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Substrate-controlled and highly stereoselective synthesis of 2-aminobut-2-ene-1,4-diones

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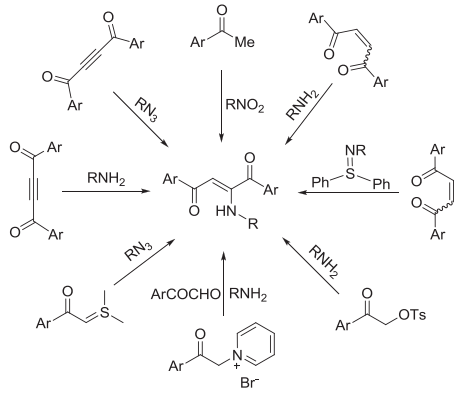
ABSTRACT

2-Methylthio-substituted 1,4-enediones, obtained from readily available aryl methyl ketones, were reacted with primary or secondary amines to afford the desired 1,4-diaryl-2-aminobut-2-ene-1,4-diones in excellent yields with high *Z*/*E*-stereoselectivity.

1. Introduction

The compounds, which have a skeleton consisting of 1,4-diaryl-2-aminobut-2-ene-1,4-diones constitute an important class of materials in the manufacture of agrochemicals, pharmaceutical and other industrial products.[1–4] They are also the building blocks of various heterocyclic compounds in organic synthesis,[5] such as hydrazine,[6] furan[7,8] and imidazo[1,2-a]pyridin-3(2*H*)-ones.[9] Therefore, the development of new methodologies for these compounds has been the driving force for numerous synthetic efforts.

Up until now, a variety of methods have been reported for the synthesis of 1,4-diaryl-2-aminobut-2-ene-1,4-diones (Scheme 1). Generally, they could be synthesized by the reaction of aryl methyl ketones with nitrobenzenes,[6] diaroylacetylene with various amines[5,9,10] or aryl azide,[11] α,β-unsaturated γ-dicarbonyl compounds with amines[12] or sulfilimines,[13] using sulfur ylides,[14] pyridinium ylides[15] or α-tosyloxyacetophenones[16] as one of substrates, as well as through other pathways.[6,17–19] Recently, we established a simple and attractive reaction for the preparation of substituted 2-butene-1,4-dione skeleton from readily available aryl methyl ketones in the presence of copper(II) oxide, iodine and dimethyl sulfoxide.[20] As a continuation of our work, we herein report an efficient and stereoselective method for the synthesis of 1,4-diaryl-2-aminobut-2-ene-1,4-diones by the treatment of 2-(methylthio)-1,4-diaryl-2-butene-1,4-dione with the primary or secondary amines (Scheme 2).



Scheme 1. Various methods for the synthesis of 2-aminobut-2-ene-1,4-diones.

2. Results and discussion

Initially, we investigated the optimum conditions for the formation of (*Z*)-1,4-diphenyl-2-(phenylamino)but-2-ene-1,4-dione (**3aa**) using the *Z*-isomer of 2-(methylthio)-1,4-diphenylbut-2-ene-1,4-dione (**1a**) and aniline (**2a**) as the model substrates in ethanol. After careful optimization of the molar ratios and reaction

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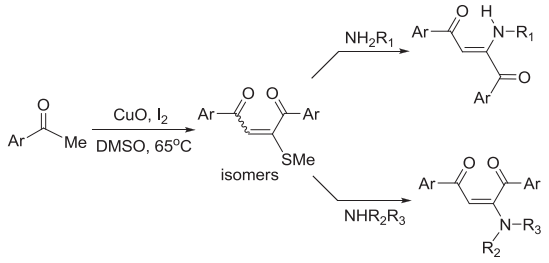
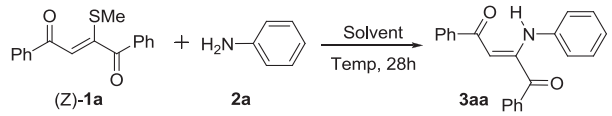


Scheme 2. Synthesis of 1,4-diaryl-2-(arylamino)but-2-ene-1,4-diones from aryl methyl ketones.

temperature (Table 1, entries 1–9), it was found that the desired product **3aa** was obtained in 95% yield with the ratio of 1:2.5 (**1a**/**2a**) at reflux (78 °C) for 28 h. This transformation was also attempted in other different solvents, such as THF, acetonitrile, toluene and DMF, **3aa** was isolated in 30–85% yields (entries 10–13). No expected product was observed in DMSO at 100 °C (entry 14). Therefore, the optimized reaction condition was identified as: **1a** reacted with 2.5 equiv of **2a** in refluxing ethanol for 28 h.

Table 1
Optimization of the reaction conditions



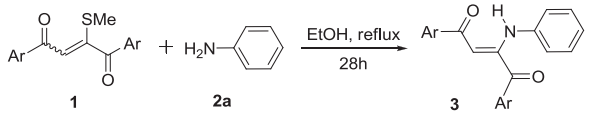
Entry	Molar ratio (*Z*)-**1a**/**2a**	Solvents	Temp (°C)	Yields[a] (%)
1	1:1	EtOH	Reflux	50
2	1:1.5	EtOH	Reflux	62
3	1:2	EtOH	Reflux	86
4	1:2.5	EtOH	Reflux	95
5	1:3	EtOH	Reflux	95
6	1:2.5	EtOH	60	75
7	1:2.5	EtOH	50	50
8	1:2.5	EtOH	40	42
9	1:2.5	EtOH	20	25
10	1:2.5	THF	Reflux	41
11	1:2.5	CH_3CN	Reflux	80
12	1:2.5	Toluene	Reflux	85
13	1:2.5	DMF	100	30
14	1:2.5	DMSO	100	0

[a] Isolated yields.

With the optimized condition in hand, we examined the scope of 2-methylthio-substituted 1,4-enediones (Table 2). It was found that **3aa** was the only product in 95% yield even if the *E*-isomer of **1a** reacted with **2a** under the above-mentioned conditions. The structure of **3aa** was confirmed by IR, ^{1}H NMR, ^{13}C NMR and HRMS. The low-field of NH resonance signal (12.57 ppm) highlighted the possibility of intramolecular hydrogen bonding, which was further confirmed by the single-crystal X-ray diffraction analysis.[19,21] As shown in Fig. 1, the molecule adopted a *Z*-configuration with respect to the carbon–carbon double bond. This was due to intramolecular six-membered ring N–H···O hydrogen-bonding, with the H1···O2 distance of 2.658(1) Å. Since both *Z*- and *E*-isomers of **1a** gave the same *Z*-configuration product **3aa**, substrates **1b**–**k** involved in this reaction were a mixture of *Z*/*E*-isomers.[20] We were pleased to find that regardless of the electronic or steric properties of substituents (Me, OMe, Cl, Br, NO_2) on the phenyl ring, the reaction proceeded smoothly to afford *Z*-configuration products **3ba**–**fa** in 89–97% yields. In addition, naphthalene ring and heterocyclic substituted substrates **1g**–**j** could also work well under these conditions (88–98%).

Encouraged by the results obtained with 2-methylthio-substituted 1,4-enediones, a variety of amines were investigated to react with **1a**. As can be seen from Table 3, aromatic primary amines, including 4-chloroaniline (**2b**), 4-aminophenol (**2c**), benzene-1,4-diamine (**2d**), naphthyl amine (**2f**) and pyridin-3-amine (**2g**) did not affect the overall efficiency, affording the corresponding products in excellent yields. However, ethyl 4-aminobenzoate (**2e**) gave the expected product **3ae** only in 45% yield after 72 h. To our delight, aliphatic amines, such as ethanamine (**2h**), propan-2-amine (**2i**), butan-1-amine (**2j**), cyclohexanamine (**2k**) and phenylmethanamine (**2l**) were also suitable substrates for the reaction, furnishing the expected products **3ah**–**al** in 89–95% yields. X-ray single-crystal diffraction analysis[22] of **3al** showed that the molecule also adopted a *Z*-configuration (Fig. 2).

