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Full Paper

New utility of electrophilic trifluoromethylthiolation reagents for the synthesis of a variety of triflones

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ABSTRACT

The synthesis of various triflones has been achieved using electrophilic trifluoromethylthiolation reagents as building blocks, and not as reagents. Trifluoromethanesulfonyl hypervalent iodonium ylide **1a** and its diazo-analogue **1b** are well-known reagents for electrophilic trifluoromethylthiolation of nucleophiles under copper catalysis. In this paper, we disclose another facet of these reagents as synthetic building blocks of triflones via intramolecular rearrangements. The diazo-compound **1b** was converted into amide-, ester- and enol-triflones via the Wolff rearrangement followed by a nucleophilic reaction with aryl- and alkylamines, amino acids, alcohols, and silyl enol ether in heated conditions. On the other hand, the ylide reagent **1a** was converted into vinyl triflone via an intramolecular *I*-*O*-rearrangement under heat. More interestingly, both **1a** and **1b** reacted with acetonitrile to give an oxazole-triflone under copper catalysis.

1. Introduction

Organofluorine compounds have commanded a central position in agrochemical and pharmaceutical research [1–3]. A variety of fluorine-containing drugs have been registered in data-bases, and they can be categorized according to the functional groups in their molecular structures such as fluorine (F), trifluormethyl (CF_3) and difluoromethyl (CF_2H) groups, among others. In recent decades, the trifluoromethylthio (SCF_3) group has gained increasing significance due to its impressive lipophilicity but similar electron-withdrawing property to the CF_3 group, which is highly advantageous as this alternation improves the cell-permeability of the original CF_3-containing drugs [4–19]. Shelf-stable electrophilic reagents for trifluoromethylthiolation have become widely developed as reagents for the preparation of trifluoromethylthio compounds, and should be useful for the late stage functionalization of target compounds [20–27]. Our group has also contributed to this area by disclosing two novel reagents, trifluoromethanesulfonyl hypervalent iodonium ylide **1a** and its diazo-analogue **1b** [28–33]. Both reagents have been revealed as being effective for electrophilic trifluoromethylthiolation reactions of enamines, indoles, β-keto esters, pyrroles, silyl enol ethers, allylsilanes and allyl alcohols under copper catalysis. Coupling-type trifluoromethylthiolation of aromatics by **1** has also been achieved in the presence of copper catalysts. During our study of the trifluoromethylthiolation reactions using **1**, we noticed that reagent **1** has potential not only for electrophilic transfer trifluoromethylthiolation under copper catalysis, but also as attractive building blocks of triflones under catalyst-free conditions. Namely, pharmaceutically attractive β-lactam-triflones were directly synthesized by the reaction of **1b** with imines in catalyst-free thermal conditions [34]. In situ generation of ketene-triflone from **1b** via the Wolff-rearrangement followed by Staudinger [2 + 2] cycloaddition with imines is proposed for this reaction mechanism, resulting in the formation of multi-substituted β-lactam-triflones in good to high yields with high diastereoselectivity (Fig. 1a).

Triflones are compounds that contain a trifluoromethanesulfonyl (triflyl, SO_2CF_3) group in their structures [35–38]. The electron-withdrawing effect of the SO_2CF_3 group is slightly stronger than that of the nitro (NO_2) group. While NO_2 is slightly hydrophilic, SO_2CF_3 is lipophilic [39,40]. The uniqueness of the SO_2CF_3 group also caught our attention for several years as a potential functional group to produce drug candidates, resulting in the development of the efficient synthesis of heteroaryl triflones containing isoxazoles, pyrazoles, pyrazolo[5,1-a]isoquinolines, indoles, pyridines, and quinolines [41–44]. The synthesis of vinyl triflones was also reported [45]. As part of our ongoing studies on the synthesis of triflones and electrophilic trifluoromethylthiolation reagents, we disclose herein the synthesis of amide-, ester-

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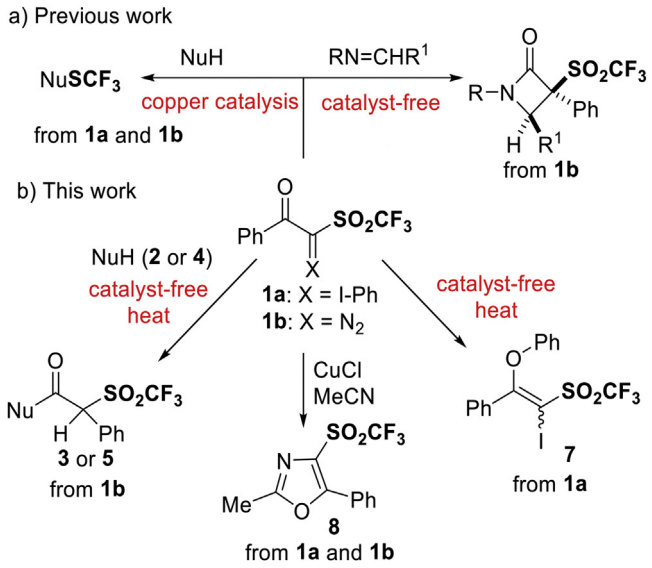


Fig. 1. Electrophilic trifluoromethylthiolation reagents **1** and their alternative utility for the synthesis of triflones.

triflones **3**, enol-triflone **5**, vinyl triflone **7** and oxazole triflone **8** from electrophilic trifluoromethylthiolation reagents **1** as triflone-containing building blocks (Fig. 1b).

