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Regioselective oxidative cross-coupling of benzo[*d*]imidazo[2,1-*b*]thiazoles with styrenes: a novel route to C3-dicarbonylation†

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A novel I_2 promoted, highly efficient metal-free and peroxide-free greener domino protocol for the C3-dicarbonylation of benzo[*d*]imidazo[2,1-*b*]thiazoles (IBTs) with styrenes has been developed *via* oxidative cleavage of the C(sp^2)–H bond, followed by C3-nucleophilic attack of IBT and oxidation. Interestingly, under these conditions 2-(benzo[*d*]imidazo[2,1-*b*]thiazol-2-yl)aniline gave the benzo[4′,5′]thiazolo[2′,3′:2,3]imidazo[4,5-*c*]quinoline derivative *via* oxidative cleavage of the C(sp^2)–H bond, followed by Pictet–Spengler cyclization and aromatization. This method offers the advantages of broad substrate scope, ecofriendly feature and high atom economy apart from higher yields.

Introduction

The oxidative cross-coupling of two different C–H bonds for the construction of specific C–C bonds in the development of effective synthetic strategies to functionalize important pharmacophores is an ongoing interest in synthetic organic chemistry, medicinal chemistry and materials science.[1] Transition metals like Pd, Cu, Ag, Rh, and Ru play a major role in many oxidative cross-coupling reactions.[2] Recent literature reveals that nonmetallic molecular iodine also plays an important role in oxidative cross-coupling reactions.[3] Molecular iodine mediated reactions are attractive and become alternatives to transition metals due to their lower toxicity, easy handling, ready availability, environmental benignity, the ability to operate under mild reaction conditions and lower costs.[4] 1,2-Dicarbonyl compounds are valuable starting materials and important synthetic intermediates in the preparation of many fine chemicals that could be readily converted to many other functional groups, and as such have become attractive targets.[5] Generally these are obtained by the oxidation of 1,2-diols, alkenes and alkynes.[6] Few successful and elegant processes for the construction of C3-dicarbonyl indoles[7] and imidazo[1,2-*a*]pyridines[8] have been reported. However, these procedures are associated with some drawbacks, such as harsh conditions, the use of expensive Pd catalysts and atom economy issues. Recently, iodine mediated 1,2-dicarbonylation indoles have been developed with methyl ketone in the presence of pyrrolidine[9] and in its absence it gave the 2,2-bisindolyl-1-arylethanones.[10] This indicated that the pyrrolidine base was essential for 1,2-dicarbonylation transformation. Later the Atmakur group reported the same type of transformation with imidazo[1,2-*a*]pyridines in the presence of acid.[11] In addition, $FeCl_3$ catalyzed C3-dicarbonylation of imidazoheterocycles with oxoaldehydes has been reported by the Hajra group.[12] Although investigation in this field has been conducted, the development of metal-free, peroxide-free, acid–base free and environmentally benign alternative methods with terminal alkenes *via* C(sp^2)–H bond cleavage is still challenging and highly desirable for 1,2-dicarbonyl functionalization *via* C–H bond cleavage to obtain biologically active heterocyclics.

On the other hand widely employed domino reactions in modern organic synthesis have attracted researchers due to their high atom economy and less waste generation. Recently by using such a strategy isatins,[13] 2-acyloxazoles,[14a] 2-acylbenzothiazoles,[14b] pyrazines,[15] quinoxalines[15,16] and α-ketoimides[17] have been synthesized. However these procedures suffer from some disadvantages like, the use of oxidants and peroxides; thus there is need to develop methods that are free from oxidants and peroxides.

Sulfur-containing heterocyclic compounds are frequently found in numerous natural products and occupy a privileged

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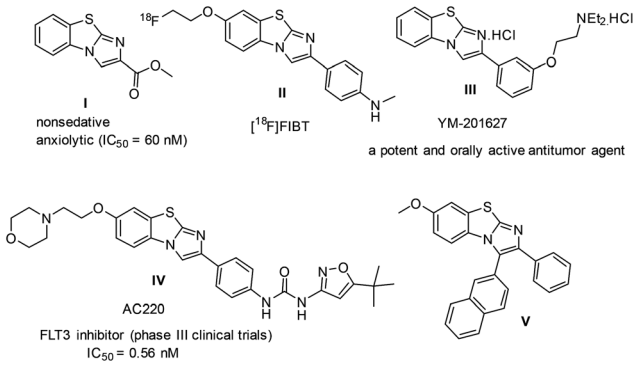


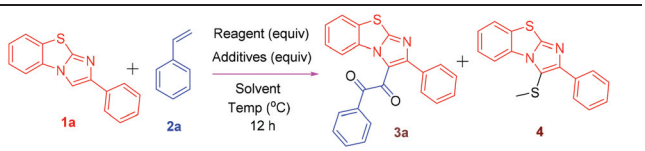
Fig. 1 Biologically active benzo[*d*]imidazo[2,1-*b*]thiazole derivatives.

position in drug discovery as they exhibit interesting activities.[18] Benzo[*d*]imidazo[2,1-*b*]-thiazole is one of the important fused tricyclic sulfur containing scaffolds (Fig. 1) as it exhibits diverse biological activities like antibacterial,[19] antimicrobial,[20] antifungal,[21] immunosuppressive,[22] antiallergic,[23] nonsedative anxiolytic[24] (**I** with IC_{50} = 60 nM) and antitumor[25] (**III**). Its other derivative AC220 (**IV**) is highly potent against FMS-like tyrosine kinase-3 (FLT3) and is in phase III clinical trials,[26] whereas another derivative (**II**) is employed for the PET imaging of brains of Alzheimer's patients as well as β-amyloid plaques.[27] The electron-rich nature of the C3 position in benzo[*d*]imidazo[2,1-*b*]-thiazole enables it to undergo direct C–H bond functionalization with electrophiles to form C–C bonds. Recently from this laboratory a potent cytotoxic agent (**V**) has been reported *via* the C3-arylation of benzo[*d*]imidazo[2,1-*b*]-thiazole.[28] In addition to this, we developed a metal free oxidative cross-coupling of imidazoheterocycles with methylhetarenes.[29] In continuation of our interest regarding benzo[*d*]imidazo[2,1-*b*]-thiazole and their derivatives, herein we describe an iodine mediated highly desirable metal-free, peroxide-free and greener approach for the 1,2-dicarbonlation of benzo[*d*]imidazo[2,1-*b*]thiazole with commercially available styrenes using the greener oxidant O_2 under mild conditions, and to the best of our knowledge, this protocol has not yet been reported.

