorter reaction times. In addition, sustainable protocols and solvent-free conditions are attractive alternative in organic synthesis.[18]

Recently, our group successfully applied an I_2/DMSO catalytic oxidant system in the chalcogenation of various compounds.[19]

Thus, in relation to our continuing interest in the organochalcogen chemistry, as well as the design of eco-friendly processes,[19] herein we describe a novel protocol for the chalcogeno-functionalization of 2-naphthols and derivatives using a half equivalent of dichalcogenides in the presence of iodine as a catalyst and an equivalent amount of DMSO as the oxidant. This method avoids the use of solvents, additives and transition-metals as well as can be performed under MW irradiations or conventional heating.

[a] Departamento de Química, Universidade Federal de Santa Catarina Florianópolis, 88040-900, SC-Brazil
braga.antonio@ufsc.br (ALB), jamal.chm@gmail.com (JR)
Homepage: http://labselen.ufsc.com/
[b] Departamento de Farmácia, Universidade Federal do Pampa, Uruguaiana, 97500-970, RS-Brazil
[c] Department of chemistry, Shaheed Benazir Bhutto Women University, Peshawar, 25000, KPK, Pakistan

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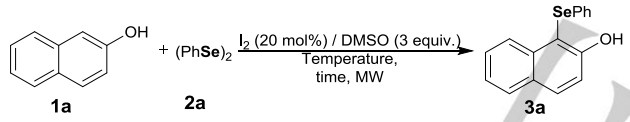
Results and Discussion

To identify the optimum reaction conditions, 2-naphthol **1a** (0.5 mmol) and diphenyl diselenide **2a** (0.25 mmol) were selected as standard substrates, in the presence of I_2 (20 mol%) and 3 equivalents of DMSO (Table 1). The performance of the reaction under different microwave irradiation times was evaluated, at 80 ^oC with 100 W of power. Carrying out the reaction for 1 min, compound **3a** was obtained in 42% yield (entry 1). An incremental increase in the yield of **3a** was observed with the increase of time (entry 2-10). When the reaction was performed in 10 min, the desired product was obtained in 83% yield (entry 5), but on increasing the time to 15 min the reaction did not show any further improvement(entry 6).

In the next step, the influence of the temperature and the microwave power was studied. Decreasing the temperature from 80 ^oC, the yield of the **3a** decreased (entry 7-8). On performing the reaction at a higher temperature, the yield of **3a** did not change (entry 9 vs 5). Next, the reaction was screened for different levels of irradiation power (entry 10-11) and 100 W was observed to be the ideal for this transformation (entry 8 vs 10-11).

In order to evaluate the influence of the heating source, the reaction was also performed in a conventional oil bath heating system (entry 12). Reaction under heating for, 1 h afforded **3a** in 95% yield, indicating that this protocol can also be extended to conventional heating.

Table 1. Optimization of Microwave Parameters[a]



1a 2a 3a

entry	power (W)	T (°C)	*t* (min)	Yield (%) [b]
1	100	80	1	42
2	100	80	2	50
3	100	80	5	51
4	100	80	7	64
5	**100**	**80**	**10**	**83**
6	100	80	15	83
7	100	40	10	22
8	100	60	10	40
9	100	100	10	83
10	50	80	10	73
11	150	80	10	84
12	-	80	1 h	95[c]

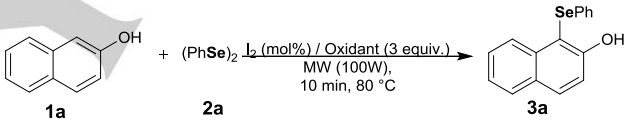
[a] Reaction conditions: **1a** (0.5 mmol) and **2a** (0.25 mmol). [b] Isolated yields. [c] Conventional heating (oil bath).

Subsequently, the influence of the catalyst and the stoichiometric oxidant on the reaction system was explored (Table 2). Carrying out the reaction with 5 mol% of iodine afforded the product **3a** in 45% yield (entry 1). A constant increase in the yield of **3a** was observed with the increase in catalyst loading (entry 2-4). There was a slight increase in the yield using 25 mol% of I_2 (entry 5), which led us to select 20 mol%(entry 4) of catalyst for this transformation. The reaction was ineffective in the absence of iodine (entry 6).

Subsequently, we investigated the influence of the oxidant on the reaction. Using 1.0 and 1.5 equivalents of DMSO, the product **3a** was obtained in 64 and 66% yields, respectively (entries 7 and 8). When the amount of oxidant was increased to 2 equivalents, the desired product was obtained in 94% yield (entry 9). In the absence of oxidant, the yield of **3a** dropped to 6%, verifying that the presence of DMSO is essential in this methodology.

Using TBHP and H_2O_2 instead of DMSO, the yields of **3a** decreased to 7 and 45%, respectively (entries 11 and 12). Lastly, the reaction was carried out applying conventional heating in order to assess the influence of the heating method (entry 13). Under this condition, **3a** was obtained in 98% yield after 1 h of reaction. Thus, the methodology can also be extended to conventional heating.

Table 2. Optimization of Reaction Conditions[a]



1a 2a 3a

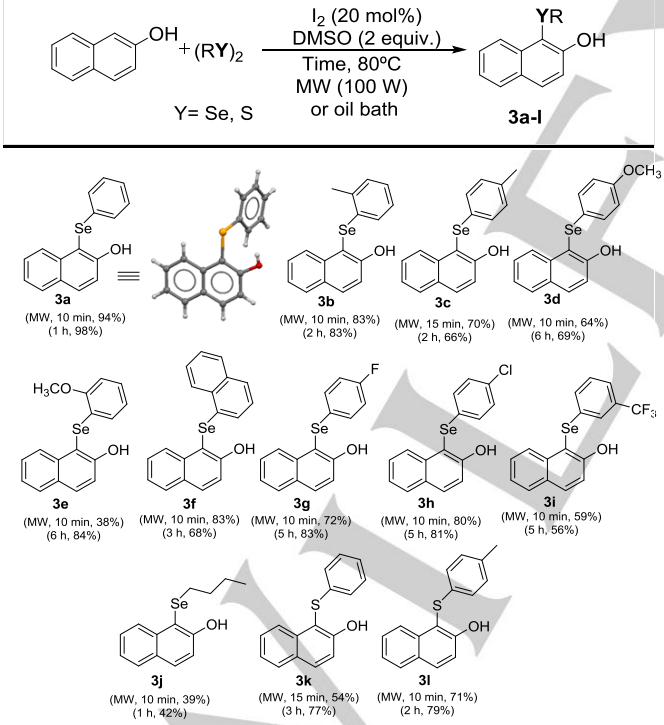
entry	I_2 (mol%)	Oxidant (equiv.)	Yield (%)[b]
1	5	DMSO (3)	45
2	10	DMSO (3)	59
3	15	DMSO (3)	70
4	20	DMSO (3)	83
5	25	DMSO (3)	85
6	-	DMSO (3)	-
7	20	DMSO (1)	64
8	20	DMSO (1.5)	66
9	20	DMSO (2)	94
10	20	-	6
11	20	TBHP (3)	7
12	20	H_2O_2 (3)	45
13	20	DMSO (2)	98[c]

[a] Reaction conditions: **1a** (0.5 mmol) and **2a** (0.25 mmol). [b] Isolated yields. [c] Conventional heating (oil bath) – 1h.

After determining the best reaction conditions, the scope of the protocol was evaluated (Table 3), under the two heating conditions: microwave and conventional.

