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Synthesis of Tetrasubstituted Unsymmetrical 1,4-Enediones via Copper-Promoted Autotandem Catalysis and Air As the Oxidant

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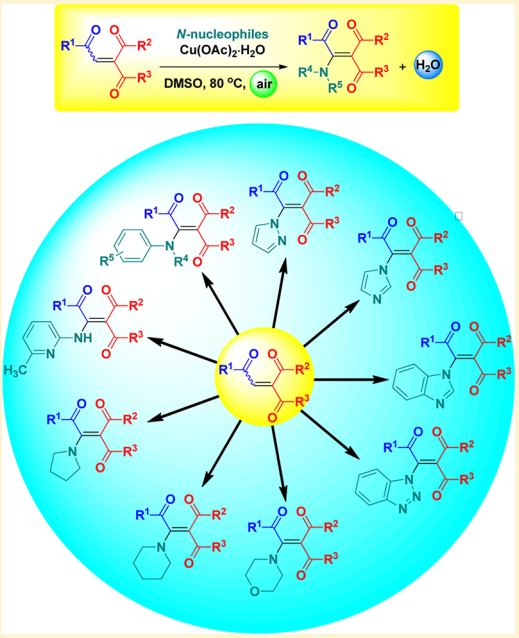
Supporting Information

ABSTRACT: An efficient procedure has been developed for the preparation of tetrasubstituted unsymmetrical 1,4-enediones via copper-promoted autotandem catalysis and air as the oxidant. Various *N*-nucleophiles are compatible with this reaction, such as morpholine, piperidine, pyrrolidine, arylamines, pyrazole, imidazole, benzimidazole, and benzotriazole. This reaction also has significant advantages in easily available substrates, atom economy, bond-forming efficiency, and environmental benignity.



INTRODUCTION

The 1,4-enedione scaffold not only exists in many natural products and pharmaceutical compounds (Figure 1)[1] but also is well-known as a versatile building block for the synthesis of various heterocyles such as furans, pyrroles, thiophenes, pyrazines, hydantoins, isoxazoles, and indolizines.[2] Thus, the development of efficient synthetic methods for 1,4-enediones has attracted much attention of chemists. To date, several methods have been established for their synthesis, such as oxidation of furans[3] or α,β-enones,[4] oxidative coupling reactions,[5] oxidative rearrangement of 2-alkynyl alcohols,[6] nucleophilic addition to dibenzoylacetylenes,[7] Stille coupling,[8] Wittig reaction,[9] and other synthetic methods.[10] However, as far as we know, there was no general method in the literature has been reported for the synthesis of tetrasubstituted unsymmetrical 1,4-enediones, which have potentially broad applications in pharmaceutical industry.

A significant goal of sustainable chemistry is maximizing reaction efficiency and minimizing chemical wastes.[11] One of the important strategies to achieve this goal is an "auto-tandem catalysis" strategy, which involves two or more mechanistically different transformations promoted by a single catalyst.[12] It is noteworthy that this strategy could greatly improve the catalyst utilization efficiency and bring about significant benefits in environmental and economic terms. Another important strategy for sustainable chemistry is utilizing the "green" natural resources as reagents. For example, air as a "green" natural oxidant has extraordinary advantages in great abundance and environmentally benign. Thus, using air as the oxidant has emerged as a hot topic in synthetic chemistry.[13]

Inspired by the excellent sustainable synthetic methods based on autotandem strategy or air as the oxidant, we wish to develop a "green" synthetic method which could efficiently combine their advantages. Recently, we have developed an efficient method for the synthesis of 4*H*-pyrido[1,2-*a*]-pyrimidin-4-ones via autotandem strategy.[14] In this reaction, tetrasubstituted 1,4-enediones were proved to be the key reaction intermediates. Considering it is highly desirable to develop an efficient and green synthetic method for preparation of tetrasubstituted unsymmetrical 1,4-enediones, we would like to report herein a general method for their efficient synthesis via autotandem strategy and air as the oxidant (Scheme 1).

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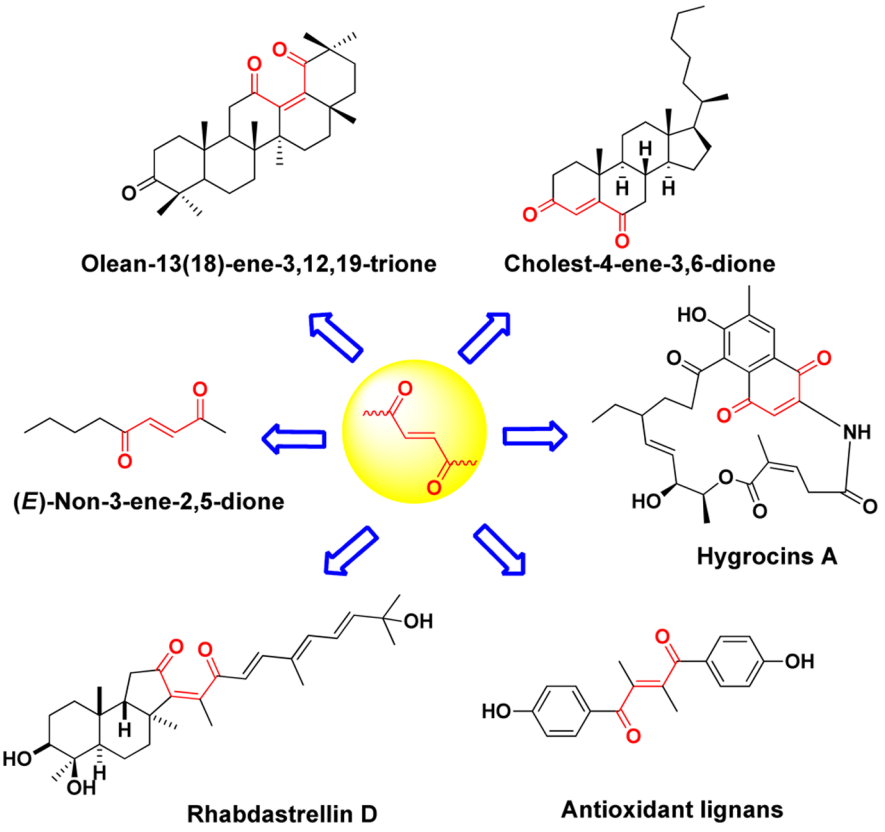
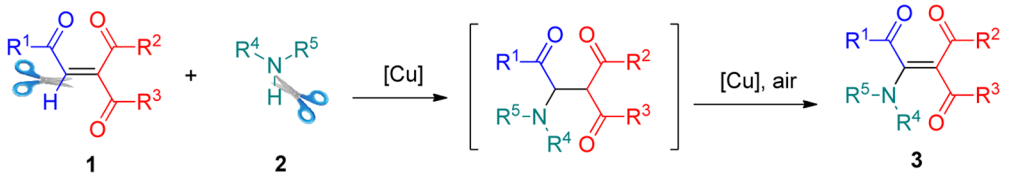


Figure 1. Natural products and pharmaceutical compounds containing 1,4-enedione motifs.

Scheme 1. Proposed Reaction Route



Cu promoted auto-tandem catalysis: **aza-Michael addition and aerobic oxidative dehydrogenation**

RESULTS AND DISCUSSION

We began the optimization process by using 1,4-enedione **1a** and pyrazole **2a** as model substrates. To our delight, the desired product **3aa** was obtained in 79% yield when the reaction was conducted in DMF with 0.05 equiv of $Cu(OAc)_2·H_2O$ as catalyst under air at 80 °C (Table 1, entry 1). Further increasing the catalyst loading to 0.1 equiv, the yield was improved to 84% (entry 2). We then screened different solvents, and found that DMSO showed the best result and the yield increased to 91% (entries 3−8). When the reaction was carried out at lower or higher temperature (60 or 100 °C), decreased yields were obtained (entries 9 and 10). We also screened various copper catalysts, but no better results were obtained (entries 11−18).