Table 2
Reaction scope of 2-methylthio-substituted 1,4-enediones **1**



Diketones[a]	Ar	Products	Yields[b] (%)
(*Z*)-**1a**	Ph	**3aa**	95
(*E*)-**1a**	Ph	**3aa**	95
1b	4-MeC_6H_4	**3ba**	97
1c	4-$MeOC_6H_4$	**3ca**	96
1d	4-ClC_6H_4	**3da**	89
1e	4-BrC_6H_4	**3ea**	90
1f	4-$O_2NC_6H_4$	**3fa**	91
1g	1-NaPh	**3ga**	88
1h	2-NaPh	**3ha**	92
1i	2-Furyl	**3ia**	96
1j	2-Thienyl	**3ja**	98

[a] Compounds **1b**–**j** involved a mixture of *Z*/*E*-isomers with the ratio of 6:1, see Ref. 20; reaction conditions: **1** (1.0 mmol), **2a** (2.5 mmol) in EtOH (2 mL) at reflux for 28 h.
[b] Isolated yields.

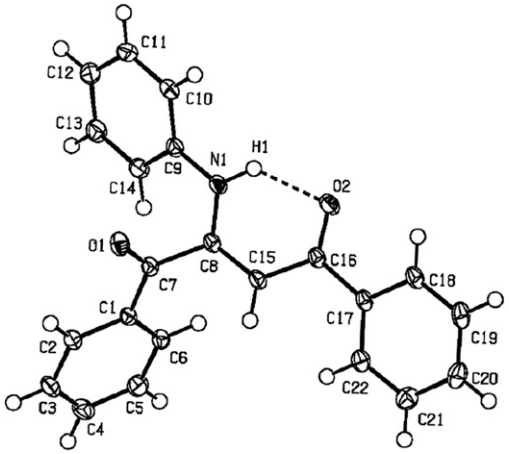
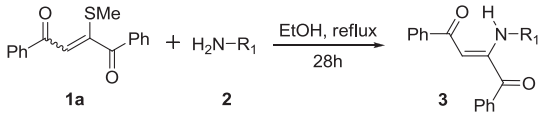


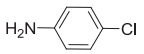
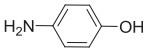
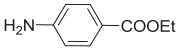
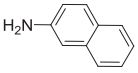
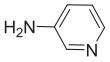
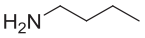
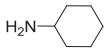
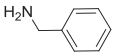
Fig. 1. X-ray crystal structure of compound **3aa**.

Next, we extended this process to secondary amines including diethylamine (**2m**), pyrrolidine (**2n**), piperidine (**2o**) and morpholine (**2p**). Much to our satisfaction, the corresponding 2-amino-substituted 1,4-diones products **3am**–**ap** were isolated in 83–92% yields (Table 4). However, the X-ray diffraction analysis of **3am**,[23] **3ao**[24] and **3ap**[25] showed that these molecules adopted an *E*-configuration, probably due to the higher thermal stability of *E*-isomers. The crystal structure of **3ap** was shown in Fig. 3.

Interestingly, the treatment of a mixture of *Z*/*E*-isomers of 2-methylthio-substituted 1,4-enediones (**1**) with primary amines provided the desired 2-amino-substituted 1,4-enediones (**3**) in a *Z*-

Table 3
Reaction scope of primary amine **2**[a]



Amines		Products	Yields[b] (%)
2b		**3ab**	81
2c		**3ac**	96
2d		**3ad**	90
2e		**3ae**	45[c]
2f		**3af**	95
2g		**3ag**	92
2h		**3ah**	95
2i		**3ai**	90
2j		**3aj**	92
2k		**3ak**	90
2l		**3al**	89

[a] Compound **1a** involved a mixture of *Z*/*E*-isomers with the ratio of 6:1, see Ref. 20; reaction conditions: **1** (1.0 mmol), **2a** (2.5 mmol) in EtOH (2 mL) at reflux for 28 h.
[b] Isolated yields.
[c] Reflux for 72 h.

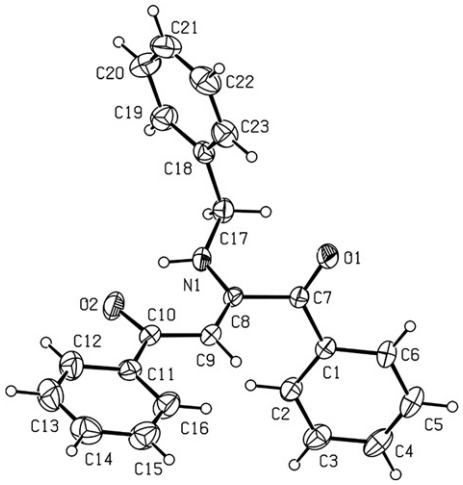
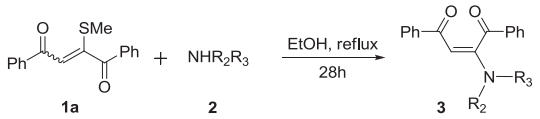
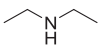


Fig. 2. X-ray crystal structure of compound **3al**.

configuration, and allowed formation of an *E*-configuration product with the secondary amines. Consequently, the plausible mechanisms were further investigated. Two potential pathways were proposed as follows using **1a** as an example (Scheme 3): (i) the saturated 1,4-diones intermediates **I** or **II** were formed by the

Table 4
Reaction scope of secondary amine **2**[a]



Amines		Products	Yields[b] (%)
2m		**3am**	83
2n		**3an**	91
2o		**3ao**	83
2p		**3ap**	92

[a] Compound **1a** involved a mixture of *Z*/*E*-isomers with the ratio of 6:1, see Ref. 20; reaction conditions: **1a** (1.0 mmol), **2** (2.5 mmol) in EtOH (2 mL) at reflux for 28 h.
[b] Isolated yields.

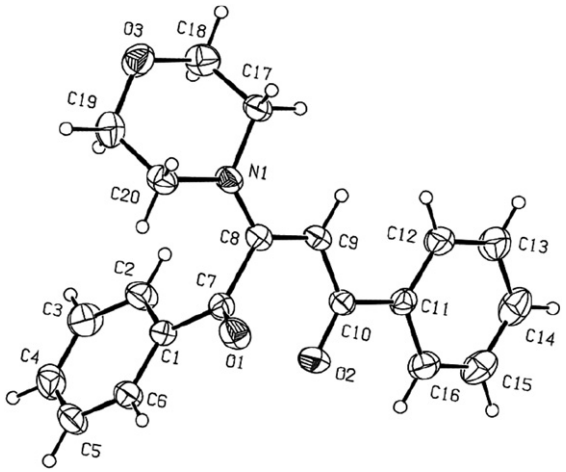
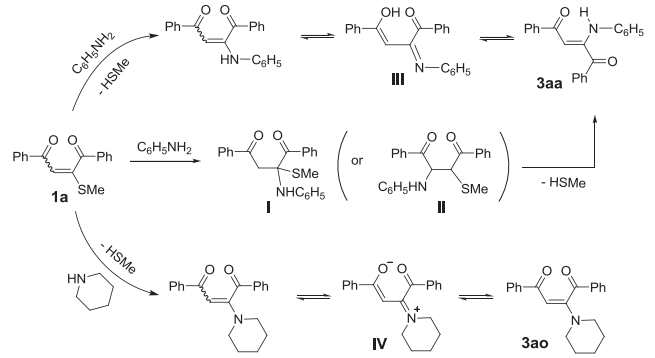
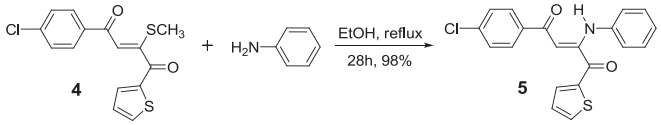


Fig. 3. X-ray crystal structure of compound **3ap**.

