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Synthesis of benzylic thioether containing α-substituted thio compounds *via* carbene insertion into an S–H bond: expeditious access to a new C–S bond

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Considering the importance of thioethers in biological systems, we developed a strategy to achieve these target molecules. In this regard, an efficient copper(II)-catalyzed synthesis of highly biologically relevant thioethers is realized, employing readily available and inexpensive starting precursors under ambient conditions. The developed new methodology is very useful to selectively synthesize a C–S bond *via* carbene insertion into an S–H bond. Our strategy also paved the way to produce a wide range of α-thio substituted benzylic esters in a single-pot method in very good yields under short reaction times. All the synthesized compounds have been fully characterized using spectroscopic and analytical techniques. The best features of the developed strategy are S–H insertion, mild reaction conditions, wide substrate scope, and excellent functional group tolerance.

Introduction

Nitrogen, oxygen, and sulphur-containing organic scaffolds are highly useful in the field of pharmaceuticals due to their wide spectrum of biological activity.[1] Among the different heteroatoms, sulfur is one of the most essential elements found in living systems in the form of proteins and amino acids. Particularly, organosulfur compounds play significant roles in the fields of biology and chemistry due to their ubiquitous biological activity.[2] Beyond amino acids (methionine and cysteine), the C–S bond is present in several natural products, significant drug molecules and functional materials from the pharmaceutical industry,[3] and in products in the food industry.[4] These motifs also play a vital role in photoelectric materials[5] due to the higher resonance energy of the sulphur atoms. Among the different organosulfur compounds, α-substituted thioethers, in particular, possess a significant role because they act as suitable precursors in the synthesis of biologically active benzothiophenes and Julia reagents.[6] Moreover, organosulfur-based structural frameworks are present in various biologically active compounds and synthetic intermediates. Sulphur-containing heterocycles exhibit many pharmacological activities. Particularly, thioethers of benzoxazoles and benzothiazoles have been important targets due to their biological activities. They are extensively useful as antibacterial, antifungal, anti-inflammatory, anticancer, antiviral, antagonizing, and antituberculosis agents and as fungicides[7–12] (Fig. 1).

Additionally, in recent years, transition metal catalysis has dramatically changed the face of modern organic chemistry by introducing novel synthetic routes. Using these facile catalytic systems, construction of several carbon–heteroatom bond formations, such as C–O, C–N and C–P, as well as other carbon–element bonds based on B, Si, Ge, and Sn, was developed. Until now, the effective construction of C–S bonds has been highly challenging or very rarely explored compared with the formation of other carbon–heteroatom bonds in the field of organic synthesis due to its own limiting factors, such as harsh reaction conditions (higher temperature, toxic and higher boiling solvents, and longer reaction times), deactivation of the catalytic system due to its strong affinity with metals, expensive starting precursors, and usage of high loading metal catalysts. Therefore, we need to develop an alternate, greener and efficient protocol for the construction of organosulphur compounds *via* C–S bond formation over existing conventional methodologies. In this study, we overcame all these drawbacks by using a new catalytic system to produce biologically relevant organosulfur compounds containing a C–S bond in an effective manner.

Generally, metal-catalysed reactions have been useful synthetic tools to access the target molecules in organic transformations. Particularly, copper-catalysed organic reactions are a promising methodology for synthesizing an important class of organic molecules used in medicinal chemistry and material science.[13] For example, diazo compounds are very useful precursors in organic transformations to construct complex organic molecular frameworks using C–C and C–X bond

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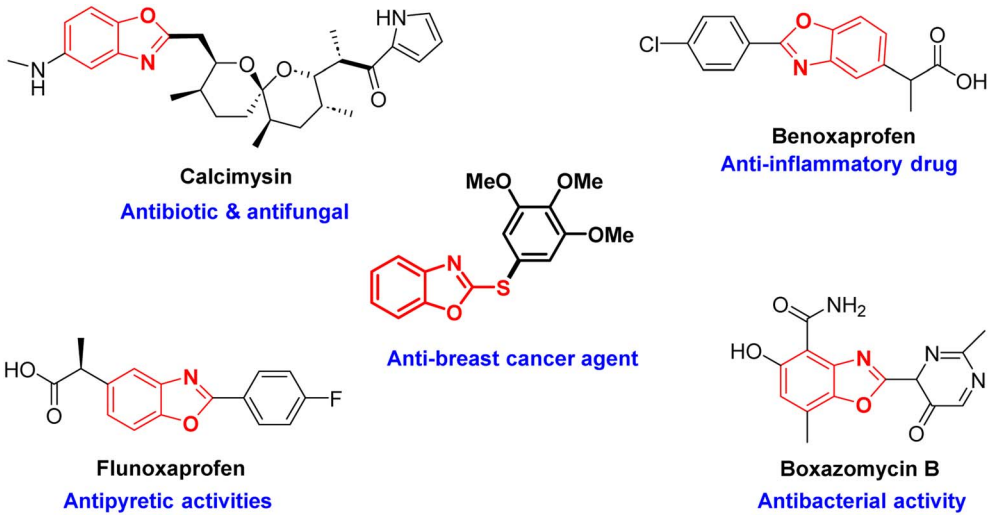
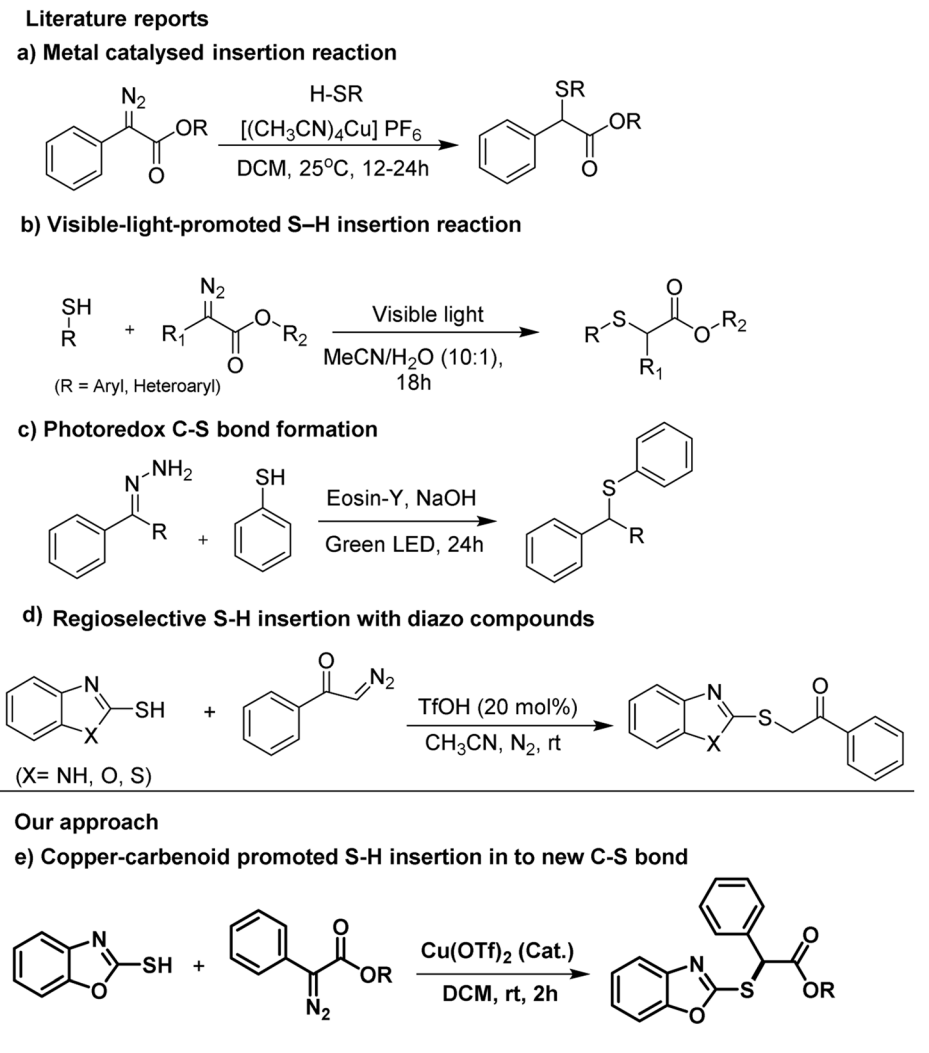


Fig. 1 Some biologically active compounds containing thioethers of the benzoxazole scaffold.



Scheme 1 Synthesis of thioethers using a carbene source (a–e).

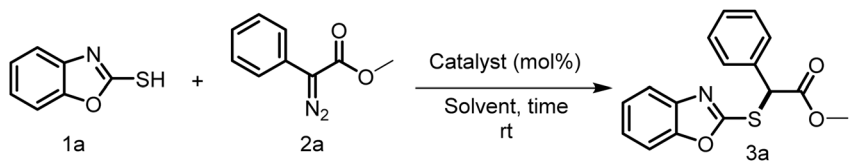
formations *via* transition metal catalysis. It is well known that reactive intermediates, such as metal carbenes or carbenoids, which are *in situ* formed from diazo compounds, can undergo various synthetic organic transformations and are sometimes ideal for initiating domino sequences, leading to the generation of structural complexity.[14] Moreover, diazo compounds are useful precursors, including C–H and X–H (X= N, O, S, P, and Si) insertion,[15] cyclopropanation[16] and ylide formation.[17] The tandem or cascade construction of biologically relevant organosulphur compounds, such as thioethers/thioesters, *via* the formation of a new C–S bond by S–H insertion through cross-coupling reactions under metal catalysis *via* a single pot process is very less due to its synthetic challenges. Particularly, the formation of C–S bonds using heterocyclic compounds containing thiols and diazo compounds is known but has not been explored much in the literature so far. Beller and coworkers have reported S–H insertion into benzoxazole–thiol to afford the product using an exotic Cu-NC/Al_2O_3 as catalyst.[18] Ollevier *et al.* have reported the synthesis of α-thioesters using α-diazocarbonyl compounds with organo-sulphur compounds *via* S–H insertion under copper(I) catalysis (Scheme 1a).[19] Huo and co-workers have utilized α-diazoesters and thiols to form α-thioethers under ambient temperature in the presence of visible light (Scheme 1b).[20] Eosin-Y-catalysed sulfenylation of hydrazones with thiols under visible light to produce the thioether derivatives was developed by the Krishna group (Scheme 1c).[21] Chens and coworkers have reported S–H insertion into benzoxazole–thiol to yield the expected product using TfOH as a catalyst (Scheme 1d).[22]

Inspired by these reports on the significance of thioethers and their biological applications and by our ongoing research program in the field of metal carbenes,[23–25] we studied the construction of biologically relevant organic molecular frameworks using a new C–S bond formation *via* a simple reaction strategy. In this line, we investigated the development of an efficient reaction strategy to construct new C–S bonds, along with chiral centers, using copper-carbenoids with heterocyclic compounds containing thiols at ambient temperature with shorter reaction times.