2. Results and discussion

We first examined the reaction of diazo-reagent **1b** with aniline (**2a**) (Table 1). The treatment of **2a** with **1b** in toluene at 100 °C afforded *N*,2-diphenyl-2-((trifluoromethyl)sulfonyl)acetamide (**3a**) in 48% yield (entry 1). This expected the production of this compound because of the nucleophilic reaction of **2a** with in-situ generated ketene triflone **B** via the Wolff rearrangement of a carbene intermediate **A**, while a considerable amount of (((trifluoromethyl)sulfonyl)methyl)benzene, $PhCH_2SO_2CF_3$) was accompanied. Encouraged by initial result, we attempted to optimize the reaction conditions. An excess amount of **2a** in different solvent conditions, including solvent-free, did not improve the results (entries 1–9). We next changed the procedure

Table 1
Optimization of reaction conditions of **1b** with **2a**.

Entry	Molar ratio **2a**:**1b**	Solvent	Yield (%)[a]
1	1:1	Toluene	48
2	1.5:1	Toluene	48
3	3:1	Toluene	48
4	10:1	Solvent-free	4
5	1:2	Toluene	33
6	1:1	DCE	46[b]
7	1:1	Dioxane	47
8	1:1	p-Xylene	48
9	1:1	Benzene	40[b]
10	1:1.5	Toluene	75[c]
11	1:1.5	Toluene	25[c,d]
12	1:2.0	Toluene	82[c]
13	1:2.0	Toluene	86[c,e]

[a] Reaction conditions: aniline **2a** (0.1 mmol for entries 10–13), **1b** (0.1 mmol for entries 1–9), solvent (1.0 mL), 100 °C for 1 h. Yields were determined by ^{19}F NMR spectroscopy with trifluoromethyl benzene as the internal standard.
[b] 8 h.
[c] **1b** in toluene (0.1 M) at 100 °C for 1 h, then aniline **2a** was added, and the mixture solution was heated for another 2 h.
[d] 80 °C.
[e] Toluene (0.03 M).

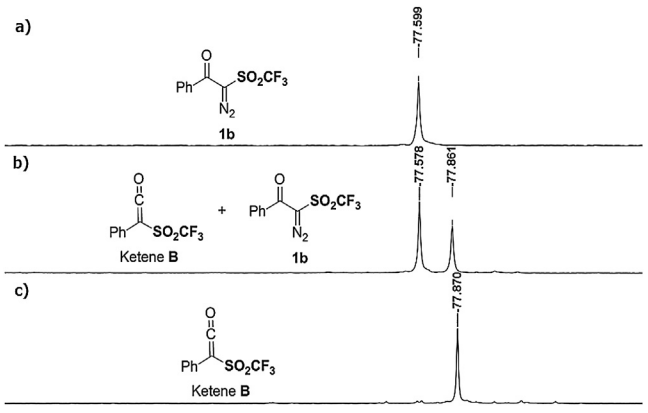
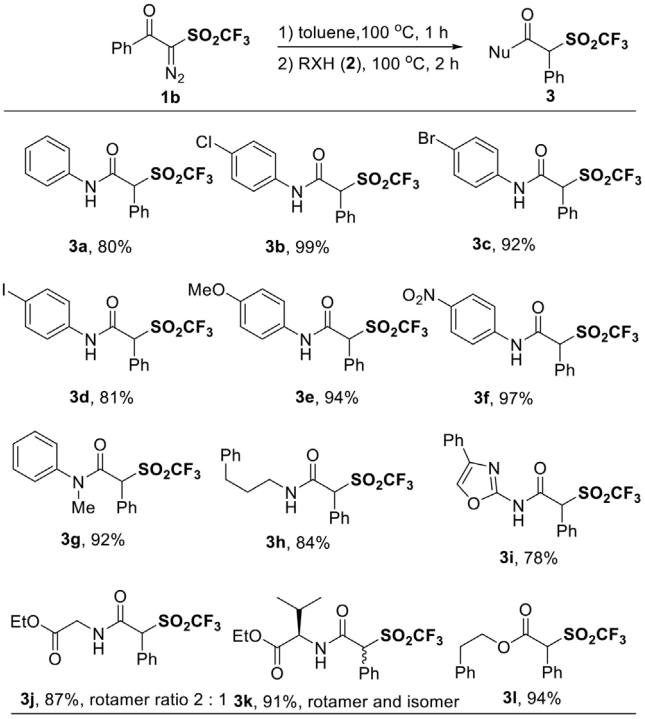