In general, good results were obtained for diorganyl diselenides and disulfides. There were electronic effects of the substituents on the yield of the desired products. Using the methyl group in the *ortho* and *para* positions of the diselenide, the corresponding products **3b** and **3c** were obtained in good yields, under both conditions. A similar effect was observed for the methoxy group in the *ortho* and *para* positions of the diselenide. In this case, the results obtained for the bis(2-methoxyphenyl)-diselenide showed that the two methods gave similar results for the formation of **3d**. However, the preparation of **3e** under conventional heating was more efficient than the microwave irradiations. Using the bulky diselenide (R = 1-naphthyl), the corresponding product **3f** was obtained in good yields under both protocols. Similarly, good results were also achieved with diaryl diselenides containing electro-withdrawing groups in the *para* position e.g. the products containing chlorine and fluorine **3g** and **3h**. With the trifluoromethyl group, CF_3, in the *meta* position, there was a decrease in the formation of **3i**, under both conditions. Furthermore, the use of an aliphatic diselenide provided the product **3j** in good yields.

Table 3. Variation of dichalcogenides

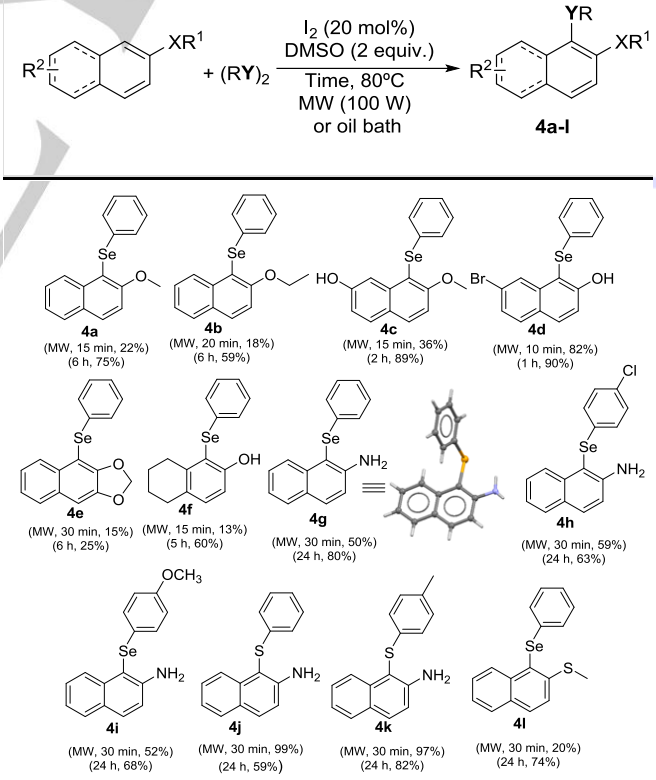


Further, the protocol was extended to synthesis 1-sulfenyl-naphthols. Using diphenyl disulfide as substrate, the product **3k** was obtained in 54% yield under microwave heating and 77% under conventional heating. Similarly, the use of di-*para*-methyl-disulfide afforded the product **3l** in 71% and 79% yields with microwave and conventional heating, respectively.

The structural variation of the oxygenated naphthalenic substrates was also examined under our optimized reaction conditions (Table 4). In general, good results were obtained in these reactions under conventional heating. Using 2-methoxynaphthalene as the substrate, the corresponding product **4a** was achieved in 22% yield in 15 min with microwave, whereas the reaction under conventional heating in 6 h increased the yield to 75%. Moreover, a decrease in the yield of the product **4b** under both conditions was observed when 2-ethoxynaphthalene was used as the substrate, possibly due to the steric hindrance of the ethoxy group. In addition, a good result was achieved when methoxy ether, substituted at the 7-position of the naphthalene ring by a hydroxyl group, was employed in the reaction to furnish the product **4c**. Similarly, 7-bromo-2-naphthol provided the product **4d** in excellent yields using both methods.

The naphthalene nucleus containing an acetal group, was also employed in order to enlarge the scope of this transformation. However, the product **4e** was obtained in low yields. Similarly, the reaction of **2a** with 5,6,7,8-tetrahydronaphthalen-2-ol gave the product **4f** in 13% yield, under microwave irradiation and 60% yield under conventional heating.

Table 4. Structural variation of naphthalenic compounds



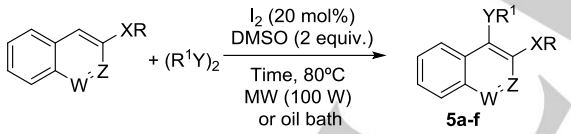
To further extend the substrate scope, naphthalen-2-amines were treated with several dichalcogenides under the optimized conditions, affording the corresponding products (**4g – 4i**). Conventional heating was found to be the best approach providing **4g** in 80% yield from the reaction of naphthalen-2-amine with diphenyl diselenide. Subsequently, the reaction of 2-naphthylamine and diaryl disulfides resulted in the corresponding thiolated products (**4j – 4k**). In this case, the use of microwave irradiation was found to be the more efficient method for the preparation of these compounds. Moreover, the selenylation of methyl-2-naphthalen-sulfide was performed using diphenyl diselenide under both conditions. In this case, the product **4l** was obtained in 20 % yield within 30 min of microwave irradiation and 74% yield within 24 h of conventional heating.

The structural assignment of compounds **3a** and **4g** was carried out based on NMR analysis and confirmed by X-ray diffraction,[20] which showed the position at which the selenium atom is connected (Table 3-4).

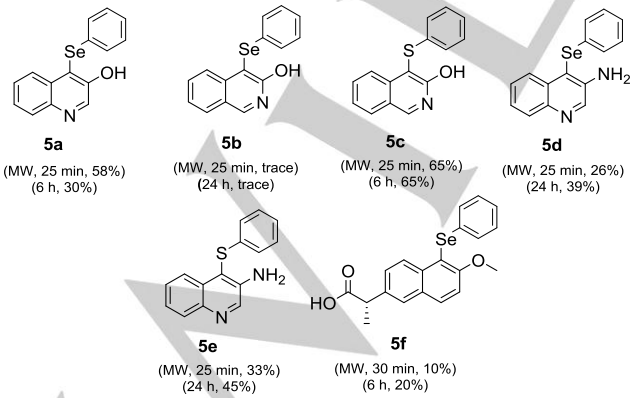
The results from 2-naphthol and naphthalen-2-amine motivated us to further extend this protocol to biologically active bicyclic arenes e.g. quinolone and isoquinoline nuclei, which are present in the structure of several drugs. The reaction of 3-hydroxyquinoline, resulted in the corresponding product **5a** in 58% under microwave irradiation (in 25 min) and 30% after 6 h under conventional heating. In case of isoquinoline, the selenylation was not successful while sulfenylation reaction gave the corresponding product **5c** in good yields with both methods. Moderated yields were obtained for the selenylation and sulfenylation of the 3-amino-quinolines to obtain the products **5d** and **5e**, respectively.

Furthermore, the reaction of the anti-inflammatory naproxen with diphenyl diselenide gave the coupled product **5f** in moderate yields with both microwave and conventional heating.