Results and discussion

Initially, 2-phenylbenzo[*d*]imidazo[2,1-*b*]thiazole (**1a**) and styrene (**2a**) were chosen as model substrates in the presence of I_2 (1 equiv.) in DMSO at 100 °C under atmospheric conditions and the results are summarized in Table 1. To our delight, we obtained the desired oxidative cross-coupling product **3a** in 62% yield, along with an *S*-methylated side-product **4** in 16% yield. Fortunately, the bisbenzo[*d*]imidazo[2,1-*b*]thiazole product like as in the case of indole with methyl ketone and styrene[10,30] as well as the iodination product of 2-phenylimidazo[2,1-*b*]benzothiazole were not observed. The structure of the desired product **3a** was confirmed by the characteristic carbonyl peaks appearing at δ 191.2 ppm and δ 183.2 ppm ($CDCl_3$, 500 MHz) in ^{13}C-NMR spectroscopy with a disappearance of the singlet at δ 7.89 ppm corresponding C3–H in the ^{1}H-NMR spectroscopy of **1a**. Then, different types of iodide reagents such as *N*-iodosuccinimide (NIS), iodosobenzene diacetate ($PhI(OAc)_2$) and tetrabutylammonium iodide (TBAI) were screened; unfortunately the desired product was not obtained (Table 1, entries 2–4), thereby indicating that molecular I_2 is essential for this conversion. Next we focused our attention towards optimizing the temperature; it is observed that the increase of temperature to 110 °C enhances the yield of both the desired product, as well as with *S*-methylated product. However further increase to 120 °C decreased the yield of the desired product and enhanced the *S*-methylated product. Moreover, when the amount of I_2 was decreased to 0.2 equiv., there was a drastic decrease in the yield (Table 1, entry 7). The desired product was obtained in high yield with trace amounts of an *S*-methylated side-product upon enhancing the equivalent of I_2 to 1.6 mol%. It was also observed that by employing the combination of molecular I_2 (1.6 equiv.) with catalytic amount of acids (Table 1, entries 11 and 12), did not further improve the yields but led to the sole desired product. Finally we got the sole desired product in high yield (84%) when the molecular oxygen was applied as the oxidant. After obtaining the promising results we had changed solvents like toluene and DMF but these did not work (Table 1, entries 14 and 15), indicating that

Table 1 Optimization conditions for the oxidative 1,2-dicarbonylation of 2-phenyl benzo[*d*]imidazo[2,1-*b*]thiazole with styrene[a]



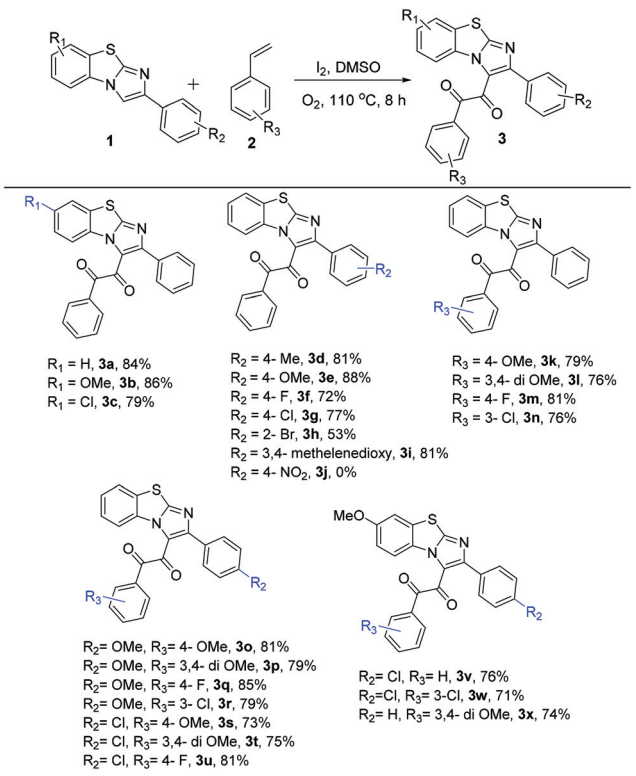
Entry	Reagent (equiv.)	Additive (equiv.)/ oxidant	Solvent	Temp. (°C)	Yield[b] (%) 3a	4
1	I_2 (1.0)	—	DMSO	100	62	16
2	NIS (1.0)	—	DMSO	100	—	—
3	$PhI(OAc)_2$ (1.0)	—	DMSO	100	—	23
4	TBAI (1.0)	—	DMSO	100	—	19
5	I_2 (1.0)	—	DMSO	110	65	17
6	I_2 (1.0)	—	DMSO	120	61	22
7	I_2 (0.2)	—	DMSO	110	29	14
8	I_2 (1.4)	—	DMSO	110	68	10
9	I_2(1.6)	—	DMSO	110	72	Trace
10	I_2 (2.0)	—	DMSO	110	71	Trace
11	I_2 (1.6)	PTSA (0.1)	DMSO	110	69	—
12	I_2 (1.6)	$BF_3{\cdot}Et_2O$ (0.1)	DMSO	110	65	—
13[c]	I_2 (1.6)	O_2	DMSO	110	84	—
14[c]	I_2 (1.6)	O_2	DMF	110	—	—
15[c]	I_2 (1.6)	O_2	Toluene	110	—	—
16[c]	I_2 (1.6)	O_2	DMSO/ H_2O (3 : 1)	110	75	—

[a] Reaction conditions: **1a** (1 mmol), **2a** (1.5 mmol), I_2, DMSO (2.0 mL) at the above mentioned conditions under open air. [b] Yield of the isolated product. [c] Dioxygen (1 atm) was used and the time was 8 h.

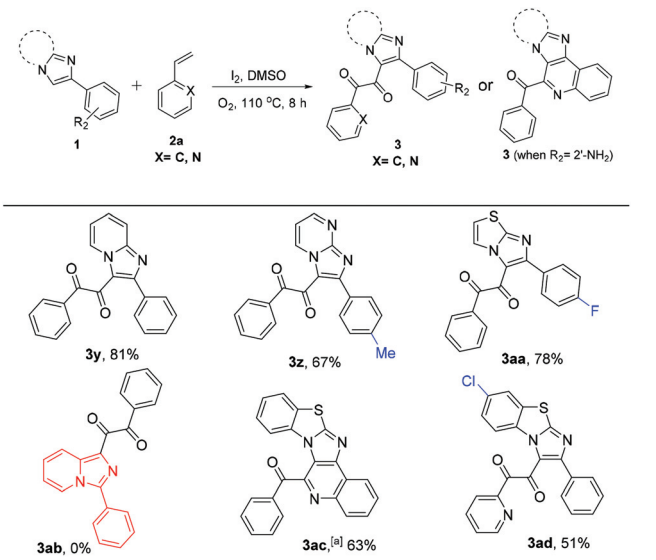
DMSO played a crucial role in this reaction. Moreover, this method well tolerated the addition of water with the solvent and gave the desired product in good yield (Table 1, entry 16).