Results and discussion

In our investigation, initially, we tested the reaction between 2-mercaptobenzoxazole (**1a**) and methyl 2-diazo-2-phenylacetate (**2a**) in the presence of 5 mol% of CuI under MeCN solvent at ambient temperature for 12 h. To our delight, we isolated the expected product methyl 2-(benzo[*d*]oxazol-2-ylthio)-2-phenylacetate (**3a**) in 76% yield and the desired product was confirmed through spectroscopic techniques such as ^{1}H-NMR, ^{13}C-NMR and mass spectrometry. An interesting feature of this intermolecular organic transformation is generating a new C–S bond, along with one chiral centre, in a single-pot reaction. Encouraged by these interesting results, we attempted to improve the yield of the desired product **3a** using optimised reaction conditions. Accordingly, we screened the following

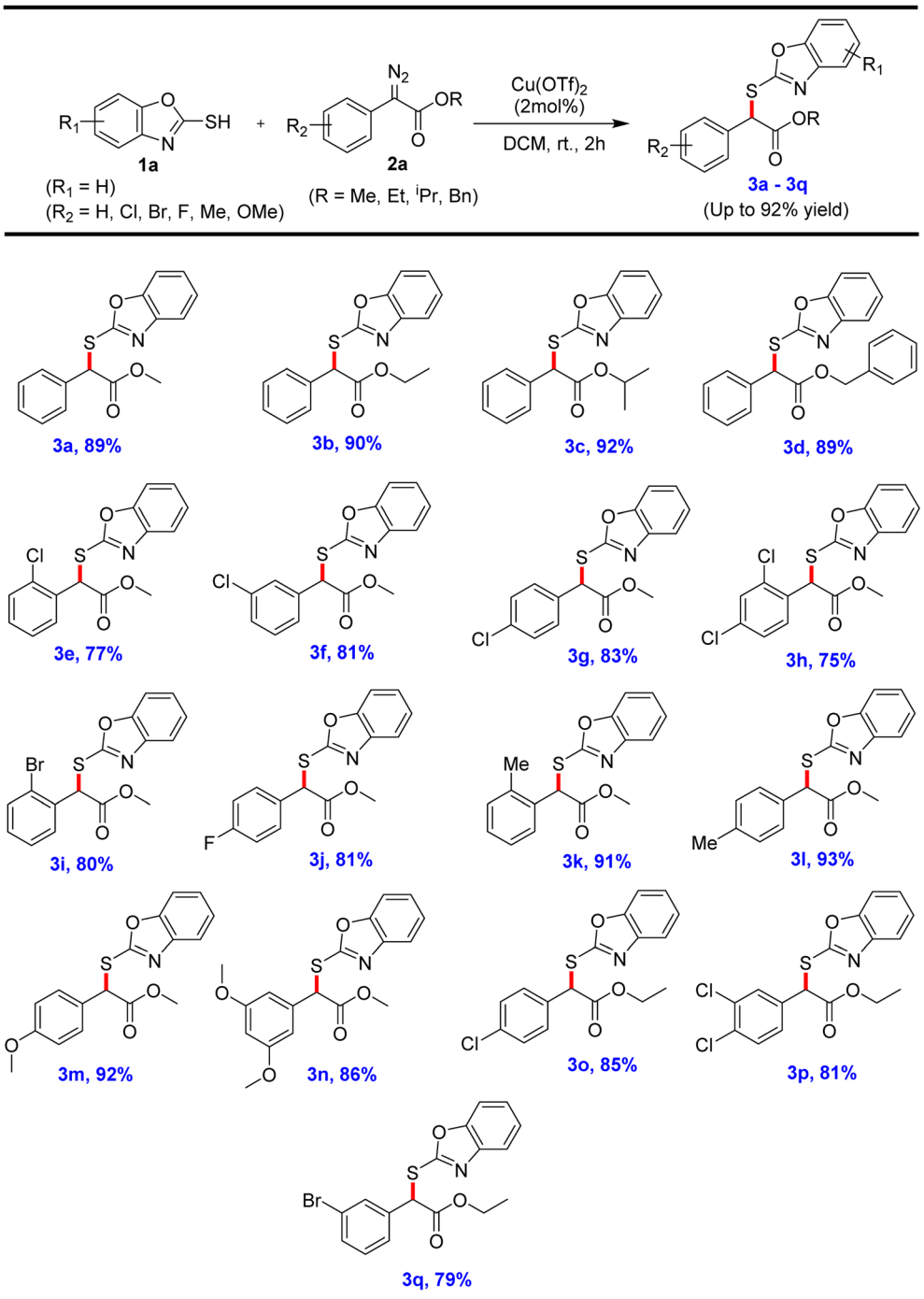
Table 1 Optimization studies for the reaction of S–H insertion[a]



S. no.	Catalyst (mol%)	Solvent	Time (h)	Isolated[b] yield (%)
1	CuI (5)	CH_3CN	12	76
2	$CuCl_2 \cdot 2H_2O$ (5)	CH_3CN	12	66
3	$CuSO_4 \cdot 5H_2O$ (5)	CH_3CN	12	72
4	$Cu(OAc)_2$ (5)	CH_3CN	12	75
5	CuBr (5)	CH_3CN	12	71
6	$Cu(CH_3CN)_4ClO_4$ (5)	CH_3CN	12	78
7	$Cu(OTf)_2$ (2)	CH_3CN	12	80
8	$Cu(OTf)_2$ (2)	THF	12	70
9	$Cu(OTf)_2$ (2)	Toluene	10	64
10	$Cu(OTf)_2$ (2)	$CHCl_3$	5	82
11	$Cu(OTf)_2$ (2)	DCE	5	84
12	$Cu(OTf)_2$ (2)	DCM	5	89
13	$Cu(OTf)_2$ (5)	MeCN	12	77
14	$Cu(OTf)_2$ (5)	DCM	2	85
15	**$Cu(OTf)_2$(2)**	**DCM**	**2**	**89**
16	No catalyst	DCM	5	nr
17	**TfOH**	**CH_3CN**	**5 min**	**Trace**

[a] All reactions were carried out with (1.0 mmol, 1 equiv.) of 2-mercaptobenzoxazole (**1a**) and (1.0 mmol, 1 equiv.) of α-diazo compound (**2a**). [b] Isolated yield of the pure product obtained after column chromatography purification.

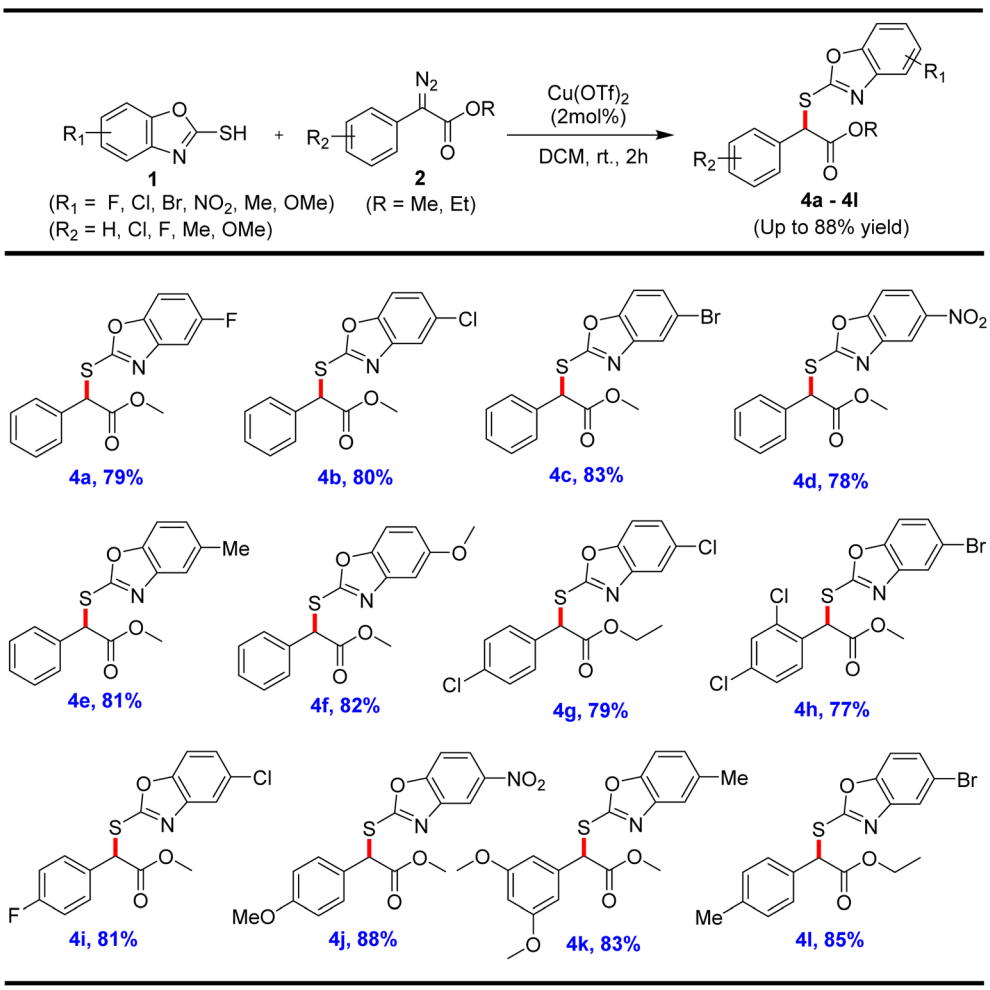
metal catalysts, $CuCl_2 \cdot 2H_2O$, $CuSO_4 \cdot 5H_2O$ and $Cu(OAc)_2$ of 5 mol%, in MeCN solvent at room temperature for 12 h; the yield of the anticipated product **3a** was not improved and the desired product **3a** was formed in 66%, 72% and 75%, respectively (Table 1, entries 2–4). Further, the yield of the anticipated product **3a** was increased from 71% to 78% when we used 5 mol% of CuBr and $Cu(CH_3CN)ClO_4$ as a metal catalyst under the same reaction conditions (Table 1, entries 5 and 6). Further, to improve the yield of product **3a**, we used 2 mol% of the metal catalyst $Cu(OTf)_2$; surprisingly, we obtained product **3a** with 80% yield (Table 1, entry 7). Further, in order to increase yield, we screened different solvent systems, ranging from MeCN to polar aprotic solvents, such as THF, $CHCl_3$, $C_2H_4Cl_2$ and CH_2Cl_2, using 5 mol% of $Cu(OTf)_2$ at ambient temperature with



