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SELECTIVE SYNTHESIS OF 2,3-DIHYDROFURAN OR CYCLOPROPANE DERIVATIVES VIA TANDEM REACTION OF β,γ-UNSATURATED α-KETOESTERS WITH HALIDES

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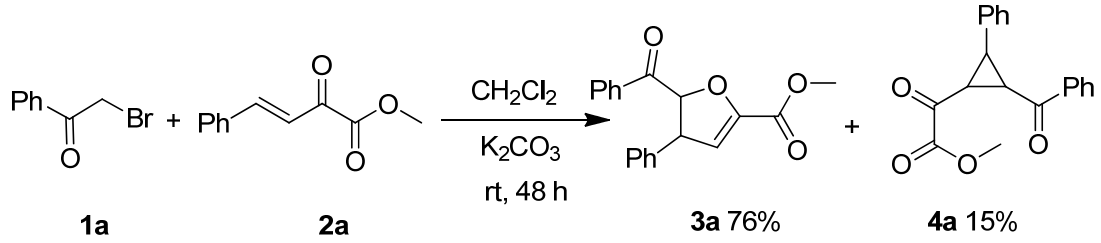
Abstract – 2,3-Dihydrofuran or cyclopropane derivatives were prepared with high selectivity via reaction of β,γ-unsaturated α-ketoesters with α-phenacyl bromide in different conditions.

Dihydrofuran derivatives which are commonly found in the molecular skeleton of natural products and bioactive substances have been studied for many years.[1-3] Cyclopropane derivatives are also important in the field of organic synthesis.[4,5] A number of methods for the synthesis of them have been reported in the literature.[6-9] Among them, stereoselective synthesis of 2,3-dihydrofuran or cyclopropane derivatives via the reaction of ylides with different α, β-unsaturated compounds have been reported.[10-14] However, there is no report on selective synthesis of 2,3-dihydrofuran or cyclopropane derivatives via the same starting materials under different conditions.

As a sort of multi-functionalized building blocks, β,γ-unsaturated α-ketoester has recently been found useful utility in organic synthesis.[15,16] In this work, we report the selective synthesis of 2,3-dihydrofuran or cyclopropane derivatives via reaction of β,γ-unsaturated α-ketoesters with α-phenacyl bromide in different conditions.

We initiated our study by treatment of 2-bromo-1-phenylethanone **(1a)**, (*E*)-methyl

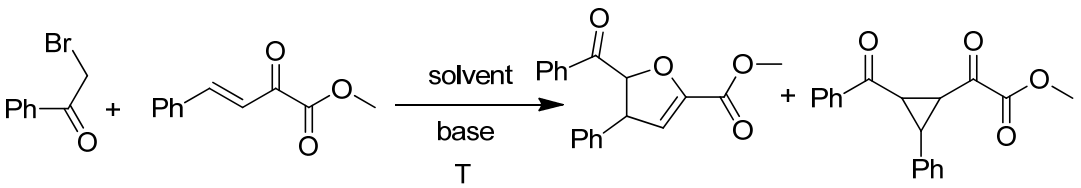
2-oxo-4-phenylbut-3-enoate **(2a)** with K_2CO_3 in CH_2Cl_2 at room temperature for 48 h (Scheme 1), the reaction afforded 2,3-dihydrofuran derivative **(3a)** in 76% yield and a single cyclopropane derivative isomer in 15% yield **(4a)**.



Scheme 1. Formation of the 2,3-dihydrofuran and cyclopropane derivatives

Further, we carried out this reaction in different conditions (Table 1). It was found that when NaOH or Et_3N was employed as base, (*E*)-methyl 2-oxo-4-phenylbut-3-enoate **(2a)** was full consumed but neither traces of **3a** nor **4a** was formed (entries 2 and 3). Completely no reaction occurred between **1a** and **2a** in the presence of DABCO in CH_2Cl_2 (entry 4). When the reaction was treated in the presence of DBU (3 eq) at room temperature, **3a** was obtained in 88% and only a few trace of cyclopropanes was detected (entry 5). When the reaction was quenched at 1.5 h, the reaction become complex and the yield of 2,3-dihydrofuran derivative reduced to 24% (entry 6). The combination of DABCO with K_2CO_3 as base did not obtain **3a**, the major product was **4a** (entry 7). CH_2Cl_2 was found to be the best solvent of choice for the synthesis of **3a**, other solvents such as THF, toluene, MeCN and DMF gave **3a** in a moderate yield (entries 8-11).