With the optimized conditions in hand, the generality and scope of this molecular iodine mediated C3-dicarbonylation of benzo[*d*]imidazo[2,1-*b*]thiazole was explored and the reaction demonstrated wide substrate scope in terms of benzo[*d*]imidazo[2,1-*b*]thiazole and styrenes (Scheme 1). Benzo[*d*]imidazo[2,1-*b*]thiazoles having electron donating substituents like –Me and –OMe afforded the corresponding products in excellent yields (**3a** and **3b**) and the chloro substitutent gave in good yield **3c** without dehalogenation. To check the effect of the C-2 substituent the scope of this reaction was subsequently extended to the 2-arylbenzo[*d*]imidazo[2,1-*b*]thiazole derivatives. Phenyl ring bearing electron-donating groups (*e.g.*, 4-Me, 4-OMe and 3,4-methelene dioxy) afforded the corresponding C3-dicarbonylation products in excellent yields (**3d**, **3e** and **3i**) and on the other hand electron withdrawing substituents like –F and –Cl produced the desired oxidative cross-coupling products smoothly in good yields (**3f** and **3g**). However, phenyl ring bearing electron withdrawing groups such as 4-NO_2 prevented the reaction from proceeding due to decreased electron density in the imidazole ring of 2-phenylbenzo[*d*]imidazo[2,1-*b*]-thiazole. Next to check the steric effects 2-bromophenyl linked to benzo[*d*]imidazo[2,1-*b*]thiazole was tested; it gave the corresponding product in moderate yield (**3h**). This indicated that steric factors influenced reaction efficiency. In contrast to styrenes the electronic factors of a phenyl ring linked to benzo[*d*]imidazo[2,1-*b*]thiazole exhibit some influence on the efficiency of this reaction. Phenyl ring bearing electron-donating groups (*e.g.*, 4-OMe) and halogenated groups (*e.g.*, 4-Cl) gave the desired oxidative cross-coupling products smoothly in moderate to good yields (72–88%; **3ba–ha**). In contrast to benzo[*d*]imidazo[2,1-*b*]thiazole, styrene bearing electron-donating groups (*e.g.*, 4-OMe, 3,4-dimethoxy) as well as electron-withdrawing halogen groups (*e.g.*, 4-F, 3-Cl) were smoothly converted to the corresponding products in good yields (**3k–3n**) under these optimized conditions. Thus the electronic factors of styrenes did not show any influence on the efficiency of the protocol. Furthermore, various substituted benzo[*d*]imidazo[2,1-*b*]thiazole and styrenes were also tested and gave the corresponding products in good to excellent yield (**3o–3x**).

Next, the scope of the substrate was tested with imidazo[2,1-*b*]pyridine and imidazo[2,1-*b*]thiazole; they gave the corresponding products (**3y** and **3aa**) in good yield; however imidazo[1,2-*a*]pyrimidine gave the corresponding product (**3z**) in moderate yield (Scheme 2). It could be because of less electron density on the C3 position of imidazo[1,2-*a*]pyrimidine when compared to imidazo[2,1-*b*]pyridine and imidazo[2,1-*b*]thiazole; unfortunately the imidazo[1,5-*a*]pyridine derivative did not provide the desired product (**3ab**). Furthermore, when 2-(benzo[*d*]imidazo[2,1-*b*]thiazol-2-yl)aniline reacted with styrene under optimized conditions it gave the corresponding benzo[4′,5′]thiazolo[2′,3′:2,3]imidazo[4,5-*c*]quinoline (**3ac**) derivative in good yield *via* oxidative cleavage of the C(sp^2)–H bond of styrene, followed by Pictet–Spengler cyclization and aromatization. Next we carried out a test with the heterocycle styrene (2-vinylpyridine)



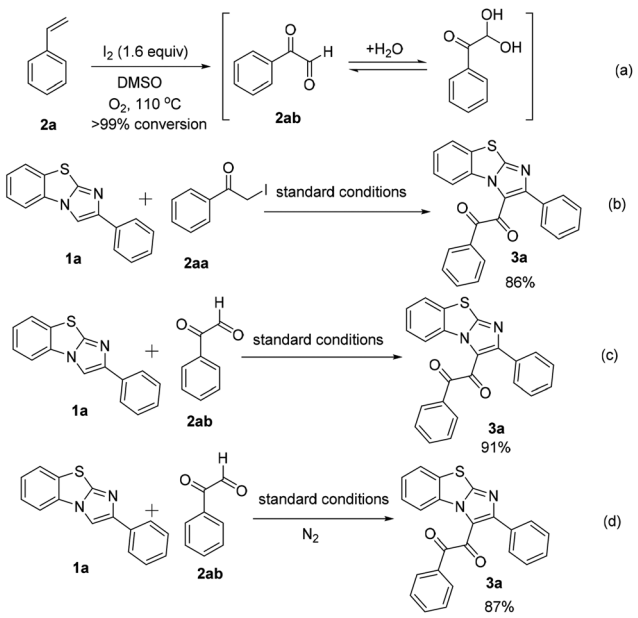
Scheme 1 Substrate scope of the present method. Reaction conditions: **1** (1 mmol), **2** (1.5 mmol) and I_2 (1.6 mmol) in DMSO (2.0 mL) at 110 °C under dioxygen (1 atm) for 8 h.



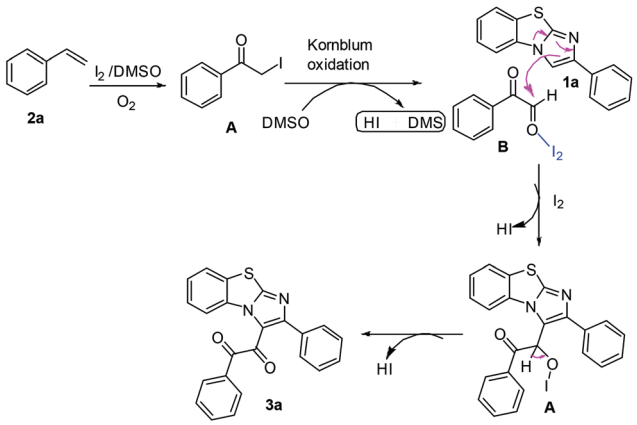
Scheme 2 Scope of the imidazoheterocycles. Reaction conditions : **1** (1 mmol), **2a** (1.5 mmol) and I_2 (1.6 mmol) in DMSO (2.0 mL) at 110 °C under dioxygen (1 atm) for 8 h. [a] **2a** (1.5 mmol) and I_2 (1.6 mmol) in DMSO (2.0 mL) heated at 110 °C for 1 h under dioxygen (1 atm) and then adding **1a** (1 mmol).

which gave the corresponding product (**3ad**) in less yield. It was also observed that 3-phenylimidazo[1,5-*a*]pyridine did not yield the corresponding coupled product, indicating that this protocol regioselectively takes place at the C3 position. To check the efficiency of aromatic benzaldehydes, 4-chlorobenzaldehyde was examined with 6-phenylimidazo[2,1-*b*]pyridine under standard protocol conditions. However, we did not observe either the C3-carbonylated or the bisimidazo[2,1-*b*]pyridine product at all.

In order to propose the mechanistic pathway, some control experiments were carried out as shown in Scheme 3. In this context, styrene (**2a**) under the standard optimized conditions afforded phenylglyoxal (**2ab**) and the corresponding hydrated species in quantitative yield (Scheme 3a). The next condensation of 2-iodo-1-phenylethan-1-one (**2aa**) and phenylglyoxal (**2ab**) with 2-phenylbenzo[*d*]imidazo[2,1-*b*]thiazole (**1a**) under standard conditions gave the corresponding dicarbonylated product (**3a**) in excellent yield (Scheme 3b and c). Based on the control experiments (Scheme 3) and literature reports,[9,11,29,31] a plausible mechanism is depicted in Scheme 4. Initially, styrene (**2a**) on reaction with I_2 in DMSO under molecular dioxygen converted into α-iodoketone (**2aa**) through consecutive iodination and oxidation. Subsequently it converted into phenylglyoxal (**2ab**) in DMSO by Kornblum oxidation. Then C3-nucleophilic addition of benzo[*d*]imidazo[2,1-*b*]thiazole with phenylglyoxal, which was activated by iodine resulted the corresponding intermediate **A**, which on further oxidation gave the desired C3-dicarbonylated benzo[*d*]imidazo[2,1-*b*]thiazole product (**3a**). The *S*-methylated side-product **4** could be formed *via* the attack of 2-phenylbenzo[*d*]imidazo[2,1-*b*]thiazole (**1a**) with *in situ* generated DMS in the presence of molecular iodine; this gave the sulfonium intermediate. Then the sequential loss of MeI afforded the *S*-methylated product **4**.[32]



Scheme 3 Control experiments.