Michael addition of aniline (**2a**) to **1a**, and then eliminated the methanethiol (HSMe) to deliver the same *Z*-configuration product **3aa**, which was thermodynamically more stable for the existence of intramolecular six-membered hydrogen-bonding. In order to confirm this addition–elimination process, (*Z*)-4-(4-chlorophenyl)-2-(methylthio)-1-(thiophen-2-yl)but-2-ene-1,4-dione (**4**) was synthesized according to our reported method.[26,27] The treatment of **4** with **2a** under the standard condition only gave the *Z*-configuration product **5** in 98% yield (Scheme 4), which was unambiguously determined by ^{1}H NOESY NMR Spectra (see Supplementary data) and X-ray crystallographic analysis (Fig. 4).[28] Obviously, the amino group was close to the thiophene ring, showing that the Michael addition reaction occurred at the carbon atom attached to the methylthio group. This experimental result indicated that the formation of intermediate **I** was possible. In addition, it has been reported that methylthio group in the aromatic ring could be easily replaced by the amines.[29] Hence we put forward another possible pathway: (ii) firstly, the methylthio group was replaced by the primary or secondary amines, respectively. Then, the corresponding thermodynamically more stable product *Z*-isomer of **3aa** or *E*-isomer of **3ao** was delivered due to the isomerization of the enamine into the tautomeric imine **III**[30] or resonance stabilized zwitterionic intermediate **IV**.[31]



Scheme 3. The plausible mechanism of the present reaction.



Scheme 4. The controlled experiment to prove the mechanism.

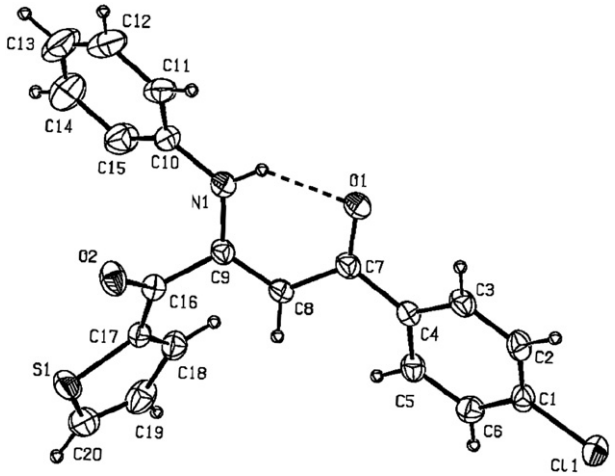


Fig. 4. X-ray crystal structure of compound **5**.

3. Conclusion

In conclusion, we have developed a convenient protocol for substrate-controlled and highly stereoselective synthesis of 1,4-diaryl-2-aminobut-2-ene-1,4-diones from readily available aryl methyl ketones. The high efficiency and wide substrate scope of this new methodology encourages and facilitates further utilization of 2-amino-substituted 1,4-enediones for the construction of more complicated molecules. Further investigations on the applications of this transformation are currently underway in our laboratory.

4. Experimental

4.1. General method

All reagents were purchased from commercial suppliers and used without further purification. All solvents were of analytical grade and dried according to published methods and distilled before use. IR spectra were recorded on an infrared spectrometer as KBr pellets with absorption in cm^{-1}. ^1H spectra were recorded in $CDCl_3$ on 400/600 MHz NMR spectrometers and resonances (δ) are given in parts per million relative to tetramethylsilane. Data are reported as follows: chemical shift, multiplicity (s=singlet, d=doublet, t=triplet, m=multiplet), coupling constants (Hz) and integration. ^{13}C spectra were recorded in $CDCl_3$ or DMSO on 100/150 MHz spectrometers and resonances (δ) are given in ppm. HRMS were obtained on a Bruker 7-T FT-ICR MS and apex-Ultra MS equipped with an electrospray source. MS was carried out on a Finnigan Trace MS spectrometer (EI, 70 eV). Column chromatography was performed on silica gel (200–300 mesh). The X-ray crystal structure determinations of compounds were obtained on a Bruker SMART APEX CCD system.

4.2. Synthesis of 2-(methylthio)-1,4-diaryl-2-butene-1,4-dione (1)

The preparation and characterization of 2-(methylthio)-1,4-diaryl-2-butene-1,4-diones (**1**) have been previously reported.[20]

4.3. Synthesis of (*Z*)-4-(4-chlorophenyl)-2-(methylthio)-1-(thiophen-2-yl)but-2-ene-1,4-dione (4)

The preparation and characterization of (*Z*)-4-(4-chlorophenyl)-2-(methylthio)-1-(thiophen-2-yl)but-2-ene-1,4-dione (**4**) have been previously reported.[20] The crystal structure data see Ref. 25 and Supplementary data.

4.4. General procedure for synthesis of 3 (3aa as an example)

The mixture of (*Z*)-2-(methylthio)-1,4-diphenyl-2-butene-1,4-dione (0.28 g, 1.0 mmol) and aniline (0.23 g, 2.5 mmol) was stirred at reflux in ethanol for 28 h. After the reactant disappeared (monitored by TLC), the mixture was cooled to room temperature, and the collected organic phase was evaporated to dryness and the resulting crude mixture was purified by column chromatography on silica gel (eluent: petroleum ether/EtOAc) to afford the desired product (*Z*)-1,4-diphenyl-2-(phenylamino)but-2-ene-1,4-dione (**3aa**)[6] as a yellow solid (0.31 g, 95%). Mp 114–115 °C; ^1H NMR ($CDCl_3$, 600 MHz): δ (ppm) 12.57 (s, 1H), 7.97 (d, J=7.8 Hz, 2H), 7.93 (d, J=7.2 Hz, 2H), 7.54–7.49 (m, 2H), 7.44 (t, J=7.5 Hz, 2H), 7.40 (t, J=7.8 Hz, 2H), 7.14 (t, J=7.8 Hz, 2H), 6.98 (d, J=8.4 Hz, 3H), 6.12 (s, 1H); ^{13}C NMR ($CDCl_3$, 150 MHz): δ (ppm) 191.9, 190.7, 156.5, 138.7, 138.4, 134.4, 134.2, 131.8, 129.5, 129.2, 129.1, 128.7, 128.6, 128.4, 128.3, 127.2, 124.9, 121.5, 94.8; IR (KBr, cm^{-1}): 3059, 1664, 1578, 1550, 1503, 1446, 1320, 1280, 1238, 1173, 1056, 1023, 979, 914, 801, 758, 696, 552; HRMS (ESI): m/z $[M+H]^+$ calcd for $C_{22}H_{17}NO_2$: 328.1332; found: 328.1327.

Compound **3aa** was also obtained in 95% yield starting from (*E*)-**1a** under the same reaction conditions.

4.5. Characterization data

*4.5.1. (Z)-2-(Phenylamino)-1,4-di-p-tolylbut-2-ene-1,4-dione (**3ba**).*[6] Yield 97%, yellow solid, mp 129–131 °C; ^1H NMR ($CDCl_3$, 400 MHz): δ (ppm) 12.56 (s, 1H), 7.89 (d, J=8.0 Hz, 2H), 7.83 (d, J=8.0 Hz, 2H), 7.25–7.12 (m, 6H), 6.97 (d, J=6.4 Hz, 3H), 6.07 (s, 1H), 2.39 (s, 3H), 2.37 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ (ppm) 191.5, 190.5, 156.5, 145.4, 142.4, 138.6, 136.2, 132.1, 129.7, 129.3, 129.0, 127.3, 124.6, 121.3, 94.7, 21.6, 21.4; IR (KBr, cm^{-1}): 3029, 2917, 1662, 1602, 1570, 1503, 1446, 1407, 1282, 1242, 1170, 1060, 1014, 980, 914, 838, 790, 751, 696, 621, 549; HRMS (ESI): m/z $[M+H]^+$ calcd for $C_{24}H_{21}NO_2$: 356.1645; found: 356.1641.