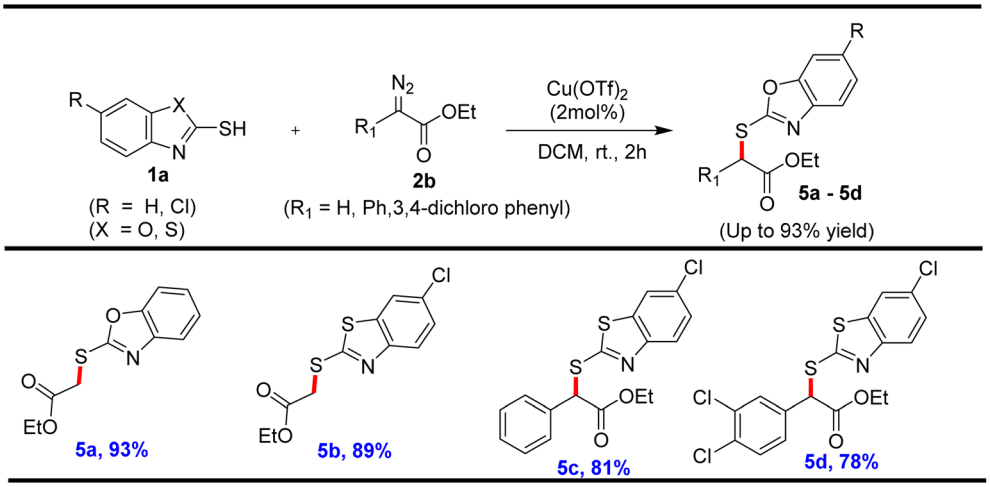
Scheme 2 Substrate scope of methyl/ethyl phenyl diazoacetate **2a** with 2-mercaptobenzoxazole derivatives. [a]All the reactions were conducted using 2-mercaptobenzoxazole (1.0 mmol, 1 equiv.) and α-aryl diazoester **2** (1.0 mmol, 1 equiv.) with 2 mol% of Cu catalyst in 3 mL of DCM solvent at ambient temperature. [b]Isolated yield of the pure products **3**.

varying reaction times (Table 1, entries 8–12). To our delight, we observed that the yield of **3a** was 77% when 5 mol% of $Cu(OTf)_2$ was used in MeCN as a solvent for 12 h (Table 1, entry 13). Further, the reaction was conducted by loading the metal catalyst, 5 mol% $Cu(OTf)_2$, in DCM for 2 h, and the yield of **3a** gradually increased to 85% (Table 1, entry 14). Finally, we tested the reaction using 2 mol% $Cu(OTf)_2$ in DCM, and the yield of **3a** was 89% (Table 1, entry 15). We tested the reaction in the absence of a metal catalyst in DCM for 5 h, and in this case, the product **3a** was not observed (Table 1, entry 16). When we used TfOH as a catalyst, we observed a trace amount of the product (Table 1, entry 17). A control experiment with TfOH confirmed that the reaction is not fully acid-promoted; however, it proceeds with poor selectivity and significant decomposition. Nevertheless, the $Cu(OTf)_2$ effectively accelerated the transformation *via* the formation of a Cu(II)–carbene intermediate, yielding the required α-thio-substituted benzylic esters in high yield. Therefore, the Lewis acidity of $Cu(OTf)_2$ prevents the excessively acidic conditions associated with TfOH and ensures controlled activation of the diazo molecule. From these optimisation studies, we finally concluded that the selective S–H insertion into the C–S bond is effective in the presence of $Cu(OTf)_2$ (2 mol%) using dichloromethane as the solvent at ambient temperature for 2 h, and TfOH is not suitable for this S–H insertion reaction with α-aryl diazoester.

Herein, we report the developed methodology for the synthesis of α-thioether derivatives *via* carbene insertion into an S–H bond to form a C–S bond, along with one chiral centre. The highlight of this reaction is the high selectivity to produce the C–S bond through S–H insertion. It is important to note that metal carbenoids can be inserted into S–H bond to create thioethers utilising 2-mercaptobenzoxazole as a sulfur source. The scope of the reaction was tested by utilizing different substituted 2-mercaptobenzoxazoles **1a** with different α-aryl-α-diazoacetates **2a** in the presence of a copper catalyst to form the corresponding α-thioethers (**3a–l**) in very good to excellent yields, and the results and conditions[a,b] are summarized in Scheme 2. The reaction between the substrates **1a** and **2a**, containing different ester functionalities, *viz.* methyl **2a**, ethyl **2b**, isopropyl **2c**, and benzyl **2d**, produced the corresponding



Scheme 3 Substrate scope of 2-mercaptobenzoxazoles with methyl/ethyl diazoacetate derivatives. [a]All the reactions were conducted using 2-mercaptobenzoxazole (1.0 mmol, 1 equiv.) and α-aryl diazoester **2** (1.0 mmol, 1 equiv.) with 2 mol% of Cu catalyst in 3 mL of DCM solvent at ambient temperature. [b]Isolated yield of the pure products **4**.



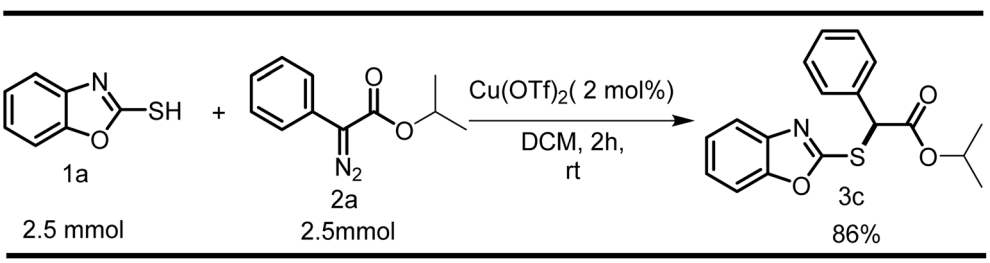
Scheme 4 Substrate scope of 2-mercaptobenzoxazoles/ethyl 2-((6-chlorobenzo[*d*]thiazol-2-yl)thio)acetate with α-diazoester derivatives. [a]All the reactions were conducted using 2-mercaptobenzoxazole/ethyl 2-((6-chlorobenzo[*d*]thiazol-2-yl)thio)acetate (1.0 mmol, 1 equiv.) and α-aryl diazoester **2** (1.0 mmol, 1 equiv.) with 2 mol% Cu catalyst in 3 mL of DCM solvent at ambient temperature. [b]Isolated yield of the pure products **5**.

products **3a**, **3b**, **3c** and **3d** in 89%, 90%, 92%, and 89% yields, respectively (Scheme 2). The aryl ring of α-diazoester **2a**, containing electron-withdrawing groups, such as chloro, bromo and fluoro, furnished the anticipated products **3e–3j** in very good to excellent yields. The electron-donating groups, such as methyl and methoxy substituted diazoesters **2a**, reacted well with 2-mercaptobenzoxazole derivatives to provide the desired products **3k–3n** in excellent yields. The aryl ring of ethyl diazoacetate **2b**, having electron-withdrawing groups, such as 4-chloro, 2,4-dichloro and 3-Br substituents, also smoothly reacted with compound **1a** to furnish the corresponding products **3o–3q** in 85%, 81%, and 79% yield, respectively (Scheme 2).

To further explore the substrate scope of the reaction, we carried out the reaction between substituted 2-mercaptobenzoxazole derivatives and methyl phenyl diazoacetate using the optimized reaction conditions, and the results and conditions[a,b] are summarised in Scheme 3. The reaction between methyl phenyl diazoacetate (**2**) and 2-mercaptobenzoxazole, whose aryl ring has halogen groups (F, Cl, and Br) at the *para* position, smoothly reacted and afforded the corresponding products **4a–c** in 79%, 80%, and 83% yields, respectively (Scheme 3). 2-Mercaptobenzoxazole, containing a strong electron-withdrawing group, such as NO_2, also reacted well with compound (**2**) to furnish the desired product **4d** in 78% yield. 2-Mercaptobenzoxazole, bearing electron-donating functionalities like Me and OMe groups at the *para* position, also reacted smoothly with methyl phenyl diazoacetate (**2**) to produce the anticipated products **4e** and **4f** in 81% and 82% yields, respectively (Scheme 3). Both substrates (**1**) and (**2**) have aryl rings that contain halogen substituents, such as chloro, bromo and fluoro, at *ortho* and *para* positions to afford the respective products **4g–i** in very good yields (Scheme 3). 2-Mercaptobenzoxazole containing NO_2 substituent at the *para* position and similarly, compound (**2**) having OMe group at the *para* position, smoothly reacted and formed the corresponding product **4j** in 88% yield. **4k** and **4l** are also produced in good yields of 83% and 85%.

Still, to further assess the substrate scope, we tested the reactions of 2-mercapto benzoxazole (**1a**) and ethyl 2-((6-chlorobenzo[*d*]thiazol-2-yl) thio) acetate (**1a**) with ethyl 2-diazoacetate (**2b**) under standard reaction conditions.[a,b] Interestingly, the reactions provided the desired products **5a** and **5b** in 93% and 89% yields, respectively. Additionally, the reaction between ethyl 2-((6-chlorobenzo[*d*]thiazol-2-yl)thio) acetate (**1a**) and ethyl 2-diazo-2-phenylacetate, ethyl 2-diazo-2-(3,4-dichlorophenyl) acetate (**2b**) formed the corresponding desired products **5c** and **5d** in 81% and 78% yields, respectively (Scheme 4).