Fig. 2. ^{19}F NMR charts of diazo-triflone **1b** and ketene **B** in $CDCl_3$ using C_6F_6 (δ = 162.2 ppm) as the internal standard. a) diazo-triflone **1b** in $CDCl_3$. b) Neat **1b** was heated at 120 °C for 30 min under N_2 atmosphere, after cooled to room temperature **1b** and $CDCl_3$ was added, then NMR analysis. c) Neat **1b** was heated at 120 °C for 30 min under N_2 atmosphere, after cooled to room temperature $CDCl_3$ was added, then NMR analysis.

of the reaction. Namely, **1b** was first heated in toluene at 100 °C for 1 h, then **2a** was added. This two-step, one-pot procedure significantly improved the yield of **3a** to 75% at 100 °C. The yield of **2a** decreased sharply to 25% when the reaction was conducted at 80 °C. Increasing the ratio of **2a** with **1b** to 1:2 and in toluene (0.03 M) under this two-step, one-pot reaction procedure gave a good yield of **3a**, 86%. The formation of ketene was ascertained by an ^{19}F NMR experiment (Fig. 2) and IR spectra [34].

With the optimal reaction conditions in hand, a series of nucleophiles **2** were next examined for transformation to the corresponding triflones **3** (Scheme 1). Substituted anilines with halogen such as chloro **2b**, bromo **2c**, iodo **2d**, electron-donating OMe **2e** and electron-withdrawing NO_2 **2f** were well-tolerated to



Scheme 1. Reaction of diazo-triflone **1b** with nucleophiles **2**. Reaction conditions: diazo-triflone **1b** (0.4 mmol), toluene (6.0 mL), 100 °C for 1 h, then nucleophiles **2** (0.2 mmol) in 1.0 mL toluene was added, stirred at 100 °C for another 2 h.

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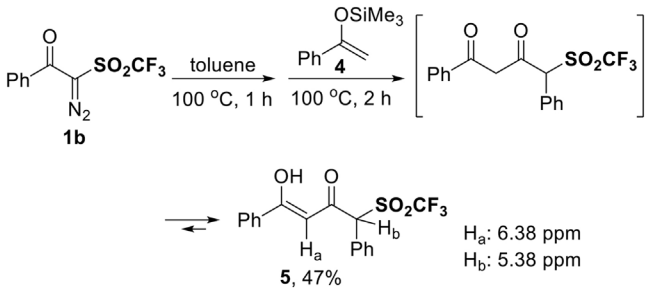


Scheme 2. Reaction of diazo-triflone **1b** with **4**.

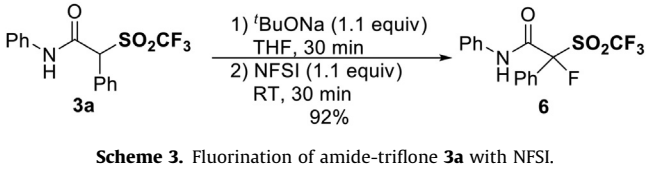
provide the corresponding amido-triflones **3b–f** in high yields. Secondary aniline, alkylamine, heteroarylamine and amino acids of glycine and leucine also reacted nicely with **1b** to furnish corresponding acyclic amide-triflones **3g–k** in high yields. Phenethyl alcohol (**2l**) also reacted with **1b** under the same conditions to furnish ester-triflone **3l** in 94% yield.

It should be noted that this reaction was extended to the reaction with silyl enol ether **4** under the same reaction conditions to provide enol-triflone **5** in 47% yield (Scheme 2). The enol structure of **5** was ascertained by the comparison of chemical shift of vinyl proton with the reported enol compounds [46].

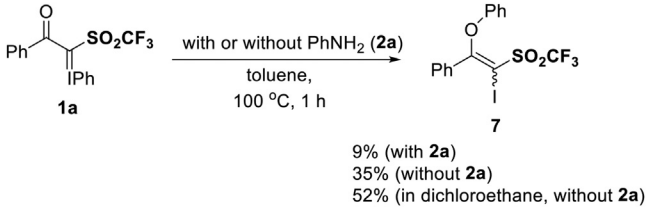
All the triflones obtained here have an α-carbonyl α-phenyl triflyl structure. Therefore, the α-hydrogen atom is exceptionally acidic and a variety of additional functionalizations at this position should be possible. Indeed, the chemistry of triflones in alkylation and conjugated addition are well summarized by Hendrickson et al. [47]. Manthorpe and co-workers recently investigated the reactivity of α-triflyl esters, amides and ketones in methylation and allylation reactions [48]. We next examined the fluorination of triflones **3** to construct a quarter carbon center. Fluorination of amide-triflone **3a** with *N*-fluorobis(phenylsulfonyl)amine (NFSI) in the presence of ^{t}BuONa provided the corresponding product **7** in 92% yield (Scheme 3).