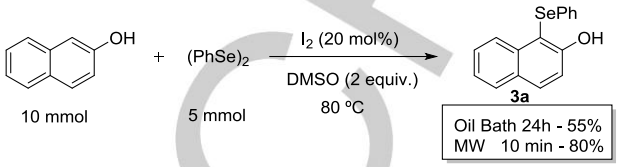
Table 5. Structural variation of biologically active compounds



5a-f

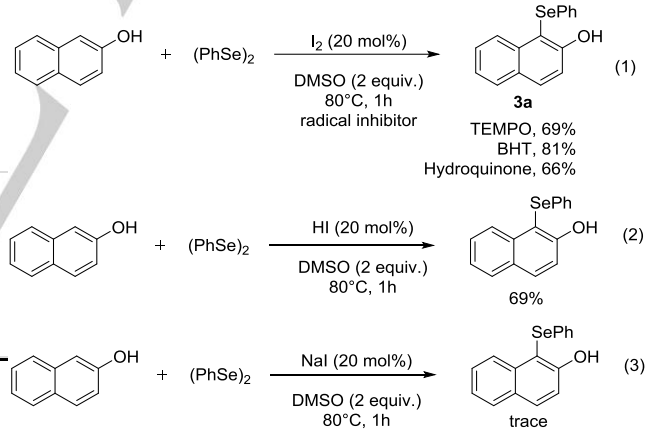


To investigate the synthetic utility of this methodology, a scale-up reaction of 10 mmol was carried out under the optimized conditions (Scheme 2). Through the reaction of 2-naphthol **1a** with diphenyl diselenide **2a**, the product **3a** was obtained in 55% yield after 24 h of reaction under conventional heating. Interestingly, the reaction under microwave afforded **3a** in 80% yield.



Scheme 2. Reactions under scale-up conditions.

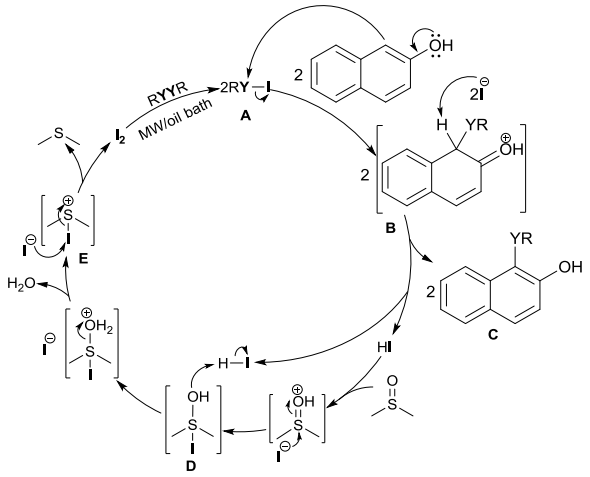
In order to gain some insight of the reaction mechanism for this transformation, some controlled experiments were performed (Scheme 3). The presence of a radical inhibitor (TEMPO, BHT or hydroquinone) did not hinder the reaction and the product **3a** was obtained in 69, 81 and 66% yields, respectively [eqn (1)]. These results indicate that the reaction does not proceed through radical formation. In previous studies by our group,[19] a catalytic amount of HI was used instead of iodine and the reaction afforded **3a** in 69%. This suggests that HI is one of the intermediates of this transformation [eqn (2)]. The importance of the presence of HI was demonstrated by the fact that the reaction did not occur [eqn (3)] when NaI was employed instead of HI.



Scheme 3. Control experiments.

Based on these results and on previous reports,[17,21] a mechanism for the chalcogenylation of 2-naphthol can be proposed (Scheme 4). Initially, the electrophilic chalcogen species **A**, RYI (Y=S, Se), is formed through the reaction between diorganoyl dichalcogenide (RYYR) and the catalyst (I_2). The naphthol nucleophile would then react with the chalcogen atom of the reactive RYI, at the 1-position, to form species **B**. This species would undergo proton elimination in order to provide the expected product **C**, with the concomitant formation of HI. Subsequently, HI would react with DMSO to give the protonated sulfur species **D**. This species would undergo water elimination and be instantly transformed into iodine-dimethyl sulfide adduct **E**. Lastly, species

E would be transformed into dimethyl sulfide, with the regeneration of the catalyst (I_2), to complete the cycle.



Scheme 4. Proposed mechanism for the reaction.

Conclusions

In summary, we have developed an effective, greener and regioselective method for the direct chalcogenylation of bicyclic arenes. This procedure afforded the desired products in good to excellent yields under solvent and metal-free conditions and can be applied using either conventional heating or microwave irradiation.

The most notable features of this protocol are that it is conducted under metal-free, solvent-free and mild conditions open to the air, and short reaction times are achieved under microwave irradiation. Additionally, with the use of this optimized protocol we were able to access biologically important Se/S-containing bicyclic arenes, such as quinolines and isoquinolines.

Experimental Section

General Procedure: Proton nuclear magnetic resonance spectra (^{1}H NMR) and carbon-13 nuclear magnetic resonance spectra (^{13}C NMR) were obtained at 400 MHz or 100 MHz on a Varian Mercury Plus and 200 MHz or 50 MHz on a Bruker AC-200 NMR spectrometer. Spectra were recorded in $CDCl_3$. Chemical shifts (δ) are reported in ppm, referenced to the solvent ($CDCl_3$) peak with tetramethylsilane (TMS) as the external reference. The H^1 NMR data reported are the chemical shift (δ), multiplicity, coupling constant (J) in Hertz and integrated intensity. Abbreviations to denote the multiplicity of a particular signal are: singlet (s), doublet (d), triplet (t), quartet (q), quintet (quint), sextet (sext) and multiplet (m). High-resolution mass spectra were recorded on a Bruker micrOTOF-Q II mass spectrometer, using APPI and APCI as ionization sources, equipped with an automatic syringe pump for sample injection. Infrared spectra (FT-IR) reporting the frequency of absorption (cm^{-1}) were recorded on a Bruker Optics Alpha benchtop FT-IR spectrometer. The melting points were determined on digital equipment (Microquimica MQRPF-301) with a heating plate. Column chromatography was conducted using silica gel (230-400 mesh). Thin layer chromatography (TLC) was performed using Merck Silica Gel GF_{254}, with 0.25 mm thickness. For the visualization, TLC plates were either placed under ultraviolet light or stained with iodine vapor and acidic vanillin. Most reactions were monitored by TLC for the disappearance of the starting material.

Chemical analysis: Unless otherwise noted, all reactions were carried out open to the atmosphere. The reagents and solvents were obtained from commercial suppliers and used without further purification. All compounds were obtained with heating in an oil bath or in a microwave reactor. The reactions were carried out in 10 mL sealed glasses tubes (borosilicate) with a cap and septum (silicon) in a commercially available CEM monomode microwave reactor with IR monitoring and a noninvasive pressure transducer. The yields are based on isolated compounds after purification.

The appropriate naphthalene or quinoline (0.5 mmol) together with diorganyl dichalcogenide (0.25 mmol), iodine (20 mol%, 240 mg) and DMSO (2 equiv., 0.073 mL) were mixed in a glass tube, which was sealed and placed in a CEM Discover microwave apparatus. A maximum irradiation power of 100 W and temperature of 80 °C were applied, in most cases, for 10 min. The reaction was also run in a flask under stirring with conventional heating in an oil bath at 80 °C. The reaction time was monitored by the disappearance of the starting material by TLC. The reaction mixture was then dissolved in ethyl acetate or dichloromethane (20 mL) and washed with 25 mL of an aqueous solution of 10% $Na_2S_2O_4$. The organic layer was separated, dried over $MgSO_4$, and concentrated under reduced pressure. The crude product was purified by column chromatography over silica gel using a mixture of hexane/ethyl acetate as the eluent.

1-(phenylselanyl)naphthalen-2-ol (3a): 140.2 mg, yield: 94% (MW); 146.6 mg, yield: 98% (Conventional heating); yellow solid; mp 77-78 °C (lit[22] 77-78 °C); purified with 97:3 hexane/ethyl acetate. ^{1}H NMR (200 MHz, $CDCl_3$) δ = 8.12 (d, J = 8.9 Hz, 1H), 7.69 (d, J = 8.9 Hz, 1H), 7.61 (d, J = 8.0, 1H), 7.39-7.12 (m, 3H), 7.09-6.84 (m, 6H); ^{13}C NMR (50 MHz, $CDCl_3$) δ = 156.3, 135.8, 132.9, 130.6, 129.5, 129.1, 128.6, 127.9, 126.9, 126.9, 126.6, 123.8, 116.7, 109.1; IR (KBr): ν = 3393, 3053, 1566, 1514, 1476, 1462, 1438, 1382, 1195, 826 cm^{-1}; HRMS (APPI+) *m/z* calculated for $C_{16}H_{13}OSe$ [M+H] 300.0048, found 300.0052.