To study the scalability of our optimized reaction conditions, we carried out a large scale reaction between 2-



Scheme 5 Larger scale synthesis of α-thio substituted benzylic ester.

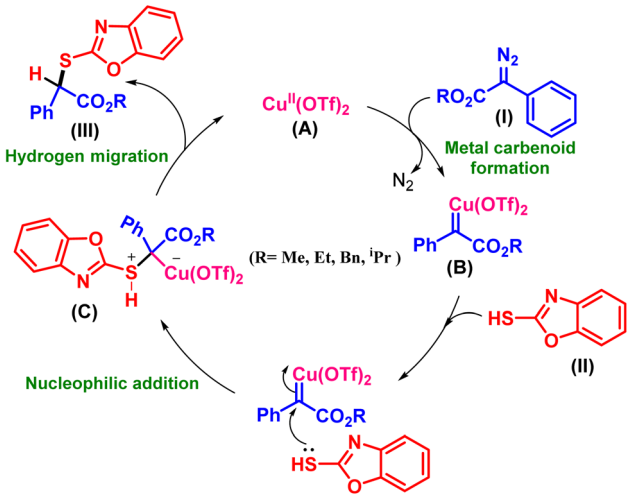


Fig. 2 Proposed reaction mechanism for the reaction of 2-mercaptobenzoxazole and α-diazoesters.

mercaptobenzoxazole (**1a**) (378 mg, 2.5 mmol, 1 equiv.) and isopropyl phenyl diazoacetate (**2a**) (510 mg, 2.5 mmol, 1 equiv.) in 10 mL DCM (0.33 M) at rt in the presence of the Cu(OTf)$_2$ catalyst (18 mg, 2 mol%). The scale-up reaction afforded the anticipated product **3c** in 86% yield (708 mg, 2.1 mmol), confirming the large-scale applicability of the method (Scheme 5).

A plausible mechanism has been proposed below for the formation of α-thio-substituted benzylic esters (**III**) from **I** and **II**, as shown in Fig. 2. Initially, the active catalyst Cu(OTf)$_2$ (**A**) would react with α-diazoester (**I**) to generate the intermediate (**B**) *via* the formation of a copper-carbenoid with the evolution of nitrogen gas. Simultaneously, 2-mercaptobenzoxazole (**II**) undergoes nucleophilic addition with the intermediate (**B**) to generate the intermediate (**C**). Eventually, the intermediate (**C**) would undergo hydrogen migration to afford the desired product (**III**) with the regeneration of the active catalyst Cu(OTf)$_2$.

Conclusion

We successfully developed an efficient protocol to access biologically relevant α-thio substituted benzylic esters from 2-mercaptobenzoxazoles and α-diazoesters in the presence of a copper catalyst. Using this newly developed protocol, we synthesized a variety of α-thioester derivatives at ambient temperature. During this organic transformation, a new C–S bond is formed with a new chiral center. These overall organic transformations proceed *via* cascade metal-carbenoid formation and S–H insertion, followed by reductive elimination to produce the anticipated product in very good yields. A wide substrate scope, shorter reaction times and excellent functional group tolerance are the best features of this reaction. The synthesized α-thioester derivatives may be useful in the pharmaceutical and chemical industry.

Experimental section

General experimental information

Commercial reagents were used without further purification. IR spectra were recorded on a PerkinElmer FTIR spectrometer using solid samples pressed into KBr pellets. For compounds, ^{1}H NMR (400 MHz, $CDCl_3$) and ^{13}C NMR (100 MHz, $CDCl_3$) spectra were recorded in deuterochloroform ($CDCl_3$) on a Bruker 400 MHz spectrometer using tetramethylsilane (TMS, $\delta = 0$) as an internal standard at room temperature. HR-MS was recorded on a UHD Q-TOF mass spectrometer. All the reagents were purchased from Sigma-Aldrich. Reactions were monitored by thin-layer chromatography (TLC) on silica gel 60 F_{254} aluminium plates. TLC plates were visualized using ultraviolet (UV) light at 254 nm. Column chromatography was performed with silica gel 60 Å (100–200 mesh) from Aldrich using the stated mixture of solvents. Based on the literature procedure, different types of α-aryl diazoesters were synthesized (see SI).

General procedure for the synthesis of compounds (3a–3q), (4a–4l). Double-distilled dry DCM (3 mL) (0.33 M) solvent was added to a mixture of 2-mercapto benzoxazoles (1.0 mmol, 1 equiv.), α-aryl diazoesters (1.0 mmol, 1 equiv.), and Cu(OTf)$_2$ (2 mol%) catalyst. The reaction mixture was allowed to stir at room temperature for 2 h under a nitrogen atmosphere. After the reaction was completed, it was monitored by TLC. The reaction mixture was filtered through Celite, and the filtrate was concentrated. To the crude reaction mixture, water (10 mL) and EtOAc (10 mL) were added, and the mixture was extracted with EtOAc (3 × 10 mL). The combined organic layer was dried over anhydrous Na_2SO_4, filtered, and concentrated under reduced pressure. The crude product was purified by column chromatography (eluted with 5% EtOAc/hexane) to give the desired product **3a** in a pure form.

Analytical data

*Methyl 2-(benzo[d]oxazol-2-ylthio)-2-phenylacetate (**3a**).* Purified by column chromatography (hexane : EtOAc, 95 : 5). White solid (266 mg, 89% yield). Mp 79–80 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.53–7.48 (m, 1H), 7.47–7.43 (m, 2H), 7.34–7.31 (m, 1H), 7.30–7.26 (m, 2H), 7.25 (dd, J = 3.9, 1.3 Hz, 1H), 7.21–7.11 (m, 2H), 5.62 (s, 1H), 3.68 (s, 3H). ^{13}C NMR (101 MHz, chloroform-*d*) δ 170.05, 162.99, 151.97, 141.82, 134.09, 129.24, 129.18, 128.54, 124.48, 124.29, 118.85, 110.12, 53.75, 53.50. IR (KBr): 1738, 1505, 1472, 1453, 1130 cm^{-1}. HRMS (ESI) *m*/*z*: [M + H] calcd for $C_{16}H_{13}NO_3S$ 299.0616, found: 300.0693.

*Ethyl 2-(benzo[d]oxazol-2-ylthio)-2-phenylacetate (**3b**).* Purified by column chromatography (hexane : EtOAc, 95 : 5). White liquid (282 mg, 90% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.47 (m, 3H), 7.32–7.26 (m, 2H), 7.26–7.22 (m, 2H), 7.18–7.09 (m, 2H), 4.13 (m, 2H), 1.13 (t, J = 7.1 Hz, 3H). ^{13}C NMR (101 MHz, chloroform-*d*) δ 169.43, 163.00, 151.88, 141.77, 134.14, 129.12, 129.05, 128.48, 124.41, 124.20, 118.72, 110.03, 62.47, 53.87, 14.05. IR (KBr): 1742, 1505, 1452, 1020, 806 cm^{-1}. HRMS (ESI) *m*/*z*: [M + H] calcd for $C_{17}H_{15}NO_3S$ 313.0773, found: 314.0859.

*Isopropyl 2-(benzo[d]oxazol-2-ylthio)-2-phenylacetate (**3c**).* Purified by column chromatography (hexane : EtOAc, 95 : 5). White solid (301 mg, 92% yield). Mp 63–64 °C; ^{1}H NMR (400

MHz, $CDCl_3$) δ 7.51–7.43 (m, 3H), 7.33 (dd, J = 7.9, 1.4 Hz, 1H), 7.31–7.26 (m, 2H), 7.26–7.11 (m, 3H), 5.55 (s, 1H), 4.99 (p, J = 6.3 Hz, 1H), 1.20 (d, J = 6.2 Hz, 3H), 1.05 (d, J = 6.2 Hz, 3H). ^{13}C NMR (101 MHz, chloroform-*d*) δ 169.00, 163.17, 151.96, 141.87, 134.25, 129.15, 129.06, 128.54, 124.48, 124.24, 118.78, 110.10, 70.29, 54.11, 21.72, 21.51. IR (KBr): 1738, 1505, 1453, 1241, 1130 cm^{-1}. HRMS (ESI) *m*/*z*: [M + H] calcd for $C_{18}H_{17}NO_3S$ 327.0929, found: 328.1011.

*Benzyl 2-(benzo[d]oxazol-2-ylthio)-2-phenylacetate (**3d**).* Purified by column chromatography (hexane : EtOAc, 95 : 5). White liquid (334 mg, 89% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.57–7.53 (m, 3H), 7.38–7.26 (m, 8H), 7.26–7.17 (m, 3H), 5.77 (d, J = 1.4 Hz, 1H), 5.31 (d, J = 12.3 Hz, 1H), 5.11 (d, J = 12.4 Hz, 1H). ^{13}C NMR (101 MHz, chloroform-*d*) δ 169.31, 162.85, 151.86, 141.72, 135.24, 133.74, 129.13, 129.10, 128.52, 128.48, 128.31, 128.07, 124.36, 124.16, 118.72, 110.02, 67.87, 53.81. IR (KBr): 1740, 1510, 1450, 1246, 1134 cm^{-1}. HRMS (ESI) *m*/*z*: [M + H] calcd for $C_{22}H_{17}NO_3S$ 375.0929, found: 376.0995.

*Methyl 2-(benzo[d]oxazol-2-ylthio)-2-(2-chlorophenyl)acetate (**3e**).* Purified by column chromatography (hexane : EtOAc, 95 : 5). White solid (257 mg, 77% yield). Mp 80–81 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.52–7.48 (m, 1H), 7.46–7.42 (m, 2H), 7.35–7.27 (m, 2H), 7.26–7.11 (m, 3H), 5.61 (s, 1H), 3.68 (s, 3H). ^{13}C NMR (101 MHz, chloroform-*d*) δ 170.07, 163.00, 151.98, 141.82, 134.07, 129.25, 129.20, 128.55, 124.49, 124.30, 118.86, 110.13, 53.74, 53.53. IR (KBr): 1738, 1505, 1453, 1275, 1130 cm^{-1}. HRMS (ESI) *m*/*z*: [M + H] calcd for $C_{16}H_{12}ClNO_3S$ 333.0226, found: 334.0299.