*4.5.2. (Z)-1,4-Bis(4-methoxyphenyl)-2-(phenylamino)but-2-ene-1,4-dione (**3ca**).*[16] Yield 97%, yellow solid, mp 132–133 °C; ^1H NMR ($CDCl_3$, 400 MHz): δ (ppm) 12.54 (s, 1H), 7.98 (d, J=8.8 Hz, 2H), 7.92 (d, J=8.8 Hz, 2H), 7.15 (t, J=7.8 Hz, 2H), 6.98 (d, J=8.4 Hz, 3H), 6.93

(d, *J*=8.8 Hz, 2H), 6.88 (d, *J*=9.2 Hz, 2H), 6.05 (s, 1H), 3.86 (s, 3H), 3.85 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ (ppm) 190.4, 189.5, 164.3, 162.5, 156.3, 138.7, 132.0, 131.5, 129.2, 129.0, 127.4, 124.4, 121.1, 113.9, 113.5, 94.4, 55.3, 55.1; IR (KBr, cm^{-1}): 2927, 2835, 1657, 1594, 1510, 1456, 1420, 1314, 1247, 1169, 1060, 1030, 912, 847, 793, 758, 696, 626, 554; HRMS (ESI): *m*/*z* $[M+H]^+$ calcd for $C_{24}H_{21}NO_4$: 388.1543; found: 388.1549.

*4.5.3. (Z)-1,4-Bis(4-chlorophenyl)-2-(phenylamino)but-2-ene-1,4-dione (**3da**).*[6] Yield 89%, yellow solid, mp 162–164 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): δ (ppm) 12.51 (s, 1H), 7.88 (q, *J*=8.4 Hz, 4H), 7.41 (d, *J*=8.4 Hz, 2H), 7.35 (d, *J*=8.4 Hz, 2H), 7.16 (t, *J*=7.6 Hz, 2H), 7.01 (t, *J*=7.4 Hz, 1H), 6.96 (d, *J*=8.0 Hz, 2H), 6.06 (s, 1H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ (ppm) 190.9, 189.6, 156.6, 140.9, 138.3, 137.1, 132.8, 130.8, 129.3, 129.1, 128.7, 125.4, 121.8, 94.6; IR (KBr, cm^{-1}): 1667, 1575, 1505, 1398, 1279, 1235, 1170, 1085, 1011, 913, 845, 757, 692, 536; HRMS (ESI): *m*/*z* $[M+H]^+$ calcd for $C_{22}H_{15}C_{l2}NO_2$: 396.0553; found: 396.0560.

*4.5.4. (Z)-1,4-Bis(4-bromophenyl)-2-(phenylamino)but-2-ene-1,4-dione (**3ea**).*[16] Yield 90%; light yellow solid; mp 163–164 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): δ (ppm) 12.49 (s, 1H), 7.80 (d, *J*=8.0 Hz, 4H), 7.59 (d, *J*=7.6 Hz, 2H), 7.54 (d, *J*=7.6 Hz, 2H), 7.17 (t, *J*=7.6 Hz, 2H), 7.03 (t, *J*=7.2 Hz, 1H), 6.96 (d, *J*=8.0 Hz, 2H), 6.04 (s, 1H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ (ppm) 191.1, 189.7, 156.6, 138.3, 137.6, 133.3, 132.2, 131.8, 130.9, 130.0, 129.9, 129.4, 129.0, 127.0, 125.5, 121.9, 94.6; IR (KBr, cm^{-1}): 1671, 1574, 1504, 1395, 1278, 1236, 1172, 1069, 1008, 790, 756, 692; HRMS (ESI): *m*/*z* $[M+H]^+$ calcd for $C_{22}H_{15}Br_2NO_2$: 483.9542; found: 485.9514.

*4.5.5. (Z)-1,4-Bis(4-nitrophenyl)-2-(phenylamino)but-2-ene-1,4-dione (**3fa**).* Yield 91%, yellow solid, mp 224.6–225 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): δ (ppm) 12.52 (s, 1H), 8.32 (d, *J*=8.4 Hz, 2H), 8.20 (d, *J*=8.0 Hz, 2H), 8.10 (d, *J*=8.4 Hz, 2H), 8.03 (d, *J*=8.4 Hz, 2H), 7.18 (t, *J*=7.4 Hz, 2H), 7.05 (t, *J*=7.2 Hz, 1H), 6.98 (d, *J*=8.0 Hz, 2H), 6.18 (s, 1H); ^{13}C NMR (DMSO-d_6, 100 MHz): δ (ppm) 190.9, 185.1, 150.0, 149.2, 143.0, 139.8, 138.4, 130.9, 130.0, 129.9, 129.8, 129.7, 129.5, 129.3, 129.2, 129.0, 128.8, 125.9, 124.3, 124.2, 123.81, 123.76, 123.0, 122.96, 122.92; IR (KBr, cm^{-1}): 1675, 1587, 1558, 1522, 1348, 1281, 1230, 1175, 1109, 1067, 1012, 857, 800, 757, 718; HRMS (ESI): *m*/*z* $[M+H]^+$ calcd for $C_{22}H_{15}N_3O_6$: 418.1034; found: 418.1039.

*4.5.6. (Z)-1,4-Di(naphthalen-1-yl)-2-(phenylamino)but-2-ene-1,4-dione (**3ga**).* Yield 88%, yellow solid, mp 160–162 °C; ^{1}H NMR ($CDCl_3$, 600 MHz): δ (ppm) 12.56 (s, 1H), 8.88 (d, *J*=9.0 Hz, 1H), 8.61 (d, *J*=8.4 Hz, 1H), 8.19 (d, *J*=7.2 Hz, 1H), 7.99 (d, *J*=8.4 Hz, 1H), 7.91 (d, *J*=8.4 Hz, 1H), 7.86 (d, *J*=7.8 Hz, 1H), 7.83 (d, *J*=8.4 Hz, 1H), 7.77 (d, *J*=7.2 Hz, 1H), 7.64 (t, *J*=7.8 Hz, 1H), 7.57 (t, *J*=7.8 Hz, 1H),7.55–7.50 (m, 2H), 7.46 (q, *J*=7.5 Hz, 2H), 7.10–7.06 (m, 4H), 6.89 (t, *J*=6.6 Hz, 1H), 6.06 (s, 1H); ^{13}C NMR ($CDCl_3$, 150 MHz): δ (ppm) 195.1, 193.4, 157.4, 138.6, 138.4, 133.8, 133.7, 132.7, 131.3, 130.8, 130.1, 129.1, 128.8, 127.1, 126.8, 126.6, 126.5, 126.2, 125.8, 125.7, 125.4, 125.0, 124.6, 124.2, 124.1, 121.8, 100.5; IR (KBr, cm^{-1}): 3045, 1658, 1584, 1556, 1502, 1339, 1278, 1249, 1115, 984, 910, 786, 749, 697, 569; HRMS (ESI): *m*/*z* $[M+H]^+$ calcd for $C_{30}H_{21}NO_2$: 428.1645; found: 428.1637.

