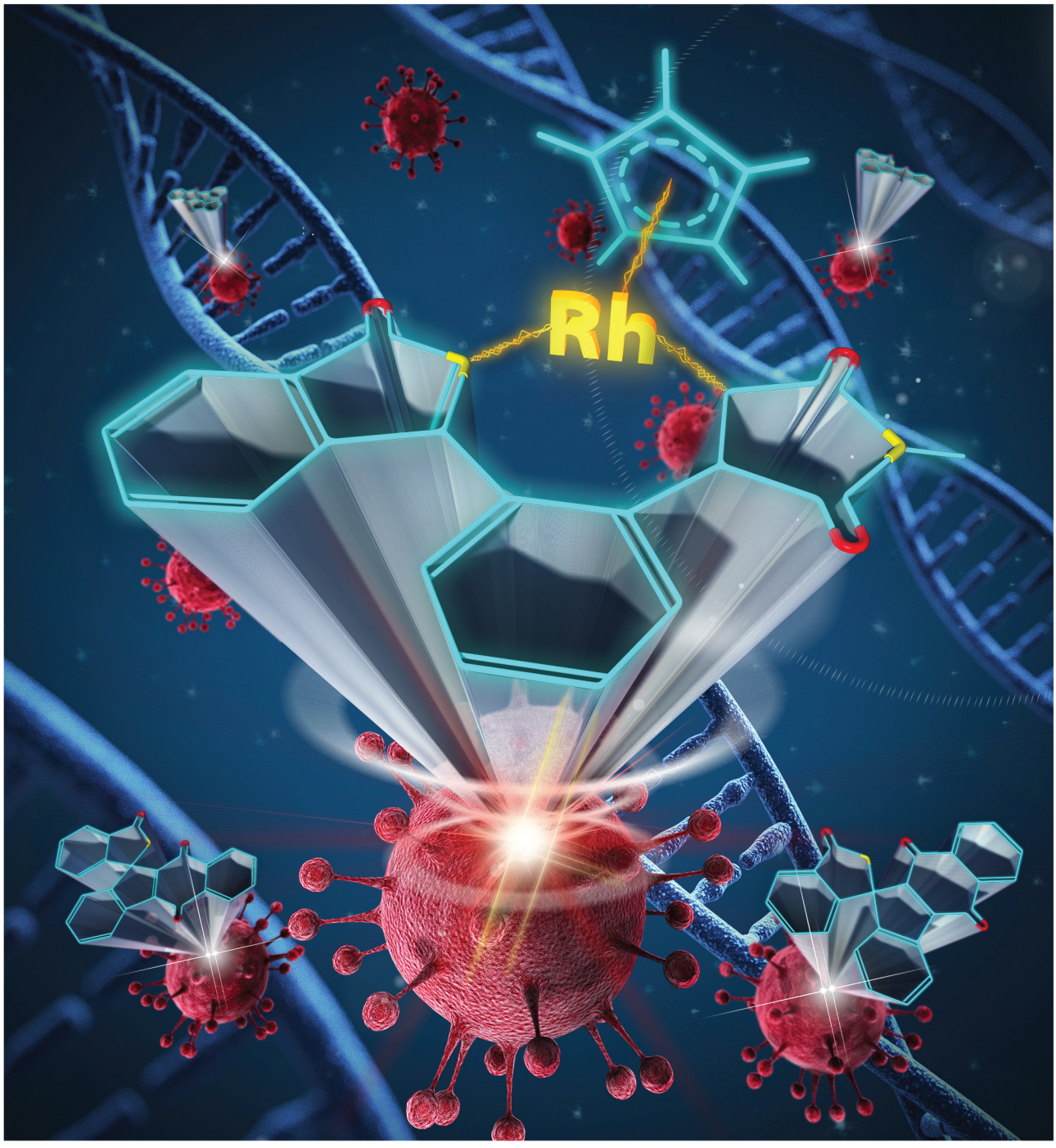
JOC
The Journal of Organic Chemistry
APRIL 7, 2017 VOLUME 82, NUMBER 7 pubs.acs.org/joc



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Oxidation of β-Ketoamides: The Synthesis of Vicinal Tricarbonyl Amides

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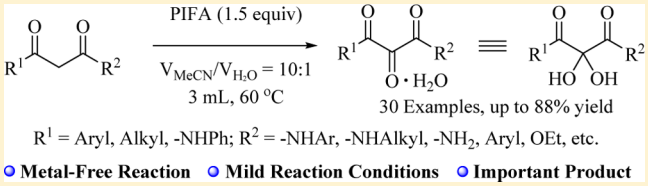
Supporting Information

ABSTRACT: A facile and direct oxidative reaction for the synthesis of vicinal tricarbonyl amides in moderate to excellent yields (53−88%) was developed starting from readily available β-ketoamides in the presence of phenyliodine(III) bis-(trifluoroacetate). The resulting products possess significant synthetic potential, making this approach a valuable addition to the group of traditional methods already available for the preparation of these molecules.