With this optimized result in hand, the generality of this reaction was then explored. On the basis of our previously reported cross-coupling reaction of 1,3-dicarbonyl compounds and methyl ketones, a series of trisubstituted 1,4-enediones **1** were prepared.[5a] As shown in Table 2, the scope of 1,4-enediones **1** was first examined with pyrazole **2a** under the optimized reaction conditions. As to R^1 substituents, substrates with electron-neutral (−H, −Me) and electron-donating (−OMe) substituents all reacted efficiently to afford the desired products in excellent yields (Table 2, entries 1−3; 89−91%). However, a lower yield was obtained with strong electron-withdrawing ($-NO_2$) R^1 substituent (entry 4; 62%). To our satisfaction, good yields were obtained with sterically hindered (1-naphthyl, 2-naphthyl), halogenated (−Cl, −Br, −F) and heteroaryl R^1 substituents (entries 5−11; 82−88%). As to R^2 or R^3 substituents, the reaction proceeded well with good to excellent yields for alkyloxy groups (OMe, OEt), electron-neutral (−H), electron-donating (−OMe), electron-withdrawing ($-NO_2$), and halogenated (−F, −Cl) aryl substituents (entries 12−16, 89%−93%). To our delight, the structures of **3ka** and (*E*)-**3pa** were further clearly confirmed by X-ray diffraction (Figure 2).[15]

To further investigate the reactivity and stability of 1,4-enediones **1** toward *N*-nucleophiles with strong basicity, we chose morpholine **2b** as a model substrate, which is a much stronger base than pyrazole **2a**. For R^1 substituents, electron-neutral (−H, −Me) and sterically hindered (1-naphthyl, 2-naphthyl) substituents could smoothly afford the desired products in good yields (Table 3, entries 1−4; 72−88%). Fortunately, the structure of **3bb** was further confirmed by X-

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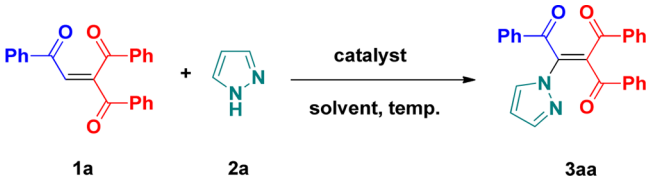
Table 1. Optimization of the Reaction Condition[a]

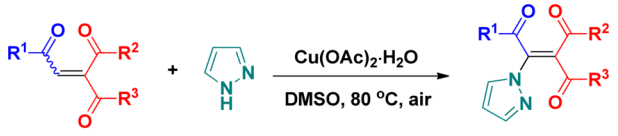


1a 2a 3aa

entry	catalyst (equiv)	solvent	temp (°C)	yield[b] (%)
1	$Cu(OAc)_2·H_2O$ (0.05)	DMF	80	79
2	$Cu(OAc)_2·H_2O$ (0.1)	DMF	80	84
3	**$Cu(OAc)_2·H_2O$ (0.1)**	**DMSO**	**80**	**91**
4	$Cu(OAc)_2·H_2O$ (0.1)	CH_3CN	80	83
5	$Cu(OAc)_2·H_2O$ (0.1)	C_2H_5OH	78	47
6	$Cu(OAc)_2·H_2O$ (0.1)	CH_3NO_2	80	72
7	$Cu(OAc)_2·H_2O$ (0.1)	AcOH	80	36
8	$Cu(OAc)_2·H_2O$ (0.1)	1,4-dioxane	80	82
9	$Cu(OAc)_2·H_2O$ (0.1)	DMSO	60	79
10	$Cu(OAc)_2·H_2O$ (0.1)	DMSO	100	85
11	$CuBr_2$ (0.1)	DMSO	80	48
12	$CuCl_2$ (0.1)	DMSO	80	47
13	$CuSO_4$ (0.1)	DMSO	80	86
14	CuO (0.1)	DMSO	80	43
15	Cu_2O (0.1)	DMSO	80	83
16	CuCl (0.1)	DMSO	80	75
17	CuBr (0.1)	DMSO	80	76
18	CuI (0.1)	DMSO	80	82

[a]Reaction conditions: **1a** (0.5 mmol), **2a** (0.55 mmol), solvent (2.5 mL), cat. (0.025 or 0.05 mmol), air (1 atm), 3 h. [b]Isolated yields.

Table 2. Scope of Unsymmetrical 1,4-Enediones 1 with Pyrazole 2a[a]



1 2a 3

entry	1	R^1	R^2	R^3	3	yield[b] (%)
1	**1a**	Ph	Ph	Ph	**3aa**	91
2	**1b**	4-Me-Ph	Ph	Ph	**3ba**	90
3	**1c**	4-OMe-Ph	Ph	Ph	**3ca**	89
4	**1d**	4-NO_2−Ph	Ph	Ph	**3da**	62
5	**1e**	1-naphthyl	Ph	Ph	**3ea**	85
6	**1f**	2-naphthyl	Ph	Ph	**3fa**	88
7	**1g**	4-Cl-Ph	Ph	Ph	**3ga**	83
8	**1h**	4-Br-Ph	Ph	Ph	**3ha**	84
9	**1i**	4-F-Ph	Ph	Ph	**3ia**	82
10	**1j**	2-furyl	Ph	Ph	**3ja**	87
11	**1k**	3-thienyl	Ph	Ph	**3ka**	86
12[c]	**1l**	Ph	Ph	OEt	**3la**	93
13[c]	**1m**	Ph	4-OMe-Ph	OEt	**3ma**	90
14[c]	**1n**	Ph	4-NO_2−Ph	OEt	**3na**	89
15[c]	**1o**	Ph	4-Cl-Ph	OMe	**3oa**	92
16[c]	**1p**	Ph	4-F-Ph	OMe	**3pa**	91

[a]Reaction was carried out using **1** (1.0 mmol), **2a** (1.1 mmol), and $Cu(OAc)_2·H_2O$ (0.1 mmol) in 5 mL of DMSO at 80 °C under air (1 atm). [b]Isolated yields. [c]A mixture of *E*/*Z*-isomers was obtained.

ray diffraction (Figure 2).[15] It is noteworthy that good yields were also obtained with halogenated (−Cl, −Br, −F) and heteroaryl (2-furyl, 3-thienyl) R^1 substituents (entries 5−9; 76−85%).

We next explored the scope of *N*-nucleophiles with 1,4-enedione **1a** as a model substrate (Table 4). For anilines, moderate to good yields were obtained with electron-neutral (−H), electron-donating (−OMe), electron-withdrawing (−CN), halogenated (−I), and sterically hindered (2-naphthyl) substituents (Table 4, 52%−79%; **3ac**−**ag**). To our delight, *N*-methylaniline and 6-methylpyridin-2-amine could also afford their corresponding products in good yields (70−78%; **3ah**−**ai**). For aliphatic *N*-nucleophiles, good yields were obtained with piperidine and pyrrolidine (72%−76%; **3aj**−**ak**). For aromatic *N*-heterocyles, high yields were obtained with imidazole, benzimidazole, and benzotriazole (73%−87%; **3al**−**an**). Fortunately, the structures of **3ac**, **3ai**, **3aj**, **3ak**, **3am**, and **3an** were clearly confirmed by X-ray diffraction (Figure 2).[15]

To provide insight into the mechanism, a control experiment was performed (Scheme 2). When the reaction of 1,4-enedione **1a** and pyrazole **2a** was conducted without $Cu(OAc)_2·H_2O$, only aza-Michael addition product **4** was obtained in 49% yield after 3 h, which could be further oxidized to product **3aa** in 99% yield with $Cu(OAc)_2·H_2O$ (0.1 equiv) as catalyst under air. When the reaction of 1,4-enedione **1a** and pyrazole **2a** was conducted with $Cu(OAc)_2·H_2O$ (0.1 equiv) under argon, a mixture of products **3aa** (10%) and **4** (55%) were obtained. Compared with the previous results that product **3aa** could be obtained in 91% yield directly from **1a** and **2a** (Table 2, entry 1), a possible reaction mechanism is proposed in Scheme 3 with 1,4-enedione **1a** and pyrazole **2a** as an example. Initially, the pyrazole **2a** underwent aza-Michael addition with **1a** to form intermediate **A** under copper catalysis,[16] which could afford the product **3aa** by copper catalyzed aerobic oxidative dehydrogenation (Scheme 3).[17] Because the reaction was conducted under air atmosphere, the formed Cu(I) species in this reaction could be oxidized to Cu(II) by air, so that the reaction can be catalytic in copper catalyst with air as terminal oxidant.

CONCLUSION

In conclusion, we have developed a practical and efficient protocol for the synthesis of tetrasubstituted unsymmetrical 1,4-enediones via copper-catalyzed tandem aza-Michael addition/aerobic oxidative dehydrogenation. This reaction has significant advantages in that it uses air as the oxidant and has a wide substrate scope and mild reaction conditions.

EXPERIMENTAL SECTION

1. General Methods. All reagents were purchased from commercial suppliers and used without further purification. 1,4-Enediones **1** were prepared according to our previous reports.[5a] 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 ppm relative to tetramethylsilane. Data are reported as follows: chemical shift, multiplicity (s = singlet, d = doublet, t = triplet, m = multiplet, bs = broad singlet), coupling constants (Hz), and integration. ^{13}C spectra were recorded in $CDCl_3$ on 100/150 MHz spectrometers and resonances (δ) are given in ppm relative to the center line of a triplet at 77.0 ppm of chloroform-*d*. HRMS were obtained by a Fourier transform ion cyclotron resonance (FTICR) mass spectrometry. Melting points were determined without correction. The structures of **3ka**, (*E*)-**3pa**, **3pa**, **3bb**, **3ac**, **3ai**, **3aj**, **3ak**, **3am**, and **3an** were confirmed by X-ray diffraction. Column chromatography was performed on silica gel (200−300 mesh).