1-(*o*-tolylselanyl)naphthalen-2-ol (3b): 129.5 mg, yield: 83% (MW); 129.5, yield: 83% (Conventional heating); brown solid; mp 77-79 °C; purified with 98:2 hexane/ethyl acetate. ^{1}H NMR (400 MHz, $CDCl_3$) δ = 8.17 (d, J = 8.2 Hz, 1H), 7.84 (d, J = 8.9 Hz, 1H), 7.74 (d, J = 8.0 Hz, 1H), 7.42 (ddd, J = 8.3, 6.9, 1.5 Hz, 1H), 7.35-7.25 (m, 2H), 7.10 (d, J = 7.4 Hz, 1H), 6.98 (m, 2H), 6.75 (ddd, J = 8.0, 7.73, 0.72 Hz, 1H), 6.53 (d, J = 7.9 Hz, 1H), 2.49 (s, 3H, CH_3); ^{13}C NMR (100 MHz, $CDCl_3$) δ = 156.7, 136.9, 136.1, 132.9, 131.2, 130.4, 129.6, 128.6, 128.0, 127.8, 127.1, 127.0, 126.4, 123.9, 116.7, 108.0, 21.56 (CH_3); IR (KBr): ν = 3379, 3063, 1594, 1566, 1514, 1454, 1396, 1378, 1201, 823, 750 cm^{-1}; HRMS

(APPI+) *m/z* calculated for $C_{17}H_{15}OSe$ [M+H] 314.02050, found 314.02046.

1-(*p*-tolylselanyl)naphthalen-2-ol (3c): 109.5 mg, yield: 70% (MW); 103.3 mg, yield: 66% (Conventional heating); brown solid; mp 54-55 °C; purified with 97:3 hexane/ethyl acetate. ^{1}H NMR (400 MHz, $CDCl_3$) δ = 8.27 (d, *J* = 8.4 Hz, 1H), 7.80 (d, *J* = 8.9 Hz, 1H), 7.72 (d, *J* = 8.0 Hz, 1H), 7.44 (ddd, *J* = 8.10, 7.43, 0.78 Hz, 1H), 7.27- 7.33 (m, 2H), 7.15 (s, 1H), 7.04 (d, *J* = 8.0 Hz, 2H), 6.88 (d, *J* = 8.0 Hz, 2H), 2.16 (s, 3H, CH_3); ^{13}C NMR (100 MHz, $CDCl_3$) δ = 156.1, 136.7, 135.8, 132.7, 130.3, 129.5, 129.5, 128.5, 127.9, 126.9, 126.8, 123.7, 116.6, 109.6, 20.9 (CH_3); IR (KBr): ν = 3360, 3050, 1596, 1464, 1460, 1457, 1384, 1381, 1199, 809 cm^{-1}; HRMS (APPI+) *m/z* calculated for $C_{17}H_{15}OSe$ [M+H] 314.0205, found 314.0208.

1-(4-methoxyphenylselanyl)naphthalen-2-ol (3d): 105.2 mg, yield: 64% (MW); 113.5 mg, yield: 69% (Conventional heating); yellow solid; mp 74-76 °C; purified with 94:6 hexane/ethyl acetate. ^{1}H NMR (200 MHz, $CDCl_3$) δ = 8.30 (d, *J* = 8.4 Hz, 1H), 7.79 (d, *J* = 8.9 Hz, 1H), 7.72 (d, *J* = 8.2, 1H), 7.46 (ddd, *J* = 8.4, 6.9, 1.4 Hz, 1H), 7.37-7.24 (m, 2H), 7.23-7.05 (m, 3H), 6.71-6.55 (m, 2H), 3.62 (s, 3H, OCH_3); ^{13}C NMR (100 MHz, $CDCl_3$) δ = 159.0, 155.9, 135.8, 132.5, 131.6, 130.6, 129.5, 128.5, 127.9, 127.0, 123.7, 120.6, 116.6, 115.3, 110.5, 98.8, 55.3 (OCH_3); IR (KBr): ν = 3347, 3061, 1617, 1592, 1491, 1457, 1349, 1248, 1179, 827 cm^{-1}; HRMS (APPI+) *m/z* calculated for $C_{17}H_{15}O_2Se$ [M+H] 330.01542, found 330.01541.

1-(2-methoxyphenylselanyl)naphthalen-2-ol (3e): 62.5 mg, yield: 38% (MW); 138.1 mg, yield: 84% (Conventional heating); red solid; mp 58-60 °C; purified with 94:6 hexane/ethyl acetate. ^{1}H NMR (400 MHz, $CDCl_3$) δ = 8.26 (d, *J* = 8.5 Hz, 1H), 7.86 (d, *J* = 8.9 Hz, 1H), 7.78 (d, *J* = 8.0 Hz, 1H), 7.46 (ddd, *J* = 8.4, 6.9, 1.3 Hz, 1H), 7.38-7.30 (m, 2H), 7.17 (s, 1H), 7.13-7.08 (m, 1H), 6.83 (dd, *J* = 8.2, 1.0 Hz, 1H), 6.64-6.55 (m, 2H), 3.94 (s, 3H, OCH_3); ^{13}C NMR (100 MHz, $CDCl_3$) δ = 157.3, 156.9, 136.4, 132.7, 129.6, 129.4, 128.6, 127.9, 127.8, 127.1, 123.8, 122.0, 119.4, 116.8, 110.7, 107.5, 56.1 (OCH_3); IR (KBr): ν = 3357, 3050, 1596, 1575, 1474, 1388, 1276, 1127, 813, 747 cm^{-1}; HRMS (APPI+) *m/z* calculated for $C_{17}H_{15}O_2Se$ [M+H] 330.0154, found 330.0155.

1-(naphthalen-1-ylselanyl)naphthalen-2-ol (3f): 144.5 mg, yield: 83% (MW); 118.5 mg, yield: 68% (Conventional heating); brown solid; mp 141-142 °C; purified with 97:3 hexane/ethyl acetate. ^{1}H NMR (400 MHz, $CDCl_3$) δ = 8.27 (d, *J* = 8.4 Hz, 1H), 8.21 (d, *J* = 8.4 Hz, 1H), 7.88 (d, *J* = 8.9 Hz, 1H), 7.78 (t, *J* = 8.0 Hz, 2H), 7.64-7.55 (m, 2H), 7.50 (t, *J* = 7.5 Hz, 1H), 7.44-7.28 (m, 3H), 7.07 (s, 1H), 7.01 (t, *J* = 7.8 Hz, 1H), 6.77 (d, *J* = 7.3 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ = 156.9, 136.2, 134.2, 133.1, 132.6, 129.7, 129.3, 128.9, 128.6, 128.1, 127.1, 126.9, 126.8, 126.4, 126.3, 126.2, 125.3, 123.9, 117.0, 108.0; IR (KBr): ν = 3364, 3051, 1617, 1600, 1564, 1502, 1460, 1384, 1199, 772 cm^{-1}; HRMS (APPI+) *m/z* calculated for $C_{20}H_{15}OSe$ [M+H] 350.0205, found 350.0207.