In contrast, the reaction of trifluoromethanesulfonyl hypervalent iodonium ylide reagent **1a** with **2a** in toluene at 100 °C did not give the desired **3a**, but *tetra*-substituted vinyl triflone **7** was obtained in 9% yield as a mixture of *E/Z* isomers via an intramolecular *I-O*-rearrangement [49]. The yield of **7** was improved to 35% in the absence of aniline and 52% yield of **7** was finally obtained in dichloroethane (Scheme 4). The intramolecular reaction was confirmed by a crossover experiment using **1a** and its derivative. None of the intermolecular products were detected and corresponding intramolecular products **7** and its derivative were isolated, respectively (see Scheme S1 in Supporting information).

More interestingly, both ylide reagent **1a** and diazo-reagent **1b** reacted with acetonitrile in the presence of a catalytic amount of CuCl to afford 2-methyl-5-phenyl-4-((trifluoromethyl)sulfonyl) oxazole **8** in 40% and 48% yield, respectively (Scheme 5).



Scheme 3. Fluorination of amide-triflone **3a** with NFSI.



Scheme 4. Reaction of **1a** (0.2 mmol) with or without **2a** (0.2 mmol) in toluene or dichloroethane (6.0 mL) at 100 °C for 1 h.

3. Conclusion

A new utility of two electrophilic trifluoromethylthiolation reagents **1a** and **1b** was described. In our previous study, reagents **1** are a powerful source for transfer-trifluoromethylthiolation under copper catalysis. On the other hand, these two reagents were found to be useful triflone-containing building blocks, depending on reaction conditions. The diazo reagent **1b** was nicely converted into a variety of triflones including vinyl-triflone, amide-, ester- and enol-triflones, and oxazole-triflone are synthesized in one step from **1** with moderate to excellent yields. The intramolecular *I-O*-rearrangement and the Wolff rearrangement triggered by thermolysis are keys for this transformation.

4. Experimental

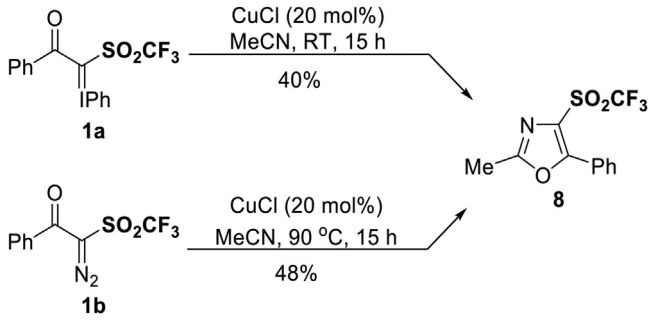
4.1. General

All reagents were used as received from commercial sources, unless specified otherwise, or prepared as described in the literature. Reactions requiring anhydrous conditions were performed in flame-dried glassware under the positive pressure of nitrogen. Thin-layer chromatography (TLC) was carried out on 0.25 mm Merck silica-gel (60-F254). ^{1}H NMR, ^{19}F NMR and ^{13}C NMR were recorded on either a Varian Mercury 300 (^{1}H at 300 MHz, ^{19}F at 282 MHz) or on a Bruker-500 (^{1}H at 500 MHz, ^{13}C at 125 MHz) spectrometer. Chemical shifts (δ) are reported in parts per million and coupling constants (J) are in hertz. Mass spectra were recorded on a SHIMAZU LCMS-2020 (ESI–MS). Infrared spectra were recorded on a JASCO FT/IR-200 spectrometer.

4.2. Reaction procedures

4.2.1. Synthesis of triflones *3* and *5*

Diazo-triflone **1b** (0.4 mmol, 2.0 equiv) was heated in 6.0 mL toluene at 100 °C for 1 h, nucleophiles **2** or **4** (0.2 mmol, 1.0 equiv) in 1.0 mL toluene was added dropwise, then heated at 100 °C for another 2 h. Solvent was removed under reduced pressure, and the residue was purified by column chromatography with ethyl acetate/hexane as the eluent to afford triflones **3** or **5**.



Scheme 5. Reaction of **1a** or **1b** in MeCN under CuCl catalysis.

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*4.2.2. Fluorination of amide-triflone **3a***

To a mixture of **3a** (0.1 mmol) in 1.5 mL THF under a nitrogen atmosphere, ^{t}BuONa (0.12 mmol) was added, and after the reaction was stirred at room temperature for 30 min, NFSI (0.11 mmol) was added in one pot. The reaction was stirred for another 30 min, quenched with 1 M HCl, and extracted with ether. The organic solvent was removed under reduced pressure, and the residue was purified by column chromatography with ethyl acetate/hexane as the eluent to afford fluorinated product **6**.

*4.2.3. Synthesis of vinyl triflone **7***

Trifluoromethanesulfonyl hypervalent iodonium ylide **1a** (0.2 mmol, 1.0 equiv) was heated in 6.0 mL DCE at 100 °C for 1 h. Solvent was removed under reduced pressure, and the residue was purified by column chromatography with ethyl acetate/hexane as the eluent to afford triflone **7**.