Table 1. Selective synthesis of **3a** and **4a**[a]



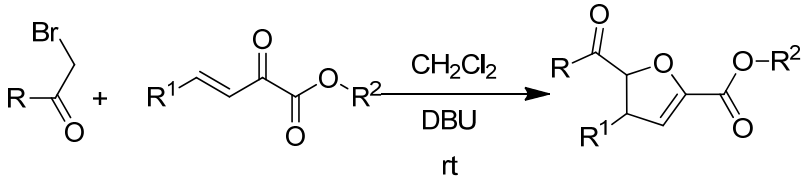
entry	base	solvent	time (h)	Yield 3a (%)[b]	dr (3a)[c]	yield 4a (%) [b]
1	K_2CO_3	CH_2Cl_2	48	76	1:1	15
2	NaOH	CH_2Cl_2	1	--		--
3	Et_3N	CH_2Cl_2	48	--		--

4	DABCO	CH_2Cl_2	48	--		--
5	DBU[d]	CH_2Cl_2	0.5	88	1:1	trace
6	DBU[d]	CH_2Cl_2	1.5	24	--	--
7	DABCO/K_2CO_3(1:1)	CH_2Cl_2	48	--		60[e]
8	DBU[d]	THF	0.2	76	1:1	trace
9	DBU[d]	toluene	0.3	70	1:1	trace
10	DBU[d]	MeCN	0.2	73	1:1	trace
11	DBU[d]	DMF	0.2	78	1:1	trace
12	DABCO/K_2CO_3(1:1)	THF	48	--		56[e]
13	DABCO/K_2CO_3(1:1)	MeCN	48	--		52[e]

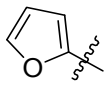
[a]reaction conditions: 2-bromo-1-phenylethanone (**1a** 1.5 mmol), (*E*)-methyl 2-oxo-4-phenylbut-3-enoate (**2a**, 1.0 mmol), base (1.5 mmol), and solvent (3 mL). [b]isolated yield. [c]determined by ^{1}H NMR. [d]base (3.0 equiv). [e]major isomer of cyclopropane derivatives.

Having established optimal reaction conditions for the synthesis of **3a**, we investigated the scope and limitation of substrates by employing various β,γ-unsaturated α-ketoesters and halides (Table 2). It was observed that aromatic substrates bearing an electron-donating groups (entries 2 and 4), and electron-withdrawing groups (entries 3 and 5) all gave the corresponding 2,3-dihydrofuran derivatives. However, (*E*)-methyl 4-(furan-2-yl)-2-oxobut-3-enoate was not suitable for such transformation and no desired product was observed (entry 6). The ester groups in R^2 have less effect on the yield (entry 7). 1-Bromopropan-2-one could also react with (*E*)-methyl 2-oxo-4-phenylbut-3-enoate to afford corresponding product (entry 8).

Table 2. Synthesis of 2,3-dihydrofuran derivatives[a]



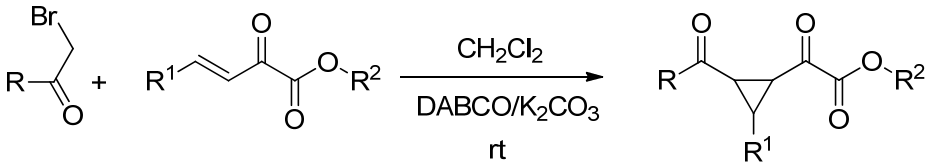
entry	R	R^1	R^2	time (h)	dr[b]	product	yield(%)[c]
1	Ph	Ph	Me	0.3	1:1	3a	88
2	*p*-MeC_6H_4	Ph	Me	0.3	1:0.8	3b	82

3	*p*-ClC_6H_4	Ph	Me	0.2	1:0.9	3c	83
4	Ph	*p*-MeC_6H_4	Me	0.2	1:1	3d	80
5	Ph	*p*-ClC_6H_4	Me	0.2	1:0.5	3e	82
6	Ph		Me	0.4	---		--
7	Ph	Ph		0.3	1:0.8	3f	84
8.	Me	Ph	Me	0.2	1:1	3g	86

[a]reaction conditions: 2-bromo-1-phenylethanone (**1a** 1.5 mmol), β,γ-unsaturated α-ketoester (1.0 mmol), DBU (3.0 mmol), solvent (3.0 mL) . [b]determined by ^{1}H NMR. [c]isolated yield.