*Methyl 2-(benzo[d]oxazol-2-ylthio)-2-(3-chlorophenyl)acetate (**3f**).* Purified by column chromatography (hexane : EtOAc, 95 : 5). White solid (270 mg, 81% yield). Mp 97–98 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.56–7.53 (m, 1H), 7.50 (d, J = 2.1 Hz, 1H), 7.40–7.35 (m, 2H), 7.27–7.16 (m, 4H), 5.63 (s, 1H), 3.74 (s, 3H). ^{13}C NMR (101 MHz, chloroform-*d*) δ 169.52, 162.49, 152.03, 141.73, 136.27, 135.00, 130.42, 129.41, 128.74, 126.81, 124.58, 124.43, 118.91, 110.19, 53.72, 53.21. IR (KBr): 1742, 1502, 1453, 1128, 1096 cm^{-1}. HRMS (ESI) *m*/*z*: [M + H] calcd for $C_{16}H_{12}ClNO_3S$ 333.0226, found: 334.0301.

*Methyl 2-(benzo[d]oxazol-2-ylthio)-2-(4-chlorophenyl)acetate (**3g**).* Purified by column chromatography (hexane : EtOAc, 95 : 5). White liquid (277 mg, 83% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.53–7.49 (m, 1H), 7.44–7.40 (m, 2H), 7.35–7.31 (m, 1H), 7.27–7.23 (m, 2H), 7.21–7.12 (m, 2H), 5.63 (s, 1H), 3.70 (s, 3H). ^{13}C NMR (101 MHz, chloroform-*d*) δ 169.57, 162.48, 151.94, 141.69, 135.13, 132.94, 129.90, 129.32, 124.49, 124.34, 118.82, 110.09, 53.54, 53.07. IR (KBr): 1743, 1503, 1453, 1132, 1095 cm^{-1}. HRMS (ESI) *m*/*z*: [M + H] calcd for $C_{16}H_{12}ClNO_3S$ 333.0226, found: 334.0277.

*Methyl 2-(benzo[d]oxazol-2-ylthio)-2-(2,4-dichlorophenyl) acetate (**3h**).* Purified by column chromatography (hexane : EtOAc, 95 : 5). White liquid (266 mg, 75% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.50–7.44 (m, 2H), 7.27 (d, J = 4.7 Hz, 1H), 7.14–7.04 (m, 4H), 6.11 (s, 1H), 3.68 (s, 3H). ^{13}C NMR (101 MHz, chloroform-*d*) δ 168.58, 162.18, 151.82, 141.43, 135.28, 134.75, 131.27, 130.85, 129.73, 127.57, 124.27, 124.11, 118.61, 109.86, 53.45, 50.29. IR (KBr): 1746, 1587, 1503, 1453, 1002 cm^{-1}. HRMS (ESI) *m*/*z*: [M + H] calcd for $C_{16}H_{11}Cl_2NO_3S$ 366.9837, found: 367.9939.

*Methyl 2-(benzo[d]oxazol-2-ylthio)-2-(2-bromophenyl)acetate (**3i**).* Purified by column chromatography (hexane : EtOAc, 95 : 5). White liquid (302 mg, 80% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.49–7.44 (m, 3H), 7.29–7.25 (m, 1H), 7.19–7.13 (m, 1H), 7.13–7.01 (m, 3H), 6.10 (s, 1H), 3.65 (s, 3H). ^{13}C NMR (101 MHz, chloroform-*d*) δ 169.26, 162.62, 151.98, 141.71, 134.02, 133.55, 130.43, 129.98, 128.13, 124.63, 124.40, 124.22, 118.81, 110.03, 53.56, 53.28. IR (KBr): 1747, 1504, 1452, 1096, 1002 cm^{-1}. HRMS (ESI) *m*/*z*: [M + H] calcd for $C_{16}H_{12}BrNO_3S$ 376.9721, found: 377.9770.

*Methyl 2-(benzo[d]oxazol-2-ylthio)-2-(4-fluorophenyl)acetate (**3j**).* Purified by column chromatography (hexane : EtOAc, 95 : 5). White solid (257 mg, 81% yield). Mp 59–60 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.59–7.52 (m, 3H), 7.37 (dd, J = 8.0, 1.3 Hz, 1H), 7.26–7.17 (m, 2H), 7.05–6.99 (m, 2H), 5.73 (s, 1H), 3.75 (s, 3H). ^{13}C NMR (101 MHz, chloroform-*d*) δ 169.66, 164.13, 162.51, 161.66, 151.80, 141.59, 130.34, 130.26, 130.11, 130.08, 124.36, 124.20, 118.67, 116.12, 115.91, 109.95, 53.32, 52.86. IR (KBr): 1742, 1603, 1509, 1096, 1002 cm^{-1}. HRMS (ESI) *m*/*z*: [M + H] calcd for $C_{16}H_{12}FNO_3S$ 317.0522, found: 318.0572.

*Methyl 2-(benzo[d]oxazol-2-ylthio)-2-(o-tolyl)acetate (**3k**).* Purified by column chromatography (hexane : EtOAc, 95 : 5). Pale yellow liquid (285 mg, 91% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.67–7.62 (m, 1H), 7.60–7.55 (m, 1H), 7.44 (dd, J = 7.7, 1.3 Hz, 1H), 7.31–7.23 (m, 5H), 6.03 (s, 1H), 3.80 (s, 3H), 2.61 (s, 3H). ^{13}C NMR (101 MHz, chloroform-*d*) δ 170.03, 163.12, 151.79, 141.63, 136.79, 132.07, 130.97, 128.97, 127.80, 127.31, 126.76, 124.25, 124.04, 118.58, 109.88, 77.36, 53.19, 50.29, 38.89, 19.48. IR (KBr): 1747, 1503, 1453, 1132, 1097 cm^{-1}. HRMS (ESI) *m*/*z*: [M + H] calcd for $C_{17}H_{15}NO_3S$ 313.0773, found: 314.0823.

*Methyl 2-(benzo[d]oxazol-2-ylthio)-2-(p-tolyl)acetate (**3l**).* Purified by column chromatography (hexane : EtOAc, 95 : 5). White solid (291 mg, 93% yield). Mp 69–70 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.62–7.58 (m, 1H), 7.44–7.41 (m, 3H), 7.29 (dd, J = 7.5, 1.5 Hz, 1H), 7.25–7.17 (m, 3H), 5.68 (s, 1H), 3.78 (s, 3H), 2.34 (s, 3H). ^{13}C NMR (101 MHz, chloroform-*d*) δ 170.17, 163.11, 151.96, 141.86, 139.19, 131.03, 129.92, 128.41, 124.45, 124.24, 118.83, 110.09, 53.52, 53.43, 21.30. IR (KBr): 1747, 1503, 1453, 1132, 1097 cm^{-1}. HRMS (ESI) *m*/*z*: [M + H] calcd for $C_{17}H_{15}NO_3S$ 313.0773, found: 314.0842.

*Methyl 2-(benzo[d]oxazol-2-ylthio)-2-(4-methoxyphenyl)acetate (**3m**).* Purified by column chromatography (hexane : EtOAc, 95 : 5). Pale yellow liquid (303 mg, 92% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.44 (dd, J = 7.6, 1.5 Hz, 1H), 7.33 (d, J = 8.7 Hz, 2H), 7.26–7.21 (m, 1H), 7.07 (m, 2H), 6.72 (d, J = 8.7 Hz, 2H), 5.56 (s, 1H), 3.61 (s, 3H), 3.59 (s, 3H). ^{13}C NMR (101 MHz, chloroform-*d*) δ 170.01, 162.89, 160.03, 151.71, 141.63, 129.61, 125.67, 124.26, 124.06, 118.59, 114.41, 109.88, 55.14, 53.16, 53.08. IR (KBr): 1738, 1609, 1511, 1481, 1031 cm^{-1}. HRMS (ESI) *m*/*z*: [M + H] calcd for $C_{17}H_{15}NO_4S$ 329.0722, found: 330.0795.

*Methyl 2-(benzo[d]oxazol-2-ylthio)-2-(3,5-dimethoxyphenyl) acetate (**3n**).* Purified by column chromatography (hexane : EtOAc, 95 : 5). White solid (309 mg, 86% yield). Mp 101–102 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.52 (dd, J = 7.2, 1.7 Hz, 1H), 7.35 (dd, J = 7.4, 1.7 Hz, 1H), 7.19 (qt, J = 7.6, 3.7 Hz, 2H), 6.60 (d, J =

2.3 Hz, 2H), 6.36 (s, 1H), 5.56 (s, 1H), 3.71 (s, 9H). ^{13}C NMR (101 MHz, chloroform-*d*) δ 169.89, 163.06, 161.31, 152.04, 141.89, 136.05, 124.51, 124.30, 118.87, 110.14, 106.60, 101.25, 55.58, 53.95, 53.53. IR (KBr): 1738, 1609, 1511, 1481, 1031 cm^{-1}. HRMS (ESI) *m*/*z*: [M + H] calcd for $C_{18}H_{17}NO_5S$ 359.0827, found: 360.0894.

*Ethyl 2-(benzo[d]oxazol-2-ylthio)-2-(4-chlorophenyl)acetate (**3o**).* Purified by column chromatography (hexane : EtOAc, 95 : 5). White solid (295 mg, 85% yield). Mp 60–61 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.52–7.47 (m, 1H), 7.45–7.40 (m, 2H), 7.33 (dd, J = 7.8, 1.4 Hz, 1H), 7.25 (d, J = 8.5 Hz, 2H), 7.21–7.12 (m, 2H), 5.59 (s, 1H), 4.16 (m, 2H), 1.16 (t, J = 7.1 Hz, 3H). ^{13}C NMR (101 MHz, chloroform-*d*) δ 169.08, 162.61, 151.97, 141.74, 135.10, 133.10, 129.94, 129.32, 124.52, 124.35, 118.82, 110.12, 62.72, 53.29, 14.09. IR (KBr): 1742, 1504, 1451, 1232, 1015 cm^{-1}. HRMS (ESI) *m*/*z*: [M + H] calcd for $C_{17}H_{14}ClNO_3S$ 347.0383, found: 348.0441.