*4.2.4. Synthesis of oxazole- triflone **8***

To a mixture of **1a** (or **1b**) (0.2 mmol) in 1.5 mL MeCN under a nitrogen atmosphere, CuCl (0.04 mmol) was added, then the reaction was performed at room temperature or heated at 90 °C for 15 h. Solvent was removed under reduced pressure, and the residue was purified by column chromatography with ethyl acetate/hexane as the eluent to afford oxzole-triflones **8**.

4.3. Characterization of products

*4.3.1. N,2-Diphenyl-2-((trifluoromethyl)sulfonyl)acet-amide (**3a**)*

White solids. M.p.: 145–146 °C; ^{1}H NMR (500 MHz, $(CD_3)_2CO$) δ 9.96 (brs, 1H), 7.83-7.81 (m, 2H), 7.61-7.60 (m, 2H), 7.55-7.50 (m, 3H), 7.36-7.33 (m, 2H), 7.16-7.13 (m, 1H), 6.03 (s, 1H); ^{13}C NMR (125 MHz, $(CD_3)_2CO$) δ 160.3, 138.7, 131.6, 131.4, 129.8, 129.8, 127.1, 125.8, 120.8 (q, J = 327.2 Hz), 120.6, 71.9; ^{19}F NMR (282 MHz, $(CD_3)_2CO$) δ −75.2; IR (KBr) 3325, 3132, 3062, 3044, 2965, 1674, 1599, 1528, 1443, 1371, 1218, 1120 cm^{-1}; HRMS (ESI) calcd. for $C_{15}H_{12}F_3NNaO_3S$ $[M+Na]^+$: 366.0388, Found: 366.0386.

4.3.2. N-(4-Chlorophenyl)-2-phenyl-2-((trifluoromethyl)-sulfonyl) acetamide (***3b***)

Colorless crystals. M.p.: 168–169 °C; ^{1}H NMR (500 MHz, $(CD_3)_2CO$) δ 10.05 (brs, 1H), 7.81-7.79 (m, 2H), 7.64 (ddd, J = 9.0, 3.0, 2.0 Hz, 2H), 7.55-7.50 (m, 3H), 7.38 (ddd, J = 9.0, 3.0, 2.0 Hz, 2H), 6.01 (s, 1H); ^{13}C NMR (125 MHz, $(CD_3)_2CO$) δ 160.5, 137.5, 131.6, 131.4, 130.2, 129.9, 129.8, 126.9, 122.2, 120.7 (q, J = 327.4 Hz), 71.9; ^{19}F NMR (282 MHz, $(CD_3)_2CO$) δ −75.1; IR (KBr) 3375, 3109, 3067, 3044, 2977, 1690, 1527, 1493, 1365, 1211, 1108 cm^{-1}; HRMS (ESI) calcd. for $C_{15}H_{11}ClF_3NNaO_3S$ $[M+Na]^+$: 399.9998, Found: 399.9995.

*4.3.3. N-(4-Bromophenyl)-2-phenyl-2-((trifluoromethyl)-sulfonyl) acetamide (**3c**)*

Colorless crystals. M.p.: 192–193 °C; ^{1}H NMR (500 MHz, $(CD_3)_2CO$) δ 10.06 (brs, 1H), 7.81-7.79 (m, 2H), 7.59 (ddd, J = 9.0, 3.0, 2.0 Hz, 2H), 7.55-7.50 (m, 5H), 6.01 (s, 1H); ^{13}C NMR (125 MHz, $(CD_3)_2CO$) δ 160.5, 137.9, 132.8, 131.5, 131.4, 129.8, 126.9, 122.5, 120.7 (q, J = 327.6 Hz), 117.9, 71.9; ^{19}F NMR (282 MHz, $(CD_3)_2CO$) δ −75.1; IR (KBr) 3377, 3098, 3065, 3042, 2975, 1695, 1597, 1526, 1490, 1364, 1210, 1108 cm^{-1}; HRMS (ESI) calcd. for $C_{15}H_{11}BrF_3NNaO_3S$ $[M+Na]^+$: 443.9493, Found: 443.9499.

*4.3.4. N-(4-Iodophenyl)-2-phenyl-2-((trifluoromethyl)-sulfonyl) acetamide (**3d**)*

White solids. M.p.: 208–209 °C; ^{1}H NMR (500 MHz, $(CD_3)_2CO$) δ 10.02 (brs, 1H), 7.80 (dd, J = 8.0, 2.0 Hz, 2H), 7.01 (ddd, J = 9.0, 3.0, 2.0 Hz, 2H), 7.55-7.50 (m, 3H), 7.46 (ddd, J = 9.0, 3.0, 2.0 Hz, 2H), 6.01 (s, 1H); ^{13}C NMR (125 MHz, $(CD_3)_2CO$) δ 160.4, 138.8, 138.5, 131.5, 131.4, 129.8, 126.9, 122.7, 120.7 (q, J = 327.6 Hz), 88.7, 71.9; ^{19}F NMR (282 MHz, $(CD_3)_2CO$) δ −75.1; IR (KBr) 3384, 3186, 3101, 3071, 2962, 1698, 1595, 1531, 1363, 1210, 1124 cm^{-1}; HRMS (ESI) calcd. for $C_{15}H_{11}F_3INNaO_3S$ $[M+Na]^+$: 491.9354, Found: 491.9369.