Further, we synthesized various cyclopropane derivatives by using various β,γ-unsaturated α-ketoesters and halides with the combination of DABCO and K_2CO_3 as base in CH_2Cl_2 at room temperature (Table 3). To our delight, smooth reactions were observed for all substrate and delivered the final products in moderate yields (entries 1-6). However, the reaction of 1-bromopropan-2-one with (*E*)-methyl 2-oxo-4-phenylbut-3-enoate did not give the desired product (entry 7).

Table 3. Synthesis of cyclopropane derivatives [a]

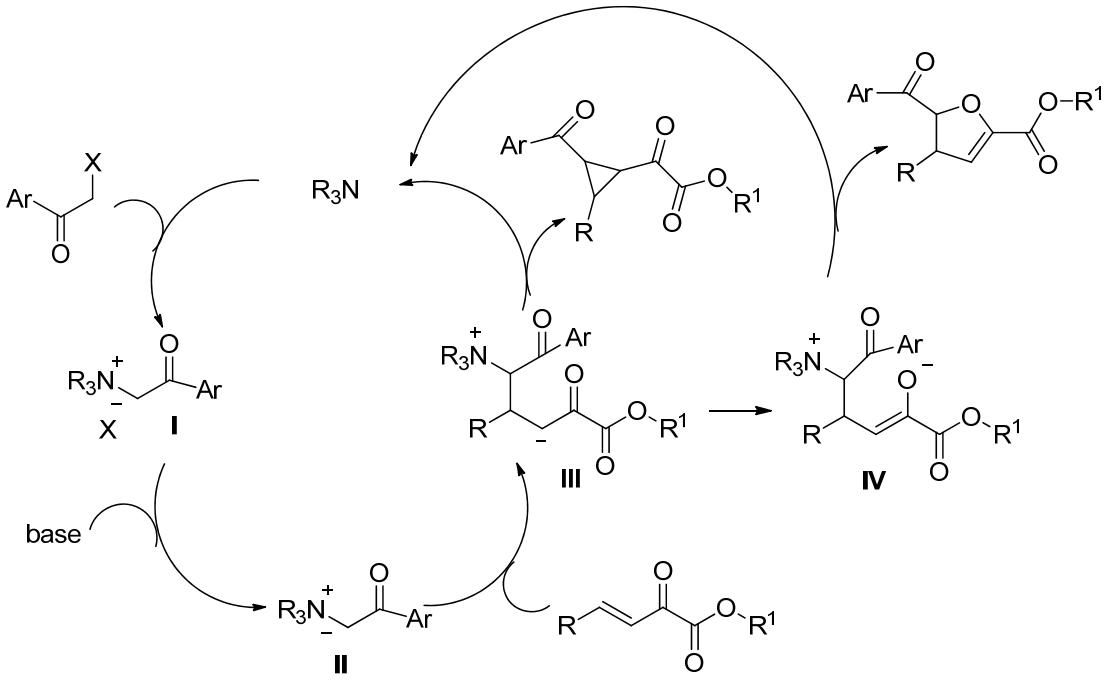


entry	R	R^1	R^2	time (h)	dr[b]	product	yield(%)[c]
1	Ph	Ph	Me	48	0.8:1:6	4a	64
2	*p*-MeC_6H_4	Ph	Me	48	1:1:5	4b	52
3	*p*-ClC_6H_4	Ph	Me	48	1:1:5	4c	54
4	Ph	*p*-MeC_6H_4	Me	48	1:1:6	4d	58
5	Ph	*p*-ClC_6H_4	Me	48	1:1:5	4e	50
6	Ph	Ph		48	0.5:1:6	4f	66

7.	Me	Ph	Me	48	--	--

[a]reaction conditions: 2-bromo-1-phenylethanone (**1a** 1.5 mmol), β,γ-unsaturated α-ketoesters (1.0 mmol), DABCO (1.5 mmol), K_2CO_3 (1.5 mmol), solvent (3.0 mL). [b]determined by isolated weight. [c]isolated yield of the major isomer of cyclopropane derivatives.