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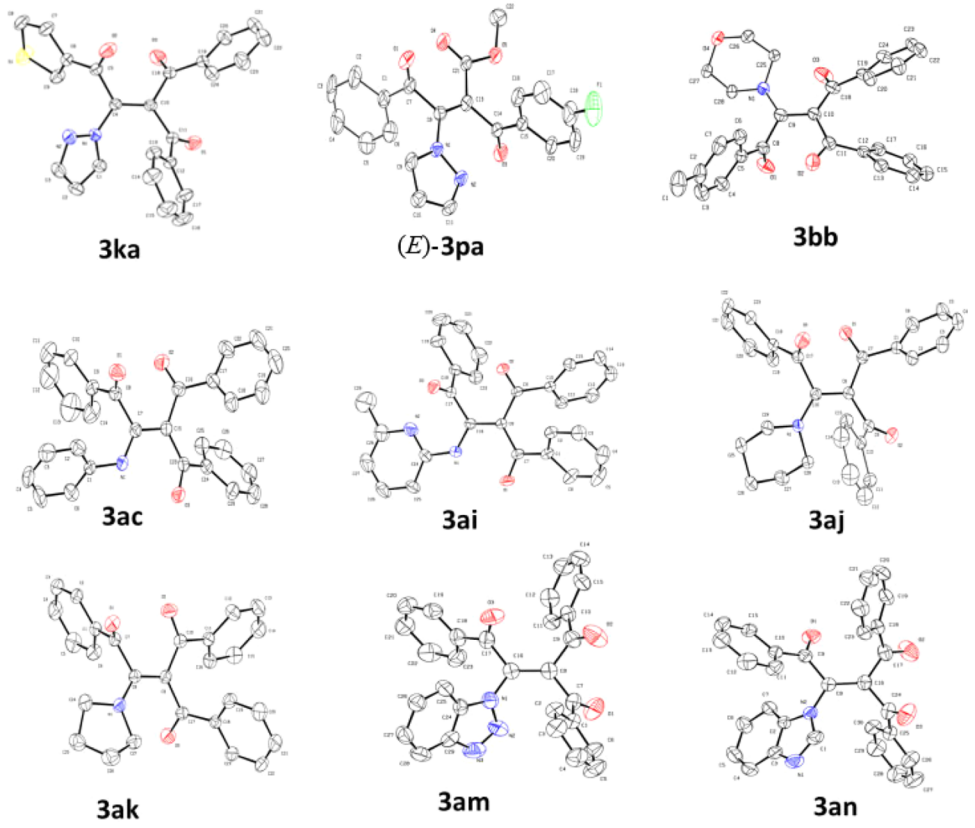
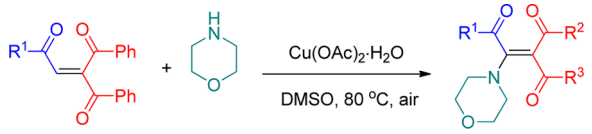


Figure 2. X-ray structures of compound **3**.

Table 3. Scope of Unsymmetrical 1,4-Enediones 1 with Morpholine 2b[a]



1 2b 3

entry	1	R^1	3	yield[b] (%)
1	**1a**	Ph	**3ab**	86
2	**1b**	4-Me-Ph	**3bb**	88
3	**1c**	1-naphthyl	**3cb**	78
4	**1d**	2-naphthyl	**3db**	72
5	**1e**	4-Cl-Ph	**3eb**	76
6	**1f**	4-Br-Ph	**3fb**	79
7	**1g**	4-F-Ph	**3gb**	81
8	**1h**	2-furyl	**3hb**	85
9	**1i**	3-thienyl	**3ib**	78

[a]Reaction was carried out using **1** (1.0 mmol), **2b** (1.1 mmol) and $Cu(OAc)_2·H_2O$ (0.1 mmol) in 5 mL DMSO at 80 °C under air. [b]Isolated yields.

2. General Experimental Procedures for Preparation of Tetrasubstituted 1,4-Enediones 3 from 1,4-Enediones 1 and N-Nucleophiles 2 (3aa as an Example). A mixture of 2-benzoyl-1,4-diphenylbut-2-ene-1,4-dione **1a** (340 mg, 1.0 mmol), pyrazole **2a** (75 mg, 1.1 mmol), and $Cu(OAc)_2·H_2O$ (20 mg, 0.1 mmol) in 5 mL of DMSO was stirred at 80 °C for 3 h under air (1 atm). After the reaction completed, the mixture was diluted with water and extracted with CH_2Cl_2 (3 × 30 mL), and the combined organic extracts were then washed with brine. After drying over Na_2SO_4 and concentration under reduced pressure, the crude product was purified by column chromatography on silica gel (eluent: CH_2Cl_2/petroleum ether = 5:1) to afford a white solid **3aa** (370 mg, 91%).

3. Experimental Procedure for Preparation of 4 from 1,4-Enedione 1a and Pyrazole 2a without Copper Catalyst. A mixture of 2-benzoyl-1,4-diphenylbut-2-ene-1,4-dione **1a** (340 mg, 1.0 mmol) and pyrazole **2a** (75 mg, 1.1 mmol) in 5 mL of DMSO was stirred at 80 °C for 3 h under air (1 atm). After the reaction completed, the mixture was diluted with water and extracted with CH_2Cl_2 (3 × 30 mL), and the combined organic extracts were then washed with brine. After drying over Na_2SO_4 and concentration under reduced pressure, the crude product was purified by column chromatography on silica gel (eluent: CH_2Cl_2/petroleum ether = 5:1) to afford a white solid **4** (200 mg, 49%).

4. Experimental Procedure for Preparation of 3aa from Compound 4. A mixture of 2-benzoyl-1,4-diphenyl-3-(1*H*-pyrazol-1-yl)butane-1,4-dione **4** (102 mg, 0.25 mmol) and $Cu(OAc)_2·H_2O$ (5 mg, 0.025 mmol) in 3 mL of DMSO was stirred at 80 °C for 2 h under air. After the reaction was complete, the mixture was diluted with water and extracted with CH_2Cl_2 (3 × 30 mL), and the combined organic extracts were then washed with brine. After drying over Na_2SO_4 and evaporation, the crude product was purified by column chromatography on silica gel (eluent: CH_2Cl_2/petroleum ether = 5:1) to afford a white solid **3aa** (101 mg, 99% yield).

5. Experimental Procedure for Reaction of 1,4-Enedione 1a and Pyrazole 2a under Argon. A mixture of 2-benzoyl-1,4-diphenylbut-2-ene-1,4-dione **1a** (340 mg, 1.0 mmol), pyrazole **2a** (75 mg, 1.1 mmol), and $Cu(OAc)_2·H_2O$ (20 mg, 0.1 mmol) in 5 mL of DMSO was stirred at 80 °C for 3 h under argon. After the reaction completed, the mixture was diluted with water and extracted with CH_2Cl_2 (3 × 30 mL), and the combined organic extracts were then washed with brine. After drying over Na_2SO_4 and concentration under reduced pressure, the crude product was purified by column chromatography on silica gel (eluent: CH_2Cl_2/petroleum ether = 5:1) to afford an inseparable mixture of **3aa** and **4** (265 mg). The molar ratio of **3aa**/**4** was determined by ^1H NMR and was found to be

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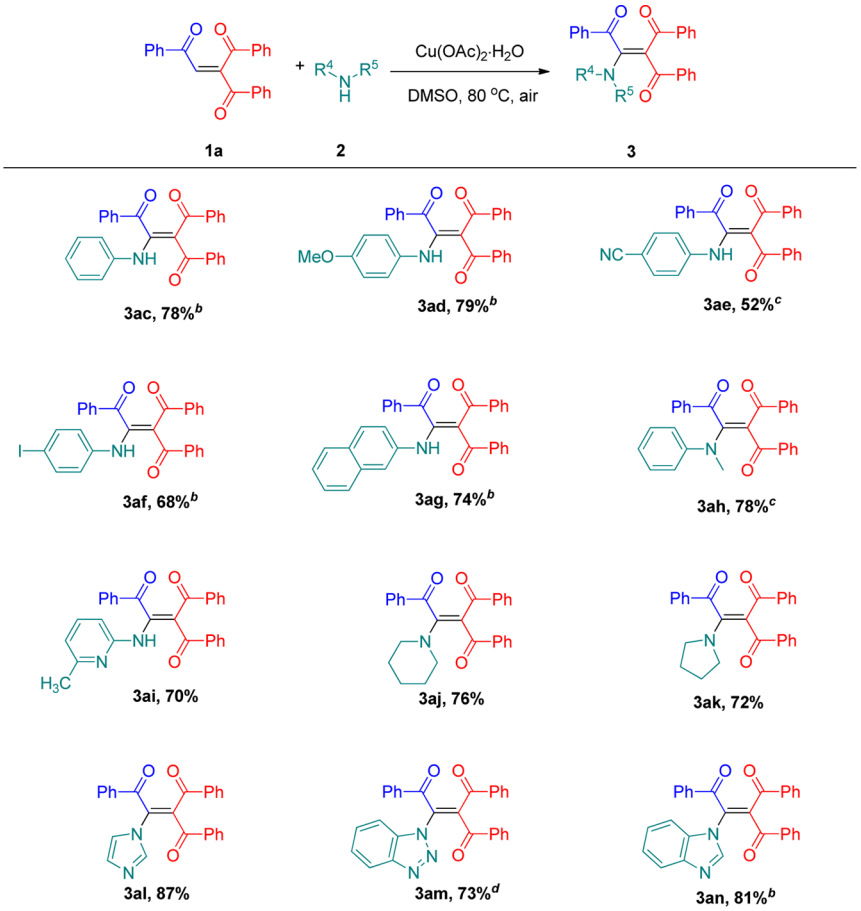
Table 4. Scope of Different *N*-Nucleophiles 2[a]