Vicinal tricarbonyls are an important moiety that appears in biologically and pharmaceutically significant compounds, such as the elastase inhibitors YM−47141 and YM−47142 (Figure 1).[1] They are also a key synthon[2] that plays an important role in the construction of some natural products[3] and useful small molecules.[4] Commonly, vicinal tricarbonyl compounds (VTCs) are usually obtained in a mixture of keto and dihydroxy forms,[5] and the *gem*-diol can be easily dehydrated to provide the original free vicinal tricarbonyls under certain conditions,[6] which is indicative of the reversible nature of this system (Figure 2, right box).[7] Recent research has indicated that the reversible addition of alcohols, amines, and thiols to the central carbonyl group of the VTCs can also occur to afford hemiketals, hemiaminals, and hemithioketals, respectively.[8] Generally, three strategies are utilized for the synthesis of VTCs, in which β-ketoamides are always employed as a special case of β-dicarbonyl compounds. First, starting with α-unfunctionalized β-dicarbonyl compounds has been the most efficient way to obtain VTCs in the presence of various oxidation catalytic systems, including DDQ/TEMPO,[9] CAN,[10] *m*-CPBA/$Cu(OAc)_2$,[11] Dess−Martin periodinane (DMP),[12] SeO_2,[13] and $^1O_2/Bu_4NF$,[14] over the past several decades (Figure 2, path a). Second, the conversion of α-mono- and disubstituted β-dicarbonyl derivatives to the desired VTCs constitutes another important route (Figure 2, path b).[13,15] Third, oxidative cleavage of the C═C, C═N, C═S, C═P, and C═I double bonds of some α-methylene-functionalized β-dicarbonyl compounds such as α-diazo-β-dicarbonyls can also afford VTCs.[2,10,16] This involves a two-step procedure consisting of functionalizing the central carbon followed by oxidation with suitable reagents such as ^{t}BuOCl/HCO_2H,[6] 2-iodoxybenzoic acid (IBX),[2] O_2 or O_3,[17] Oxone,[18] DMP,[19] and

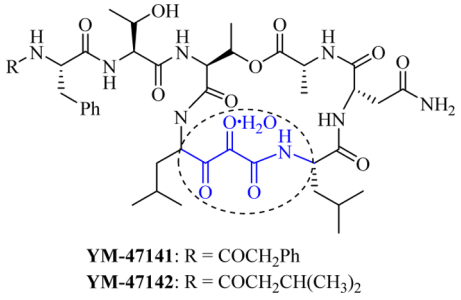


Figure 1. Structure of YM−47141 and YM−47142.

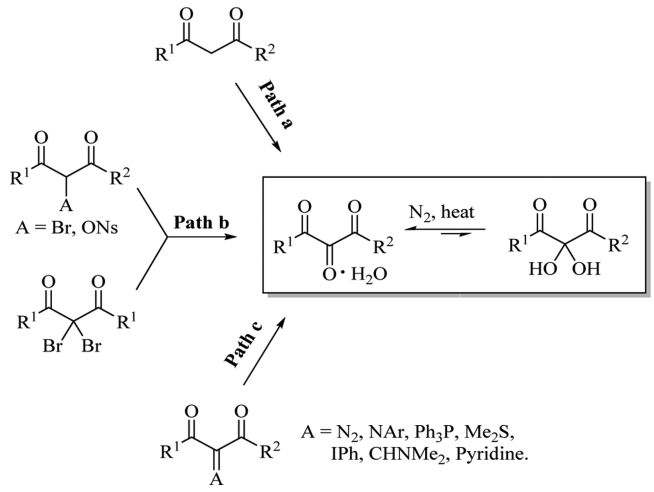
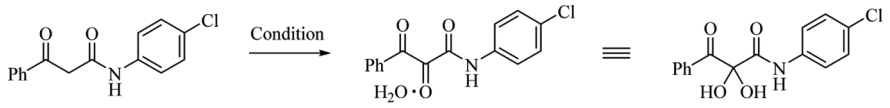


Figure 2. Representative routes to the VTCs and the equilibrium of the dihydroxyl and keto forms.

Received: December 22, 2016
Published: February 23, 2017

DOI: 10.1021/acs.joc.6b03062
J. Org. Chem. 2017, 82, 3901−3907

Table 1. Survey of the Reaction Conditions[a]



1g **2g** **3g**

entry	oxidant (equiv)	solvent	time (h)	yield (%)
1	PIFA (1.5)	MeCN	36	82
2	PIFA (1.5)	MeCN/H_2O (10:1)	10	84
3	PIFA (1.0)	MeCN/H_2O (10:1)	13	74
4	PIFA (2.0)	MeCN/H_2O (10:1)	12	71
5	PIFA (1.5)/40 °C	MeCN/H_2O (10:1)	12	69
6	PIFA (1.5)/80 °C	MeCN/H_2O (10:1)	10	74
7	PIDA (1.5)	MeCN/H_2O (10:1)	13	58
8	PhIO (1.5)	MeCN/H_2O (10:1)	13	63
9	IBX (1.5)	MeCN/H_2O (10:1)	13	49
10	DMP (1.5)	MeCN/H_2O (10:1)	13	55
11	PIFA (1.5)	PEG-400	72	72
12	PIFA (1.5)	EtOH	48	58
13	PIFA (1.5)	dioxane	72	trace[b]
14	PIFA (1.5)	DCE	72	20[c]
15	PIFA (1.5)	DMSO	46	73
16	PIFA (1.5)	DMF	48	74
17	PIFA (1.5)	THF	60	0[d]

[a]Unless otherwise indicated, all reactions were performed with **1** (0.5 mmol) in 3 mL of solvent at 60 °C. [b]71% of **1g** was recovered. [c]61% of **1g** was recovered. [d]93% of **1g** was recovered.

$NaIO_4$ (Figure 2, path c).[20] Although numerous, efficient approaches have been established, a literature review showed a limited number of existing works addressing the systematic construction of vicinal tricarbonyl amides (VTAs) directly using β-ketoamides through a one-step reaction,[12] except for several examples using the strategy of α-methylene-functionalized β-ketoamides by multistep reactions.[17b,19−21] While this work was being prepared, Zhang and co-workers[22] reported a complementary approach to VTCs by an iodosobenzene-mediated direct oxidation of the β-dicarbonyl C−H activation/annulation cascade using electrophilic α-halo and α-pseudohalo ketones assisted by $Fe(NO_3)_3{\cdot}9H_2O$ under mild and environmentally friendly conditions. In their work, only two types of secondary amides were employed, and the desired VTAs were obtained in 67 and 68% yields, respectively. Thus, as one can see, the synthesis of a VTA series using a simple catalytic system with a high yield of the target products has largely been unexplored. Here, we present our recent efforts regarding the PIFA-mediated α-C−H bond oxidative reaction of β-ketoamide derivatives for the synthesis of VTAs.[23]