A plausible reaction mechanism is proposed in Scheme 2. First, the quaternary ammoonium salt **I** was produced from the addition of α-phenacyl bromide to the tertiary amine. Deprotonation of **I** with base forms the ylide **II**, which undergoes Michael addition with β,γ-unsaturated α-ketoester to afford the intermediate **III**. The intermediate **III** under ring-closing reaction by internal S_N2 reactions forms cyclopropane derivatives, whereas tautomerization of the intermediate **III** leads to generation of **IV**, followed by intramolecular cyclization of **IV** to form 2,3-dihydrofurans.



Scheme 2. Formation of dihydrofurans and cyclopropanes

In summary, we have developed a convenient and efficient method for the synthesis of 2,3-dihydrofuran and cyclopropane derivatives. The reaction takes place via [4+1] or [2+1]-cycloaddition of β,γ-unsaturated α-ketoesters with α-phenacyl bromide. We believe that this method would give a new viable entry to highly functionalized dihydrofurans and cyclopropanes.

EXPERIMENTAL

Column chromatography was carried out on silica gel. The ^{1}H and ^{13}C NMR spectra were recorded at 300 and 75 MHz, respectively. All reagents were used directly as obtained commercially unless otherwise noted.

General procedure for the synthesis of 2,3-dihydrofuran derivatives

DBU (3.0 mmol) was added to a solution of 2-bromo-1-phenylethanone **1a** (1.5 mmol) and (*E*)-methyl 2-oxo-4-phenylbut-3-enoate **2a** (1.0 mmol) in CH_2Cl_2 (3 mL) at room temperature. The reaction was then stirred and followed by TLC. Upon full consumption of 2-oxo-4-phenylbut-3-enoate **2a.** The solvent was evaporated under reduced pressure. The residue was purified by column chromatography on silica (EtOAc/petroleum ether = 1:6-1:4) to give 2,3-dihydrofuran derivatives.

General procedure for the synthesis of cyclopropane derivatives

K_2CO_3 (3.0 mmol) was added to a solution of 2-bromo-1-phenylethanone **1a** (1.5 mmol), (*E*)-methyl 2-oxo-4-phenylbut-3-enoate **2a** (1.0 mmol) and DABCO (1.5 mmol) in CH_2Cl_2 (3.0 mL) at room temperature. The reaction was then stirred and followed by TLC. Upon full consumption of 2-oxo-4-phenylbut-3-enoate **2a.** The reaction was quenched with 5 mL of water and extracted with CH_2Cl_2 (3×5 mL). The combined organic extracts were washed with water and brine, and dried ($MgSO_4$). After evaporating the solvent under reduced pressure, the residue was purified on silica gel (gelusing EtOAc/petroleum ether = 1:6-1:4) to give cyclopropane derivatives.

Methyl 5-benzoyl-4-phenyl-4,5-dihydrofuran-2-carboxylate (3a)

^{1}H NMR (300 MHz, $CDCl_3$): δ 8.03 (d, *J* = 6.9, 2H), 7.63–7.26 (m, 8H), 7.26 (d, *J* = 16.2, 1H), 6.66 (d, *J* = 16.2, 1H), 4.21 (s, 1H), 3.68 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 190.9, 166.8, 135.2, 135.1, 134.2, 133.8, 128.9, 128.8, 128.5, 126.9, 120.9, 65.7, 63.1, 52.9.

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.91 (d, *J* = 7.2, 2H), 7.62–7.57 (m, 3H), 7.49–7.44 (m, 5H), 6.80 (d, *J* = 16.2, 1H), 6.40 (d, *J* = 16.2, 1H), 4.63 (s, 1H), 3.92 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 190.2, 168.3, 135.7, 135.3, 135.2, 134.2, 129.0, 128.5128.5, 128.3, 127.0, 115.8, 64.8, 61.5, 53.5.

HRMS EI (*m/z*): calcd for $C_{19}H_{16}O_4$, 308.1049; found, 308.1047.