[a]Reaction was carried out using **1a** (1.0 mmol), **2** (1.1 mmol), and $Cu(OAc)_2·H_2O$ (0.1 mmol) in 5 mL of DMSO at 80 °C under air (1 atm). [b]$Cu(OAc)_2·H_2O$ (0.2 mmol) was used. [c]**2** (2.5 mmol) and $Cu(OAc)_2·H_2O$ (0.2 mmol) were used. [d]$Cu(OAc)_2·H_2O$ (0.2 mmol) was used at 100 °C.

15:85. Their respective yields were thus calculated to be **3aa** (41 mg, 10%) and **4** (224 mg, 55%).

Spectroscopic Data. *2-Benzoyl-1,4-diphenyl-3-(1H-pyrazol-1-yl)but-2-ene-1,4-dione (**3aa**):* yield 91% (370 mg); white solid; mp 123.4−124.3 °C; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 7.99 (d, J = 6.8 Hz, 2H), 7.81−7.79 (m, 4H), 7.55−7.49 (m, 2H), 7.45−7.36 (m, 7H), 7.28 (t, J = 8.4 Hz, 2H), 6.18 (t, J = 2.0 Hz, 1H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 191.9, 191.7, 189.1, 143.3, 142.9, 136.6 136.2, 135.3, 134.1, 133.7, 133.4, 130.6, 129.4, 129.1, 129.0, 128.8, 128.7, 128.4, 109.4; IR (KBr) 1675, 1647, 1265 cm^{-1}; HRMS (ESI) m/z [M + H]$^+$ calcd for $C_{26}H_{19}N_2O_3$ 407.1390, found 407.1394.

*2-Benzoyl-1-phenyl-3-(1H-pyrazol-1-yl)-4-(p-tolyl)but-2-ene-1,4-dione (**3ba**):* yield 90% (378 mg); white solid; mp 127.6−128.3 °C; ^{1}H NMR ($CDCl_3$, 600 MHz) δ 7.99 (d, J = 7.8 Hz, 2H), 7.81 (d, J = 7.8 Hz, 2H), 7.70 (d, J = 7.2 Hz, 2H), 7.51 (t, J = 7.8 Hz, 1H), 7.45−7.37 (m, 5H), 7.29 (t, J = 7.8 Hz, 2H), 7.19 (d, J = 7.8 Hz, 2H), 6.18 (bs, 1H), 2.37 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 192.0, 191.7, 188.7, 145.5, 143.5, 142.8, 136.5, 136.2, 133.6, 133.4, 133.2, 132.7, 130.5, 129.5, 129.33, 129.27, 128.9, 128.7, 128.3, 109.4, 21.8; IR (KBr) 1668, 1652, 1601, 1263 cm^{-1}; HRMS (ESI) m/z [M + H]$^+$ calcd for $C_{27}H_{21}N_2O_3$ 421.1547, found 421.1549.

*2-Benzoyl-4-(4-methoxyphenyl)-1-phenyl-3-(1H-pyrazol-1-yl)-but-2-ene-1,4-dione (**3ca**):* yield 89% (388 mg); light yellow solid; mp 104.9−106.3 °C; ^{1}H NMR ($CDCl_3$, 600 MHz) δ 7.99 (d, J = 7.8 Hz, 2H), 7.82 (d, J = 7.8 Hz, 2H), 7.77 (d, J = 8.4 Hz, 2H), 7.50 (t, J = 7.2 Hz, 1H), 7.45−7.38 (m, 5H), 7.29 (t, J = 7.8 Hz, 2H), 6.86 (d, J = 8.4 Hz, 2H), 6.19 (bs, 1H), 3.83 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 192.0, 191.8, 187.6, 164.4, 143.4, 142.8, 136.5, 136.2, 133.5, 133.4, 133.0, 131.7, 130.5, 129.4, 128.9, 128.7, 128.33, 128.27, 114.1, 109.3, 55.5; IR (KBr) 1660, 1598, 1258, 1175 cm^{-1}; HRMS (ESI) m/z [M + H]$^+$ calcd for $C_{27}H_{21}N_2O_4$ 437.1496, found 437.1497.

*2-Benzoyl-4-(4-nitrophenyl)-1-phenyl-3-(1H-pyrazol-1-yl)but-2-ene-1,4-dione (**3da**):* yield 62% (280 mg); white solid; mp 167.3−168.2 °C; ^{1}H NMR ($CDCl_3$, 600 MHz) δ 8.25 (d, J = 7.8 Hz, 2H), 8.00−7.96 (m, 4H), 7.78 (d, J = 7.8 Hz, 2H), 7.56 (t, J = 7.2 Hz, 1H), 7.49−7.42 (m, 5H), 7.32 (t, J = 7.2 Hz, 2H), 6.22 (bs, 1H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 191.6, 191.5, 187.5, 150.4, 143.5, 143.3, 139.8, 136.1, 135.6, 134.2, 133.8, 130.6, 129.8, 129.2, 129.0, 128.6, 124.0, 110.0; IR (KBr) 1677, 1654, 1599, 1527, 1349, 1255 cm^{-1}; HRMS (ESI) m/z [M + H]$^+$ calcd for $C_{26}H_{18}N_3O_5$ 452.1241, found 452.1239.

*2-Benzoyl-4-(naphthalen-1-yl)-1-phenyl-3-(1H-pyrazol-1-yl)but-2-ene-1,4-dione (**3ea**):* yield 85% (388 mg); light yellow solid; mp 134.9−136.2 °C; ^{1}H NMR ($CDCl_3$, 600 MHz) δ 8.72 (d, J = 8.4 Hz, 1H), 8.03−8.00 (m, 3H), 7.96 (d, J = 7.8 Hz, 1H), 7.82 (d, J = 8.4 Hz, 1H), 7.77 (d, J = 7.8 Hz, 2H), 7.59 (t, J = 7.8 Hz, 1H), 7.54−7.50 (m, 2H), 7.42−7.37 (m, 6H), 7.26−7.23 (m, 2H), 6.14 (bs, 1H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 191.8, 191.6, 190.7, 143.6, 142.6, 136.4, 136.0, 134.8, 133.7, 133.5, 132.2, 131.8, 130.7, 130.6, 129.3, 129.0, 128.8, 128.7, 128.4, 126.8, 125.2, 124.2, 109.1; IR (KBr) 1672, 1645, 1597, 1245 cm^{-1}; HRMS (ESI) m/z [M + H]$^+$ calcd for $C_{30}H_{21}N_2O_3$ 457.1547, found 457.1548.