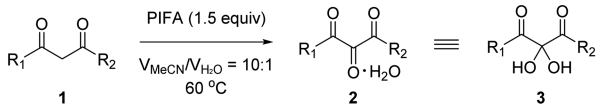
Hypervalent iodine reagents are advanced oxidants and advantageous because of their ready availability, nontoxicity, ease of handling, and environmentally benign characteristics; they have been vastly utilized in many useful organic transformations.[24] Previous works[25] have demonstrated that, in the presence of PIFA and water,[26] the oxidization of amides bearing more active α-positions can generate alcohols, which are easily oxidized to α-diketones.[27] Very recently, we developed two reliable, efficient, green oxidative C−N bond formation reactions in the presence of hypervalent iodine reagents for the synthesis of 1*H*-indazoles[28] and spirocyclopropane quinolinediones under mild conditions.[29] These metal-free reactions inspired us to synthesize other useful synthons, such as VTAs, via α-C−H bond oxidative reactions starting from readily available β-ketoamides in the presence of organoiodine reagents.

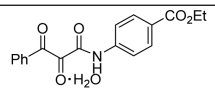
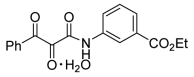
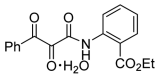
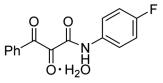
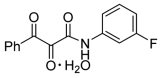
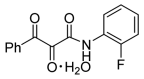
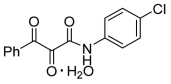
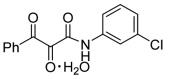
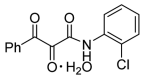
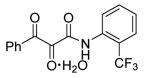
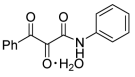
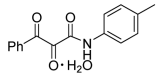
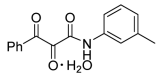
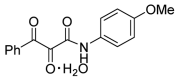
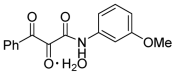
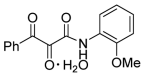
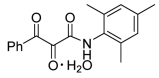
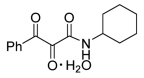
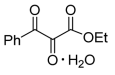
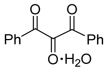
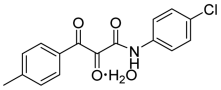
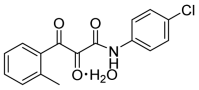
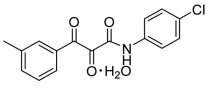
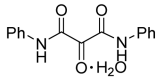
With this assumption in mind, *N*-(4-chlorophenyl)-3-oxo-3-phenylpropanamide (**1g**) was selected as the model substrate to explore the optimal conditions for the oxidative reaction. A portion of the key results are summarized in Table 1. At the beginning, we treated **1g** with 1.5 equiv of PIFA in MeCN (3 mL) at 60 °C. After 36 h, compound **2g**, which was identified by ^{1}H NMR, ^{13}C NMR, and MS, could be obtained in 82% yield after workup followed by column chromatography (Table 1, entry 1). The spectroscopic analysis showed product **2g** was a mixture of the dihydroxy and keto forms; the keto form was the major form. This spectral evidence corresponds with that available in the literature.[2,10] It is worth noting that the ratio of compounds **2** and **3** could be determined on the basis of ^{1}H NMR, but the ratio will vary with the amount of water. Further investigation of the solvent indicated that a certain proportion of water can shorten the reaction time greatly (Table 1, entry 2 vs entry 1), and after many attempts, the ratio of acetonitrile to water was finally determined to be 10:1 (Table 1, entry 2). The yield of **2g** decreased slightly if 1.0 or 2.0 equiv of PIFA was loaded or a lower or higher reaction temperature was employed (Table 1, entries 3−6). Other organoiodine reagents, including diacetoxyiodobenzene (PIDA), PhIO, IBX, and DMP, were screened and found to be not as efficient as PIFA (Table 1, entries 7−10, respectively). Several other solvents, such as PEG-400, EtOH, dioxane, DCE, DMSO, DMF, and THF, resulted in lower yields of **2g** compared with those in the mixed solvent of acetonitrile and water (V_{CH_3CN/H_2O} = 10:1) (Table 1, entries 11−17, respectively).

After having optimized the reaction conditions (Table 1, entry 2), we investigated the substrate scope of this oxidative reaction (Table 2). Initially, various β-ketoamides were investigated (R^2): a number of functional aromatic amine groups bearing -CO_2Et, -CF_3, -F, -Cl, -Me, or -MeO at the

DOI: 10.1021/acs.joc.6b03062
J. Org. Chem. 2017, 82, 3901−3907

Table 2. Reaction Extension[a]



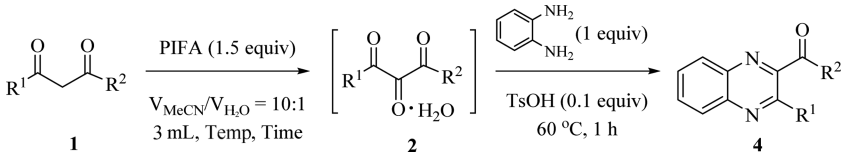
 **2a**: 13 h, 88% (3:1)	 **2b**: 13 h, 76% (4:1)	 **2c**: 13 h, 70% (10:1)	 **2d**: 10 h, 79% (3:1)
 **2e**: 15 h, 86% (2:1)	 **2f**: 11 h, 83% (2:1)	 **2g**: 12 h, 84% (14:1)	 **2h**: 12 h, 84% (9:1)
 **2i**: 11 h, 85% (2:1)	 **2j**: 15 h, 84% (2:1)	 **2k**: 14 h, 72% (5:1)	 **2l**: 13 h, 71% (3:1)
 **2m**: 11 h, 71% (4:1)	 **2n**: 12 h, 80% (5:1)	 **2o**: 14 h, 86% (6:1)	 **2p**: 15 h, 83% (10:1)
 **2q**: 20 h, 71% (2:1)	 **2r:** 12 h, 81% (2:1)	 **2s**: 6 h, 72% (6:1)[b]	 **2t**: 2 h, 88% (7:1)[c]
 **2u**: 12 h, 81% (3:1)	 **2v**: 11 h, 77% (>95:5)	 **2w**: 20 h, 77% (20:1)	 **2x**: 10 h, 53% (>95:5)