*4.3.5. N-(4-Methoxyphenyl)-2-phenyl-2-((trifluoro-methyl)sulfonyl) acetamide (**3e**)*

White solids. M.p.: 178–180 °C; ^{1}H NMR (500 MHz, $(CD_3)_2CO$) δ 9.80 (brs, 1H), 7.81 (dd, J = 8.0, 2.0 Hz, 2H), 7.55-7.50 (m, 5H), 6.90 (ddd, J = 9.0, 3.0, 2.0 Hz, 2H), 5.97 (s, 1H), 3.77 (s, 3H); ^{13}C NMR (125 MHz, $(CD_3)_2CO$) δ 159.8, 157.8,131.6, 131.5, 131.3, 129.8, 127.9, 122.3, 120.7 (q, J = 327.4 Hz), 114.9, 71.8, 55.6; ^{19}F NMR (282 MHz, $(CD_3)_2CO$) δ −75.3; IR (KBr) 3329, 3125, 3078, 3012, 2950, 2838, 1671, 1530, 1370, 1216, 1120, 1032 cm^{-1}; HRMS (ESI) calcd. for $C_{16}H_{14}F_3NNaO_4S$ $[M+Na]^+$: 396.0493, Found: 396.0492.

*4.3.6. N-(4-Nitrophenyl)-2-phenyl-2-((trifluoromethyl)-sulfonyl) acetamide (**3f**)*

Colorless crystals. M.p.: 167–168 °C; ^{1}H NMR (500 MHz, $(CD_3)_2CO$) δ 10.46 (brs, 1H), 8.26 (ddd, J = 9.0, 3.0, 2.0 Hz, 2H), 7.89 (ddd, J = 9.0, 3.0, 2.0 Hz, 2H), 7.81 (dd, J = 8.0, 2.0 Hz, 2H), 7.58-7.53 (m, 3H), 6.09 (s, 1H); ^{13}C NMR (125 MHz, $(CD_3)_2CO$) δ 161.2, 145.0, 144.3, 131.7, 131.6, 130.0, 126.5, 125.7, 120.7 (q, J = 327.2 Hz), 120.6, 72.0; ^{19}F NMR (282 MHz, $(CD_3)_2CO$) δ −75.0; IR (KBr) 3378, 3167, 3098, 3074, 2963, 1706, 1617, 1598, 1557, 1515, 1342, 1208, 1110 cm^{-1}; HRMS (ESI) calcd. for $C_{15}H_{11}F_3N_2NaO_5S$ $[M+Na]^+$: 411.0238, Found: 411.0234.

*4.3.7. N-Methyl-N,2-diphenyl-2-((trifluoromethyl)-sulfonyl) acetamide (**3g**)*

Brown oil; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.38-7.34 (m, 4H), 7.29-7.28 (m, 4H), 7.00 (s, 2H), 5.22 (s, 1H), 3.25 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 161.6, 142.0, 130.6, 130.5, 130.4, 129.5, 129.2, 127.6, 125.8, 119.8 (q, J = 328.5 Hz), 68.3, 38.0; ^{19}F NMR (282 MHz, $CDCl_3$) δ −73.9; IR (KBr) 3065, 3036, 2965, 2943, 1673, 1595, 1495, 1372, 1208, 1118 cm^{-1}; HRMS (ESI) calcd. for $C_{16}H_{14}F_3NNaO_3S$ $[M+Na]^+$: 380.0544, Found: 380.0546.

*4.3.8. 2-Phenyl-N-(3-phenylpropyl)-2-((trifluoromethyl)-sulfonyl) acetamide (**3h**)*

White solids. M.p.: 145–146 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.49-7.47 (m, 2H), 7.43-7.35 (m, 3H), 7.21-7.17 (m, 2H), 7.13-7.10 (m, 1H), 7.06-7.04 (m, 2H), 6.41 (brs, 1H), 5.13 (s, 1H), 3.31-3.22 (m, 2H), 2.54 (t, J = 8.0 Hz, 2H), 1.77 (dddd, J = 8.0, 8.0, 7.0, 7.0 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 160.9, 141.0, 130.9, 130.6, 129.5, 128.7, 128.5, 126.3, 125.2, 119.9 (q, J = 327.8 Hz), 71.4, 40.3, 33.2, 30.7; ^{19}F NMR (282 MHz, $CDCl_3$) δ −73.4; IR (KBr) 3376, 3086, 3063, 3029, 2977, 2951, 2923, 2865, 1680, 1520, 1363, 1209, 1117 cm^{-1}; HRMS (ESI) calcd. for $C_{18}H_{18}F_3NNaO_3S$ $[M+Na]^+$: 408.0857, Found: 408.0858.