Methyl 5-(4-methylbenzoyl)-4-phenyl-4,5-dihydrofuran-2-carboxylate (3b)

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.82 (d, *J* = 6.9, 2H), 7.28–7.20 (m, 7H), 6.80 (d, *J* = 15.9, 1H), 6.39 (d, *J* = 15.9, 1H), 4.61 (s, 1H), 3.92 (s, 3H), 2.39 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 189.6, 168.4, 145.4, 135.6, 135.4, 132.7, 129.6, 128.7, 128.5, 128.4, 126.9, 116.0, 64.9, 61.4, 53.4, 21.8.

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.93–7.86 (m, 2H), 7.43–7.29 (m, 7H), 6.90 (d, *J* = 15.9, 1H), 6.66 (d, *J* = 15.9, 1H), 4.20 (s, 1H), 3.68 (s, 3H), 2.42 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 190.4, 166.9, 145.4, 135.2, 133.7, 132.6, 129.6, 128.8, 128.7, 126.9, 121.0, 65.7, 63.1, 52.9, 21.9.

HRMS EI (*m/z*): calcd for $C_{20}H_{18}O_4$, 322.1205; found, 322.1204.

Methyl 5-(4-chlorobenzoyl)-4-phenyl-4,5-dihydrofuran-2-carboxylate (3c)

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.99–7.97 (d, *J* = 8.1, 2H), 7.50–7.43 (m, 4H), 7.38–7.25 (m, 3H), 6.89 (d, *J* = 16.2, 1H), 6.64 (d, *J* = 16.2, 1H), 4.15 (s, 1H), 3.68 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 190.0, 166.7, 140.8, 135.1, 133.8, 133.4, 130.0, 129.3, 128.9, 128.8, 126.9, 120.6, 65.7, 63.1, 53.0.

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.86 (d, *J* = 7.5, 2H), 7.46–7.43 (m, 2H), 7.34–7.25 (m, 5H), 6.76 (d, *J* = 15.9, 1H), 6.37 (d, *J* = 15.9, 1H), 4.58 (s, 1H), 3.92 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 189.2, 166.1, 140.8, 135.7, 135.2, 133.5, 129.7, 129.3, 128.6, 126.9, 115.6, 64.7, 61.4, 53.5.

HRMS EI (*m/z*): calcd for $C_{19}H_{15}ClO_4$, 342.0659; found, 342.0654.

Methyl 5-benzoyl-4-*p*-tolyl-4,5-dihydrofuran-2-carboxylate (3d)

^{1}H NMR (300 MHz, $CDCl_3$): δ 8.02 (d, *J* = 7.2, 2H), 7.63–7.61 (m, 1H), 7.53–7.48 (m, 2H), 7.35–7.33 (m, 2H), 7.17–7.15 (m, 2H), 6.88 (d, *J* = 16.2, 1H), 6.59 (d, *J* = 16.2, 1H), 4.21 (s, 1H), 3.68 (s, 3H), 2.35 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 191.0, 166.9, 138.9, 135.1, 134.2, 133.8, 132.4, 129.5, 128.9, 128.5, 126.9, 119.8, 65.7, 63.3, 52.9, 21.3.

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.96–7.79 (m, 2H), 7.60–7.47 (m, 3H), 7.15–7.04 (m, 4H), 6.76 (d, *J* = 15.6, 1H), 6.76 (d, *J* = 15.9, 1H), 4.16 (s, 1H), 3.93 (s, 3H), 2.29 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 190.2, 168.4, 138.5, 135.6, 135.2, 134.2, 132.5, 129.2, 128.9, 128.3, 126.9, 114.7, 64.9, 61.5, 53.4, 21.2.

HRMS EI (*m/z*): calcd for $C_{20}H_{18}O_4$, 322.1205; found, 322.1203.

Methyl 5-benzoyl-4-(4-chlorophenyl)-4,5-dihydrofuran-2-carboxylate (3e)

^{1}H NMR (300 MHz, $CDCl_3$): δ 8.01 (d, *J* = 7.2, 2H), 7.62–7.60 (m, 1H), 7.52–7.47 (m, 2H), 7.37–7.29 (m, 4H), 6.85 (d, *J* = 15.9, 1H), 6.64 (d, *J* = 15.9, 1H), 4.16 (s, 1H), 3.66 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 190.8, 166.7, 135.0, 134.5, 134.3, 133.9, 132.5, 129.0, 128.9, 128.5, 128.2, 121.6, 65.7, 63.0, 53.0.