*2-Benzoyl-4-(naphthalen-2-yl)-1-phenyl-3-(1H-pyrazol-1-yl)but-2-ene-1,4-dione (**3fa**):* yield 88% (402 mg); light yellow solid; mp 139.5−141.0 °C; ^{1}H NMR ($CDCl_3$, 600 MHz) δ 8.33 (s, 1H), 8.03 (d, J = 7.8 Hz, 2H), 7.87−7.80 (m, 6H), 7.59 (t, J = 7.8 Hz, 1H), 7.52 (t, J = 7.2 Hz, 2H), 7.43−7.39 (m, 5H), 7.27−7.25 (m, 2H), 6.18 (bs, 1H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 192.0, 191.7, 189.1, 143.6, 142.9, 136.5, 136.1, 135.9, 133.7, 133.4, 132.6, 132.2, 131.8, 130.6, 129.8,

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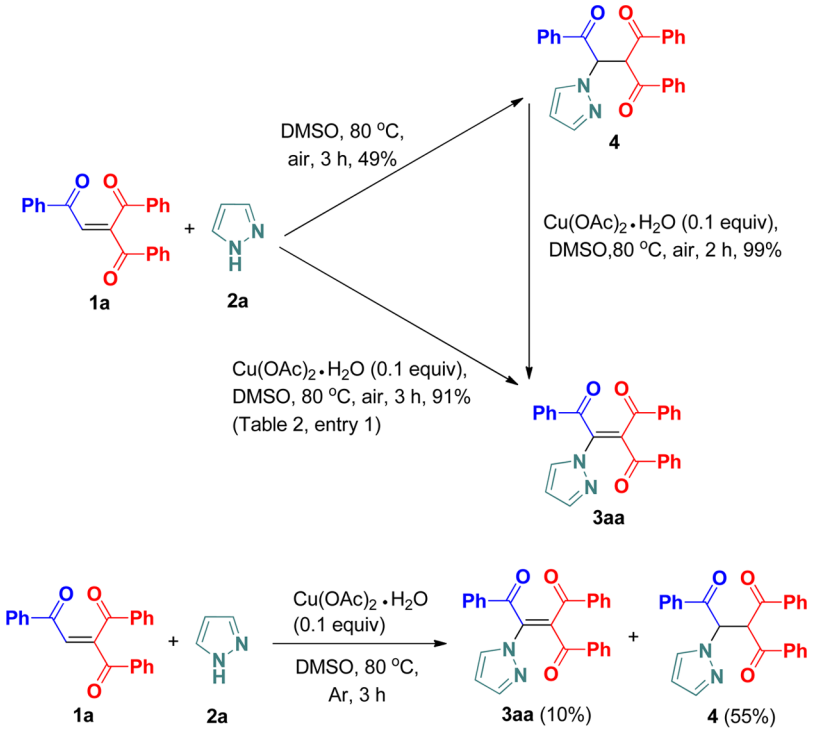
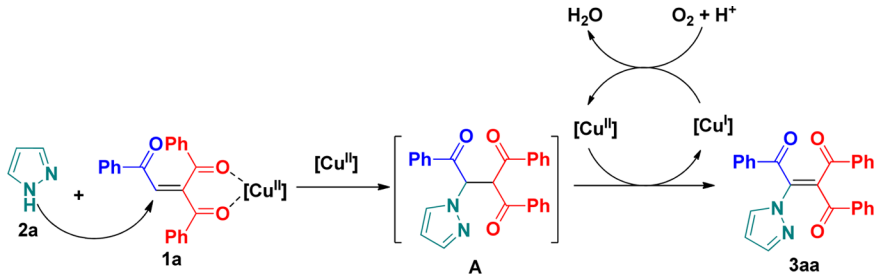
Scheme 2. Control Experiment



Scheme 3. Proposed Reaction Mechanism



129.3, 129.2, 128.92, 128.86, 128.7, 128.4, 127.7, 127.0, 123.8, 109.5; IR (KBr) 1655, 1279 cm^{-1}; HRMS (ESI) m/z $[M + H]^+$ calcd for $C_{30}H_{21}N_2O_3$ 457.1547, found 457.1547.

*2-Benzoyl-4-(4-chlorophenyl)-1-phenyl-3-(1H-pyrazol-1-yl)but-2-ene-1,4-dione (**3ga**):* yield 83% (366 mg); white solid; mp 115.1−116.4 °C; ^1H NMR ($CDCl_3$, 600 MHz) δ 7.98 (d, J = 7.8 Hz, 2H), 7.80 (d, J = 7.8 Hz, 2H), 7.73 (d, J = 7.8 Hz, 2H), 7.51 (t, J = 7.2 Hz, 1H), 7.45−7.35 (m, 7H), 7.29 (t, J = 7.2 Hz, 2H), 6.19 (bs, 1H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 191.7, 191.6, 187.9, 143.3, 143.1, 140.7, 136.3, 135.9, 133.8, 133.6, 133.5, 130.5, 130.4, 129.3, 129.2, 128.9, 128.8, 128.5, 109.6; IR (KBr) 1674, 1655, 1586, 1280, 1257 cm^{-1}; HRMS (ESI) m/z $[M + H]^+$ calcd for $C_{26}H_{18}ClN_2O_3$ 441.1001, found 441.1001.

*2-Benzoyl-4-(4-bromophenyl)-1-phenyl-3-(1H-pyrazol-1-yl)but-2-ene-1,4-dione (**3ha**):* yield 84% (408 mg); white solid; mp 140.0−141.8 °C; ^1H NMR ($CDCl_3$, 600 MHz) δ 7.98 (d, J = 7.2 Hz, 2H), 7.79 (d, J = 7.8 Hz, 2H), 7.66 (d, J = 7.8 Hz, 2H), 7.55−7.51 (m, 3H), 7.47−7.38 (m, 5H), 7.31 (t, J = 7.8 Hz, 2H), 6.20 (bs, 1H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 191.8, 191.6, 188.2, 143.4, 143.2, 136.3, 135.9, 134.0, 133.9, 133.6, 132.2, 130.4, 129.6, 129.3, 128.9, 128.8, 128.5, 109.7; IR (KBr) 1677, 1642, 1585, 1261 cm^{-1}; HRMS (ESI) m/z $[M + H]^+$ calcd for $C_{26}H_{18}BrN_2O_3$ 485.0495, found 485.0495.

*2-Benzoyl-4-(4-fluorophenyl)-1-phenyl-3-(1H-pyrazol-1-yl)but-2-ene-1,4-dione (**3ia**):* yield 82% (348 mg); white solid; mp 114.2−116.4 °C; ^1H NMR ($CDCl_3$, 600 MHz) δ 7.98 (d, J = 7.2 Hz, 2H), 7.84−7.80 (m, 4H), 7.52 (t, J = 7.2 Hz, 1H), 7.47−7.39 (m, 5H), 7.30 (t, J = 7.2 Hz, 2H), 7.07 (t, J = 7.8 Hz, 2H), 6.21 (bs, 1H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 191.8, 191.7, 187.6, 167.4, 164.8, 143.4, 143.1, 136.4, 135.9, 133.8, 133.6, 131.9, 131.8, 131.7, 130.5, 129.3, 128.9, 128.8, 128.4, 116.3, 116.1, 109.6; IR (KBr) 1670, 1644, 1618, 1597, 1264, 1240 cm^{-1}; HRMS (ESI) m/z $[M + H]^+$ calcd for $C_{26}H_{18}FN_2O_3$ 425.1296, found 425.1297.

*2-Benzoyl-4-(furan-2-yl)-1-phenyl-3-(1H-pyrazol-1-yl)but-2-ene-1,4-dione (**3ja**):* yield 87% (345 mg); white solid; mp 133.1−134.0 °C; ^1H NMR ($CDCl_3$, 600 MHz) δ 7.98 (d, J = 7.8 Hz, 2H), 7.89 (d, J = 7.8 Hz, 2H), 7.54−7.47 (m, 5H), 7.40 (t, J = 7.2 Hz, 2H), 7.34 (t, J = 7.2 Hz, 2H), 6.87 (bs, 1H), 6.47 (bs, 1H), 6.29 (bs, 1H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 191.7, 191.3, 175.5, 151.1, 148.3, 140.5, 136.3, 135.7, 135.6, 133.8, 133.6, 129.3, 129.1, 128.7, 128.4, 121.0, 113.0; IR (KBr) 1649, 1599, 1455, 1393, 1281 cm^{-1}; HRMS (ESI) m/z $[M + H]^+$ calcd for $C_{24}H_{17}N_2O_4$ 397.1183, found 397.1183.

*2-Benzoyl-1-phenyl-3-(1H-pyrazol-1-yl)-4-(thiophene-3-yl)but-2-ene-1,4-dione (**3ka**):* yield 86% (355 mg); white solid; mp 78.0−80.1 °C; ^1H NMR ($CDCl_3$, 600 MHz) δ 7.97 (d, J = 7.8 Hz, 2H), 7.87 (d, J = 7.2 Hz, 2H), 7.77 (s, 1H), 7.52−7.46 (m, 4H), 7.40 (t, J = 7.8 Hz, 2H), 7.32 (t, J = 7.8 Hz, 2H), 7.26−7.23 (m, 1H), 6.25 (bs, 1H), 5.30 (bs, 1H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 191.8, 191.5, 182.1, 142.2, 139.9, 136.3, 135.8, 135.2, 135.1, 133.7, 133.6, 129.4, 129.0, 128.7, 128.4, 126.9, 126.8; IR (KBr) 1651, 1597, 1601, 1417, 1252 cm^{-1}; HRMS (ESI) m/z $[M + H]^+$ calcd for $C_{24}H_{17}N_2O_3S$ 413.0954, found 413.0956.