1-(4-fluorophenylselanyl)naphthalen-2-ol (3g): 114.1 mg, yield: 72% (MW); 131.5 mg, yield: 83% (Conventional heating); brown solid; mp 87-89 °C; purified with 97:3 hexane/ethyl acetate. ^{1}H NMR (200 MHz, $CDCl_3$) δ = 8.23 (d, *J* = 8.5 Hz, 1H), 7.81 (d, *J* = 8.9 Hz, 1H), 7.73 (d, *J* = 8.1 Hz, 1H), 7.46 (ddd, *J* = 8.4, 6.9, 1.4 Hz, 1H), 7.37-7.23 (m, 2H), 7.19-6.98 (m, 3H), 6.87-6.65 (m, 2H); ^{13}C NMR (50 MHz, $CDCl_3$) δ = 162.0 (d, $J_{C\text{-}F}$ = 250 Hz), 156.2, 135.7, 132.9, 131.2 (d, $J_{C\text{-}F}$ = 7.8 Hz), 129.6, 128.3 (d, $J_{C\text{-}}$ = 28.6 Hz), 126.8, 125.0 (d, $J_{C\text{-}F}$ = 3.3 Hz), 123.9, 116.9, 116.7, 116.4, 109.5; IR (KBr): ν = 3402, 3350, 3061, 1596, 1484, 1461, 1387, 1220, 827, 754 cm^{-1}; HRMS (APPI+) *m/z* calculated for $C_{16}H_{11}FOSe$ [M] 317.9954, found 317.9951.

1-(4-chlorophenylselanyl)naphthalen-2-ol (3h): 133.5 mg, yield: 80% (MW); 135.2 mg, yield: 81% (Conventional heating); brown solid, mp 98-99 °C; purified with 97:3 hexane/ethyl acetate. ^{1}H NMR (400 MHz, $CDCl_3$) δ = 8.20 (d, *J* = 8.5 Hz, 1H), 7.86 (d, *J* = 8.9 Hz, 1H), 7.77 (d, *J* = 8.0 Hz, 1H), 7.5-7.43 (m, 1H), 7.37-7.32 (m, 2H), 7.14-6.97 (m, 5H); ^{13}C NMR (100 MHz, $CDCl_3$) δ = 156.3, 135.6, 133.1, 132.8, 130.4, 129.6, 129.5, 128.8, 128.7, 128.2, 126.8, 123.9, 116.7, 108.8; IR (KBr): ν = 3364, 3058, 1593, 1568, 1475, 1436, 1384, 1196, 820, 754 cm^{-1}; HRMS (APPI+) *m/z* calculated for $C_{16}H_{11}ClOSe$ [M] 333.9656, found 333.9654.

1-(4-(trifluoromethyl)phenylselanyl)naphthalen-2-ol (3i): 108.2 mg, yield: 59% (MW); 102.7 mg, yield: 56% (Conventional heating); brown solid, mp 75-76 °C; purified with 98:2 hexane/ethyl acetate. ^{1}H NMR (400 MHz, $CDCl_3$) δ = 8.19 (d, *J* = 8.5 Hz, 1H), 7.88 (d, *J* = 8.9 Hz, 1H), 7.78 (d, *J* = 8.3 Hz, 1H), 7.55 – 7.45 (m, 2H), 7.39-7.32 (m, 3H), 7.17-7.08 (m, 2H), 7.01 (s, 1H); ^{13}C NMR (50 MHz, $CDCl_3$) δ = 156.5, 135.7, 133.4, 132.1, 130,4 (q, $J_{C\text{-}F}$ = 33.07), 129.9, 129.6, 128.7, 128.3, 126.6, 125.77 (q, $J_{C\text{-}F}$ = 3.5 Hz), 124.1, 123.7 (q, $J_{C\text{-}F}$ = 271.5), 123.5 (q, $J_{C\text{-}F}$ = 3.5 Hz), 120.9, 116.8, 108.1; IR (KBr): ν = 3371, 3057, 1596, 1464, 1390, 1328, 1161, 1123, 827, 106 cm^{-1}; HRMS (APPI+) *m/z* calculated for $C_{17}H_{11}F_3OSe$ [M] 367.9922, found 367.9917.

1-(butylselanyl)naphthalen-2-ol (3j): 54.5 mg, yield: 39% (MW); 58.6 mg, yield: 42% (Conventional heating); brown oil; purified with hexane. ^{1}H NMR (400 MHz, $CDCl_3$) δ = 8.33 (d, *J* = 8.5 Hz, 1H), 7.80- 7.74 (m, 2H), 7.53 (ddd, *J* = 8.21, 6.99, 1.17 Hz, 1H), 7.35 (ddd, *J* = 8.17, 7.08, 1.0 Hz, 1H), 7.27 (m, 2H), 2.69 (t, *J* = 7.3 Hz, 2H, CH_2), 1,57 (quint, *J* = 7.43, 2H, CH_2). 1.36 (sext, *J* = 4.48, 2H, CH_2), 0.84 (t, *J* = 7.3 Hz, 3H, CH_3); ^{13}C NMR (100 MHz, $CDCl_3$) δ = 155.9, 135.9, 131.7, 129.4, 128.6, 127.5, 126.9, 123.6, 116.2, 109.9, 32.4(CH_2), 28.8(CH_2), 22.7(CH_2), 13.4 (CH_3); IR (KBr): ν = 3357, 3058, 2960, 2946, 2870, 1617, 1596, 1516, 1464, 1388, 1349, 1203, 820, 754 cm^{-1}; HRMS (APPI+) *m/z* calculated for $C_{14}H_{16}OSe$ [M] 280.0361, found 280.0359.

1-(phenylthio)naphthalen-2-ol (3k): 68.0 mg, yield: 54% (MW); 97.0 mg, yield: 77% (Conventional heating); white solid, mp 62-63 °C (lit[23] 61.5-62.5°); purified with 99:1 hexane/ethyl acetate. ^{1}H NMR (400 MHz, $CDCl_3$) δ = 8.20 (d, *J* = 8.4 Hz, 1H), 7.85 (d, *J* = 8.9 Hz, 1H), 7.76 (d, *J* = 7.9 Hz, 1H), 7.5-7.42 (m, 1H), 7.40-7.26 (m, 2H), 7.19 (s, 1H), 7.09 (m, 5H); ^{13}C NMR (100 MHz, $CDCl_3$) δ = 157.08, 135.66, 135.44, 132.91, 129.55, 129.25, 128.66,

128.04, 126.42, 125.95, 124.77, 123.95, 116.86, 108.06; IR (KBr): ν = 3381, 3061, 1596, 1474, 1460, 1391, 1206, 1126, 824, 740 cm^{-1}; HRMS (APPI+) *m/z* calculated for $C_{16}H_{13}OS$ [M+H] 253.0682, found 253.0685.

1-(*p*-tolylthio)naphthalen-2-ol (3l): 94.4 mg, yield: 71% (MW); 105.1 mg, yield: 79% (Conventional heating); white solid, mp 73-74 °C (lit[23] 61.5-63.5°); purified with 97:3 hexane/ethyl acetate. ^{1}H NMR (400 MHz, $CDCl_3$) δ = 8.22 (d, *J* = 8.5 Hz, 1H), 7.84 (d, *J* = 8.9 Hz, 1H, 7.76 (d, *J* = 8.10 Hz, 1H), 7.45 (ddd, *J* = 8.3, 6.9, 1.5 Hz, 1H), 7.37-7.27 (m, 2H), 7.22 (s, 1H), 6.93 (s, 4H), 2.20 (s, 3H, CH_3); ^{13}C NMR (100 MHz, $CDCl_3$) δ = 157.02, 135.99, 135.61, 132.72, 131.91, 130.06, 129.63, 128.65, 127.97, 126.87, 124.88, 123.89, 116.97, 108.93, 20.96 (CH_3); IR (KBr): ν = 3399, 3061, 3022, 1596, 1620, 1464, 1258, 1203, 823, 754 cm^{-1}.