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.89 (d, *J* = 7.5, 2H), 7.80–7.56 (m, 3H), 7.48–7.03 (m, 4H), 6.74 (d, *J* = 16.2, 1H), 6.38 (d, *J* = 15.9, 1H), 4.64 (s, 1H), 3.92 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 190.1, 168.1, 135.1, 134.4, 134.3, 133.8, 129.0, 128.7, 128.3, 128.2, 128.2, 116.5, 64.8, 61.3, 53.5.

HRMS EI (*m/z*): calcd for $C_{19}H_{15}ClO_4$, 342.0659; found, 342.0658.

Isopropyl 5-benzoyl-4-phenyl-4,5-dihydrofuran-2-carboxylate (3f)

^{1}H NMR (300 MHz, $CDCl_3$): δ 8.06–7.90 (m, 2H), 7.63–7.25 (m, 8H), 6.93–6.34 (m, 2H), 5.28–5.22 (m, 1H), 4.58–4.21 (m, 1H), 1.41–1.01 (m, 6H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 190.6, 190.4, 167.3, 165.7, 135.5, 135.5, 135.3, 135.3,135.1, 134.2, 134.1, 133.7,128.9, 128.9, 128.8, 128.7, 128.6, 128.5, 128.4, 128.3, 126.9 121.3, 116.2, 70.7, 70.3, 66.0, 64.8, 62.8, 61.6, 21.7, 21.4, 21.3.

HRMS EI (*m/z*): calcd for $C_{21}H_{20}O_4$, 336.1362; found, 336.1362.

Methyl 5-acetyl-4-phenyl-4,5-dihydrofuran-2-carboxylate (3g)

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.34-7.23 (m, 5H), 6.88–6.82 (m, 1H), 6.46–6.41 (m, 1H), 3.94–3.55 (4H), 2.24–2.06 (3H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 201.51, 200.58, 167.96, 166.85, 135.52, 135.13, 133.55, 128.72, 126.90, 126.87, 121.15, 116.44, 66.66, 65.31, 63.09, 60.91, 53.26, 53.01, 28.31, 27.57, 23.46, 22.67.

HRMS EI (*m/z*): calcd for $C_{16}H_{18}O_4$, 274.1205; found, 274.1201.

Methyl 2-(2-benzoyl-3-phenylcyclopropyl)-2-oxoacetate (4a)

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.96–7.93 (m, 2H), 7.57–7.23 (m, 7H), 3.87 (s, 3H), 3.46–3.41 (m, 2H), 3.33–3.30 (m, 1H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 194.2, 188.7, 161.0, 137.4, 136.0, 133.8, 128.9, 128.8, 128.6, 127.6, 126.5, 53.2, 39.5, 34.8, 32.2.

HRMS EI (*m/z*): calcd for $C_{19}H_{16}O_4$, 308.1049; found, 308.1046.

Methyl 2-(2-(4-methylbenzoyl)-3-phenylcyclopropyl)-2-oxoacetate (4b)

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.87–7.84 (m, 2H), 7.35–7.24 (m, 7H), 3.87 (s, 3H), 3.45–3.42 (m, 2H), 3.30–3.27 (m, 1H), 2.39 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 193.8, 188.8, 161.0, 144.8, 137.6, 133.6, 129.5, 128.9, 128.8, 127.5, 126.5, 53.2, 39.6, 34.7, 32.0, 21.8.

HRMS EI (*m/z*): calcd for $C_{20}H_{18}O_4$, 322.1205; found, 322.1199.

Methyl 2-(2-(4-chlorobenzoyl)-3-phenylcyclopropyl)-2-oxoacetate (4c)

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.90–7.87 (m, 2H), 7.43–7.23 (m, 7H), 3.88 (s, 3H), 3.42–3.33 (m, 3H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 193.0, 188.5, 160.9, 140.3, 137.2, 134.4, 130.0, 129.1, 129.0, 127.7, 126.4, 53.3, 39.3, 34.8, 32.3.

HRMS EI (*m/z*): calcd for $C_{19}H_{15}ClO_4$, 342.0659; found, 342.0657.