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*Ethyl 2-benzoyl-4-oxo-4-phenyl-3-(1H-pyrazol-1-yl)but-2-enoate (**3la**):* yield 93% (348 mg); white solid; (*E*:*Z* = 53:47). (*E*)-Isomer: white solid (yield 42%, recrystallized from ethanol/hexane); mp 140.1−142.4 °C; ^{1}H NMR ($CDCl_3$, 600 MHz) δ 8.07 (d, *J* = 7.8 Hz, 2H), 8.02 (d, *J* = 7.8 Hz, 2H), 7.64 (t, *J* = 7.2 Hz, 1H), 7.58−7.51 (m, 3H), 7.47−7.45 (m, 3H), 7.38 (bs, 1H), 6.24 (bs, 1H), 4.05−4.02 (m, 2H), 0.97 (t, *J* = 7.2 Hz, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 191.1, 189.0, 163.8, 144.5, 143.5, 136.6, 135.0, 134.4, 133.3, 130.2, 129.1, 128.9, 128.7, 128.6, 118.7, 109.6, 61.9, 13.5; IR (KBr) 1710, 1681, 1624, 1245 cm^{-1}; HRMS (ESI) *m*/*z* [M + H]$^+$ calcd for $C_{22}H_{19}N_2O_4$ 375.1339, found 375.1339.

*Ethyl 2-(4-methoxybenzoyl)-4-oxo-4-phenyl-3-(1H-pyrazol-1-yl)-but-2-enoate (**3ma**):* yield 90% (364 mg); (*E*:*Z* = 47:53); white solid; mp 87.6−89.9 °C; ^{1}H NMR ($CDCl_3$, 600 MHz) δ 8.04 (d, *J* = 7.8 Hz, 2H), 8.00 (d, *J* = 7.8 Hz, 2H), 7.84 (d, *J* = 7.8 Hz, 2H), 7.78 (d, *J* = 8.4 Hz, 2H), 7.70 (bs, 1H), 7.62 (t, *J* = 7.8 Hz, 2H), 7.52−7.49 (m, 4H), 7.44 (bs, 1H), 7.37 (t, *J* = 7.2 Hz, 2H), 6.94 (d, *J* = 7.8 Hz, 2H), 6.87 (d, *J* = 8.4 Hz, 2H), 6.40 (bs, 1H), 6.24 (bs, 1H), 4.25−4.22 (m, 2H), 4.06−4.02 (m, 2H), 3.86 (s, 3H), 3.85 (s, 3H), 1.15 (t, *J* = 7.2 Hz, 3H), 0.98 (t, *J* = 7.2 Hz, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 189.7, 189.1, 188.9, 188.5, 164.5, 163.9, 163.8, 144.4, 143.6, 143.4, 142.8, 135.1, 135.0, 134.2, 134.0, 131.3, 131.1, 130.5, 130.2, 129.5, 129.4, 129.0, 128.8, 128.6, 127.2, 119.0, 113.9, 113.7, 109.4, 109.1, 62.0, 61.8, 55.4, 13.7, 13.4; IR (KBr) 1708, 1600, 1255 cm^{-1}; HRMS (ESI) *m*/*z* [M + H]$^+$ calcd for $C_{23}H_{21}N_2O_5$ 405.1445, found 405.1446.

*Ethyl 2-(4-nitrobenzoyl)-4-oxo-4-phenyl-3-(1H-pyrazol-1-yl)but-2-enoate (**3na**):* yield 89% (373 mg); white solid; (*E*:*Z* = 87:13); (*E*)-isomer: white solid (yield 70%, recrystallized from ethanol/hexane); mp 140.6−141.8 °C; ^{1}H NMR ($CDCl_3$, 600 MHz) δ 8.32 (d, *J* = 8.4 Hz, 2H), 8.17 (d, *J* = 7.8 Hz, 2H), 8.07 (d, *J* = 7.8 Hz, 2H), 7.68 (t, *J* = 7.8 Hz, 1H), 7.56 (t, *J* = 7.8 Hz, 2H), 7.45 (bs, 1H), 7.33 (bs, 1H), 6.28 (bs, 1H), 4.07−4.03 (m, 2H), 0.98 (t, *J* = 7.2 Hz, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 189.0, 188.7, 163.4, 150.1, 144.9, 143.8, 141.7, 134.9, 134.7, 130.3, 129.5, 129.3, 129.0, 123.8, 117.0, 110.1, 62.2, 13.5; IR (KBr) 1717, 1684, 1613, 1526, 1244, 1195 cm^{-1}; HRMS (ESI) *m*/*z* [M + H]$^+$ calcd for $C_{22}H_{18}N_3O_6$: 420.1190; found: 420.1192.

*Methyl 2-(4-chlorobenzoyl)-4-oxo-4-phenyl-3-(1H-pyrazol-1-yl)-but-2-enoate (**3oa**).* Yield 92% (363 mg); white solid; (*E*:*Z* = 63:37). (*E*)-Isomer: white solid (yield 49%, recrystallized from ethanol/hexane); mp 165.7−167.4 °C; ^{1}H NMR ($CDCl_3$, 600 MHz) δ 8.05 (d, *J* = 7.8 Hz, 2H), 7.95 (d, *J* = 7.8 Hz, 2H), 7.66 (t, *J* = 7.8 Hz, 1H), 7.53 (t, *J* = 7.8 Hz, 2H), 7.47 (bs, 1H), 7.44 (d, *J* = 7.2 Hz, 2H), 7.36 (bs, 1H), 6.26 (bs, 1H), 3.58 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 189.7, 189.0, 164.2, 145.0, 143.7, 139.7, 135.1, 134.7, 134.6, 130.2, 130.1, 129.2, 129.0, 128.9, 117.3, 109.8, 52.9; IR (KBr) 1716, 1681, 1622, 1250 cm^{-1}; HRMS (ESI) *m*/*z* [M + H]$^+$ calcd for $C_{21}H_{16}ClN_2O_4$ 395.0793, found 395.0796.

*Methyl 2-(4-fluorobenzoyl)-4-oxo-4-phenyl-3-(1H-pyrazol-1-yl)-but-2-enoate (**3pa**):* yield 91% (344 mg); white solid; (*E*:*Z* = 71:29). (*E*)-Isomer: white solid (yield 56%, recrystallized from ethanol/hexane); mp 148.4−149.5 °C; ^{1}H NMR ($CDCl_3$, 600 MHz) δ 8.06−8.03 (m, 4H), 7.65 (t, *J* = 7.2 Hz, 1H), 7.53 (t, *J* = 7.2 Hz, 2H), 7.48 (bs, 1H), 7.37 (bs, 1H), 7.13 (t, *J* = 8.4 Hz, 2H), 6.26 (bs, 1H), 3.59 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 189.4, 189.0, 167.0, 164.5, 164.3, 145.0 143.7, 134.7, 134.6, 133.1, 131.4, 131.3, 130.3, 129.2, 128.9, 117.5, 116.0, 115.8, 109.8, 52.8; IR (KBr) 1715, 1683, 1624, 1598, 1247 cm^{-1}; HRMS (ESI) *m*/*z* [M + H]$^+$ calcd for $C_{21}H_{16}FN_2O_4$ 379.1089, found 379.1090.

*2-Benzoyl-3-morpholino-1,4-diphenylbut-2-ene-1,4-dione (**3ab**):* yield 86% (366 mg); yellow solid; mp 199.5−200.2 °C; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 8.08 (d, *J* = 7.6 Hz, 2H), 7.56−7.13 (m, 13H), 3.66 (bs, 4H), 3.21 (bs, 4H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 194.3, 192.6, 165.5, 140.1, 136.1, 133.9, 131.5, 128.8, 127.9, 114.6, 65.9, 51.8; IR (KBr) 1630, 1593, 1505, 1413, 1259, 1120 cm^{-1}; HRMS (ESI) *m*/*z* [M + H]$^+$ calcd for $C_{27}H_{24}NO_4$ 426.1700, found 426.1699.

*2-Benzoyl-3-morpholino-1-phenyl-4-(p-tolyl)but-2-ene-1,4-dione (**3bb**):* yYield 88% (386 mg); yellow solid; mp 114.3−116.8 °C; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 7.99 (d, *J* = 7.6 Hz, 2H), 7.50−7.12 (m, 12H), 3.66 (bs, 4H), 3.20 (m, 4H), 2,36 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 194.4, 165.6, 145.0, 133.7, 131.6, 129.4, 128.8, 128.7, 127.8, 65.9, 51.7, 21.7,; IR (KBr) 1599, 1508, 1294, 1261 cm^{-1}; HRMS (ESI) *m*/*z* [M + H]$^+$ calcd for $C_{28}H_{26}NO_4$ 440.1856, found 440.1855.