*Ethyl 2-(benzo[d]oxazol-2-ylthio)-2-(3,4-dichlorophenyl)acetate (**3p**).* Purified by column chromatography (hexane : EtOAc, 95 : 5). White solid (309 mg, 81% yield). Mp 61–62 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.55 (d, J = 2.0 Hz, 1H), 7.45–7.41 (m, 1H), 7.30–7.22 (m, 3H), 7.13–7.03 (m, 2H), 5.53 (s, 1H), 4.10 (m, 2H), 1.10 (t, J = 7.1 Hz, 3H). ^{13}C NMR (101 MHz, chloroform-*d*) δ 168.47, 162.09, 151.87, 141.53, 134.85, 133.23, 133.03, 130.85, 130.46, 127.84, 124.45, 124.32, 118.72, 110.01, 62.81, 52.77, 13.98. IR (KBr): 1739, 1504, 1452, 1096, 1032 cm^{-1}. HRMS (ESI) *m*/*z*: [M + H] calcd for $C_{17}H_{13}Cl_2NO_3S$ 380.9993, found: 382.0070.

*Ethyl 2-(benzo[d]oxazol-2-ylthio)-2-(3-bromophenyl)acetate (**3q**).* Purified by column chromatography (hexane : EtOAc, 95 : 5). White liquid (310 mg, 79% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.60–7.57 (m, 1H), 7.52–7.48 (m, 3H), 7.46–7.41 (m, 3H), 7.31–7.26 (m, 2H), 5.65 (s, 1H), 4.30–4.18 (m, 2H), 1.25 (t, 3H). ^{13}C NMR (101 MHz, chloroform-*d*) δ 169.02, 162.59, 151.99, 141.75, 133.65, 132.30, 131.71, 130.24, 129.93, 124.54, 124.38, 123.30, 118.84, 110.14, 62.76, 53.37, 14.11. IR (KBr): 1747, 1504, 1452, 1096, 1002 cm^{-1}. HRMS (ESI) *m*/*z*: [M + H] calcd for $C_{17}H_{14}BrNO_3S$ 390.9878, found: 391.9950.

*Methyl 2-((4-fluorobenzo[d]oxazol-2-yl)thio)-2-phenylacetate (**4a**).* Purified by column chromatography (hexane : EtOAc, 95 : 5). White solid (250 mg, 79% yield). Mp 89–90 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.48–7.42 (m, 2H), 7.30 (td, J = 5.2, 3.2 Hz, 2H), 7.28–7.17 (m, 3H), 6.87 (td, J = 9.1, 2.6 Hz, 1H), 5.61 (s, 1H), 3.70 (s, 3H). ^{13}C NMR (101 MHz, chloroform-*d*) δ 169.81, 164.95, 161.22, 158.82, 148.21, 142.60, 142.47, 133.84, 129.18, 129.16, 128.45, 111.66, 111.40, 110.24, 110.14, 105.61, 105.35, 53.75, 53.44. IR (KBr): 1742, 1603, 1509, 1096, 1002 cm^{-1}. HRMS (ESI) *m*/*z*: [M + H] calcd for $C_{16}H_{12}FNO_3S$ 317.0522, found: 318.0589.

*Methyl 2-((4-chlorobenzo[d]oxazol-2-yl)thio)-2-phenylacetate (**4b**).* Purified by column chromatography (hexane : EtOAc, 95 : 5). White solid (267 mg, 80% yield). Mp 100–101 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.49–7.46 (m, 1H), 7.44–7.40 (m, 2H), 7.28–7.21 (m, 4H), 7.16–7.08 (m, 1H), 5.58 (s, 1H), 3.68 (s, 3H). ^{13}C NMR (101 MHz, chloroform-*d*) δ 169.87, 164.83, 150.57, 142.92, 133.91, 130.07, 129.29, 128.56, 124.46, 118.92, 110.76, 53.90, 53.57. IR (KBr): 1743, 1503, 1453, 1132, 1095 cm^{-1}. HRMS (ESI) *m*/*z*: [M + H] calcd for $C_{16}H_{12}ClNO_3S$ 333.0226, found: 334.0299.

*Methyl 2-((4-bromobenzo[d]oxazol-2-yl)thio)-2-phenylacetate (**4c**).* Purified by column chromatography (hexane : EtOAc, 95 : 5). White solid (314 mg, 83% yield). Mp 90–91 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.66 (d, J = 2.0 Hz, 1H), 7.48–7.43 (m, 2H), 7.34–7.26 (m, 4H), 7.24–7.18 (m, 1H), 5.61 (s, 1H), 3.71 (s, 3H). ^{13}C NMR (101 MHz, chloroform-*d*) δ 169.86, 164.70, 151.00, 143.37, 133.90, 129.29, 128.56, 127.20, 121.89, 117.34, 111.28, 53.92, 53.58. IR (KBr): 1747, 1504, 1452, 1096, 1002 cm^{-1}. HRMS (ESI) *m*/*z*: [M + H] calcd for $C_{16}H_{12}BrNO_3S$ 376.9721, found: 377.9795.

*Methyl 2-((4-nitrobenzo[d]oxazol-2-yl)thio)-2-phenylacetate (**4d**).* Purified by column chromatography (hexane : EtOAc, 95 : 5). White liquid (268 mg, 78% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.38 (d, J = 2.3 Hz, 1H), 8.13 (dd, J = 8.9, 2.3 Hz, 1H), 7.48–7.41 (m, 3H), 7.33–7.29 (m, 3H), 5.63 (s, 1H), 3.72 (s, 3H). ^{13}C NMR (101 MHz, chloroform-*d*) δ 169.58, 167.15, 155.34, 145.34, 142.22, 133.53, 129.42, 129.33, 128.89, 128.54, 120.42, 114.89, 110.17, 54.16, 53.65. IR (KBr): 1742, 1510, 1460, 1131, 1085 cm^{-1}. HRMS (ESI) *m*/*z*: [M + H] calcd for $C_{16}H_{12}N_2O_5S$ 344.0467, found: 345.0477.

*Methyl 2-((4-methylbenzo[d]oxazol-2-yl)thio)-2-phenylacetate (**4e**).* Purified by column chromatography (hexane : EtOAc, 95 : 5). White solid (253 mg, 81% yield). Mp 75–76 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.56–7.50 (m, 2H), 7.41–7.33 (m, 4H), 7.29 (d, J = 8.3 Hz, 1H), 7.04 (dd, J = 8.4, 1.7 Hz, 1H), 5.70 (s, 1H), 3.78 (s, 3H), 2.43 (s, 3H). ^{13}C NMR (101 MHz, chloroform-*d*) δ 170.09, 162.84, 150.28, 142.04, 134.34, 134.24, 129.22, 129.15, 128.57, 125.27, 118.94, 109.48, 53.76, 53.46, 21.55. IR (KBr): 1747, 1503, 1453, 1132, 1097 cm^{-1}. HRMS (ESI) *m*/*z*: [M + H] calcd for $C_{17}H_{15}NO_3S$ 313.0773, found: 314.0839.

*Methyl 2-((4-methoxybenzo[d]oxazol-2-yl)thio)-2-phenylacetate (**4f**).* Purified by column chromatography (hexane : EtOAc, 95 : 5). Pale yellow liquid (270 mg, 82% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.56–7.50 (m, 2H), 7.37–7.30 (m, 3H), 7.26 (d, J = 8.9 Hz, 1H), 7.09 (d, J = 2.5 Hz, 1H), 6.80 (dd, J = 8.9, 2.6 Hz, 1H), 5.70 (s, 1H), 3.78 (s, 3H), 3.75 (s, 3H). ^{13}C NMR (101 MHz, chloroform-*d*) δ 169.87, 163.33, 157.21, 146.50, 142.54, 134.06, 129.09, 129.02, 128.39, 112.20, 110.01, 102.26, 55.84, 53.66, 53.29. IR (KBr): 1738, 1609, 1511, 1481, 1031 cm^{-1}. HRMS (ESI) *m*/*z*: [M + H] calcd for $C_{17}H_{15}NO_4S$ 329.0722, found: 330.0795.

*Ethyl 2-((4-chlorobenzo[d]oxazol-2-yl)thio)-2-(4-chlorophenyl) acetate (**4g**).* Purified by column chromatography (hexane : EtOAc, 95 : 5). White solid (291 mg, 79% yield). Mp 74–75 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.60 (d, J = 2.0 Hz, 1H), 7.55–7.51 (m, 2H), 7.40–7.35 (m, 3H), 7.25 (ddd, J = 8.7, 2.1, 0.9 Hz, 1H), 5.68 (s, 1H), 4.35–4.20 (m, 2H), 1.31–1.27 (m, 3H). ^{13}C NMR (101 MHz, chloroform-*d*) δ 168.94, 164.48, 150.57, 142.83, 135.25, 132.87, 130.13, 129.95, 129.40, 124.54, 118.88, 110.78, 62.84, 53.45, 14.13. IR (KBr): 1743, 1503, 1453, 1132, 1095 cm^{-1}. HRMS (ESI) *m*/*z*: [M + H] calcd for $C_{17}H_{13}Cl_2NO_3S$ 380.9993, found: 382.0058.

*Methyl 2-((4-bromobenzo[d]oxazol-2-yl)thio)-2-(2,4-dichlorophenyl) acetate (**4h**).* Purified by column chromatography (hexane : EtOAc, 95 : 5). Orange liquid (344 mg, 77% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.69 (d, J = 2.0 Hz, 1H), 7.50 (d, J = 8.4 Hz, 1H), 7.41 (d, J = 2.2 Hz, 1H), 7.32 (ddd, J = 8.6, 1.9, 0.6 Hz, 1H), 7.25–7.19 (m, 2H), 6.10 (s, 1H), 3.76 (s, 3H). ^{13}C NMR (101 MHz, chloroform-*d*)

δ 168.82, 164.16, 151.15, 143.26, 135.81, 135.11, 131.26, 131.07, 130.17, 127.94, 127.34, 122.00, 117.45, 111.33, 53.86, 50.64. IR (KBr): 1746, 1587, 1503, 1453, 1002 cm^{-1}. HRMS (ESI) *m/z*: [M + H] calcd for $C_{16}H_{10}BrCl_2NO_3S$ 444.8942, found: 445.8997.