(2-methoxynaphthalen-1-yl)(phenyl)selane (4a): 34.4 mg, yield: 22% (MW); 117.3 mg, yield: 75% (Conventional heating); yellow solid, mp 89-90 °C (lit[24] pale yellow liquid); purified with 98:2 hexane/ethyl acetate. ^{1}H NMR (400 MHz, $CDCl_3$) δ = 8.36 (d, *J* = 7.4 Hz, 1H), 7.75 (d, *J* = 9.0 Hz, 1H), 7.63 (d, *J* = 8.1 Hz, 1H), 7.34-7.28 (m, 1H), 7.23-7.17 (m, 1H), 7.14 (d, *J* = 9.0 Hz, 1H), 7.06-7.01 (m, 2H), 6.98-6.86 (m, 3H), 3.73 (s, 3H, OCH_3); ^{13}C NMR (100 MHz, $CDCl_3$) δ = 158.8, 136.5, 133.3, 131.9, 129.8, 129.4, 128.9, 128.3, 127.9, 127.7, 125.7, 124.1, 113.6, 29.8(OCH_3); IR (KBr): ν = 3447, 3058, 1617, 1589, 1502, 1464, 1443, 1353, 1335, 1269, 1064, 1022, 810, 744 cm^{-1}; HRMS (APPI+) *m/z* calculated for $C_{17}H_{14}OSe$ [M] 314.0205, found 314.0210.

(2-ethoxynaphthalen-1-yl)(phenyl)selane (4b): Reaction at 0.25 mmol of 2-ethoxynaphthalene and 0.13 mmol of diphenyl diselenide. 14.5 mg, yield: 18% (MW); 48.2 mg, yield: 59% (Conventional heating); yellow solid, mp 49-50 °C; purified with 98:2 hexane/ethyl acetate. ^{1}H NMR (400 MHz, $CDCl_3$) δ = 8.49 (d, *J* = 8.1 Hz, 1H), 7.90 (d, *J* = 9.0 Hz, 1H), 7.79 (d, *J* = 8.1 Hz, 1H), 7.48 (ddd, *J* = 8.4, 6.8, 1.3 Hz, 1H), 7.36 (ddd, *J* = 8.0, 6.8, 1.1 Hz, 1H), 7.30 (d, *J* = 9.0 Hz, 1H), 7.24-7.17 (m, 2H), 7.15- 7.05 (m, 3H), 4.15 (q, *J* = 7.0 Hz, 2H, OCH_2), 1.29 (t, *J* = 7.0 Hz, 3H, CH_3); ^{13}C NMR (100 MHz, $CDCl_3$) δ = 158.2, 136.6, 133.6, 131.7, 129.9, 128.9, 128.3, 128.0, 127.6, 125.8, 124.2, 119.1, 115.1, 114.4, 65.9(OCH_2), 14.9 (CH_3); IR (KBr): ν = 3067, 1580, 1476, 1462, 1455, 1375, 1263, 1059, 805, 732 cm^{-1}; HRMS (APPI+) *m/z* calculated for $C_{18}H_{16}OSe$ [M] 328.0362, found 328.0361.

7-methoxy-1-(phenylselanyl)naphthalen-2-ol (4c): 59.3 mg, yield: 36% (MW); 146.5 mg, yield: 89% (Conventional heating); little purple; mp 82-83 °C; purified with 93:7 hexane/ethyl acetate. ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.76 (d, *J* = 8.8 Hz, 1H), 7.65 (d, *J* = 8.8 Hz, 1H), 7.59 (d, *J* = 2.3 Hz, 1H), 7.22-7.06 (m, 7H), 6.98 (dd, *J* = 8.8, 2.4 Hz, 1H), 3.80 (s, 3H, OCH_3); ^{13}C NMR (100 MHz, $CDCl_3$) δ = 159.6, 156.9, 137.7, 132.5, 130.5, 130.2, 129.5, 129.4, 126.8, 124.8, 116.0, 114.0, 108.5, 106.3, 55.4 (OCH_3); IR (KBr): ν = 3358, 3053, 1614, 1475, 1458, 1423, 1375, 1278, 1218, 840, 732 cm^{-1}; HRMS (APPI+) *m/z* calculated for $C_{17}H_{15}O_2Se$ [M+H] 331.0232, found 331.0230.

7-bromo-1-(phenylselanyl)naphthalen-2-ol (4d): 154.9 mg, yield: 82% (MW); 170.1 mg, yield: 90% (Conventional heating); yellow solid; mp 79-80 °C; purified with 98:2 hexane/ethyl acetate. ^{1}H NMR (400 MHz, $CDCl_3$) δ = 8.43 (s, 1H), 7.76 (d, *J* = 8.9 Hz, 1H), 7.57 (d, *J* = 8.6 Hz, 1H), 7.38 (dd, *J* = 8.6, 1.9 Hz, 1H), 7.30 (d, *J* = 8.9 Hz, 1H), 7.13 (s, 1H), 7.10 (s, 5H); ^{13}C NMR (100 MHz, $CDCl_3$) δ = 157.0, 137.3, 132.7, 130.2, 129.6, 129.5, 129.3, 129.2, 127.9, 127.3, 126.9, 122.8, 116.9, 108.5; IR (KBr): ν = 3654, 3063, 1580, 1507, 1475, 1271, 1149, 815, 746, 527 cm^{-1}; HRMS (APPI+) *m/z* calculated for $C_{16}H_{11}BrOSe$ [M] 377.9150, found 377.9151.

4-(phenylselanyl)naphtho[2,3-*d*][1,3]dioxole (4e): 24.5 mg, yield: 15% (MW); 40.9 mg, yield: 25% (Conventional heating); yellow solid; mp 63-64 °C; purified with 98:2 hexane/ethyl acetate. ^{1}H NMR (400 MHz, $CDCl_3$) δ = δ 8.28 (dd, *J* = 6.0, 3.5 Hz, 1H), 7.67 (dd, *J* = 6.1, 3.3 Hz, 1H), 7.38-7.34 (m, 2H), 7.26-7.21 (m, 2H), 7.18 (s, 1H), 7.17-7.10 (m, 3H), 6.07 (s, 2H, OCH_2O); ^{13}C NMR (100 MHz, $CDCl_3$) δ = 151.2, 146.5, 131.8, 131.2, 130.2, 129.9, 129.3, 127.7, 127.1, 126.4, 125.6, 125.1, 105.9, 102.9, 101.2 (OCH_2O); IR (KBr): ν = 3072, 1600, 1572, 1474, 1318, 1241 1049, 837, 730 cm^{-1}; HRMS (APPI+) *m/z* calculated for $C_{17}H_{12}O_2Se$ [M] 327.9998, found 327.9998.

(4*a*,5,6,7,8,8*a*-hexahydronaphthalen-1-yl)(phenyl)selane (4f): 19.7 mg, yield: 13% (MW); 90.9 mg, yield: 60% (Conventional heating); red oil; purified with 9:1 hexane/ethyl acetate. ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.25-7.06 (m, 5H), 6.91 (d, *J* = 8.3 Hz, 1H), 6.67 (s, 1H), 2.81 (t, *J* = 5.7 Hz, 2H, CH_2), 2.71 (t, *J* = 5.7 Hz, 2H, CH_2), 1.76-1.65 (m, 4H, $2CH_2$); ^{13}C NMR (100 MHz, $CDCl_3$) δ = 155.2, 142.0, 132.9, 130.8, 130.3, 129.6, 129.0, 126.6, 116.0, 112.3, 30.9(CH_2), 29.6(CH_2), 23.6(CH_2), 22.9 (CH_2); IR (KBr): ν = 3392, 3061, 1586, 1474, 1468, 1440, 1304, 1206, 816, 737 cm^{-1}; HRMS (APPI+) *m/z* calculated for $C_{16}H_{17}OSe$ [M+H] 304.0361, found 304.0362.