*2-Benzoyl-3-morpholino-4-(naphthalen-1-yl)-1-phenylbut-2-ene-1,4-dione (**3cb**):* yield 78% (371 mg); yellow solid; mp 194.1−195.5 °C; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 9.06 (d, *J* = 8.8 Hz, 1H), 8.12 (d, *J* = 6.0 Hz, 1H), 7.97 (d, *J* = 8.4 Hz, 1H), 7.81 (d, *J* = 8.0 Hz, 1H), 7.67 (t, *J* = 7.2 Hz, 2H), 7.54−7.48 (m, 3H), 7.26−7.17 (m, 8H), 3.76 (bs, 4H), 3.35 (bs, 4H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 194.0, 168.9, 134.7, 133.9, 132.7, 130.8, 128.9, 128.4, 128.0, 126.8, 126.2, 123.9, 66.2, 52.5; IR (KBr) 1595, 1569, 1507, 1285, 1240 cm^{-1}; HRMS (ESI) *m*/*z* [M + H]$^+$ calcd for $C_{31}H_{26}NO_4$ 476.1856, found 476.1855.

*2-Benzoyl-3-morpholino-4-(naphthalen-2-yl)-1-phenylbut-2-ene-1,4-dione (**3db**):* yield 72% (342 mg); yellow solid; mp 168.0−169.4 °C; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 8.65 (s, 1H), 8.11 (d, *J* = 8.4 Hz, 1H), 7.99 (d, *J* = 7.6 Hz, 1H), 7.88 (d, *J* = 8.4 Hz, 1H), 7.81 (d, *J* = 7.6 Hz, 1H), 7.56−7.12 (m, 12H), 3.67 (bs, 4H), 3.25 (bs, 4H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 194.3, 165.6, 135.8, 132.2, 130.6, 129.6, 128.9, 128.8, 127.9, 127.7, 126.9, 123.9, 66.0, 51.8; IR (KBr) 1595, 1572, 1506, 1263, 1237 cm^{-1}; HRMS (ESI) *m*/*z* [M + H]$^+$ calcd for $C_{31}H_{26}NO_4$ 476.1856, found: 476.1854.

*2-Benzoyl-4-(4-chlorophenyl)-3-morpholino-1-phenylbut-2-ene-1,4-dione (**3eb**):* yield 76% (349 mg); yellow solid; mp 105.1−106.9 °C; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 8.01 (d, *J* = 7.6 Hz, 2H), 7.45−7.16 (m, 12H), 3.68 (bs, 4H), 3.22 (bs, 4H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 194.1, 164.8, 140.2, 139.7, 134.5, 132.2, 129.8, 129.2, 128.9, 128.1, 114.6, 66.0, 51.9; IR (KBr) 1513, 1249 cm^{-1}; HRMS (ESI) *m*/*z* [M + H]$^+$ calcd for $C_{27}H_{23}ClNO_4$ 460.1310, found 460.1309.

*2-Benzoyl-4-(4-bromophenyl)-3-morpholino-1-phenylbut-2-ene-1,4-dione (**3fb**):* yield 79% (397 mg); yellow solid; mp 111.3−113.3 °C; ^{1}H NMR ($CDCl_3$, 600 MHz) δ 7.96 (d, *J* = 7.8 Hz, 2H), 7.68−7.07 (m, 12H), 3.67 (bs, 4H), 3.19 (bs, 4H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 194.2, 191.5, 164.8, 139.8, 134.8, 132.1, 130.0, 129.2, 128.0, 114.6, 65.9, 51.7; IR (KBr) 1584, 1513, 1250 cm^{-1}; HRMS (ESI) *m*/*z* [M + H]$^+$ calcd for $C_{27}H_{23}BrNO_4$ 504.0805, found 504.0803.

*2-Benzoyl-4-(4-fluorophenyl)-3-morpholino-1-phenylbut-2-ene-1,4-dione (**3gb**):* yield 81% (359 mg); yellow solid; mp 158.7−160.2 °C; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 8.14−8.10 (m, 2H), 7.45−7.11 (m, 12H), 3.68 (m, 4H), 3.21 (m, 4H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 194.3, 167.3, 164.7, 139.9, 132.6, 131.4, 131.3, 128.8, 128.7, 128.0, 116.2, 116.0, 114.7, 66.0, 51.8; IR (KBr) 1595, 1507, 1246 cm^{-1}; HRMS (ESI) *m*/*z* [M + H]$^+$ calcd for $C_{27}H_{23}FNO_4$ 444.1606, found 444.1605.

*2-Benzoyl-4-(furan-2-yl)-3-morpholino-1-phenylbut-2-ene-1,4-dione (**3hb**):* yield 85% (353 mg); yellow solid; mp 192.9−194.6 °C; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 7.59−7.17 (m, 12H), 6.50 (bs, 1H), 3.71 (m, 4H), 3.17 (m, 4H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 194.4, 179.7, 163.4, 152.2, 147.7, 139.9, 131.6, 128.7, 127.9, 119.8, 115.4, 112.6, 66.0, 51.8; IR (KBr) 1665, 1506, 1453, 1289, 1234 cm^{-1}; HRMS (ESI) *m*/*z* [M + H]$^+$ calcd for $C_{25}H_{22}NO_5$ 416.1492, found 416.1492.

*2-Benzoyl-3-morpholino-1-phenyl-4-(thiophene-3-yl)but-2-ene-1,4-dione (**3ib**):* yield 78% (336 mg); yellow solid; mp 207.9−208.6 °C; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 8.30 (s, 1H), 7.61−7.53 (m, 5H), 7.31−7.14 (m, 7H), 3.73 (bs, 4H), 3.23 (bs, 4H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 194.3, 165.9, 141.2, 139.9, 134.0, 131.9, 128.9, 128.0, 127.2, 126.9, 114.6, 66.1, 51.9; IR (KBr) 1668, 1505, 1252 cm^{-1}; HRMS (ESI) *m*/*z* [M + H]$^+$ calcd for $C_{25}H_{22}NO_4S$ 432.1264, found 432.1263.

*2-Benzoyl-1,4-diphenyl-3-(phenylamino)but-2-ene-1,4-dione (**3ac**):* yield 78% (336 mg); Yellow solid; mp 180.2−181.1 °C; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 13.36 (s, 1H), 7.88 (d, *J* = 7.6 Hz, 2H), 7.51−7.45 (m, 6H), 7.36 (t, *J* = 7.6 Hz, 2H), 7.17−7.05 (m, 10H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 196.1, 195.0, 190.8, 164.7, 141.3, 140.1, 136.6, 135.4, 133.8, 131.5, 130.9, 129.10, 129.07, 128.7, 128.5, 128.1, 127.8, 127.6, 127.1, 124.8, 110.7; IR (KBr) 1532, 1598 cm^{-1}; HRMS (ESI) *m*/*z* [M + H]$^+$ calcd for $C_{29}H_{22}NO_3$ 432.1594, found 432.1595.

*2-Benzoyl-3-((4-methoxyphenyl)amino)-1,4-diphenylbut-2-ene-1,4-dione (**3ad**):* yield 79% (365 mg); yellow solid; mp 179.8−181.3

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°C; ^{1}H NMR ($CDCl_3$, 600 MHz) δ 13.26 (s, 1H), 7.89 (d, J = 7.8 Hz, 2H), 7.49−7.47 (m, 3H), 7.44 (d, J = 7.8 Hz, 2H), 7.38 (t, J = 7.8 Hz, 2H), 7.16−7.15 (m, 2H), 7.10 (t, J = 7.2 Hz, 2H), 7.07−7.03 (m, 4H), 6.68 (d, J = 8.4 Hz, 2H), 3.70 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 196.1, 195.0, 190.9, 165.6, 158.4, 141.3, 140.2, 135.3, 133.8, 131.4, 130.8, 129.1, 128.7, 128.5, 128.2, 127.8, 127.6, 126.6, 114.1, 55.3; IR (KBr) 1540, 1512, 1250 cm^{-1}; HRMS (ESI) m/z [M + H]$^+$ calcd for $C_{30}H_{24}NO_4$ 462.1700, found 462.1700.

*4-((3-Benzoyl-1,4-dioxo-1,4-diphenylbut-2-en-2-yl)amino)-benzonitrile (**3ae**):* yield 52% (237 mg); yellow solid; mp 229.3−230.7 °C; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 13.41 (s, 1H), 7.92−7.90 (m, 2H) 7.54−7.38 (m, 9H), 7.22−7.17 (m, 4H), 7.14−7.07 (m, 4H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 196.4, 194.7, 162.3, 141.0, 140.7, 139.6, 135.1, 134.5, 133.3, 132.0, 131.4, 129.10, 129.06, 128.6, 128.1, 128.0, 127.9, 124.0, 117.9, 112.4, 110.0; IR (KBr) 2224, 1549, 1277 cm^{-1}; HRMS (ESI) m/z [M + H]$^+$ calcd for $C_{30}H_{21}N_2O_3$ 457.1547, found 457.1545.