Scheme 4 Possible reaction mechanism.

Conclusion

In conclusion, we have successfully established a novel, highly efficient molecular I_2 mediated metal-free, peroxide-free, acid–base free and greener domino approach for the site selective oxidative C3-dicarbonylation of IBTs with styrenes *via* oxidative cleavage of the C(sp^2)–H bond, followed by the electron rich C3 attack of IBT and oxidation. This method proceeds under mild conditions with high regioselectivity and broad substrate scope under the greener oxidant molecular oxygen. Furthermore, using this simple method a library of C3-dicarbonylated imidazoheterocycle derivatives have been synthesized in good to excellent yields.

Experimental section

General information

All reagents and chemicals were purchased from commercial sources and used directly without further purification. The reaction courses and product mixtures were routinely checked by TLC which was done on a silica gel coated glass slide containing 60 GF-254, and visualized under UV irradiation and iodine. Column chromatography was performed using Merck 60–120 mesh silica gel. Proton (^{1}H) NMR spectra were recorded on Bruker UXNMR/XWIN-NMR (300 MHz) or Inova Varian-VXRunity (400, 500 MHz) instruments. Chemical shifts (δ) are reported in δ units, parts per million (ppm) downfield from an internal standard TMS and coupling constants (J) were expressed in hertz (Hz). Signal multiplicity patterns are designed as follows: s (singlet), d (doublet), t (triplet), quartet (q) ds (double singlet), dd (double doublet), m (multiplet) and br s (broad singlet). ESI spectra were recorded on a Micromass Quattro LC system using ESI+ software with a capillary voltage of 3.98 kV and an ESI mode positive ion trap detector. High-resolution mass spectra (HRMS) were recorded on a QSTAR XL hybrid MS–MS mass spectrometer. All the melting points were determined in an open glass capillary tube with an electrothermal melting point apparatus. All the substituted imidazo-

heterocycles were synthesized by previously reported methods.[28,33–35] All the commercially available solvents were freshly distilled before use.

General experimental procedure for the synthesis of 3 (3a as an example)

To a solution of 2-phenylbenzo[*d*]imidazo[2,1-*b*]thiazole (**1a**, 1.0 equiv.) and styrene (**2a**, 1.5 equiv.) in DMSO (2.0 mL) I_2 (1.6 equiv.) was added and stirred at 110 °C for 8 h under molecular dioxygen atmosphere. TLC analysis indicated completion of the reaction. Upon completion, the mixture was diluted with ice cold water and extracted with EtOAc (3 × 20 mL). The extract was washed with 10% $Na_2S_2O_3$ solution (w/w), dried over anhydrous Na_2SO_4 and concentrated *in vacuo*. The residue was purified by column chromatography on silica gel (60–120 mesh) by using a petroleum ether and ethyl acetate solvent system (9 : 1) to afford the pure title compounds (**3a**).

1-Phenyl-2-(2-phenylbenzo[*d*]imidazo[2,1-*b*]thiazol-3-yl)ethane-1,2-dione (3a)

Light yellow solid; yield 84%; m. p. 181–183 °C (lit.[12] m. p. 179–180 °C); ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.20 (d, J = 8.4 Hz, 1H), 7.78 (d, J = 8.39 Hz, 1H), 7.71 (dd, J = 7.1, 1.1 Hz, 2H), 7.55 (tt, J = 7.4, 1.5 Hz, 2H), 7.46 (t, J = 8.0 Hz, 1H), 7.37 (t, J = 7.9 Hz, 2H), 7.28 (dd, J = 8.2, 1.2 Hz, 2H), 7.22 (t, J = 7.6 Hz, 1H), 7.06 (t, J = 7.7 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 191.2, 183.2, 160.3, 155.1, 134.0, 133.8, 133.4, 132.6, 130.1, 129.7, 129.4, 128.4, 127.7, 126.6, 125.8, 125.0, 123.5, 118.6; HRMS (ESI) (*m*/*z*) calcd for $C_{23}H_{15}N_2O_2S$ $[M + H]^+$ 383.0849; found 383.0874.

3-(Methylthio)-2-phenylbenzo[*d*]imidazo[2,1-*b*]thiazole (4)

Light yellow solid; m. p. 141–143 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.66 (d, J = 8.1 Hz, 1H), 8.17 (d, J = 7.3 Hz, 2H), 7.72 (d, J = 7.8 Hz, 1H), 7.50–7.344 (m, 3H), 7.38–7.34 (m, 2H), 2.39 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 150.8, 149.3, 133.7, 133.6, 130.2, 128.2, 127.8, 127.6, 126.2, 124.7, 124.0, 115.2, 114.0, 20.3; HRMS (ESI) (*m*/*z*) calcd for $C_{16}H_{13}N_2S_2$ $[M + H]^+$ 297.0515; found 297.0529.

1-(7-Methoxy-2-phenylbenzo[*d*]imidazo[2,1-*b*]thiazol-3-yl)-2-phenylethane-1,2-dione (3b)

Light yellow solid; yield 86%; m. p. 119–121 °C (lit.[12] m. p. 119–120 °C); ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.13 (d, J = 9.2 Hz, 1H), 7.71 (dd, J = 8.3, 1.2 Hz, 2H), 7.56 (tt, J = 7.4, 1.2 Hz, 1H), 7.37 (t, J = 7.7 Hz, 2H), 7.28–7.26 (m, 1H), 7.26–7.23 (m, 2H), 7.23–7.19 (m, 1H), 7.11 (dd, J = 9.2, 2.5 Hz, 1H), 7.05 (t, J = 7.8 Hz, 2H), 3.91 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 191.3, 183.2, 159.7, 157.7, 154.4, 134.0, 133.2, 132.7, 131.3, 130.1, 129.4, 129.3, 128.4, 128.1, 127.7, 124.8, 119.4, 113.9, 107.5, 55.8; HRMS (ESI) (*m*/*z*) calcd for $C_{24}H_{17}N_2O_3S$ $[M + H]^+$ 413.0954; found 413.0964.