*4.5.7. (Z)-1,4-Di(naphthalen-2-yl)-2-(phenylamino)but-2-ene-1,4-dione (**3ha**).* Yield 92%, red oil, ^{1}H NMR ($CDCl_3$, 400 MHz): δ (ppm) 12.74 (s, 1H), 8.57 (s, 1H), 8.50 (s, 1H), 8.07–8.04 (m, 2H), 7.93–7.82 (m, 5H), 7.61–7.48 (m, 3H), 7.12 (t, *J*=7.8 Hz, 2H), 7.05 (d, *J*=7.6 Hz, 2H), 6.94 (t, *J*=7.2 Hz, 1H), 6.35 (s, 1H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ (ppm) 191.9, 190.5, 156.7, 138.5, 136.0, 135.8, 134.8, 132.5, 132.0, 131.8, 129.6, 129.3, 129.2, 129.1, 128.7, 128.3, 128.1, 127.7, 127.6, 127.5, 126.8, 126.3, 124.8, 123.9, 123.6, 121.4, 95.2; IR (KBr, cm^{-1}): 3054, 1732, 1667, 1569, 1501, 1465, 1355, 1285, 1238, 1185, 1122, 1047, 950, 911, 862, 755, 692, 554; HRMS (ESI): *m*/*z* $[M+H]^+$ calcd for $C_{30}H_{21}NO_2$: 428.1645; found: 428.1636.

*4.5.8. (Z)-1,4-Di(furan-2-yl)-2-(phenylamino)but-2-ene-1,4-dione (**3ia**).* Yield 96%, red solid, mp 53–55 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): δ (ppm) 12.05 (s, 1H), 7.61 (s, 1H), 7.55 (s, 1H), 7.30–7.16 (m, 4H), 7.04 (t, *J*=7.2 Hz, 1H), 6,98 (d, *J*=8.0 Hz, 2H), 6.51 (d, *J*=7.8 Hz, 2H), 6.13 (s, 1H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ (ppm) 179.7, 178.4, 155.0, 153.3, 150.5, 148.5, 145.5, 138.7, 129.2, 124.8, 122.1, 121.3, 115.0, 112.6, 112.3, 95.7; IR (KBr, cm^{-1}): 3123, 1659, 1575, 1460, 1389, 1272, 1229, 1156, 1070, 1026, 917, 881, 757, 693, 590, 557; HRMS (ESI): *m*/*z* $[M+H]^+$ calcd for $C_{18}H_{13}NO_4$: 308.0917; found: 308.0922.

*4.5.9. (Z)-2-(Phenylamino)-1,4-di(thiophen-2-yl)but-2-ene-1,4-dione (**3ja**).* Yield 98%, tan solid, mp 127–128 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): δ (ppm) 12.12 (s, 1H), 7.81 (d, *J*=3.6 Hz, 1H), 7.71 (d, *J*=4.8 Hz, 1H), 7.66 (d, *J*=3.6 Hz, 1H), 7.59 (d, *J*=5.2 Hz, 1H), 7.20 (t, *J*=7.6 Hz, 2H), 7.12 (t, *J*=8.0 Hz, 1H), 7.08 (t, *J*=4.2 Hz, 1H), 7.04–6.99 (m, 3H), 6.08 (s, 1H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ (ppm) 183.6, 183.5, 155.3, 145.7, 141.4, 138.6, 136.3, 135.6, 132.3, 129.6, 129.2, 129.0, 128.4, 128.0, 124.8, 121.1, 118.1, 114.8, 95.6; IR (KBr, cm^{-1}): 3092, 1646, 1581, 1506, 1410, 1349, 1295, 1249, 1059, 1005, 854, 792, 738, 692, 538; HRMS (ESI): *m*/*z* $[M+H]^+$ calcd for $C_{18}H_{13}NO_2S_2$: 340.0460; found: 340.0457.

*4.5.10. (Z)-2-((4-Chlorophenyl)amino)-1,4-diphenylbut-2-ene-1,4-dione (**3ab**).*[6] Yield 81%, yellow solid, mp 153–155 °C; ^{1}H NMR ($CDCl_3$, 600 MHz): δ (ppm) 12.51 (s, 1H), 7.97 (d, *J*=7.2 Hz, 2H), 7.93 (d, *J*=7.2 Hz, 2H), 7.58 (t, *J*=7.2 Hz, 1H), 7.52 (t, *J*=7.5 Hz, 1H), 7.44 (q, *J*=7.8 Hz, 4H), 7.12 (d, *J*=9.0 Hz, 2H), 6.91 (d, *J*=9.0 Hz, 2H), 6.14 (s, 1H); ^{13}C NMR ($CDCl_3$, 150 MHz): δ (ppm) 191.8, 191.0, 156.1, 138.6, 137.3, 134.5, 134.4, 132.1, 130.3, 129.6, 129.3, 128.8, 128.4, 127.3, 122.8, 95.51, 95.48; IR (KBr, cm^{-1}): 3060, 1668, 1598, 1581, 1556, 1501, 1447, 1320, 1282, 1238, 1171, 1080, 1060, 1024, 1008, 980, 909, 852, 819, 763, 725, 703, 686, 653, 557, 540, 496; HRMS (ESI): *m*/*z* $[M+H]^+$ calcd for $C_{22}H_{16}ClNO_2$: 362.0942; found: 362.0937.

*4.5.11. (Z)-2-((4-Hydroxyphenyl)amino)-1,4-diphenylbut-2-ene-1,4-dione (**3ac**).* Yield 96%, red solid, mp 177–179 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): δ (ppm) 12.38 (s, 1H), 7.94–7.89 (m, 4H), 7.57–7.48 (m, 2H), 7.45–7.38 (m, 4H), 6.80 (d, *J*=8.4 Hz, 2H), 6.62 (d, *J*=8.8 Hz, 2H), 6.41(s, 1H), 6.05(s, 1H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ (ppm) 192.5, 191.0, 158.0, 153.9, 138.8, 134.5, 134.4, 131.9, 131.1, 129.7, 128.8, 128.5, 127.3, 124.2, 116.2, 93.8; IR (KBr, cm^{-1}): 3458, 3436, 2974, 2927, 2372, 1666, 1598, 1571, 1513, 1446, 1405, 1386, 1323, 1302, 1278, 1236, 1167, 1065, 984, 913, 759, 711, 554; MS (EI): *m*/*z* 343.17.

*4.5.12. (Z)-2-((4-Aminophenyl)amino)-1,4-diphenylbut-2-ene-1,4-dione (**3ad**).* Yield 90%, red solid, mp 148–150 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): δ (ppm) 12.47(s, 1H), 7.94–7.91 (m, 4H), 7.51–7.46 (m, 2H), 7.44–7.36 (m, 4H), 6.78 (d, *J*=8.4 Hz, 2H), 6.42 (d, *J*=8.4 Hz, 2H), 6.02 (s, 1H), 3.59 (br s, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ (ppm) 192.5, 191.3, 157.8, 153.9, 144.3, 139.0, 134.5, 134.2, 131.6, 129.5, 128.6, 128.3, 127.2, 123.9, 115.4, 93.1; IR (KBr, cm^{-1}): 3466, 3439, 3366, 3346, 3057, 1672, 1593, 1571, 1517, 1447, 1385, 1323, 1279, 1237, 1173, 1061, 1025, 984, 911, 825, 760, 713, 690, 551, 506; MS (EI): *m*/*z* 342.22.