1-(phenylselanyl)naphthalen-2-amine (4g): 74.5 mg, yield: 50% (MW); 119.3 mg, yield: 80% (Conventional heating); brown red solid; mp 75-76 °C; purified with 97:3 hexane/ethyl acetate. ^{1}H NMR (400 MHz, $CDCl_3$) δ = 8.31 (d, *J* = 8.5 Hz, 1H), 7.72 (d, *J* = 8.8, 1H), 7.68 (d, *J* = 8.0 Hz, 1H), 7.41 (ddd, *J* = 8.4, 6.9, 1.5 Hz, 1H), 7.26-7.20 (m, 1H), 7.15-7.06 (m, 5H), 7.03 (d, *J* = 8.7 Hz, 1H), 4.70 (s, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ = 148.1, 137.0, 131.9, 131.8, 129.3, 128.7, 128.4, 128.4, 127.9, 126.7, 125.9, 122.6, 117.4, 105.5; IR (KBr): ν = 3381, 3065, 1613, 1558, 1474, 1064, 816, 733 cm^{-1}; HRMS (APPI+) *m/z* calculated for $C_{16}H_{14}NSe$ [M+H] 300.0286, found 300.0287.

1-(4-chlorophenylselanyl)naphthalen-2-amine (4h): 97.9 mg, yield: 59% (MW); 104.6 mg, yield: 63% (Conventional heating); brown solid; mp 64-65 °C; purified with 97:3 hexane/ethyl acetate. ^{1}H NMR (400 MHz, $CDCl_3$) δ = 8.25 (d, *J* = 8.5 Hz, 1H), 7.70 (d, *J* = 8.8 Hz, 1H), 7.67 (d, *J* = 8.0 Hz, 1H), 7.40 (ddd, *J* = 8.4, 6.9, 1.3 Hz, 1H), 7.23 (ddd, *J* = 8.0, 6.9, 1.1 Hz, 1H), 7.06-7.00 (m, 4H), 6.99 (d, *J* = 8.8 Hz, 1H), 4.67 (s, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ = 148.2, 136.8, 132.1, 131.9, 130.2, 130.1, 129.4, 128.5, 128.4, 127.9, 126.4, 122.7, 117.5, 105.2; IR (KBr): ν = 3392, 3058,

1617, 1505, 1471, 1011, 813, 750 cm^{-1}; HRMS (APPI+) *m/z* calculated for $C_{16}H_{13}ClNSe$ [M+H] 333.9894, found 333.9888.

1-(4-methoxyphenylselanyl)naphthalen-2-amine (4i): 83.2 mg, yield: 52% (MW); 108.8 mg, yield: 68% (Conventional heating); brown red solid; mp 89-90 °C; purified with 98:2 hexane/ethyl acetate. ^1H NMR (400 MHz, $CDCl_3$) δ = 8.37 (d, *J* = 8.5 Hz, 1H), 7.73-7.67 (m, 2H), 7.43 (ddd, *J* = 8.4, 6.9, 1.3 Hz, 1H), 7.27-7.22 (m, 1H), 7.16 – 7.11 (m, 2H), 7.04 (d, *J* = 8.7 Hz, 1H), 6.72 – 6.67 (m, 2H), 4.75 (s, 2H), 3.70 (s, 3H, OCH_3); ^{13}C NMR (100 MHz, $CDCl_3$) δ = 158.6, 158.4, 147.9, 137.0, 131.6, 130.9, 128.4, 127.8, 126.8, 122.6, 121.9, 117.5, 115.2, 107.0, 55.4 (OCH_3); IR (KBr): ν = 3437, 3051, 1614, 1492, 1464, 1248, 1026, 820, 758 cm^{-1}; HRMS (APPI+) *m/z* calculated for $C_{17}H_{16}NOSe$ [M+H] 329.0314, found 329.0313.1

1-(phenylthio)naphthalen-2-amine (4j): 123.7 mg, yield: 99% (MW); 73.8 mg, yield: 59% (Conventional heating); brown solid, mp 64-65 °C (lit[25] 73.4-74.8 °C); purified with 97:3 hexane/ethyl acetate. ^1H NMR (400 MHz, $CDCl_3$) δ = 8.26 (d, *J* = 8.5 Hz, 1H), 7.71-7.65 (m, 2H), 7.39 (ddd, *J* = 8.4, 6.9, 1.3 Hz, 1H), 7.22 (ddd, *J* = 8.0, 6.9, 1.1 Hz, 1H), 7.16-7.06 (m, 2H), 7.04-6.97 (m, 3H), 6.95 (d, *J* = 8.8 Hz, 1H), 4.63 (s, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ = 148.6, 136.9, 136.8, 131.9, 129.1, 128.5, 128.5, 127.9, 126.0, 125.1, 124.3, 122.7, 117.7, 104.7; IR (KBr): ν = 3399, 3305, 3169, 3050, 1617, 1474, 1349, 820, 740 cm^{-1}; HRMS (APPI+) *m/z* calculated for $C_{16}H_{14}NS$ [M+H] 252.0841, found 252.0842.

1-(*p*-tolylthio)naphthalen-2-amine (4k): 128.5 mg, yield: 97% (MW); 108.6 mg, yield: 82% (Conventional heating); white solid, mp 73-74 °C (lit[23] 72.5-73.5 °C); purified with 97:3 hexane/ethyl acetate. ^1H NMR (400 MHz, $CDCl_3$) δ = 8.28 (d, *J* = 8.5 Hz, 1H), 7.74 (d, *J* = 8.8 Hz, 1H), 7.71 (d, *J* = 8.0 Hz, 1H), 7.43 (ddd, *J* = 8.4, 6.9, 1.3 Hz, 1H), 7.25 (ddd, *J* = 8.0, 5.7, 1.1 Hz, 1H), 7.04 (d, *J* = 8.8 Hz, 1H), 6.99-6.90 (m, 4H), 4.70 (s, 2H), 2.23 (s, 3H, CH_3); ^{13}C NMR (100 MHz, $CDCl_3$) δ = 148.5, 136.9, 135.0, 133.4, 131.8, 129.9, 128.6, 128.5, 127.9, 126.3, 124.5, 122.7, 117.8, 105.6, 20.9(CH_3); IR (KBr): ν = 3475, 3370, 3054, 1620, 1471, 1429, 1356, 1081, 806, 750 cm^{-1}; HRMS (APPI+) *m/z* calculated for $C_{17}H_{16}NS$ [M+H] 266.0998, found 266.1002.

methyl(1-(phenylselanyl)naphthalen-2-yl)sulfane (4l): 32.9 mg, yield: 20% (MW); 121.7 mg, yield: 74% (Conventional heating); yellow solid, mp 73-74 °C; purified with hexane. ^1H NMR (400 MHz, $CDCl_3$) δ = 8.47 (d, *J* = 8.5 Hz, 1H), 7.84 (d, *J* = 8.8 Hz, 1H), 7.74 (d, *J* = 7.9 Hz, 1H), 7.44 (ddd, *J* = 8.4, 6.9, 1.3 Hz, 1H), 7.39-7.31 (m, 2H), 7.18-7.02 (m, 5H), 2.44 (s, 3H, SCH_3); ^{13}C NMR (100 MHz, $CDCl_3$) δ = 146.0, 136.1, 132.5, 131.4, 130.8, 129.4, 129.2, 128.5, 127.9, 127.9, 126.0, 125.3, 124.0, 122.2, 16.7(SCH_3); IR (KBr): ν = 3058, 2915, 1579, 1474, 1435, 1384, 900, 855, 731, 689 cm^{-1}; HRMS (APPI+) *m/z* calculated for $C_{17}H_{14}SSe$ [M] 329.9976, found 329.9978.