1-(7-Chloro-2-phenylbenzo[*d*]imidazo[2,1-*b*]thiazol-3-yl)-2-phenylethane-1,2-dione (3c)

Light yellow solid; yield 79%; m. p. 142–144 °C (lit.[12] m. p. 144–145 °C); ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.18 (d, J = 9.0 Hz, 1H), 7.76 (d, J = 2.1 Hz, 1H), 7.71 (dd, J = 8.3, 1.3 Hz, 2H), 7.57 (td, J = 7.4, 1.0 Hz, 1H), 7.53 (dd, J = 9.0, 1.9 Hz, 1H), 7.38 (t, J = 7.9 Hz, 2H), 7.27 (s, 1H), 7.26 (s, 1H), 7.23 (t, J = 7.4 Hz, 1H), 7.05 (t, J = 7.6 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 191.1, 183.4, 160.4, 154.9, 134.1, 133.0, 132.5, 132.4, 131.6, 131.3, 130.1, 129.5, 129.4, 128.4, 127.9, 127.1, 125.1, 123.2, 119.6; HRMS (ESI) (*m*/*z*) calcd for $C_{23}H_{14}ClN_2O_2S$ $[M + H]^+$ 417.0459; found 417.0464.

1-Phenyl-2-(2-(*p*-tolyl)benzo[*d*]imidazo[2,1-*b*]thiazol-3-yl) ethane-1,2-dione (3d)

Light yellow solid; yield 81%; m. p. 99–101 °C (lit.[12] m. p. 95–96 °C); ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.20 (d, J = 8.3 Hz, 1H), 7.76 (d, J = 8.3 Hz, 1H), 7.1 (d, J = 8.2 Hz, 2H), 7.58–7.54 (m, 2H), 7.46 (t, J = 7.3 Hz, 1H), 7.38 (t, J = 7.6 Hz, 2H), 7.16 (d, J = 7.9 Hz, 2H), 6.85 (d, J = 7.7 Hz, 2H), 2.24 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 191.4, 183.2, 160.6, 152.2, 139.5, 133.9, 133.2, 130.0, 129.7, 129.7, 129.4, 128.5, 128.2, 126.6, 125.7, 125.0, 123.6, 118.6, 21.2; HRMS (ESI) (*m*/*z*) calcd for $C_{24}H_{17}N_2O_2S$ $[M + H]^+$ 397.1005; found 397.1010.

1-(2-(4-Methoxyphenyl)benzo[*d*]imidazo[2,1-*b*]thiazol-3-yl)-2-phenylethane-1,2-dione (3e)

Light yellow solid; yield 88%; m. p. 104–106 °C (lit.[12] m. p. 96–97 °C); ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.19 (d, J = 8.4 Hz, 1H), 7.78 (d, J = 7.9 Hz, 1H), 7.73 (dd, J = 8.3, 1.2 Hz, 2H), 7.56 (t, J = 7.4 Hz, 2H), 7.46 (t, J = 7.3 Hz, 1H), 7.38 (t, J = 7.9 Hz, 2H), 7.19 (d, J = 8.6, 2H), 6.57 (d, J = 8.6, 2H), 3.72 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 191.5, 183.3, 160.6, 155.3, 134.0, 133.2, 131.6, 129.8, 129.4, 128.4, 126.7, 125.8, 125.0, 123.6, 118.7, 113.3, 55.2; HRMS (ESI) (*m*/*z*) calcd for $C_{24}H_{17}N_2O_3S$ $[M + H]^+$ 413.0954; found 413.0970.

1-(2-(4-Fluorophenyl)benzo[*d*]imidazo[2,1-*b*]thiazol-3-yl)-2-phenylethane-1,2-dione (3f)

Light yellow solid; yield 72%; m. p. 140–142 °C (lit.[12] m. p. 139–140 °C); ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.21 (d, J = 8.3 Hz, 1H), 7.80 (d, J = 8.0 Hz, 1H), 7.71 (d, J = 8.0 Hz, 2H), 7.55 (t, J = 7.4 Hz, 2H), 7.49 (t, J = 7.6 Hz, 1H), 7.40 (t, J = 7.6 Hz, 2H), 7.25–7.22 (m, 2H), 6.65 (t, J = 8.5 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 191.5, 183.1, 163.4 ($J_{C–F}$ = 249 Hz), 159.2, 155.3, 134.3, 133.9, 133.0, 132.1 ($J_{C–F}$ = 9 Hz), 129.8, 129.4, 128.7, 128.5, 126.8, 126.0, 125.2, 123.6, 118.7, 114.8 ($J_{C–F}$ = 21 Hz); HRMS (ESI) (*m*/*z*) calcd for $C_{23}H_{14}FN_2O_2S$ $[M + H]^+$ 401.0755; found 401.0762.

1-(2-(4-Chlorophenyl)benzo[*d*]imidazo[2,1-*b*]thiazol-3-yl)-2-phenylethane-1,2-dione (3g)

Yellow solid; yield 77%; m. p. 167–169 °C (lit.[12] m. p. 166–168 °C); ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.20 (d, J = 8.4 Hz, 1H), 7.78 (dd, J = 8.0, 1.1 Hz, 1H), 7.71 (dd, J = 8.4,

1.3 Hz, 2H), 7.62–7.56 (m, 2H), 7.49 (td, J = 8.0, 1.2 Hz, 1H), 7.41 (t, J = 7.9 Hz, 2H), 7.18 (d, J = 8.4 Hz, 2H), 7.03 (d, J = 8.4 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 191.5, 183.0, 158.9, 155.3, 135.7, 134.3, 133.9, 133.0, 131.5, 131.0, 129.8, 129.4, 128.5, 128.0, 126.8, 126.0, 125.2, 123.7, 118.7; HRMS (ESI) (m/z) calcd for $C_{23}H_{14}ClN_2O_2S$ $[M + H]^+$ 417.0459; found 417.0462.

1-(2-(2-Bromophenyl)benzo[*d*]imidazo[2,1-*b*]thiazol-3-yl)-2-phenylethane-1,2-dione (3h)

Yellow solid; yield 53%; m. p. 199–201 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.23 (d, J = 8.3 Hz, 1H), 7.81 (d, J = 7.7 Hz, 1H), 7.62–7.58 (m, 3H), 7.55–7.48 (m, 2H), 7.33 (t, J = 7.7 Hz, 2H), 7.24–7.18 (m, 2H), 7.07–7.02 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 191.7, 182.9, 158.2, 155.1, 134.3, 133.8, 133.2, 133.0, 132.2, 132.1, 130.8, 130.0, 129.3, 128.3, 126.8, 126.2, 126.1, 125.9, 124.7, 123.7, 118.8; ^{13}C NMR (125 MHz, $CDCl_3$) δ 191.7, 182.9, 158.2, 155.1, 134.3, 133.8, 133.2, 133.0, 132.2, 132.1, 130.8, 130.0, 129.3, 128.3, 126.8, 126.2, 126.1, 125.9, 124.7, 123.7, 118.8; HRMS (ESI) (m/z) calcd for $C_{23}H_{13}BrN_2O_2S$ $[M + H]^+$ 459.9881; found 460.9976.

1-(2-(Benzo[*d*][1,3]dioxol-5-yl)benzo[*d*]imidazo[2,1-*b*]thiazol-3-yl)-2-phenylethane-1,2-dione (3i)

Light yellow solid; yield 81%; m. p. 197–199 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.19 (d, J = 8.3 Hz, 1H), 7.79–7.76 (m, 3H), 7.61–7.54 (m, 2H), 7.50–7.41 (m, 3H), 6.79 (s, 1H), 6.69 (dd, J = 7.9, 1.5 Hz, 1H), 6.39 (d, J = 7.9 Hz, 1H), 5.88 (s, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 191.2, 182.9, 159.5, 155.0, 148.3, 146.7, 134.4, 133.3, 132.5, 129.4, 129.1, 126.0, 124.9, 124.9, 124.5, 117.6, 109.7, 107.2, 101.2; HRMS (ESI) (m/z) calcd for $C_{24}H_{15}N_2O_4S$ $[M + H]^+$ 427.0747; found 427.0764.