*2-Benzoyl-3-((4-iodophenyl)amino)-1,4-diphenylbut-2-ene-1,4-dione (**3af**):* yield 68% (379 mg); yellow solid; mp 206.9−208.5 °C; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 13.31 (s, 1H), 7.90 (d, J = 7.2 Hz, 2H), 7.49−7.37 (m, 9H) 7.16−7.04 (m, 6H), 6.85 (d, J = 7.2 Hz, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 196.3, 194.9, 190.7, 164.0, 141.1, 140.0, 138.3, 136.5, 135.3, 134.2, 131.7, 131.1, 129.1, 128.9, 128.6, 128.2, 127.9, 127.7, 126.3, 91.9; IR (KBr) 1527, 1274 cm^{-1}; HRMS (ESI) m/z [M + H]$^+$ calcd for $C_{29}H_{21}INO_3$ 558.0561, found 558.0558.

*2-Benzoyl-3-(naphthalen-2-ylamino)-1,4-diphenylbut-2-ene-1,4-dione (**3ag**):* yield 74% (356 mg); yellow solid; mp 176.0−176.8 °C; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 13.56 (s, 1H), 7.91 (d, J = 7.6 Hz, 2H), 7.69−7.46 (m, 8H), 7.40−7.38 (m, 3H), 7.30 (t, J = 7.6 Hz, 2H), 7.24−7.05 (m, 7H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 196.1, 195.0, 190.4, 164.6, 141.2, 140.0, 135.4, 134.0, 133.8, 133.0, 131.6, 131.0, 129.23, 129.15, 128.7, 128.5, 128.2, 127.9, 127.71, 127.68, 127.5, 126.8, 126.4, 122.9, 122.7, 110.9; IR (KBr) 1535, 1272 cm^{-1}; HRMS (ESI) m/z [M + H]$^+$ calcd for $C_{33}H_{24}NO_3$ 482.1751, found 482.1750.

*2-Benzoyl-3-(methyl(phenyl)amino)-1,4-diphenylbut-2-ene-1,4-dione (**3ah**):* yield 78% (347 mg); yellow solid; mp 172.9−173.7 °C; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 7.90 (d, J = 7.2 Hz, 2H), 7.69 (bs, 2H), 7.51−7.44 (m, 3H), 7.38−7.00 (m, 13H), 3.20 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 195.0, 193.6, 192.7, 163.4, 144.3, 140.0, 136.6, 133.0, 132.3, 131.2, 129.0, 128.9, 128.6, 128.4, 128.2, 127.7, 126.9, 125.5, 119.1, 44.8; IR (KBr) 1615, 1502, 1245 cm^{-1}; HRMS (ESI) m/z [M + H]$^+$ calcd for $C_{30}H_{24}NO_3$ 446.1751, found 446.1749.

*2-Benzoyl-3-((6-methylpyridin-2-yl)amino)-1,4-diphenylbut-2-ene-1,4-dione (**3ai**):* yield 70% (312 mg); yellow solid; mp 178.6−179.5 °C; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 13.56 (s, 1H), 8.00 (d, J = 7.2 Hz, 2H), 7.51−7.39 (s, 8H), 7.18 (t, J = 7.2 Hz, 2H), 7.12−7.05 (m, 4H), 6.82 (d, J = 8.0 Hz, 1H), 6.70 (d, J = 7.6 Hz, 1H), 1.92 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 196.4, 195.3, 159.7, 157.0, 148.4, 141.2, 140.2, 138.7, 137.8, 132.3, 131.8, 131.1, 129.1, 128.3, 127.94, 127.86, 127.7, 119.3, 113.1, 110.0, 22.2; IR (KBr) 1534, 1265 cm^{-1}; HRMS (ESI) m/z [M + H]$^+$ calcd for $C_{29}H_{23}N_2O_3$ 447.1703, found 447.1702.

*2-Benzoyl-1,4-diphenyl-3-(piperidin-1-yl)but-2-ene-1,4-dione (**3aj**):* yield 76% (322 mg); yellow solid; mp 163.9−165.5 °C; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 8.09−8.08 (m, 2H), 7.55−7.45 (m, 7H), 7.21−7.12 (m, 6H), 3.21 (bs, 4H), 1.59 (bs, 6H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 194.4, 192.9, 166.7, 140.5, 136.3, 133.5, 131.2, 128.8, 128.7, 128.5, 127.8, 114.0, 53.0, 25.5, 22.7; IR (KBr) 1503, 1321, 1247 cm^{-1}; HRMS (ESI) m/z [M + H]$^+$ calcd for $C_{28}H_{26}NO_3$ 424.1907, found 424.1907.

*2-Benzoyl-1,4-diphenyl-3-(pyrrolidin-1-yl)but-2-ene-1,4-dione (**3ak**):* yield 72% (295 mg); yellow solid; mp 166.8−168.6 °C; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 8.11 (d, J = 7.2 Hz, 2H), 7.54−7.09 (m, 13H), 3.80−2.85 (m, 4H), 1.96−1.67 (m, 4H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 193.4, 190.7, 161.9, 140.9, 135.4, 133.5, 128.7, 128.4, 127.6, 113.2, 54.0, 51.3, 25.1; IR (KBr) 1683, 1594, 1558, 1511, 1317, 1248 cm^{-1}; HRMS (ESI) m/z [M + H]$^+$ calcd for $C_{27}H_{24}NO_3$ 410.1751, found 410.1750.

*2-Benzoyl-3-(1H-imidazol-1-yl)-1,4-diphenylbut-2-ene-1,4-dione (**3al**):* yield 87% (353 mg); yellow solid; mp 140.8−141.8 °C; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 8.00 (d, J = 7.6 Hz, 2H), 7.86 (d, J = 8.0 Hz, 2H), 7.70 (d, J = 7.6 Hz, 2H), 7.54−7.27 (m, 10H), 6.96 (bs, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 191.5, 190.6, 189.0, 138.6, 135.8, 134.8, 134.4, 133.9, 129.32, 129.29, 129.1, 129.0, 128.9, 128.6; IR (KBr) 1670, 1650, 1596, 1319, 1269 cm^{-1}; HRMS (ESI) m/z [M + H]$^+$ calcd for $C_{26}H_{19}N_2O_3$ 407.1390, found 407.1389.

*2-(1H-Benzo[d][1,2,3]triazol-1-yl)-3-benzoyl-1,4-diphenylbut-2-ene-1,4-dione (**3am**):* yield 73% (334 mg); yellow solid; mp 197.2−198.4 °C; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 7.97−7.78 (bs, 7H), 7.52−7.26 (m, 12H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 191.0, 190.8, 188.7, 145.9, 141.6, 138.8, 136.0, 135.3, 134.7, 134.5, 134.1, 133.9, 132.1, 129.5, 129.3, 129.1, 128.91, 128.86, 128.7, 128.5, 124.9, 120.4, 110.0; IR (KBr) 1671, 1651, 1594, 1450, 1318, 1285, 1257 cm^{-1}; HRMS (ESI) m/z [M + H]$^+$ calcd for $C_{29}H_{20}N_3O_3$ 458.1499, found 458.1503.

*2-(1H-Benzo[d]imidazol-1-yl)-3-benzoyl-1,4-diphenylbut-2-ene-1,4-dione (**3an**):* yield 81% (369 mg); yellow solid; mp 206.5−208.3 °C; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 7.96−7.27 (m, 5H), 7.72 (d, J = 7.2 Hz, 2H), 7.58 (d, J = 6.4 Hz, 1H), 7.51 (t, J = 7.6 Hz, 1H), 7.45 (t, J = 7.6 Hz, 1H), 7.39−7.35 (m, 4H), 7.30−7.18 (m, 6H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 191.6, 190.9, 189.7, 141.8, 141.3, 139.4, 135.9, 134.7, 134.6, 134.5, 134.4, 134.1, 129.3, 129.0, 128.9, 128.85, 128.76, 124.9, 123.9, 120.5, 111.1; IR (KBr) 1667, 1647, 1594, 1493, 1450, 1311, 1287, 1257 cm^{-1}; HRMS (ESI) m/z [M + H]$^+$ calcd for $C_{30}H_{21}N_2O_3$ 457.1547, found 457.1546.

*2-Benzoyl-1,4-diphenyl-3-(1H-pyrazol-1-yl)butane-1,4-dione (**4**):* yield 49% (200 mg); white solid; mp 132.2−133.9 °C; ^{1}H NMR ($CDCl_3$, 600 MHz) δ 7.95 (d, J = 7.8 Hz, 2H), 7.90 (d, J = 7.8 Hz, 2H), 7.84 (d, J = 8.4 Hz, 2H), 7.51−7.49 (m, 4H), 7.40−7.33 (m, 6H), 7.30 (s, 1H), 6.95 (d, J = 10.2 Hz, 1H), 6.74 (d, J = 10.2 Hz, 1H), 5.99 (s, 1H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 194.6, 192.5, 191.7, 141.1, 135.9, 135.6, 134.6, 133.9, 133.6, 130.7, 128.7, 128.6, 128.5, 106.8, 66.1, 57.6; IR (KBr) 1688, 1596, 1448, 1278 cm^{-1}; MS (EI, 70 ev) m/z 408.39.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

NMR spectra of products. This material is available free of charge via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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