Methyl 2-(2-benzoyl-3-*p*-tolylcyclopropyl)-2-oxoacetate (4d)

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.96–7.93 (m, 2H), 7.57–7.55 (m, 1H), 7.46–7.41 (m, 2H), 7.25–7.15 (m, 4H), 3.88 (s, 3H), 3.43–3.39 (m, 2H), 3.29–3.27 (m, 1H), 2.45 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$): δ

194.3, 188.8, 161.0, 137.3, 136.1, 134.4, 133.8, 129.6, 128.8, 128.6, 126.4, 53.2, 39.8, 34.8, 32.1, 21.1.

HRMS EI (*m/z*): calcd for $C_{20}H_{18}O_4$, 322.1205; found, 322.1203.

Methyl 2-(2-benzoyl-3-(4-chlorophenyl)cyclopropyl)-2-oxoacetate (4e)

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.94–7.91 (m, 2H), 7.60–7.55 (m, 1H), 7.47–7.42 (m, 2H), 7.34–7.31 (m, 2H), 7.19–7.17 (m, 2H), 3.87 (s, 3H), 3.42–3.38 (m, 2H), 3.30–3.25 (m, 1H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 193.9, 188.3, 160.9, 136.0, 135.9, 133.9, 133.3, 129.1, 128.8, 128.6, 127.9, 53.3, 39.3, 34.7, 31.4.

HRMS EI (*m/z*): calcd for $C_{19}H_{15}ClO_4$, 342.0659; found, 342.0656.

Isopropyl 2-(2-benzoyl-3-phenylcyclopropyl)-2-oxoacetate (4f)

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.98–7.96 (m, 2H), 7.57–7.25 (m, 8H), 5.16–5.12 (m, 1H), 3.45–3.42 (m, 2H), 3.33–3.28 (m, 1H), 1.33–1.31 (m, 6H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 194.0, 189.1, 160.1, 137.6, 136.2, 133.7, 128.9, 128.7, 128.6, 128.3, 127.5, 126.5, 70.8, 39.0, 35.1, 32.1, 29.7, 21.6.

HRMS EI (*m/z*): calcd for $C_{21}H_{20}O_4$, 336.1362; found, 336.1360.

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REFERENCES AND NOTES

1. M. M. Faul and B. E. Huff, *Chem. Rev.*, 2000, **100**, 2407.
2. A. Schoop, H. Greiving, and A. Gohrt, *Tetrahedron Lett.*, 2000, **41**, 1913.
3. S. Schabbert and E. Schaumann, *Eur. J. Org. Chem.*, 1998, 1873.
4. T. Tsuji and S. Nishida, 'The Chemistry of the Cyclopropyl Group,' ed. by S. Patai, Wiley and Sons Press, Inc., New York, 1987.
5. F. Gnad and O. Reiser, *Chem. Rev*., 2003, **103**, 1603.
6. J. W. Lee and Y. Dong, *Heterocycles*, 1990, **31**, 1417.
7. K. S. Feldman and M. L. Wrobleski, *J. Org. Chem.*, 2000, **65**, 8659.
8. H. Lebel, J. F. Marcoux, C. Molinaro, and A. B. Charette, *Chem. Rev.*, 2003, **103**, 977.
9. J. Krysiak, T. Kato, H. Gornizka, A. Baceiredo, M. Mikolajczyk, and G. Bertrand, *J. Org. Chem.*, 2001, **66**, 8240.
10. W. Cao, H. Zhang, J. Chen, X. H. Zhou, M. Shao, and C. M. Mark, *Tetrahedron*, 2008, **64**, 163.

11. W. Cao, G. Chen, J. Chen, and R. Chen, *Synth. Commun.*, 2005, **35**, 527.
12. Z. J. Yang, M. J. Fan, R. Z. Mu, W. M. Liu, and Y. M. Liang, *Tetrahedron*, 2005, **61**, 9140.
13. C. Feng, C. F. Lu, Z. X. Chen, N. G. Dong, J. W. Shi, and G. C. Yang, *J. Heterocycl. Chem.,* 2010, **47**, 671.
14. C. P. Chuang and A. I. Tsai, *Synthesis*, 2006, 675.
15. M. Rueping, B. J. Nachtsheim, S. A. Moreth, and M. Bolte, *Angew. Chem. Int. Ed.*, 2008, **47**, 593.
16. Q. G. Wang, X. M. Deng, B. H. Zhu, L.W. Ye, X. L. Sun, C. Y. Zhu, and Y. Tang, *J. Am. Chem. Soc.,* 2008, **130**, 5408.