1-(4-Methoxyphenyl)-2-(2-phenylbenzo[*d*]imidazo[2,1-*b*]thiazol-3-yl)ethane-1,2-dione (3k)

Light yellow solid; yield 79%; m. p. 151–153 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.18 (d, J = 8.5 Hz, 1H), 7.74 (d, J = 7.9 Hz, 1H), 7.70 (d, J = 8.8 Hz, 2H), 7.54 (t, J = 7.7 Hz, 1H), 7.45 (t, J = 7.6 Hz, 1H), 7.30 (d, J = 7.2 Hz, 2H), 7.23 (t, J = 7.4 Hz, 1H), 7.10 (t, J = 7.6 Hz, 2H), 6.86 (d, J = 8.8 Hz, 2H), 3.87 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 189.9, 183.5, 164.2, 160.1, 154.9, 133.9, 132.7, 131.8, 130.0, 129.8, 129.3, 127.6, 126.6, 126.4, 125.7, 125.1, 123.5, 118.6, 113.7, 55.4; HRMS (ESI) (m/z) calcd for $C_{24}H_{17}N_2O_3S$ $[M + H]^+$ 413.0954; found 413.0960.

1-(3,4-Dimethoxyphenyl)-2-(2-phenylbenzo[*d*]imidazo[2,1-*b*]thiazol-3-yl)ethane-1,2-dione (3l)

Light yellow solid; yield 76%; m. p. 173–175 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.20 (d, J = 8.3 Hz, 1H), 7.78 (dd, J = 8.0, 0.8 Hz, 1H), 7.56 (td, J = 7.3, 1.2 Hz, 1H), 7.48–7.44 (m, 2H), 7.29 (dd, J = 6.8, 1.2 Hz, 2H), 7.23 (t, J = 7.4 Hz, 1H), 7.11–7.08 (m, 3H), 6.83 (d, J = 8.5 Hz, 1H), 3.96 (s, 3H), 3.83 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 190.2, 183.3, 160.1, 154.9, 148.9, 133.9, 132.8, 130.0, 129.8, 129.1, 127.7, 126.6, 125.8, 125.4, 125.2, 123.5, 118.6, 110.2, 109.8, 56.0, 55.8; HRMS (ESI) (m/z) calcd for $C_{25}H_{19}N_2O_4S$ $[M + H]^+$ 443.1060; found 443.1068.

1-(4-Fluorophenyl)-2-(2-phenylbenzo[*d*]imidazo[2,1-*b*]thiazol-3-yl)ethane-1,2-dione (3m)

Yellow solid; yield 81%; m. p. 201–203 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.17 (d, J = 7.2 Hz, 1H), 7.78–7.74 (m, 3H), 7.56 (s, 1H), 7.47 (s, 1H), 7.27–7.24 (m, 3H), 7.10–7.05 (m, 4H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 189.7, 182.8, 166.1(J_{C-F} = 257 Hz), 160.4, 155.3, 133.8, 13 2.6, 132.1 (J_{C-F} = 9 Hz), 130.1, 129.8 (J_{C-F} = 15 Hz), 129.5, 127.8, 126.7, 125.9, 125., 123.6, 118.5, 115.6 (J_{C-F} = 21 Hz); HRMS (ESI) (m/z) calcd for $C_{23}H_{14}FN_2O_2S$ $[M + H]^+$ 401.0755; found 401.0760.

1-(3-Chlorophenyl)-2-(2-phenylbenzo[*d*]imidazo[2,1-*b*]thiazol-3-yl)ethane-1,2-dione (3n)

Light yellow solid; yield 76%; m. p. 183–185 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.19 (d, J = 8.5 Hz, 1H), 7.80 (d, J = 8.0 Hz, 1H), 7.61–7.56 (m, 3H), 7.53–7.47 (m, 2H), 7.32 (t, J = 7.7 Hz, 1H), 7.30–7.22 (m, 4H), 7.10 (t, J = 7.6 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 190.1, 182.4, 160.7, 155.5, 134.8, 134.7, 133.9, 132.5, 130.2, 129.8, 129.7, 129.6, 129.0, 127.9, 127.5, 126.8, 126.0, 124.9, 123.7, 118.6; HRMS (ESI) (m/z) calcd for $C_{23}H_{14}ClN_2O_2S$ $[M + H]^+$ 417.0459; found 417.0461.

1-(4-Methoxyphenyl)-2-(2-(4-methoxyphenyl)benzo[*d*]imidazo[2,1-*b*]thiazol-3-yl)ethane-1,2-dione (3o)

Yellow solid; yield 81%; m. p. 187–189 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.19 (d, J = 8.4 Hz, 1H), 7.77 (d, J = 7.8 Hz, 1H), 7.71 (d, J = 8.8 Hz, 2H), 7.55 (t, J = 7.47 Hz, 1H), 7.46 (t, J = 7.3 Hz, 1H), 7.26 (d, J = 8.68 Hz, 2H), 6.86 (d, J = 9.0 Hz, 2H), 6.56 (d, J = 8.7 Hz, 2H), 3.88 (s, 3H), 3.74 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 190.2, 183.6, 164.2, 160.5, 160.2, 155.0, 134.0, 131.8, 131.5, 129.7, 126.6, 126.5, 125.7, 125.2, 125.1, 123.6, 118.6, 113.7, 113.2, 55.5, 55.2; HRMS (ESI) (m/z) calcd for $C_{25}H_{19}N_2O_4S$ $[M + H]^+$ 443.1060; found 443.1067.

1-(3,4-Dimethoxyphenyl)-2-(2-(4-methoxyphenyl)benzo[*d*]imidazo[2,1-*b*]thiazol-3-yl)ethane-1,2-dione (3p)

Yellow solid; yield 79%; m. p. 143–145 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.20 (d, J = 8.4 Hz, 1H), 7.77 (d, J = 7.9 Hz, 1H), 7.55 (t, J = 7.9 Hz, 1H), 7.47–7.42 (m, 2H), 7.18 (d, J = 8.5 Hz, 2H), 7.10 (s, 1H), 6.81 (d, J = 8.4 Hz, 1H), 6.61 (d, J = 8.5 Hz, 2H), 3.95 (s, 3H), 3.83 (s, 3H), 3.72 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 190.6, 183.4, 160.4, 160.3, 154.1, 149.0, 134.0, 131.6, 129.7, 126.8, 126.7, 125.7, 125.3, 125.2, 123.6, 118.7, 113.1, 110.1, 109.8, 56.1, 55.8, 55.1; HRMS (ESI) (m/z) calcd for $C_{26}H_{21}N_2O_5S$ $[M + H]^+$ 473.1166; found 473.1171.