[a]Unless otherwise indicated, all reactions were performed with **1** (0.5 mmol) and PIFA (1.5 equiv) in 3 mL of mixed solvents of CH_3CN and H_2O (V_{CH_3CN}:V_{H_2O} = 10:1) at 60 °C, and the ratio of **2** and **3** in parentheses is based on current ^1H NMR. [b]12% of **1s** was recovered, and the yield of **2s** could not be increased by adding 2.5 equiv of PIFA. [c]Reaction performed at room temperature.

ortho, *meta*, or *para* positions were tolerated well (products **2a**–**q**). The ester group, which can be converted easily to other useful functional groups, was suitable for the oxidative reaction and gave **2a**–**c** in good yields (70–88%). Importantly, the chloro and fluoro substituents could be tolerated well in this reaction, thereby facilitating additional modifications at these positions (**2d**–**i**). Furthermore, the CF_3 group also showed high reactivity, leading to **2j** in good yield (84%). Gratifyingly, starting materials **1k**–**q** bearing electron-donating groups on the aromatic ring were also viable for the construction of **2k**–**q**, respectively, in high yields (71–86%). Subsequently, the aliphatic amine substituent cyclohexyl was employed in the reaction and gave a satisfying yield of **2r** (81%). The investigation using *β*-keto ester (**1s**; R^2 = OMe) resulted in an incomplete oxidative reaction. Compound **2s** was isolated in 72% yield along with the recovered starting material **1s** (12%), and the yield of **2s** could not be increased further by prolonging the reaction times. It was found that the dibenzoylmethane compound (**1t**; R^2 = Ph) gave only product **2t** in 53% yield. The reaction toward the benzoyl group (R^1) bearing a -Me at the *ortho*, *meta*, or *para* position on the phenyl ring was also performed with **1u**–**w** under the optimized conditions, and they gave the corresponding VTAs **2u**–**w**, respectively, in 77–81% yields. However, fewer experiments were conducted with

DOI: 10.1021/acs.joc.6b03062
J. Org. Chem. 2017, 82, 3901–3907

Table 3. One-Pot Synthesis of Quinoxaline Derivative 4



entry	R^1	R^2	temp (°C)	time	yield of **4** (%)
1	Me	NHPh	40	4 h	**4y**, 70
2	Me	NH_2	rt	15 min	**4z**, 41
3	Me	$N(Me)_2$	40	4 h	**4a′**, 83
4	^{t}Bu	NHPh	60	8 h	**4b′**, 85
5	^{n}Bu	NHPh	60	5 h	**4c′**, 87
6	^{n}Bu	OMe	60	5 h	**4d′**, 75

varying other arylcarbonyl groups because of the limited number of available substrates at this position. To our delight, diamide **1x** also afforded desired compound **2x** in 53% yield, along with some unidentified complex mixture. This case suggested that the method presented here might be utilized in oxidative reactions including a plurality of amino groups.[30] It should be emphasized that all of the synthesized VTAs are stable enough to be stored at room temperature.

It should be noted that, like in Deng's work in 2014,[9] we also failed to purify aliphatic VTC product **2y** by flash chromatography on silica gel, although a high yield was observed on the thin-layer chromatography (TLC) plate. Accordingly, after **2y** had been produced in situ at 40 °C under the optimal conditions, further derivatization was performed with benzene-1,2-diamine in the presence of 4-methylbenzenesulfonic acid at 60 °C in one pot. As expected, quinoxaline derivative **4y** was isolated in 70% yield after 1 h, which proved the formation of **2y** (Table 3, entry 1). To our delight, four types of other aliphatic β-ketoamides, including **1z**−**c′** and aliphatic β-keto ester **1d′**, could also afford derivatives **4z**−**d′**, respectively, in 41−87% total yields (Table 3, entries 2−5).

In summary, we have demonstrated a facile method for the direct synthesis of VTAs from readily available β-ketoamides in moderate to excellent yields through PIFA-mediated oxidative activation of the sp^3 C−H bond. The advantage of this protocol is associated with readily available starting materials, excellent yields, dense and flexible substituted patterns, and the important synthetic potential of the products. It is noted that different from previous literature reports on the synthesis of VTCs from 1,3-dicarbonyls, our method focuses on the preparation of VTA series. Moreover, as an alternative and valuable route, it may be more practical for the construction of VTA analogue-containing biomolecules.[1,3a,e,31]

EXPERIMENTAL SECTION

General Remarks. All reactions were performed under an air atmosphere, unless otherwise indicated. Other all reagents were purchased from commercial sources and used without further treatment, unless otherwise indicated. Petroleum ether (PE) refers to the 60−90 °C boiling point fraction of petroleum. Ethyl acetate is abbreviated as EA. ^{1}H NMR and ^{13}C{^{1}H} NMR spectra were recorded on a Bruker Avance/600 (600 MHz for ^{1}H and 150 MHz for ^{13}C{^{1}H} at 25 °C) or Bruker Avance/400 (400 MHz for ^{1}H and 100 MHz for ^{13}C{^{1}H} at 25 °C) instrument, with TMS as the internal standard. Data are represented as follows: chemical shift, integration, multiplicity (br, broad; s, singlet; d, doublet; dd, double doublet; t, triplet; q, quartet; m, multiplet), coupling constants in hertz. All high-resolution mass spectra (HRMS) were recorded on a mass spectrometer by using electrospray ionization (ESI-oa-TOF), and the purity of all samples used for HRMS (>95%) was confirmed by ^{1}H NMR and ^{13}C{^{1}H} NMR spectroscopic analysis. Melting points were measured on a melting point apparatus equipped with a thermometer and were uncorrected. All reactions were monitored by TLC with GF254 silica gel-coated plates. Flash chromatography was performed on SiO_2 (silica gel 200−300 mesh).