*4.3.9. 2-Phenyl-N-(4-phenylthiazol-2-yl)-2-((trifluoro-methyl) sulfonyl)acetamide (**3i**)*

White solids. M.p.: 165–166 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 12.26 (brs, 1H), 7.81-7.79 (m, 2H), 7.44-7.41 (m, 2H), 7.36 (tt, J = 7.5, 2.0 Hz, 1H), 7.29-7.26 (m, 2H), 7.14 (t, J = 7.5 Hz, 2H), 7.14 (d, J = 7.5 Hz, 2H), 4.70 (s, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 159.8, 159.4, 149.4, 133.4, 130.9, 130.5, 129.8, 129.3, 129.2, 126.0, 123.9, 119.5 (q, J = 328.5 Hz), 109.4, 70.9; ^{19}F NMR (282 MHz, $CDCl_3$) δ −73.0; IR (KBr) 317.0, 3065, 2942, 2915, 2861, 1697, 1562, 1372, 1213, 1113 cm^{-1}; HRMS (ESI) calcd. for $C_{18}H_{13}F_3N_2NaO_3S_2$ $[M+Na]^+$: 449.0217, Found: 449.0227.

*4.3.10. Ethyl 2-(2-phenyl-2-((trifluoromethyl)sulfonyl)-acetamido) acetate (**3j**)*

White solids. M.p.: 103–104 °C; The compound was observed two mixture rotamers (**3j'** and **3j"**) in ^{1}H NMR with a ratio of 2: 1.

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3j': ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.55-7.53 (m, 2H), 7.44-7.36 (m, 3H), 6.98 (brs, 1H), 5.32 (s, 1H), 4.17-4.11 (m, 2H), 4.09-3.95 (m, 2H), 1.22-1.18 (m, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 169.1, 161.3, 131.0, 130.8, 129.5, 124.9, 119.9 (q, J = 328.0 Hz), 71.1, 62.2, 42.1, 14.2; **3j"**: ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.55-7.53 (m, 2H), 7.44-7.36 (m, 3H), 6.87 (brs, 1H), 5.25 (s, 1H), 4.17-4.11 (m, 2H), 4.09-3.95 (m, 2H), 1.22-1.18 (m, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 169.0, 161.1, 131.1, 130.8, 129.6, 124.8, 119.9 (q, J = 328.0 Hz), 71.2, 62.1, 42.1, 14.2; ^{19}F NMR (282 MHz, $CDCl_3$) δ −73.3; IR (KBr) 3293, 3090, 2990, 2947, 1747, 1660, 1561, 1370, 1212, 1119 cm^{-1}; HRMS (ESI) calcd. for $C_{13}H_{14}F_3NNaO_5S$ $[M+Na]^+$: 376.0442, Found: 376.0449.

*4.3.11. Ethyl 3-methyl-2-(2-phenyl-2-((trifluoromethyl)-sulfonyl) acetamido)butanoate (**3k**)*

White solids. M.p.: 75–76 °C; The compound was observed mixture of rotamers and isomers in ^{1}H NMR with the ratio couldn't calculated. ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.55-7.50 (m, 2H), 7.42-7.32 (m, 3H), 7.04 (brs, 1H), 5.30-5.27 (m, 1H), 4.54-4.50 (m, 1H), 4.18-4.08 (m, 2H), 2.21-2.14 (m, 1H), 1.21-1.18 (m, 3H), 0.90-0.79 (m, 6H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 171.3, 160.5, 130.8, 130.6, 129.3, 125.1, 119.8 (q, J = 328.2 Hz), 71.2, 61.9, 58.2, 31.7, 18.9, 17.7, 14.2; ^{19}F NMR (282 MHz, $CDCl_3$) δ −73.3, −73.4; IR (KBr) 3340, 3067, 3036, 2972, 2881, 1742, 1668, 1529, 1368, 1203, 1115 cm^{-1}; HRMS (ESI) calcd. for $C_{16}H_{20}F_3NNaO_5S$ $[M+Na]^+$: 418.0912, Found: 418.0914.

*4.3.12. Phenethyl 2-phenyl-2-((trifluoromethyl)sulfonyl)-acetate (**3l**)*

Colorless crystals. M.p.: 57–58 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.57-7.55 (m, 2H), 7.54-7.50 (m, 1H), 7.47-7.44 (m, 2H), 7.32-7.25 (m, 3H), 7.19 (d, J = 7.5 Hz, 2H), 5.32 (s, 1H), 4.51 (t, J = 7.0 Hz, 2H), 3.02 (t, J = 7.0 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 162.4, 136.7, 130.9, 130.8, 129.4, 129.0, 128.8, 127.0, 124.4, 119.9 (q, J = 328.0 Hz), 70.4, 68.0, 34.7; ^{19}F NMR (282 MHz, $CDCl_3$) δ −73.6; IR (KBr) 3085, 3030, 3005, 2953, 2877, 1739, 1373, 1213, 1121 cm^{-1}; HRMS (ESI) calcd. for $C_{17}H_{15}F_3NaO_4S$ $[M+Na]^+$: 395.0541, Found: 395.0537.