*Methyl 2-((4-chlorobenzo[d]oxazol-2-yl)thio)-2-(4-fluorophenyl) acetate (**4i**).* Purified by column chromatography (hexane : EtOAc, 95 : 5). White solid (285 mg, 81% yield). Mp 70–71 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.57 (d, *J* = 2.0 Hz, 1H), 7.53 (dd, *J* = 8.5, 5.2 Hz, 2H), 7.33 (d, *J* = 8.6 Hz, 1H), 7.21 (dd, *J* = 8.6, 2.1 Hz, 1H), 7.06 (t, *J* = 8.5 Hz, 2H), 5.68 (s, 1H), 3.79 (s, 3H). ^{13}C NMR (101 MHz, chloroform-*d*) δ 169.68, 164.52, 164.40, 161.92, 150.58, 142.86, 130.50, 130.42, 130.14, 130.02, 129.99, 124.54, 118.93, 116.38, 116.16, 110.77, 53.60, 53.15. IR (KBr): 1742, 1603, 1509, 1096, 1002 cm^{-1}. HRMS (ESI) *m/z*: [M + H] calcd for $C_{16}H_{11}ClFNO_3S$ 351.0132, found: 352.0199.

*Methyl 2-((4-methoxybenzo[d]oxazol-2-yl)thio)-2-(4-nitrophenyl) acetate (**4j**).* Purified by column chromatography (hexane : EtOAc, 95 : 5). White solid (329 mg, 88% yield). Mp 121–122 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.46 (d, *J* = 2.3 Hz, 1H), 8.21 (dd, *J* = 8.9, 2.4 Hz, 1H), 7.48 (dd, *J* = 20.7, 8.6 Hz, 3H), 6.90 (d, *J* = 8.2 Hz, 2H), 5.67 (s, 1H), 3.80 (s, 6H). ^{13}C NMR (101 MHz, chloroform-*d*) δ 169.80, 167.33, 160.44, 155.36, 145.39, 142.32, 129.87, 125.33, 120.40, 114.89, 114.74, 110.15, 55.46, 53.72, 53.58. IR (KBr): 1742, 1510, 1460, 1131, 1085 cm^{-1}. HRMS (ESI) *m/z*: [M + H] calcd for $C_{17}H_{14}N_2O_6S$ 374.0573, found: 375.0645.

*Methyl 2-(3,5-dimethoxyphenyl)-2-((4-methylbenzo[d]oxazol-2-yl)thio)acetate (**4k**).* Purified by column chromatography (hexane : EtOAc, 95 : 5). White liquid (310 mg, 83% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.22 (dt, *J* = 39.6, 5.6 Hz, 2H), 6.93 (t, *J* = 7.5 Hz, 1H), 6.62–6.54 (m, 2H), 6.32 (t, *J* = 7.2 Hz, 1H), 5.53 (s, 1H), 3.68 (s, 10H), 2.32 (s, 3H). ^{13}C NMR (101 MHz, chloroform-*d*) δ 169.84, 162.78, 161.20, 150.18, 141.94, 136.00, 134.24, 125.18, 118.80, 109.38, 106.49, 101.10, 55.46, 53.82, 53.41, 21.44. IR (KBr): 1747, 1503, 1453, 1132, 1097 cm^{-1}. HRMS (ESI) *m/z*: [M + H] calcd for $C_{19}H_{19}NO_5S$ 373.0984, found: 374.1046.

*Ethyl 2-((4-bromobenzo[d]oxazol-2-yl)thio)-2-(p-tolyl)acetate (**4l**).* Purified by column chromatography (hexane : EtOAc, 95 : 5). Orange liquid (345 mg, 85% yield). ^{1}H NMR (400 MHz, $CDCl_3$) 7.69 (d, *J* = 1.9 Hz, 1H), 7.38 (d, *J* = 8.2 Hz, 2H), 7.31 (dd, *J* = 8.6, 1.9 Hz, 1H), 7.23 (d, *J* = 5.9 Hz, 1H), 7.14 (d, *J* = 7.8 Hz, 2H), 5.59 (s, 1H), 4.20 (m, 2H), 2.31 (s, 3H), 1.22 (t, *J* = 7.1 Hz, 3H). ^{13}C NMR (101 MHz, chloroform-*d*) δ 169.46, 164.94, 151.00, 143.47, 139.25, 130.98, 129.94, 128.45, 127.14, 121.84, 117.32, 111.24, 62.58, 53.89, 21.33, 14.17. IR (KBr): 1747, 1504, 1452, 1096, 1002 cm^{-1}. HRMS (ESI) *m/z*: [M + H] calcd for $C_{18}H_{16}BrNO_3S$ 405.0034, found: 406.0037.

*Ethyl 2-(benzo[d]oxazol-2-ylthio)acetate (**5a**).* Purified by column chromatography (hexane : EtOAc, 95 : 5). White solid (221 mg, 93% yield). ^{1}H NMR (400 MHz, chloroform-*d*) δ 7.59 (d, *J* = 7.6 Hz, 1H), 7.46–7.41 (m, 1H), 7.31–7.21 (m, 2H), 4.25 (q, *J* = 7.1 Hz, 2H), 4.12 (s, 2H), 1.29 (t, *J* = 7.2 Hz, 3H). ^{13}C NMR (101 MHz, chloroform-*d*) δ 167.90, 163.32, 152.11, 141.78, 124.42, 124.13, 118.65, 110.01, 62.21, 34.28, 14.11. IR (KBr): 1735, 1502, 1470, 1450, 1130 cm^{-1}. HRMS (ESI) *m/z*: [M + H] calcd for $C_{11}H_{11}NO_3S$ 237.0460, found: 238.0526.

*Ethyl 2-((6-chlorobenzo[d]thiazol-2-yl)thio)acetate (**5b**).* Purified by column chromatography (hexane : EtOAc, 95 : 5). White solid (288 mg, 89% yield). ^{1}H NMR (400 MHz, chloroform-*d*) δ 7.81 (d, *J* = 2.1 Hz, 1H), 7.63 (dd, *J* = 8.5, 1.7 Hz, 1H), 7.25 (dq, *J* = 8.4, 2.5, 2.0 Hz, 1H), 4.24 (q, *J* = 7.1 Hz, 2H), 4.15 (s, 2H), 1.29 (t, *J* = 7.2 Hz, 3H). ^{13}C NMR (101 MHz, chloroform-*d*) δ 168.13, 167.13, 153.70, 133.80, 132.25, 124.87, 121.75, 121.61, 62.18, 35.18, 14.21. IR (KBr): 1741, 1501, 1452, 1130, 1095 cm^{-1}. HRMS (ESI) *m/z*: [M + H] calcd for $C_{11}H_{10}ClNO_2S_2$ 286.9841, found: 287.9917.

*Ethyl-2-((6-chlorobenzo[d]thiazol-2-yl)thio)-2-phenylacetate (**5c**).* Purified by column chromatography (hexane : EtOAc, 95 : 5). White liquid (295 mg, 81% yield). ^{1}H NMR (400 MHz, chloroform-*d*) δ 7.75 (s, 1H), 7.51 (d, *J* = 8.6 Hz, 1H), 7.45 (dd, *J* = 7.8, 1.8 Hz, 2H), 7.29 (d, *J* = 6.1 Hz, 2H), 7.24 (d, *J* = 1.0 Hz, 1H), 7.16 (dd, *J* = 8.5, 2.1 Hz, 1H), 5.70 (s, 1H), 4.15 (m, 2H), 1.17 (t, *J* = 7.1 Hz, 3H). ^{13}C NMR (101 MHz, chloroform-*d*) δ 169.46, 166.85, 153.75, 134.18, 133.77, 132.22, 129.15, 129.11, 129.07, 129.00, 128.62, 124.91, 121.78, 121.59, 62.38, 54.76, 14.16. IR (KBr): 1740, 1500, 1450, 1130, 1090 cm^{-1}. HRMS (ESI) *m/z*: [M + H] calcd for $C_{17}H_{14}ClNO_2S_2$ 363.0154, found: 364.0224.

*Ethyl-2-((6-chlorobenzo[d]thiazol-2-yl)thio)-2-(3,4-dichlorophenyl)acetate (**5d**).* Purified by column chromatography (hexane : EtOAc, 95 : 5). White liquid (377 mg, 78% yield). ^{1}H NMR (400 MHz, chloroform-*d*) δ 7.83 (s, 1H), 7.67 (s, 1H), 7.63 (d, *J* = 8.5 Hz, 1H), 7.45–7.37 (m, 2H), 7.27 (d, *J* = 8.7 Hz, 1H), 5.77 (s, 1H), 4.25 (m, 2H), 1.27 (t, *J* = 7.1 Hz, 3H). ^{13}C NMR (101 MHz, chloroform-*d*) δ 168.70, 165.86, 153.64, 134.90, 133.80, 133.32, 133.19, 132.43, 130.97, 130.67, 128.03, 125.19, 121.87, 121.72, 62.84, 53.54, 14.16. IR (KBr): 1741, 1504, 1455, 1133, 1096 cm^{-1}. HRMS (ESI) *m/z*: [M + H] calcd for $C_{17}H_{12}Cl_3NO_2S_2$ 430.9375, found: 431.9447.

Author contributions

Arumugam Jayarani contributed majorly to this work. The corresponding author developed the methodology, supervised the work, helped in fund generation and analysed the data, and the other co-author contributed to data collection.

Conflicts of interest

There are no conflicts to declare.

Data availability

The data underlying this study are available in the published article and its supplementary information (SI). Supplementary information: experimental details and spectroscopic data (^{1}H and ^{13}C NMR). See DOI: **https://doi.org/10.1039/d5ra06843f**.

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Notes and references

1 (*a*) D. R. Taylor, M. MacCoss and D. G. A. Lawson, *J. Med. Chem.*, 2014, **57**, 5845–5859; (*b*) E. Vitaku, T. D. Smith and T. J. Njardarson, *J. Med. Chem.*, 2014, **57**, 10257–10274; (*c*) M. Baumann and R. I. Baxendale, *Beilstein J. Org. Chem.*, 2013, **9**, 2265–2319; (*d*) A. Cagir, H. S. Jones, R. GaO, M. B. Eisenhauer and M. S. Hecht, *J. Am. Chem. Soc.*, 2003, **125**, 13628–13629; (*e*) H. D. Boschelli, T. D. Connor, A. D. Bornemeier, D. R. Dyer, A. J. Kennedy, J. P. Kuipers, C. G. Okonkwo, J. D. Schrier and D. C. Wright, *J. Med. Chem.*, 1993, **36**, 1802–1810; (*f*) P. Kohli, D. S. Srivastava and K. S. Srivastava, *J. Chin. Chem. Soc.*, 2007, **54**, 1003–1010.