Typical Experimental Procedure for 2 (2g as an example). To a round-bottom flask (25 mL) were added **1g** (137 mg, 0.5 mmol) and PIFA (323 mg, 0.75 mmol), and the mixture was stirred well in a CH_3CN/H_2O solvent (3 mL) at 60 °C (the whole process was closely monitored by TLC). After 12 h, the residue was purified by short flash silica gel column chromatography (eluent, 3:10 EA/PE) to give *N*-(4-chlorophenyl)-2,3-dioxo-3-phenylpropanamide **2g** as a white solid (128 mg, 84%).

*Ethyl 4-(2,3-Dioxo-3-phenylpropanamido)benzoate (**2a**).* The product was isolated by flash chromatography (eluent, 3:10 EA/PE) as a white solid (151 mg, 88%) with a 3:1 **2a**:**3a** ratio: ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.76 (s, 1H), 8.09 (d, J = 8.4 Hz, 2H), 7.93 (d, J = 7.6 Hz, 2H), 7.76 (d, J = 8.8 Hz, 2H), 7.56 (t, J = 7.6 Hz, 2H), 4.37 (t, J = 7.0 Hz, 2H), 1.40 (t, J = 7.2 Hz, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 193.6, 193.1, 188.5, 167.4, 166.0, 165.9, 156.8, 140.6, 139.7, 135.7, 134.9, 132.0, 131.3, 131.0, 130.84, 130.8, 130.77, 130.6, 129.6, 129.2, 128.8, 127.6, 127.0, 119.4, 119.3, 61.2, 61.1, 14.3; IR (KBr, neat) ν 3503, 3408, 3343, 1713, 1688, 1597, 1525, 1411, 1288, 1182, 1115, 1008, 856, 769 cm^{-1}; HRMS (ESI) calcd for $C_{18}H_{15}NO_5$ ([M + Na]$^+$) m/z 348.0842, found m/z 348.0845.

*Ethyl 3-(2,3-Dioxo-3-phenylpropanamido)benzoate (**2b**).* The product was isolated by flash chromatography (eluent, 3:10 EA/PE) as a white solid (130 mg, 76%) with a 4:1 **2b**:**3b** ratio: ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.90 (s, 1H), 8.24 (s, 1H), 8.06−7.99 (m, 1H), 7.90 (t, J = 9.0 Hz, 2H), 7.69 (t, J = 7.6 Hz, 1H), 7.53 (t, J = 7.8 Hz, 2H), 7.34−7.47 (m, 2H), 4.41−4.32 (m, 2H), 1.38 (t, J = 7.2 Hz, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 193.2, 188.7, 165.8, 156.7, 136.0, 135.59, 134.9, 132.0, 131.8, 130.8, 129.6, 129.5, 129.3, 129.2, 128.8, 126.9, 126.4, 124.3, 124.1, 120.9, 61.4, 14.3; IR (KBr, neat) ν 3265, 3195, 3126, 1733, 1684, 1597, 1533, 1493, 1403, 1092, 827 cm^{-1}; HRMS (ESI) calcd for $C_{18}H_{15}NO_5$ ([M + H]$^+$) m/z 326.1023, found m/z 326.1023.

*Ethyl 2-(2,3-Dioxo-3-phenylpropanamido)benzoate (**2c**).* The product was isolated by flash chromatography (eluent, 3:10 EA/PE) as a white solid (120 mg, 70%) with a 10:1 **2c**:**3c** ratio: ^{1}H NMR (400 MHz, $CDCl_3$) δ 12.58 (s, 1H), 8.72 (d, J = 8.4 Hz, 1H), 8.14 (dd, J = 8.0, 1.6 Hz, 1H), 7.94 (dd, J = 8.4 Hz, 2H), 7.69 (t, J = 7.4 Hz, 1H), 7.57 (m, 3H), 7.27−7.18 (m, 1H), 4.47 (dd, J = 14.4, 7.2 Hz, 2H), 1.45 (t, J = 7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.8, 188.7, 167.8, 157.5, 139.2, 135.4, 134.7, 132.2, 131.3, 129.6, 129.1, 124.4, 120.7, 116.9, 62.0, 14.2; IR (KBr, neat) ν 3234, 3185, 3119, 1697, 1666, 1589, 1529, 1451, 1303, 1281, 1222, 1102, 866, 767, 752 cm^{-1}; HRMS (ESI) calcd for $C_{18}H_{15}NO_5$ ([M + Na]$^+$) m/z 348.0842, found m/z 348.0843.

DOI: 10.1021/acs.joc.6b03062
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*N-(4-Fluorophenyl)-2,3-dioxo-3-phenylpropanamide (**2d**).* The product was isolated by flash chromatography (eluent, 3:10 EA/PE) as a white solid (114 mg, 79%) with a 3:1 **2d**:**3d** ratio: ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.64 (s, 1H), 7.92 (dd, J = 8.4 Hz, 2H), 7.71 (t, J = 7.5 Hz, 1H), 7.67−7.64 (m, 2H), 7.55 (t, J = 7.8 Hz, 2H), 7.11−7.07 (m, 2H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 193.3, 189.0, 161.0, 159.4, 156.4, 135.6, 135.0, 132.1, 130.8, 129.6, 129.2, 128.8, 122.0, 121.9, 121.7, 121.68, 116.3, 116.1, 116.0, 115.9; IR (KBr, neat) ν 3419, 3352, 3067, 1680, 1658, 1595, 1558, 1509, 1209, 1110, 1090, 834 cm^{-1}; HRMS (ESI) calcd for $C_{15}H_{10}FNO_3$ ([M + Na]$^+$) m/z 294.0537, found m/z 294.0541.