*4.5.13. (Z)-Ethyl 4-((1,4-dioxo-1,4-diphenylbut-2-en-2-yl)amino) benzoate (**3ae**).* Yield 45%, yellow oil, ^{1}H NMR ($CDCl_3$, 400 MHz): δ (ppm) 12.63(s, 1H), 8.01(d, *J*=7.6 Hz, 2H), 7.94 (d, *J*=7.6 Hz, 2H), 7.84 (d, *J*=8.0 Hz, 2H), 7.59–7.51 (m, 3H), 7.47–7.42 (m, 3H), 6.99 (d, *J*=8.4 Hz, 2H), 6.21(s, 1H), 4.29 (d, *J*=6.8 Hz, 2H), 1.32 (t, *J*=7.0 Hz, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ (ppm) 191.8, 191.3, 165.7, 155.1, 142.6, 138.5, 134.9, 134.8, 134.6, 134.3, 132.3, 131.2, 130.9, 129.7,

128.9, 128.5, 127.7, 127.5, 126.1, 120.1, 96.8, 60.8, 14.2; IR (KBr, cm^{-1}): 3423, 3110, 3061, 2979, 1713, 1675, 1594, 1517, 1448, 1366, 1318, 1276, 1233, 1176, 1106, 1055, 1020, 977, 914, 854, 766, 723, 694, 639, 570; MS (EI): *m/z* 399.21.

*4.5.14. (Z)-2-(Naphthalene-2-ylamino)-1,4-diphenylbut-2-ene-1,4-dione (**3af**).* Yield 95%, orange solid, mp 131–132 °C; ^1H NMR ($CDCl_3$, 400 MHz): δ (ppm) 12.75 (s, 1H), 8.00–7.95 (m, 4H), 7.66–7.58 (m, 4H), 7.52–7.42 (m, 4H), 7.38–7.30 (m, 4H), 7.14 (d, *J*=8.8 Hz, 1H), 6.18 (s, 1H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ (ppm) 192.3, 190.9, 156.6, 138.8, 136.1, 134.5, 134.3, 133.4, 131.9, 130.7, 129.5, 129.3, 128.7, 128.4, 127.5, 127.3, 127.2, 126.6, 125.3, 121.0, 118.5, 95.3; IR (KBr, cm^{-1}): 3053, 1667, 1599, 1577, 1557, 1513, 1448, 1321, 1282, 1238, 1213, 1176, 1122, 1061, 1024, 964, 857, 807, 757, 726, 702; HRMS (ESI): *m/z* $[M+H]^+$ calcd for $C_{26}H_{19}NO_2$: 378.1489; found: 378.1482.

*4.5.15. (Z)-1,4-Diphenyl-2-(pyridin-3-ylamino)but-2-ene-1,4-dione (**3ag**).* Yield 92%, yellow solid, mp 120–121 °C; ^1H NMR ($CDCl_3$, 600 MHz): δ (ppm) 12.50 (s, 1H), 8.34 (br s, 1H), 8.24 (d, *J*=4.2 Hz, 1H), 7.99 (d, *J*=7.8 Hz, 2H), 7.94 (d, *J*=7.8 Hz, 2H), 7.59 (t, *J*=7.2 Hz, 1H), 7.53 (t, *J*=7.5 Hz, 1H), 7.45 (q, *J*=6.6 Hz, 4H), 7.27 (d, *J*=6.6 Hz, 1H), 7.09 (q, *J*=4.2 Hz, 1H), 6.22 (s, 1H); ^{13}C NMR ($CDCl_3$, 150 MHz): δ (ppm) 191.3, 191.2, 155.7, 145.6, 143.0, 138.3, 135.3, 134.6, 134.3, 132.2, 129.6, 128.8, 128.4, 128.3, 127.3, 123.4, 96.42, 96.37; IR (KBr, cm^{-1}): 3055, 1671, 1593, 1572, 1482, 1447, 1321, 1277, 1234, 1180, 1057, 1021, 979, 907, 803, 765, 722, 703, 613; HRMS (ESI): *m/z* $[M+H]^+$ calcd for $C_{21}H_{16}N_2O_2$: 329.1285; found: 329.1279.

*4.5.16. (Z)-2-(Ethylamino)-1,4-diphenylbut-2-ene-1,4-dione (**3ah**).* Yield 95%, orange solid, mp 120–122 °C; ^1H NMR ($CDCl_3$, 400 MHz): δ (ppm) 10.81 (s, 1H), 8.06 (d, *J*=8.4 Hz, 2H), 7.85 (d, *J*=8.0 Hz, 2H), 7.67 (t, *J*=7.6 Hz, 1H), 7.53 (t, *J*=7.6 Hz, 2H), 7.47–7.37 (m, 3H), 5.73 (s, 1H), 3.22 (q, *J*=6.8 Hz, 2H), 1.23 (t, *J*=7.2 Hz, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ (ppm) 191.6, 189.7, 160.9, 139.3, 134.8, 134.3, 131.4, 131.2, 130.0, 129.2, 129.0, 128.6, 128.3, 128.2, 127.0, 89.9, 40.0, 15.99, 15.92; IR (KBr, cm^{-1}): 3240, 3055, 2976, 1678, 1581, 1485, 1423, 1332, 1286, 1219, 1148, 1059, 970, 918, 857, 792, 714, 580; HRMS (ESI): *m/z* $[M+H]^+$ calcd for $C_{18}H_{17}NO_2$: 280.1332; found: 280.1325.

*4.5.17. (Z)-2-(Isopropylamino)-1,4-diphenylbut-2-ene-1,4-dione (**3ai**).* Yield 90%, light yellow solid, mp 102–104 °C; ^1H NMR ($CDCl_3$, 400 MHz): δ (ppm) 10.83 (s, 1H), 8.07 (d, *J*=7.6 Hz, 2H), 7.84 (d, *J*=7.2 Hz, 2H), 7.68 (t, *J*=7.4 Hz, 1H), 7.54 (t, *J*=7.8 Hz, 2H), 7.45–7.37 (m, 3H), 5.69 (s, 1H), 3.56–3.51 (m, 1H), 1.25 (d, *J*=6.4 Hz, 6H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ (ppm) 191.5, 189.4, 160.0, 139.2, 134.7, 134.3, 131.1, 129.9, 128.8, 128.1, 126.9, 126.8, 89.5, 47.1, 24.0; IR (KBr, cm^{-1}): 3062, 2976, 2931, 1676, 1578, 1550, 1447, 1325, 1297, 1238, 1207, 1158, 1066, 1024, 939, 763, 724, 694, 581; HRMS (ESI): *m/z* $[M+H]^+$ calcd for $C_{19}H_{19}NO_2$: 294.1489; found: 294.1485.

*4.5.18. (Z)-2-(Butylamino)-1,4-diphenylbut-2-ene-1,4-dione (**3aj**).* Yield 92%, yellow solid, mp 45–47 °C; ^1H NMR ($CDCl_3$, 600 MHz): δ (ppm) 10.89 (s, 1H), 8.06 (d, *J*=7.2 Hz, 2H), 7.85 (d, *J*=7.8 Hz, 2H), 7.67 (t, *J*=7.2 Hz, 1H), 7.53 (t, *J*=7.5 Hz, 2H), 7.45 (t, *J*=7.2 Hz, 1H), 7.39 (t, *J*=7.5 Hz, 2H), 5.74 (s, 1H), 3.17 (q, *J*=6.6 Hz, 2H), 1.59–1.55(m, 2H), 1.37 (q, *J*=7.5 Hz, 2H), 0.87 (t, *J*=7.2 Hz, 3H); ^{13}C NMR ($CDCl_3$, 150 MHz): δ (ppm) 191.6, 189.7, 161.1, 139.3, 134.7, 134.3, 131.2, 130.0, 129.0, 128.4, 128.2, 127.0, 89.9, 44.8, 32.4, 19.6, 13.5; IR (KBr, cm^{-1}): 2956, 2869, 1677, 1582, 1451, 1325, 1293, 1236, 1177, 1058, 932, 717, 689, 578; HRMS (ESI): *m/z* $[M+H]^+$ calcd for $C_{20}H_{21}NO_2$: 308.1645; found: 308.1641.