2 (*a*) N. Kharasch and C. Y. Meyers, *The chemistry of organic sulfur compound*, New york, 1996; (*b*) R. J. Cremlyn, *An Introduction to Organosulfur Chemistry*, John Wiley & Sons, Chichester, U.K., 1996.

3 For selected reviews, see. (*a*) F. Bernardi, G. I. Csizmadia and A. Mangini, *The Chemistry of Organic Selenium and Tellurium Compounds*, Elsevier, Amsterdam, the Netherlands, 1985, vol. 19; (*b*) C. K. Nicolaou, H. R. C. Hale, C. Nilewski and A. H. Ioannidou, *Chem. Soc. Rev.*, 2012, **41**, 5185–5238; (*c*) F. Minghao, T. Bingqing, L. H. Steven and J. Xuefeng, *Curr. Top. Med. Chem.*, 2016, **16**, 1200–1216.

4 (*a*) Y. D. Lin, Z. S. Zhang, E. Block and C. L. Katz, *Nature*, 2005, **434**, 470–477; (*b*) E. C. Sansom, S. V. Jones, I. N. Joyce, M. B. Smallfield, B. N. Perry and V. W. J. Klink, *J. Agric. Food Chem.*, 2015, **63**, 1833–1838.

5 E. M. Cinar and T. Ozturk, *Chem. Rev.*, 2015, **115**, 3036–3140.

6 For application of the Julia olefination: (*a*) A. Kumar, S. Sharma, D. V. Tripathi and S. Srivastava, *Tetrahedron*, 2010, **66**, 9445–9449; (*b*) For application of benzothiophene synthesis: J. M. Rospondek, L. Marynowski and M. Gora, *Org. Geochem.*, 2007, **38**, 1729–1756.

7 (*a*) S. Aiello, G. Wells, E. L. Stone, H. Kadri, R. Bazzi, D. R. Bell, M. F. G. Stevens, C. S. T. Matthews, D. Bradshaw and A. D. Westwell, *J. Med. Chem.*, 2008, **51**, 5135–5139; (*b*) J. P. Davidson and E. J. Corey, *J. Am. Chem. Soc.*, 2003, **125**, 13486–13489; (*c*) S. M. Sondhi, N. Singh, A. Kumar, O. Lozach and L. Meijer, *Bioorg. Med. Chem.*, 2006, **14**, 3758–3765; (*d*) C. K. Ryu, R. Y. Lee, N. Y. Kim, Y. H. Kim and A. L. Song, *Bioorg. Med. Chem. Lett.*, 2009, **19**, 5924–5926; (*e*) S. M. Rida, F. A. Ashour, S. A. M. El-Hawash, M. M. ElSemary, M. H. Badr and M. A. Shalaby, *Eur. J. Med. Chem.*, 2005, **40**, 949–959; (*f*) H. Razavi, S. K. Palaninathan, E. T. Powers, R. L. Wiseman, H. E. Purkey, N. N. Mohamedmohaideen, S. Deechongkit, K. P. Chiang, M. T. A. Dendle, J. C. Sacchettini and J. W. Kelly, *Angew. Chem., Int. Ed.*, 2003, **42**, 2758–2761; (*g*) E. H. Sessions, Y. Yin, T. D. Bannister, A. Weiser, E. Griffin, J. Pocas, M. D. Cameron, C. Ruiz, L. Lin, S. C. Schürer, T. Schröter, P. LoGrasso and Y. Feng, *Bioorg. Med. Chem. Lett.*, 2008, **18**, 6390–6393; (*h*) P. Vianello, P. Cozzi, A. Galvani, M. Meroni, M. Varasi, D. Volpi and T. Vandiera, *Bioorg. Med. Chem.*, 2004, **14**, 657–661; (*i*) A. Halama, J. Jirman, O. Bouskov, P. Gibala and K. Jarrah, *Org. Process Res. Dev.*, 2010, **14**, 425–431.

8 R. Mitra and G. A. Samuelson, *Eur. J. Inorg. Chem.*, 2014, **11**, 3536–3546.

9 T. Tankam, J. Srisa, M. Sukwattanasinitt and S. Wacharasindhu, *J. Org. Chem.*, 2018, **83**, 11936–11943.

10 C. Safak, R. Simsek, K. Erol and K. Vural, *Pharmazie*, 1996, **51**, 180–182.

11 Y. Xiao, B. Jing, X. Liu, H. Xue and Y. Liu, *Beilstein J. Org. Chem.*, 2019, **15**, 279–284.

12 J. Mentado, H. Flores and P. Amador, *J. Chem. Thermodyn.*, 2008, **40**, 1106–1109.

13 (*a*) L. Feng, T. Hu, S. Zhang, Y.-H. Xiong and G. Zhang, *Org. Lett.*, 2019, **21**, 9487–9492; (*b*) P. Liu, M. Yang, Y. Gong, Y. Yu and L.-Y. Zhao, *Org. Lett.*, 2020, **22**, 36–40; (*c*) Y. Liu and J.-P. Wan, *Chem.–Asian J.*, 2012, **7**(7), 1488–1501; (*d*) Q. Liao, X. Yang and C. Xi, *J. Org. Chem.*, 2014, **79**, 8507–8515.

14 (*a*) D. Gillingham and N. Fei, *Chem. Soc. Rev.*, 2013, **42**, 4918–4931; (*b*) H. M. L. Davies and J. R. Denton, *Chem. Soc. Rev.*, 2009, **38**, 3061–3071.

15 Selected recent reviews for carbene from diazo compound insertion into C–H and X–H bonds, see: (*a*) H. M. L. Davies and S. J. Hedley, *Chem. Soc. Rev.*, 2007, **36**, 1109–1119; (*b*) M. P. Doyle, R. Duffy, M. Ratnikov and L. Zhou, *Chem. Rev.*, 2010, **110**, 704–724; (*c*) S.-F. Zhu and Q.-L. Zhou, *Acc. Chem. Res.*, 2012, **45**, 1365–1377; (*d*) J. Wang, *Tetrahedron Lett.*, 2022, **108**, 154135; (*e*) A. Ford, H. Miel, A. Ring, C. N. Slattery, A. R. Maguire and M. A. Mckervey, *Chem. Rev.*, 2015, **115**, 9981–10080; (*f*) B. Xu, S.-F. Zhu, Z.-C. Zhang, Z.-X. Yu, Y. Ma and Q.-L. Zhou, *Chem. Sci.*, 2014, **5**, 1442–1448; (*g*) Y.-Z. Zhang, S.-F. Zhu, Y. Cai, H.-X. Mao and Q.-L. Zhou, *Chem. Commun.*, 2009, **36**, 5362–5364; (*h*) Z. Zhang, Z. He, Y. Xie, T. He, Y. Fu, Y. Yu and F. Huang, *Org. Chem. Front.*, 2021, **8**, 1233–1242; (*i*) Z. He, W. Zhao, Y. Li, Y. Yu and F. Huang, *Org. Biomol. Chem.*, 2022, **20**, 8078–8082, ; (*j*) P. Wang, Y. Gong, X. Wang, Y. Ren, L. Wang, L. Zhai, H. Li and X. She, *Chem.–Asian J.*, 2022, **17**, e202200465; (*k*) Y.-T. Sun, X. Rao, W. Xu and M.-H. Xu, *Org. Chem. Front.*, 2022, **9**, 3467–3472.

16 M. Brookhart and B. W. Studabaker, *Chem. Rev.*, 1987, **87**, 411–432.

17 (*a*) V. Aggarwal and C. L. Winn, *Acc. Chem. Res.*, 2004, **37**, 611–620; (*b*) Y. Zhang and J. Wang, *Coord. Chem. Rev.*, 2010, **254**, 941–953.

18 Q. Wang, H. Qi, Y. Ren, Z. Cao, K. Junge, R. V. Jagadeesh and M. Beller, *Chem*, 2024, **10**, 1897–1909.

19 H. Keipour, A. Jalba, L. L. Delage and T. Ollevier, *J. Org. Chem.*, 2017, **82**, 3000–3010.

20 J. Yang, G. Wang, S. Chen, B. Ma, H. Zhou, M. Song, C. Liu and C. Huo, *Org. Biomol. Chem.*, 2020, **18**, 9494–9498.

21 S. Chand, P. A. Kumar, R. Singh, S. Kumar and S. K. Nand, *Chem.–Asian J.*, 2019, **14**, 4712–4716.

22 C. Li, R. Wang, L. Huang, J. Chen, J. Jin, Q. Yan, W. Wang, H. Wang and F. Chen, *J. Org. Chem.*, 2023, **88**, 4452–4457.

23 (*a*) K. Ramakrishna, M. Murali and C. Sivasankar, *Org. Lett.*, 2015, **17**, 3814–3817; (*b*) K. Ramakrishna and C. Sivasankar, *J. Org. Chem.*, 2016, **81**, 6609–6616.

24 (*a*) K. Ramakrishna, A. Jayarani, F. F. Koothradan and C. Sivasankar, *Appl. Organomet. Chem.*, 2020, **34**, e5748; (*b*) A. H. Khan, S. Sarkar, M. Shobana and C. Sivasankar, *Adv. Synth. Catal.*, 2023, **365**, 4616–4622.

25 (*a*) F. F. Koothradan, A. Jayarani and C. Sivasankar, *J. Org. Chem.*, 2024, **89**, 4294–4308; (*b*) F. F. Koothradan, S. B. Anusree, P. P. Krishnendu, A. Jayarani and C. Sivasankar, *J. Org. Chem.*, 2022, **87**, 10564–10575; (*c*) G. Jelakam, S. Dey, V. Wotsa and C. Sivasankar, *ChemistrySelect*, 2025, **10**, e202405088; (*d*) A. Jayarani, M. Deepa, A. H. Khan, F. F. Koothradan, S. Yoganandhini, V. Sreelakshmi and C. Sivasankar, *J. Org. Chem.*, 2023, **88**, 15817–15831.