*N-(3-Fluorophenyl)-2,3-dioxo-3-phenylpropanamide (**2e**).* The product was isolated by flash chromatography (eluent, 3:10 EA/PE) as a white solid (124 mg, 86%) with a 2:1 **2e**:**3e** ratio: ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.66 (s, 1H), 7.82 (d, J = 7.8 Hz, 2H), 7.62 (t, J = 7.5 Hz, 1H), 7.52 (d, J = 10.2 Hz, 1H), 7.46 (t, J = 7.8 Hz, 2H), 7.25 (s, 2H), 6.86−6.81 (m, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 193.1, 188.6, 163.8, 162.2, 156.6, 137.2, 137.16, 135.6, 132.0, 130.8, 130.6, 130.55, 129.6, 129.2, 128.8, 115.5, 115.4, 112.9, 112.7, 107.7, 107.5; IR (KBr, neat) ν 3454, 3305, 3210, 1737, 1686, 1671, 1614, 1551, 1493, 1449, 1147, 1095, 967, 775 cm^{-1}; HRMS (ESI) calcd for $C_{15}H_{10}FNO_3$ ([M + Na]$^+$) m/z 294.0537, found m/z 294.0538.

*N-(2-Fluorophenyl)-2,3-dioxo-3-phenylpropanamide (**2f**).* The product was isolated by flash chromatography (eluent, 3:10 EA/PE) as a white solid (120 mg, 83%) with a 2:1 **2f**:**3f** ratio: ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.93 (s, 1H), 7.93 (d, J = 7.2 Hz, 2H), 7.56 (t, J = 7.8 Hz, 2H), 7.47 (m, 2H), 7.18 (dd, J = 7.8, 4.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.0, 188.2, 167.2, 156.5, 154.0, 135.6, 134.8, 132.0, 130.8, 129.6, 129.2, 128.7, 126.3, 126.2, 125.7, 124.9, 124.6, 121.8, 121.5, 115.4, 115.2, 115.1; IR (KBr, neat) ν 3386, 3350, 3074, 1696, 1680, 1598, 1530, 1487, 1456, 1412, 1263, 1196, 1116, 992, 925, 846, 780, 754 cm^{-1}; HRMS (ESI) calcd for $C_{15}H_{10}FNO_3$ ([M + Na]$^+$) m/z 294.0537, found m/z 294.0539.

*N-(4-Chlorophenyl)-2,3-dioxo-3-phenylpropanamide (**2g**).* The product was isolated by flash chromatography (eluent, 3:10 EA/PE) as a white solid (128 mg, 84%) with a 14:1 **2g**:**3g** ratio: ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.73 (s, 1H), 7.89 (dd, J = 8.4, 1.6 Hz, 2H), 7.72−7.67 (m, 1H), 7.65−7.60 (m, 2H), 7.53 (t, J = 7.8 Hz, 2H), 7.36−7.32 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.1, 188.6, 156.4, 135.6, 134.3, 131.9, 131.0, 129.5, 129.4, 129.2, 121.2; IR (KBr, neat) ν 3315, 3115, 3061, 1728, 1694, 1666, 1596, 1539, 1493, 1449, 1403, 1220, 1011, 870, 827, 758 cm^{-1}; HRMS (ESI) calcd for $C_{15}H_{10}ClNO_3$ ([M + Na]$^+$) m/z 310.0241, found m/z 310.0246.

*N-(3-Chlorophenyl)-2,3-dioxo-3-phenylpropanamide (**2h**).* The product was isolated by flash chromatography (eluent, 3:10 EA/PE) as a white solid (128 mg, 84%) with a 9:1 **2h**:**3h** ratio: ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.63 (s, 1H), 7.94−7.89 (m, 2H), 7.80 (t, J = 2.0 Hz, 1H), 7.72 (t, J = 7.6 Hz, 1H), 7.59−7.49 (m, 3H), 7.33 (t, J = 8.2 Hz, 1H), 7.23−7.18 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.1, 188.5, 156.5, 136.8, 135.6, 135.0, 131.9, 130.3, 129.5, 129.2, 126.0, 120.1, 117.9; IR (KBr, neat) ν 3300, 3133, 3063, 1734, 1686, 1670, 1597, 1549, 1485, 1449, 1430, 1417, 1225, 1092, 909, 876, 781 cm^{-1}; HRMS (ESI) calcd for $C_{15}H_{10}ClNO_3$ ([M + Na]$^+$) m/z 310.0241, found m/z 310.0240.

*N-(2-Chlorophenyl)-2,3-dioxo-3-phenylpropanamide (**2i**).* The product was isolated by flash chromatography (eluent, 3:10 EA/PE) as a white solid (130 mg, 85%) with a 2:1 **2i**:**3i** ratio: ^{1}H NMR (600 MHz, $CDCl_3$) δ 9.11 (s, 1H), 8.21 (d, J = 8.4 Hz, 1H), 7.93 (d, J = 7.8 Hz, 1H), 7.71 (t, J = 9.0 Hz, 1H), 7.61 (t, J = 6.6 Hz, 2H), 7.55 (dd, J = 16.5, 8.7 Hz, 2H), 7.46 (t, J = 7.8 Hz, 1H), 7.27 (t, J = 6.6 Hz, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 193.4, 192.7, 188.1, 167.5, 156.6, 135.6, 134.9, 133.3, 133.0, 132.0, 131.2, 130.7, 129.6, 129.2, 128.8, 126.6, 126.5, 126.3, 125.8, 125.5, 124.2, 123.2; IR (KBr, neat) ν 3384, 1743, 1700, 1594, 1537, 1462, 1321, 1289, 1190, 1130, 1098, 1037, 765 cm^{-1}; HRMS (ESI) calcd for $C_{15}H_{10}ClNO_3$ ([M + Na]$^+$) m/z 310.0241, found m/z 310.0241.