*4.5.19. (Z)-2-(Cyclohexylamino)-1,4-diphenylbut-2-ene-1,4-dione (**3ak**).* Yield 90%, light yellow solid; mp 104–106 °C; ^1H NMR ($CDCl_3$, 400 MHz): δ (ppm) 11.01 (s, 1H), 8.07 (d, *J*=7.6 Hz, 2H), 7.84 (d, *J*=7.6 Hz, 2H), 7.67 (t, *J*=7.2 Hz, 1H), 7.53 (t, *J*=7.6 Hz, 2H), 7.44–7.36 (m, 3H), 5.69 (s, 1H), 3.21–3.19 (br s, 1H), 1.88–1.85 (m, 2H), 1.72–1.70 (m, 2H), 1.51(s, 1H), 1.41–1.37 (m, 2H), 1.26–1.20 (m, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ (ppm) 191.7, 189.5, 160.1, 139.4, 134.7, 134.5, 131.1, 130.0, 128.9, 128.2, 127.0, 89.8, 53.7, 34.1, 25.0, 24.2; IR (KBr, cm^{-1}): 3061, 2928, 2851, 1679, 1576, 1447, 1328, 1294, 1237, 1148, 1055, 1024, 954, 775, 733, 597; HRMS (ESI): *m/z* $[M+H]^+$ calcd for $C_{22}H_{23}NO_2$: 334.1802; found: 334.1787.

*4.5.20. (Z)-2-(Benzylamino)-1,4-diphenylbut-2-ene-1,4-dione (**3al**).* Yield 89%, light yellow solid, mp 91–93 °C; ^1H NMR ($CDCl_3$, 600 MHz): δ (ppm) 11.12 (s, 1H), 8.02 (d, *J*=7.6 Hz, 2H), 7.85 (d, *J*=7.6 Hz, 2H), 7.64 (t, *J*=7.2 Hz, 1H), 7.50–7.43 (m, 3H), 7.38 (t, *J*=7.4 Hz, 2H), 7.30–7.21 (m, 4H), 5.82 (s, 1H), 4.39 (d, *J*=6.4 Hz, 2H); ^{13}C NMR ($CDCl_3$, 150 MHz): δ (ppm) 191.5, 189.9, 160.3, 139.1, 137.1, 134.6, 134.3, 131.3, 130.0, 128.8, 128.6, 128.2, 127.7, 127.5, 127.1, 127.0, 91.1, 48.7; IR (KBr, cm^{-1}): 3061, 2939, 1671, 1580, 1450, 1324, 1297, 1240, 1176, 1054, 1024, 996, 924, 773, 736, 574; HRMS (ESI): *m/z* $[M+H]^+$ calcd for $C_{23}H_{19}NO_2$: 342.1489; found: 342.1482.

*4.5.21. (E)-2-(Diethylamino)-1,4-diphenylbut-2-ene-1,4-dione (**3am**).* Yield 83%, light yellow solid, mp 159–162 °C; ^1H NMR ($CDCl_3$, 400 MHz): δ (ppm) 8.01 (d, *J*=7.2 Hz, 2H), 7.84 (d, *J*=6.8 Hz, 2H), 7.53 (t, *J*=7.4 Hz, 1H), 7.47–7.33 (m, 5H), 6.00 (s, 1H), 3.46 (br s, 2H), 3.14 (br s, 2H), 1.39 (br s, 3H), 1.08 (br s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ (ppm) 193.6, 186.3, 160.4, 139.3, 135.8, 133.2, 131.1, 128.8, 128.0, 127.9, 127.7, 127.6, 91.4, 46.2, 44.3, 14.3, 11.3, 11.2; IR (KBr, cm^{-1}): 3060, 2977, 1672, 1605, 1573, 1512, 1463, 1388, 1354, 1224, 1151, 1067, 1006, 965, 895, 779, 708, 596; HRMS (ESI): *m/z* $[M+H]^+$ calcd for $C_{20}H_{21}NO_2$: 308.1645; found: 308.1639.

*4.5.22. (E)-1,4-Diphenyl-2-(pyrrolidin-1-yl)but-2-ene-1,4-dione (**3an**).* Yield 91%, light yellow solid, mp 171–172 °C; ^1H NMR ($CDCl_3$, 400 MHz): δ (ppm) 8.02 (d, *J*=7.6 Hz, 2H), 7.87 (d, *J*=7.6 Hz, 2H), 7.54 (t, *J*=7.4 Hz 1H), 7.47–7.40 (m, 3H), 7.35 (t, *J*=7.4 Hz 2H), 5.92 (s, 1H), 3.52–3.42 (m, 3H), 3.09–3.06 (br s, 1H), 2.02 (t, *J*=6.6 Hz, 2H), 1.92–1.79 (m, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ (ppm) 193.6, 186.1, 159.2, 138.9, 134.9, 133.1, 131.0, 128.7, 128.0, 127.9, 127.4, 92.7, 48.7, 48.2, 25.4, 24.3; IR (KBr, cm^{-1}): 2965, 2870, 1678, 1613, 1574, 1515, 1450, 1395, 1340, 1220, 1176, 1058, 995, 915, 760, 717, 623, 552; HRMS (ESI): *m/z* $[M+H]^+$ calcd for $C_{20}H_{19}NO_2$: 306.1489; found: 306.1487.

*4.5.23. (E)-1,4-Diphenyl-2-(piperidin-1-yl)but-2-ene-1,4-dione (**3ao**).*[31] Yield 83%, light yellow solid, mp 169–171 °C; ^1H NMR ($CDCl_3$, 400 MHz): δ (ppm) 8.04 (d, *J*=8.0 Hz, 2H), 7.85 (d, *J*=8.0 Hz, 2H), 7.55 (t, *J*=7.0 Hz, 1H), 7.48–7.41 (m, 3H), 7.36 (t, *J*=7.4 Hz, 2H), 6.11 (s, 1H), 3.38 (br s, 4H), 1.66 (br s, 6H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ (ppm) 193.9, 186.5, 160.8, 139.0, 135.6, 133.0, 131.0, 128.6, 127.8, 127.7, 127.4, 91.6, 23.6; IR (KBr, cm^{-1}): 3059, 2938, 2856, 1668, 1616, 1575, 1518, 1450, 1362, 1284, 1220, 1131, 1061, 1026, 968, 905, 852, 766, 730, 696, 606; HRMS (ESI): *m/z* $[M+H]^+$ calcd for $C_{21}H_{21}NO_2$: 320.1645; found: 320.1640.

*4.5.24. (E)-2-Morpholino-1,4-diphenylbut-2-ene-1,4-dione (**3ap**).*[8] Yield 98%, light yellow solid, mp 171–172 °C; ^1H NMR ($CDCl_3$, 400 MHz): δ (ppm) 8.03 (d, *J*=8.0 Hz, 2H), 7.84 (d, *J*=7.6 Hz, 2H), 7.57 (t, *J*=7.0 Hz, 1H), 7.50–7.43 (m, 3H), 7.37 (t, *J*=7.4 Hz, 2H), 6.15 (s, 1H), 3.74 (s, 4H), 3.42 (s, 2H), 3.32 (s, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ (ppm) 193.5, 186.6, 160.5, 138.4, 135.3, 133.1, 131.2, 128.6, 127.8, 127.6, 127.3, 92.9, 65.7, 47.2; IR (KBr, cm^{-1}): 2968, 2918, 2858, 1668, 1614, 1574, 1519, 1448, 1357, 1271, 1221, 1115, 1065, 973,

908, 764, 696, 618, 583; HRMS (ESI): m/z $[M+H]^+$ calcd for $C_{20}H_{19}NO_3$: 322.1438; found: 322.1439.