1-(4-Fluorophenyl)-2-(2-(4-methoxyphenyl)benzo[*d*]imidazo[2,1-*b*]thiazol-3-yl)ethane-1,2-dione (3q)

Light brown solid; yield 85%; m. p. 173–175 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.17 (d, J = 8.0 Hz, 1H), 7.78–7.73 (m, 3H), 7.56 (td, J = 7.4, 1.2 Hz, 1H), 7.46 (td, J = 7.0, 1.1 Hz, 1H), 7.20 (d, J = 7.6, 2H), 7.06 (t, J = 8.5, 2H), 6.61 (d, J = 8.6, 2H), 3.73 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 189.9, 182.8, 166.1 (J_{C-F} = 257 Hz), 160.6, 160.5, 155.4, 133.9, 132.1 (J_{C-F} = 10 Hz), 131.6, 129.7, 126.7, 125.8, 125.0, 124.9, 123.6, 118.5, 115.7 (J_{C-F} = 22 Hz),

113.3, 55.2; HRMS (ESI) (*m*/*z*) calcd for $C_{24}H_{16}FN_2O_3S$ $[M + H]^+$ 431.0860; found 431.0866.

1-(3-Chlorophenyl)-2-(2-(4-methoxyphenyl)benzo[*d*]imidazo[2,1-*b*]thiazol-3-yl)ethane-1,2-dione (3r)

Light yellow solid; yield 79%; m. p. 165–167 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.18 (d, J = 8.4 Hz, 1H), 7.77 (d, J = 8.0 Hz, 1H), 7.62–7.45 (m, 5H), 7.32 (t, J = 7.8 Hz, 1H), 7.17 (d, J = 8.8 Hz, 2H), 6.62 (d, J = 8.6 Hz, 2H), 3.76 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 190.5, 182.6, 161.0, 155.7, 135.0, 134.9, 134.1, 134.0, 131.8, 129.9, 129.8, 129.0, 127.6, 126.9, 126.0, 125.1, 125.0, 123.8, 118.8, 113.5, 55.4; HRMS (ESI) (*m*/*z*) calcd for $C_{24}H_{16}ClN_2O_3S$ $[M + H]^+$ 447.0565; found 447.0568.

1-(2-(4-Chlorophenyl)benzo[*d*]imidazo[2,1-*b*]thiazol-3-yl)-2-(4-methoxyphenyl)ethane-1,2-dione (3s)

Light yellow solid; yield 73%; m. p. 197–199 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.16 (d, J = 8.4 Hz, 1H), 7.79 (dd, J = 7.9, 0.9 Hz, 1H), 7.69 (d, J = 8.9, 2H), 7.57 (td, J = 8.5, 1.2 Hz, 1H), 7.47 (td, J = 7.0, 0.9 Hz, 1H), 7.21 (d, J = 8.4 Hz, 2H), 7.05 (d, J = 8.4 Hz, 2H), 6.87 (d, J = 8.9 Hz, 2H), 3.90 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 190.1, 183.4, 164.5, 158.6, 155.1, 135.6, 133.9, 131.8, 131.4, 131.2, 129.8, 127.9, 126.7, 126.2, 125.9, 125.3, 123.6, 118.7, 113.9, 55.6; HRMS (ESI) (*m*/*z*) calcd for $C_{24}H_{15}ClN_2NaO_3S$ $[M + Na]^+$ 469.0384; found 469.0391.

1-(2-(4-Chlorophenyl)benzo[*d*]imidazo[2,1-*b*]thiazol-3-yl)-2-(3,4-dimethoxyphenyl)ethane-1,2-dione (3t)

Light yellow solid; yield 75%; m. p. 169–171 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.21 (d, J = 8.4 Hz, 1H), 7.8 (dd, J = 8.0, 0.8 Hz, 1H), 7.58 (td, J = 8.5, 1.2 Hz, 1H), 7.48 (td, J = 7.0, 1.1 Hz, 1H), 7.44 (dd, J = 8.3, 1.9 Hz, 1H), 7.20 (d, J = 8.4 Hz, 2H), 7.08–7.03 (m, 3H), 6.84 (d, J = 8.4 Hz, 1H), 3.97 (s, 3H), 3.87 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 190.4, 183.1, 158.7, 155.1, 154.5, 149.2, 135.5, 133.9, 131.4, 131.3, 129.8, 129.1, 127.9, 126.8, 126.5, 126.0, 125.4, 123.6, 118.7, 109.9, 109.9, 56.1, 55.9; HRMS (ESI) (*m*/*z*) calcd for $C_{25}H_{18}ClN_2O_4S$ $[M + H]^+$ 477.0670; found 477.0674.

1-(2-(4-Chlorophenyl)benzo[*d*]imidazo[2,1-*b*]thiazol-3-yl)-2-(4-fluorophenyl)ethane-1,2-dione (3u)

Yellow solid; yield 81%; m. p. 175–177 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.17 (d, J = 8.3 Hz, 1H), 7.79 (d, J = 7.9 Hz, 1H), 7.76–7.73 (m, 2H), 7.58 (t, J = 8.4 Hz, 1H), 7.49 (t, J = 8.1 Hz, 1H), 7.18 (d, J = 8.4 Hz, 2H), 7.14–7.01 (m, 4H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 189.9, 182.6, 166.3 (J_{C-F} = 258 Hz), 165.3, 159.0, 155.4, 135.9, 133.8, 132.1 (J_{C-F} = 10 Hz), 131.5, 131.1, 129.8, 129.5, 128.0, 126.8, 126.1, 123.7, 118.7, 115.9 (J_{C-F} = 21 Hz); HRMS (ESI) (*m*/*z*) calcd for $C_{23}H_{13}ClFN_2O_2S$ $[M + H]^+$ 435.0365; found 435.0336.

1-(2-(4-Chlorophenyl)-7-methoxybenzo[*d*]imidazo[2,1-*b*]thiazol-3-yl)-2-phenylethane-1,2-dione (3v)

Yellow solid; yield 76%; m. p. 175–177 °C; ^{1}H NMR (300 MHz, $CDCl_3$ + DMSO-d_6) δ 9.10 (d, J = 9.2 Hz, 1H), 7.69 (d, J = 7.7 Hz, 2H), 7.61 (s, 1H), 7.43 (t, J = 7.4 Hz, 2H), 7.38 (d, J = 2.2 Hz, 1H), 7.18–7.10 (m, 3H), 7.03 (d, J = 8.3 Hz, 2H), 3.93 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 190.3, 182.2, 158.5, 157.9, 154.8, 135.9, 135.0, 134.6, 134.1, 131.5, 131.1, 129.8, 129.1, 128.1, 127.3, 124.8, 119.5, 114.1, 107.6, 55.9; HRMS (ESI) (*m*/*z*) calcd for $C_{24}H_{16}ClN_2O_3S$ $[M + H]^+$ 447.0565; found 447.0571.