*N-(2-Trifluoromethyl)- 2,3-dioxo-3-phenylpropanamide (**2j**).* The product was isolated by flash chromatography (eluent, 3:10 EA/PE) as a white solid (142 mg, 84%) with a 2:1 **2j**:**3j** ratio: ^{1}H NMR (600 MHz, $CDCl_3$) δ 9.12 (s, 1H), 8.21 (d, J = 7.8 Hz, 1H), 7.93 (d, J = 7.8 Hz, 1H), 7.71 (t, J = 10.2 Hz, 1H), 7.61 (t, J = 8.1 Hz, 2H), 7.58−7.52 (m, 2H), 7.45 (t, J = 7.8 Hz, 1H), 7.27 (t, J = 7.5 Hz, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 193.4, 192.7, 188.1, 167.5, 156.6, 135.6, 134.9, 133.3, 133.0, 132.0, 131.2, 130.7, 129.6, 129.2, 128.8, 126.6, 126.5, 126.3, 125.8, 125.5, 124.2, 123.2; IR (KBr, neat) ν 3396, 1709, 1594, 1537, 1456, 1321, 1293, 1174, 1120, 1035, 937, 866, 766 cm^{-1}; HRMS (ESI) calcd for $C_{16}H_{10}F_3NO_3$ ([M + Na]$^+$) m/z 344.0505, found m/z 344.0521.

*N-2,3-Dioxo-3-diphenylpropanamide (**2k**).* The product was isolated by flash chromatography (eluent, 3:10 EA/PE) as a white solid (98 mg, 72%) with a 5:1 **2k**:**3k** ratio: ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.82 (s, 1H), 7.96 (d, J = 7.2 Hz, 2H), 7.73 (d, J = 7.6 Hz, 3H), 7.57 (t, J = 7.4 Hz, 2H), 7.42 (t, J = 7.6 Hz, 2H), 7.26 (t, J = 7.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.5, 189.0, 156.5, 135.7, 135.4, 132.0, 130.7, 129.5, 129.3, 129.1, 129.0, 128.6, 125.8, 125.3, 120.0, 119.9; IR (KBr, neat) ν 3345, 3284, 3194, 1689, 1648, 1596, 1532, 1492, 1395, 1325, 1315, 1244, 1164, 1006, 935, 828, 816 cm^{-1}; HRMS (ESI) calcd for $C_{15}H_{11}NO_3$ ([M + H]$^+$) m/z 254.0812, found m/z 254.0810.

*2,3-Dioxo-3-phenyl-N-(p-tolyl)propanamide (**2l**).* The product was isolated by flash chromatography (eluent, 3:10 EA/PE) as a white solid (101 mg, 71%) with a 3:1 **2l**:**3l** ratio: ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.63 (s, 1H), 7.91 (d, J = 7.8 Hz, 2H), 7.54 (dd, J = 15.3, 7.5 Hz, 4H), 7.44 (t, J = 7.2 Hz, 1H), 7.18 (d, J = 7.8 Hz, 2H), 2.34 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 193.9, 193.6, 189.3, 166.9, 156.4, 135.8, 135.5, 134.8, 133.9, 133.3, 132.2, 131.4, 130.8, 129.9, 129.6, 129.5, 129.2, 128.8, 120.2, 119.9, 21.0; IR (KBr, neat) ν 3343, 3033, 2921, 1679, 1598, 1530, 1453, 1403, 1242, 1113, 996, 925, 811, 763 cm^{-1}; HRMS (ESI) calcd for $C_{16}H_{13}NO_3$ ([M + Na]$^+$) m/z 290.0788, found m/z 290.0788.

*2,3-Dioxo-3-phenyl-N-(m-tolyl)propanamide (**2m**).* The product was isolated by flash chromatography (eluent, 3:10 EA/PE) as a white solid (101 mg, 71%) with a 4:1 **2m**:**3m** ratio: ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.59 (s, 1H), 7.91 (d, J = 8.4 Hz, 2H), 7.70 (t, J = 7.5 Hz, 1H), 7.54 (t, J = 7.8 Hz, 3H), 7.28 (d, J = 7.8 Hz, 1H), 7.03 (d, J = 7.8 Hz, 1H), 2.36 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 193.6, 189.3, 156.4, 139.5, 135.7, 135.5, 134.9, 132.2, 130.8, 129.5, 129.2, 129.18, 129.0, 128.8, 126.8, 126.2, 120.5, 117.0, 21.5; IR (KBr, neat) ν 3357, 3066, 2923, 1680, 1614, 1546, 1538, 1491, 1451, 1257, 1113, 1003, 988, 932, 849, 777 cm^{-1}; HRMS (ESI) calcd for $C_{16}H_{13}NO_3$ ([M + H]$^+$) m/z 268.0968, found m/z 268.0968.

*N-(4-Methoxyphenyl)-2,3-dioxo-3-phenylpropanamide (**2n**).* The product was isolated by flash chromatography (eluent, 3:10 EA/PE) as a white solid (120 mg, 80%) with a 5:1 **2n**:**3n** ratio: ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.62 (s, 1H), 7.91 (d, J = 7.8 Hz, 2H), 7.69 (t, J = 7.2 Hz, 1H), 7.60 (d, J = 7.8 Hz, 2H), 7.53 (t, J = 7.5 Hz, 2H), 6.90 (d, J = 7.8 Hz, 2H), 3.81 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 193.6, 189.4, 166.8, 157.4, 156.1, 149.5, 135.4, 129.5, 129.1, 121.4, 114.4, 55.5; IR (KBr, neat) ν 3495, 3323, 3057, 1678, 1598, 1534, 1514, 1448, 1303, 1247, 1125, 1034, 931, 824 cm^{-1}; HRMS (ESI) calcd for $C_{16}H_{13}NO_4$ ([M + Na]$^+$) m/z 306.0737, found m/z 306.0731.