*4.5.25. (Z)-4-(4-Chlorophenyl)-2-(phenylamino)-1-(thiophen-2-yl) but-2-ene-1,4-dione (**5**).* Yield 98%, yellow solid, mp 136–138 °C; ^{1}H NMR ($CDCl_3$, 600 MHz): δ (ppm) 12.44 (s, 1H), 7.87 (d, J=8.4 Hz, 2H), 7.80 (d, J=3.6 Hz, 1H), 7.69 (d, J=4.8 Hz, 1H), 7.22 (d, J=8.4 Hz, 2H), 7.19 (t, J=7.8 Hz, 2H), 7.07–7.01 (m, 4H), 6.15 (s, 1H); ^{13}C NMR ($CDCl_3$, 150 MHz): δ (ppm) 189.5, 183.6, 156.3, 141.5, 138.5, 138.2, 137.1, 136.4, 135.7, 129.3, 128.72, 128.67, 128.5, 125.1, 121.5, 94.94, 94.92; IR (KBr, cm^{-1}): 3090, 2922, 1641, 1590, 1571, 1553, 1504, 1447, 1411, 1353, 1308, 1286, 1243, 1178, 1089, 1060, 1012, 910, 885, 851, 790, 754, 724, 698, 655, 545; HRMS (ESI): m/z $[M+H]^+$ calcd for $C_{20}H_{14}ClNO_2S$: 368.0507; found: 368.0501.

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Supplementary data

^{1}H NMR, ^{13}C NMR and HRMS spectra for all new compounds, ^{1}H NOESY NMR spectra of compound **5**, X-ray crystal structures of compounds **3am**, **3ao** and **4**. Supplementary data associated with this article can be found in the online version, at doi:10.1016/j.tet.2012.03.049. These data include MOL files and InChIKeys of the most important compounds described in this article.

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21. Crystal structure data for compound **3aa**: CCDC number 854744, $C_{22}H_{17}NO_2$, monoclinic, space group $P2(1)/n$, a=5.8740(6), b=13.4335(13), c=21.203(2) Å, α=90°, β=94.1700(10)°, γ=90°, V=1668.6(3) Å^3, T=100(2) K, Z=4, D_C=1.410 mg/m^3, μ=0.083 mm^{-1}, λ=0.71073 Å, F(000) 688, crystal size 0.20×0.10×0.10 mm^3, 4851 independent reflections [R(int)=0.0993], reflections collected 17035, refinement method: full-matrix least-squares on F^2: goodness-of-fit on F^2 1.086, final R indices [$I>2\sigma(I)$], R_1=0.0464, wR_2=0.1268, largest diff. peak and hole 0.464 and −0.285 e Å^{-3}.
22. Crystal structure data for compound **3al**: CCDC number 854743, $C_{23}H_{19}NO_2$, Orthorhombic, space group $P2(1)2(1)2(1)$, a=5.9779(11), b=8.2434(16), c=37.358(7) Å, α=90°, β=90°, γ=90°, V=1840.9(6) Å^3, T=296(2) K, Z=4, D_C=1.232 mg/m^3, μ=0.078 mm^{-1}, λ=0.71073 Å, F(000) 720, crystal size 0.16×0.12×0.10 mm^3, 5304 independent reflections [R(int)=0.0211], reflections collected 10367, refinement method: full-matrix least-squares on F^2: goodness-of-fit on F^2 1.035, final R indices [$I>2\sigma(I)$], R_1=0.0510, wR_2=0.1339, largest diff. peak and hole 0.182 and −0.180 e Å^{-3}.
23. Crystal structure data for compound **3am**: CCDC number 854742, $C_{20}H_{21}NO_2$, orthorhombic, space group $Pna2(1)$, a=11.3970(15), b=16.715(2), c=9.1167(12) Å, α=90°, β=90°, γ=90°, V=1736.8(4) Å^3, T=296(2) K, Z=4, D_C=1.176 mg/m^3, μ=0.075 mm^{-1}, λ=0.71073 Å, F(000) 656, crystal size 0.16×0.12×0.10 mm^3, 2863 independent reflections [R(int)=0.0246], reflections collected 10875, refinement method: full-matrix least-squares on F^2: goodness-of-fit on F^2 1.064, final R indices [$I>2\sigma(I)$], R_1=0.0312, wR_2=0.0861, largest diff. peak and hole 0.155 and −0.091 e Å^{-3}.
24. Crystal structure data for compound **3ao**: CCDC number 852470, $C_{21}H_{21}NO_2$, triclinic, space group $P-1$, a=6.707(2), b=10.031(4), c=13.162(5) Å, α=89.847(6)°, β=77.706(6)°, γ=87.938(6)°, V=864.7(5) Å^3, T=298(2) K, Z=2, D_C=1.227 mg/m^3, μ=0.078 mm^{-1}, λ=0.71073 Å, F(000) 340, crystal size 0.20×0.10×0.10 mm^3, 3175 independent reflections [R(int)=0.0245], reflections collected 5319, refinement method: full-matrix least-squares on F^2: goodness-of-fit on F^2 1.013, final R indices [$I>2\sigma(I)$], R_1=0.0569, wR_2=0.1270, largest diff. peak and hole 0.170 and −0.157 e Å^{-3}.
25. Crystal structure data for compound **3ap**: CCDC number 850000, $C_{20}H_{19}NO_3$, triclinic, space group $P-1$, a=6.6038(8), b=10.0280(11), c=12.7507(15) Å, α=85.679(2)°, β=79.496°, γ=88.506(2)°, V=827.81(17) Å^3, T=298(2) K, Z=2, D_C=1.289 mg/m^3, μ=0.087 mm^{-1}, λ=0.71073 Å, F(000) 340, crystal size 0.16×0.12×0.10 mm^3, 3236 independent reflections [R(int)=0.0387], reflections collected 8669, refinement method: full-matrix least-squares on F^2: goodness-of-fit on F^2 1.037, final R indices [$I>2\sigma(I)$], R_1=0.0594, wR_2=0.1178, largest diff. peak and hole 0.134 and −0.159 e Å^{-3}.
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27. Crystal structure data for compound **4**: CCDC number 850001, $C_{15}H_{11}ClO_2S_2$, triclinic, space group $P-1$, a=7.8406(13), b=11.8382(13), c=17.047(2) Å, α=75.778(2)°, β=87.508(2)°, γ=81.0000(10)°, V=1514.8(4) Å^3, T=298(2) K, Z=4, D_C=1.415 mg/m^3, μ=0.525 mm^{-1}, λ=0.71073 Å, F(000) 664, crystal size 0.16×0.12×0.10 mm^3, 5270 independent reflections [R(int)=0.0173], reflections collected 8005, refinement method: full-matrix least-squares on F^2: goodness-of-fit on F^2 1.129, final R indices [$I>2\sigma(I)$], R_1=0.0687, wR_2=0.1481, largest diff. peak and hole 0.238 and −0.256 e Å^{-3}.
28. Crystal data for compound **5**: CCDC number 850002, $C_{20}H_{14}ClNO_2S$, monoclinic, space group $P2(1)/c$, a=14.788(3), b=6.3291(13), c=19.418(4) Å; α=90°, β=101.59(3)°, γ=90°, V=1780.4(6) Å^3, T=293(2) K, Z=4, D_C=1.372 mg/m^3, μ=0.344 mm^{-1}, λ=0.71073 Å, F(000) 760, crystal size 0.16×0.12×0.10 mm^3, 2262 independent reflections [R(int)=0.0360], reflections collected 7966, refinement method: full-matrix least-squares on F^2: goodness-of-fit on F^2 1.059, final R indices [$I>2\sigma(I)$], R_1=0.0414, wR_2=0.1240, largest diff. peak and hole 0.218 and −0.292 e Å^{-3}.
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