1-(3-Chlorophenyl)-2-(2-(4-chlorophenyl)-7-methoxybenzo[*d*]imidazo[2,1-*b*]thiazol-3-yl)ethane-1,2-dione (3w)

Light yellow solid; yield 71%; m. p. 171–173 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.10 (d, J = 9.1 Hz, 1H), 7.69 (d, J = 7.4 Hz, 2H), 7.59 (t, J = 7.4 Hz, 1H), 7.40 (t, J = 7.6 Hz, 2H), 7.18 (d, J = 8.2 Hz, 2H), 7.10 (dd, J = 9.3, 2.4 Hz, 1H), 7.02 (d, J = 8.2 Hz, 2H), 3.92 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 191.6, 183.0, 158.2, 157.8, 154.5, 135.6, 134.3, 133.0, 131.5, 131.3, 131.1, 129.4, 128.5, 128.0, 125.0, 119.6, 114.0, 107.6, 55.8; HRMS (ESI) (*m*/*z*) calcd for $C_{24}H_{15}Cl_2N_2O_3S$ $[M + H]^+$ 481.0175; found 481.0174.

1-(3,4-Dimethoxyphenyl)-2-(7-methoxy-2-phenylbenzo[*d*]imidazo[2,1-*b*]thiazol-3-yl)ethane-1,2-dione (3x)

Light yellow solid; yield 74%; m. p. 213–215 °C; ^{1}H NMR (300 MHz, $CDCl_3$ + DMSO-d_6) δ 9.10 (d, J = 9.2 Hz, 1H), 7.54–7.51 (m, 1H), 7.44 (dd, J = 8.4, 1.8 Hz, 1H), 7.34 (s, 1H), 7.24 (d, J = 5.0 Hz, 2H), 7.14–7.04 (m, 4H), 6.88 (d, J = 8.49 Hz, 1H), 3.97 (s, 3H), 3.93 (s, 3H), 3.82 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$ + DMSO-d_6) δ 190.0, 183.1, 158.7, 157.2, 154.1, 148.5, 132.6, 131.1, 129.9, 129.0, 127.4, 125.7, 125.4, 124.4, 118.5, 114.1, 110.6, 110.0, 108.5, 55.8, 55.7, 55.4; HRMS (ESI) (*m*/*z*) calcd for $C_{26}H_{21}N_2O_5S$ $[M + H]^+$ 473.1165; found 473.1162.

1-Phenyl-2-(2-phenylimidazo[1,2-*a*]pyridin-3-yl)ethane-1,2-dione (3y)

Yellow solid; yield 81%; m. p. 121–123 °C (lit.[12] m. p. 121–122 °C); ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.83 (d, J = 6.8 Hz, 1H), 7.86 (d, J = 9.0 Hz, 1H), 7.72 (dd, J = 8.3, 1.2 Hz, 2H), 7.68–7.65 (m, 1H), 7.56 (t, J = 8.5 Hz, 1H), 7.38 (t, J = 7.6 Hz, 1H), 7.30 (dd, J = 8.2, 1.3 Hz, 2H), 7.26–7.22 (m, 2H), 7.09 (t, J = 7.7 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 191.2, 184.4, 158.5, 148.2, 134.0, 133.3, 132.8, 130.9, 129.9, 129.4, 129.3, 129.2, 128.4, 127.8, 118.8, 117.5, 115.7; HRMS (ESI) (*m*/*z*) calcd for $C_{21}H_{15}N_2O_2$ $[M + H]^+$ 327.1128; found 327.1138.

1-Phenyl-2-(2-(*p*-tolyl)imidazo[1,2-*a*]pyrimidin-3-yl)ethane-1,2-dione (3z)

White solid; yield 67%; m. p. 164–166 °C (lit.[12] m. p. 165–167 °C); ^{1}H NMR (500 MHz, $CDCl_3$) δ 10.03 (d, J = 6.8 Hz, 1H), 8.89 (s, 1H), 7.76 (d, J = 7.4 Hz, 2H), 7.61 (t, J = 7.3 Hz, 2H), 7.42 (t, J = 7.6 Hz, 3H), 7.24 (s, 1H), 6.92 (d, J = 7.6 Hz, 2H), 2.28 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 190.7, 185.2, 159.9, 154.7, 150.7, 140.2, 136.8, 134.3, 130.0, 130.0, 129.5, 129.2, 128.7, 128.6, 117.0, 111.6, 21.3; HRMS (ESI) (*m*/*z*) calcd for $C_{21}H_{16}N_3O_2$ $[M + H]^+$ 342.1237; found 342.1265.

1-(6-(4-Fluorophenyl)imidazo[2,1-*b*]thiazol-5-yl)-2-phenylethane-1,2-dione (3aa)

Yellow solid; yield 78%; m. p. 153–155 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.56 (d, J = 4.4 Hz, 1H), 7.75 (dd, J = 8.4, 1.3 Hz, 2H), 7.60 (t, J = 7.4 Hz, 1H), 7.43 (t, J = 7.8 Hz, 2H), 7.30–7.26 (m, 2H), 7.15 (d, J = 4.4 Hz, 1H), 6.81 (t, J = 8.6 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 191.7, 182.8, 163.3 (J_{C-F} = 250 Hz), 157.3, 156.0, 134.5, 133.0, 131.6 (J_{C-F} = 8 Hz), 129.4, 128.7, 121.9, 115.0 (J_{C-F} = 22 Hz), 115.0; HRMS (ESI) (m/z) calcd for $C_{19}H_{12}FN_2O_2S$ $[M + H]^+$ 351.0598; found 351.0603.

Benzo[4′,5′]thiazolo[2′,3′:2,3]imidazo[4,5-*c*]quinolin-6-yl(phenyl)methanone (3ac)

Yellow solid; yield 63%; m. p. 238–240 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.74–8.70 (m, 1H), 8.31–8.21 (m, 2H), 8.27–8.23 (m, 1H), 7.80–7.50 (m, 3H), 7.72 (t, J = 7.4 Hz, 1H), 7.59 (t, J = 7.6 Hz, 2H), 7.54–7.51 (m, 1H), 7.41–7.36 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 194.2, 158.3, 151.4, 143.0, 137.5, 135.6, 134.4, 133.2, 131.5, 129.7, 129.0, 128.7, 128.0, 126.7, 125.0, 124.1, 122.2, 122.0, 116.1; HRMS (ESI) (m/z) calcd for $C_{23}H_{14}N_3OS$ $[M + H]^+$ 380.0852; found 380.0867.

1-(7-Chloro-2-phenylbenzo[*d*]imidazo[2,1-*b*]thiazol-3-yl)-2-(pyridin-2-yl)ethane-1,2-dione (3ad)

Yellow solid; yield 51%; m. p. 203–205 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.29 (d, J = 9.0 Hz, 1H), 8.63 (d, J = 4.4 Hz, 1H), 7.76 (d, J = 1.9 Hz, 1H), 7.70 (td, J = 7.7, 1.3 Hz, 1H), 7.57 (d, J = 7.7 Hz, 1H), 7.51 (dd, J = 9.0, 1.9 Hz, 1H), 7.44–7.41 (m, 1H), 7.28 (d, J = 7.0 Hz, 2H), 7.20 (t, J = 7.4 Hz, 1H), 7.02 (t, J = 7.6 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 191.2, 184.3, 160.3, 154.8, 151.4, 149.1, 136.8, 132.7, 132.5, 131.6, 131.2, 130.4, 129.5, 127.7, 127.5, 127.1, 125.3, 123.1, 123.0, 120.1; HRMS (ESI) (m/z) calcd for $C_{22}H_{23}N_3O_2ClS$ $[M + H]^+$ 418.0411; found 418.0417.

Conflicts of interest

There are no conflicts of interest to declare.

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