*4.3.13. (Z)-4-Hydroxy-1,4-diphenyl-1-((trifluoromethyl)-sulfonyl) but-3-en-2-one (**5**)*

White solids. M.p.: 112–113 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.86 (d, J = 7.5 Hz, 2H), 7.66 (d, J = 7.5 Hz, 2H), 7.57 (t, J = 7.5 Hz, 1H), 7.50-7.43 (m, 5H), 6.38 (s, 1H), 5.38 (s, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 185.8, 182.0, 133.4, 132.6, 130.7, 130.6, 129.3, 128.8, 127.2, 125.5, 119.8 (q, J = 327.2 Hz), 96.9, 73.9; ^{19}F NMR (282 MHz, $CDCl_3$) δ −73.4; IR (KBr) 3424, 3066, 2965, 1601, 1570, 1365, 1211, 1117 cm^{-1}; HRMS (ESI) calcd. for $C_{17}H_{13}F_3NaO_4S$ $[M+Na]^+$: 393.0384, Found: 393.0384.

*4.3.14. 2-Fluoro-N,2-diphenyl-2-((trifluoromethyl)-sulfonyl) acetamide (**6**)*

White solids. M.p.: 105–106 °C; ^{1}H NMR (300 MHz, $(CD_3)_2CO$) δ 10.23 (brs, 1H), 7.95 (d, J = 7.5 Hz, 2H), 7.72-7.60 (m, 5H), 7.37 (t, J = 7.5 Hz, 2H), 7.22 (t, J = 7.5 Hz, 1H); ^{13}C NMR (125 MHz, $(CD_3)_2CO$) δ 159.1 (d, J = 18.7 Hz), 136.6, 132.0, 129.0 (d, J = 2.5 Hz), 126.8 (d, J = 8.7 Hz), 125.9 (d, J = 7.5 Hz), 125.7, 120.9, 120.8, 120.3 (q, J = 330.0 Hz), 107.0 (d, J = 121.2 Hz); ^{19}F NMR (282 MHz, $(CD_3)_2CO$) δ −70.7 (s, 3F), −152.1 (m, 1F); IR (KBr) 3312, 3067, 2923, 1686, 1598, 1532, 1449, 1386, 1211, 1118 cm^{-1}; HRMS (ESI) calcd. for $C_{15}H_{11}F_4NNaO_3S$ $[M+Na]^+$: 384.0293, Found: 384.0301.

*4.3.15. (2-Iodo-1-phenoxy-2-((trifluoromethyl)sulfonyl)-vinyl) benzene **(7)***

Pale yellow oil. The compound was observed two mixture E/Z isomers (**7'** and **7"**) in crude ^{19}F NMR with a ratio of 2.5: 1. **7'**: ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.30-7.27 (m, 1H), 7.24-7.19 (m, 4H), 7.17-7.14 (m, 2H), 7.02 (t, J = 7.5 Hz, 1H), 6.85-6.83 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 176.4, 153.3, 131.0, 130.2, 129.6, 129.3, 127.7, 125.8, 121.3, 120.0 (q, J = 325.7 Hz), 68.2; ^{19}F NMR (282 MHz, $CDCl_3$) δ −74.1; IR (KBr) 3090, 3063, 3028, 1599, 1579, 1539, 1485, 1356, 1260, 1213, 1194, 1117 cm^{-1}; HRMS (ESI) calcd. for $C_{15}H_{10}F_3INaO_3S$ $[M+Na]^+$: 476.9245, Found: 476.9241; **7"** (mix with **7'**): ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.53-7.51 (m, 2H), 7.36-7.32 (m, 3H), 7.18-7.15 (m, 2H), 7.01-6.98 (m, 1H), 6.89-6.87 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 171.3, 155.1, 132.7, 132.0, 130.5, 129.7, 128.7, 124.9, 119.5, 119.2 (q, J = 326.7 Hz), 72.3; ^{19}F NMR (282 MHz, $CDCl_3$) δ −73.7; IR (KBr) 3086, 3063, 1600, 1581, 1541, 1353, 1278, 1206, 1188, 1118, 1096 cm^{-1}; HRMS (ESI) calcd. for $C_{15}H_{10}F_3INaO_3S$ $[M+Na]^+$: 476.9245, Found: 476.9249.

*4.3.16. 2-Methyl-5-phenyl-4-((trifluoromethyl)sulfonyl)-oxazole (**8**)*

White solids. M.p.: 61–62 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.87 (dd, J = 8.1, 1.5 Hz, 2H), 7.56-7.48 (m, 3H), 2.62 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 161.4, 159.6, 131.9, 129.0, 128.7, 126.2, 123.6, 119.7 (q, J = 323.7 Hz), 13.8; ^{19}F NMR (282 MHz, $CDCl_3$) δ −77.6; IR (KBr) 3111, 3068, 3006, 2923, 2853, 1599, 1551, 1485, 1372, 1225, 1128, 1097 cm^{-1}; HRMS (ESI) calcd. for $C_{11}H_8F_3NNaO_3S$ $[M+Na]^+$: 314.0075, Found: 314.0078.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.jfluchem.2016.12.012.

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