4-(phenylselanyl)quinolin-3-ol (5a): 87.1 mg, yield: 58% (MW); 45.0 mg, yield: 30% (Conventional heating); yellow solid, mp 110-111 °C; purified with 80:20 hexane/ethyl acetate. ^1H NMR (200 MHz, $CDCl_3$) δ = 8.85 (s, 1H), 8.27-8.17 (m, 1H), 8.12-8.04 (m, 1H), 7.60-7.49 (m, 2H), 7.26-7.08 (m, 6H), ^{13}C NMR (50 MHz, $CDCl_3$) δ = 151.2, 143.9, 142.2, 130.3, 130.2, 129.9, 129.8, 129.2, 128.5, 127.4, 126.9, 126.9, 118.6; IR (KBr): ν = 3653, 3057, 1655, 1587, 1475, 1331, 1269, 761, 736 cm^{-1}; HRMS (APPI+) *m/z* calculated for $C_{15}H_{12}NOSe$ [M+H] 302.0079, found 302.0077.

4-(phenylthio)isoquinolin-3-ol (5c): 82.2 mg, yield: 65% (MW); 82.2 mg, yield: 65% (Conventional heating); yellow solid, mp 121-122 °C; purified with 80:20 hexane/ethyl acetate. ^1H NMR (400 MHz, $CDCl_3$) δ = 8.68 (s, 1H), 8.20-8.16 (m, 1H), 7.72-7.68 (m, 1H), 7.54 (ddd, *J* = 8.8, 6.7, 1.3 Hz, 1H), 7.26-7.11 (m, 5H), 7.10-7.02 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ = 162.6, 147.4, 144.1, 137.1, 133.4, 129.1, 129.0, 126.8, 125.4, 124.3, 123.9, 122.2, 106.6; IR (KBr): ν = 3400, 3050, 2925, 1624, 1481, 1439, 1342, 1150, 754 cm^{-1}; HRMS (APCI+) *m/z* calculated for $C_{15}H_{12}NOS$ [M+H] 254.0634, found 254.0635.

4-(phenylselanyl)quinolin-3-amine (5d): 39.0 mg, yield: 26% (MW); 58.5 mg, yield: 39% (Conventional heating); golden solid, mp 153-154 °C; purified with 80:20 hexane/ethyl acetate. ^1H NMR (400 MHz, $CDCl_3$) δ = 8.59 (s, 1H), 8.27-8.23 (m, 1H), 8.01-7.97 (m, 1H), 7.51-7.43 (m, 2H), 7.20-7.13 (m, 5H), 4.69 (s, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ = 142.9, 142.8, 142.2, 131.2, 130.2, 129.9, 129.7, 129.6, 128.3, 126.8, 126.5, 125.6, 114.3; IR (KBr): ν = 3442, 3309, 3055, 2922, 1610, 1474, 1150, 765, 734 cm^{-1}; HRMS (APCI+) *m/z* calculated for $C_{15}H_{13}N_2Se$ [M+H] 301.02389, found 301.02390.

4-(phenylthio)quinolin-3-amine (5e): 41.6 mg, yield: 33% (MW); 56.7 mg, yield: 45% (Conventional heating); golden solid, mp 157-158 °C; purified with 80:20 hexane/ethyl acetate. ^1H NMR (400 MHz, $CDCl_3$) δ = 8.62 (s, 1H), 8.25-8.20 (m, 1H), 8.03-7.98 (m, 1H), 7.51-7.44 (m, 2H), 7.21-7.16 (m, 2H), 7.14-7.09 (m, 1H), 7.07-7.03 (m, 2H), 4.69 (s, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ = 143.1, 142.9, 142.7, 134.8, 130.8, 129.8, 129.3, 128.3, 126.9, 126.0, 125.6, 124.2, 113.9; IR (KBr): ν = 3447, 3322, 3061, 1699, 1614, 1579, 1475, 768, 740 cm^{-1}; HRMS (APCI+) *m/z* calculated for $C_{15}H_{13}N_2S$ [M+H] 253.0794, found 253.0796.

(*S*)-2-(6-methoxy-5-(phenylselanyl)naphthalen-2-yl) propanoic acid (5f): 19.2 mg, yield: 10% (MW); 38.4 mg, yield: 20% (Conventional heating); pale yellow solid, mp 125-126 °C; purified with 80:20 hexane/ethyl acetate. ^1H NMR (400 MHz, $CDCl_3$) δ = 8.44 (d, *J* = 8.8 Hz, 1H), 7.89 (d, *J* = 9.1 Hz, 1H), 7.70 (s, 1H), 7.43 (dd, *J* = 8.9, 1.5 Hz, 1H), 7.32 (d, *J* = 9.0 Hz, 1H), 7.23-6.99 (m, 6H), 3.91 (s, 3H, OCH_3), 3.91 (d, *J* = 7.1, 1H, CH), 1.57 (d, *J* = 7.1 Hz, 3H, CH_3); ^{13}C NMR (50 MHz, $CDCl_3$) δ = 180.3, 158.9, 135.9, 135.5, 133.2, 131.9, 129.8, 129.6, 129.1, 128.6, 127.6, 126.7, 125.8, 113.9, 113.1, 57.2 (OCH_3), 45.2 (CH), 18.2 (CH_3); IR (KBr): ν = 3068, 2934, 1704, 1593, 1475, 1461, 1440, 1380, 1067, 802, 737 cm^{-1}; HRMS (APPI+) *m/z* calculated for $C_{20}H_{18}O_3Se$ [M] 386.0417, found 386.0419.

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[20] Selected crystal data are presented at the end of the Electronic Supplementary Information (ESI) available: See DOI: 10.1039/x0xx00000x. Full crystallographic tables (including

structure factors) for compounds **3a** and **4g** have been deposited with the Cambridge Crystallographic Data Centre as supplementary publication numbers CCDC 1541566 (**3a**) and CCDC 1541567 (**4g**). These data can be obtained free of charge from the Cambridge Crystallographic Data Centre via www.ccdc.cam.ac.uk/data_request/cif.

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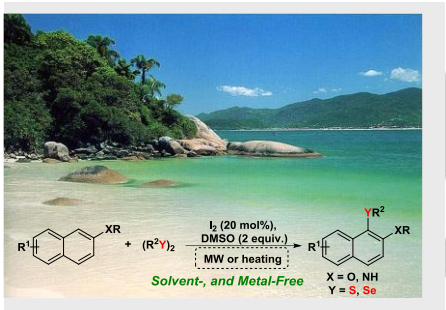
Entry for the Table of Contents

FULL PAPER

A greener and efficient protocol for the chalcogenylation of bicyclic arenes using the I_2/DMSO catalytic system under solvent- and metal-free conditions, was developed. This protocol allowed access to several chalcogenated bicyclic arenes through C(sp^2)-H bond functionalization.



Organoselenium chemistry, Organosulfur chemistry, Green chemistry

Lais T. Silva, Juliano B. Azeredo, Sumbal Saba, Jamal Rafique, Adailton J. Bortoluzzi, and Antonio L. Braga**

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Solvent- and metal-free chalcogenation of bicyclic arenes using I_2/DMSO as non-metallic catalytic system