*N-(3-Methoxyphenyl)-2,3-dioxo-3-phenylpropanamide (**2o**).* The product was isolated by flash chromatography (eluent, 3:10 EA/PE) as a white solid (130 mg, 86%) with a 6:1 **2o**:**3o** ratio: ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.65 (s, 1H), 7.95−7.84 (m, 2H), 7.71−7.65 (m, 1H), 7.52 (t, J = 7.6 Hz, 2H), 7.42 (t, J = 2.2 Hz, 1H), 7.26 (m, 1H), 7.14−7.08 (m, 1H), 6.73−6.77 (m, 1H), 3.78 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.5, 189.0, 160.2, 156.4, 136.9, 135.5, 132.0, 130.7, 130.0, 129.5, 129.1, 128.7, 112.1, 112.0, 105.4, 55.3; IR (KBr, neat) ν 3361, 3072, 2994, 1720, 1700, 1672, 1609, 1552, 1498, 1448, 1420, 1294, 1265, 1202, 1176, 1156, 1097, 1045, 960, 851, 839, 786 cm^{-1}; HRMS (ESI) calcd for $C_{16}H_{13}NO_4$ ([M + Na]$^+$) m/z 306.0737, found m/z 306.0738.

*N-(2-Methoxyphenyl)-2,3-dioxo-3-phenylpropanamide (**2p**).* The product was isolated by flash chromatography (eluent, 3:10 EA/PE) as a white solid (125 mg, 83%) with a 10:1 **2p**:**3p** ratio: ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.34 (s, 1H), 8.39 (dd, J = 8.0 Hz, 1H), 7.92 (dd, J = 8.4 Hz, 2H), 7.69 (t, J = 7.4 Hz, 1H), 7.54 (t, J = 7.8 Hz, 2H), 7.16 (m, 1H), 6.99 (t, J = 7.8 Hz, 1H), 6.95 (d, J = 8.4 Hz, 1H), 3.96 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.8, 189.2, 156.4, 148.7, 135.4,

DOI: 10.1021/acs.joc.6b03062
J. Org. Chem. 2017, 82, 3901−3907

132.2, 129.5, 129.2, 125.8, 125.5, 121.2, 120.1, 110.3, 55.9; IR (KBr, neat) ν 3382, 3025, 2970, 1721, 1688, 1669, 1596, 1535, 1488, 1465, 1450, 1318, 1292, 1254, 1217, 1120, 1082, 1025, 937, 865, 785, 757 cm^{-1}; HRMS (ESI) calcd for $C_{16}H_{13}NO_4$ ([M + Na]$^+$) m/z 306.0737, found m/z 306.0738.

*2,3-Dioxo-3-phenyl-N-mesitylpropanamide (**2q**).* The product was isolated by flash chromatography (eluent, 3:10 EA/PE) as a white solid (111 mg, 71%) with a 2:1 **2q**:**3q** ratio: ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.13 (s, 1H), 7.93 (d, J = 7.2 Hz, 2H), 7.70 (t, J = 7.6 Hz, 1H), 7.55 (t, J = 7.8 Hz, 2H), 6.93 (s, 2H), 2.29 (s, 3H), 2.24 (s, 6H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 193.2, 189.1, 157.5, 137.9, 135.4, 134.9, 134.7, 132.1, 130.9, 129.6, 129.2, 129.1, 129.0, 128.7, 21.0, 20.9, 18.4, 17.7; IR (KBr, neat) ν 3335, 3229, 3061, 1660, 1598, 1520, 1449, 1255, 1121, 1006, 927, 854 cm^{-1}; HRMS (ESI) calcd for $C_{18}H_{17}NO_3$ ([M + H]$^+$) m/z 296.1281, found m/z 296.1286.

*2,3-Dioxo-3-phenyl-N-cyclohexylpropanamide (**2r**).* The product was isolated by flash chromatography (eluent, 3:10 EA/PE) as a white solid (112 mg, 81%) with a 2:1 **2r**:**3r** ratio: ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.14 (d, J = 7.2 Hz, 1H), 7.87 (dd, J = 8.4 Hz, 1H), 7.67 (t, J = 7.4 Hz, 1H), 7.51 (t, J = 7.8 Hz, 2H), 3.82 (m, 1H), 1.97 (d, J = 12.0 Hz, 2H), 1.83−1.58 (m, 5H), 1.44−1.00 (m, 7H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.8, 189.2, 168.2, 158.1, 135.2, 130.5, 129.5, 129.0, 128.6, 49.4, 48.7, 32.5, 32.3, 25.2, 24.6; IR (KBr, neat) ν 3305, 3064, 2932, 2855, 1651, 1530, 1450, 1385, 1253, 1178, 1151, 1099, 1062, 1028, 892 cm^{-1}; HRMS (ESI) calcd for $C_{15}H_{17}NO_3$ ([M + Na]$^+$) m/z 282.1101, found m/z 282.1100.

*2,3-Dioxo-3-phenyl-ethylpropanoate (**2s**).*[10] The product was isolated by flash chromatography (eluent, 3:10 EA/PE) as a yellow solid (81 mg, 72%) with a 6:1 **2s**:**3s** ratio: ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.07 (d, J = 7.2 Hz, 2H), 7.62 (t, J = 7.4 Hz, 1H), 7.47 (t, J = 7.8 Hz, 2H), 4.21 (q, J = 7.2 Hz, 2H), 1.08 (t, J = 7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 191.5, 169.9, 134.6, 131.4, 130.1, 130.0, 129.1, 128.8, 63.2, 13.6; HRMS (ESI) calcd for $C_{11}H_{10}O_4$ ([M + Na]$^+$) m/z 229.0471, found m/z 229.0468.

*1,3-Diphenylpropane-1,2,3-trione (**2t**).*[10] The product was isolated by flash chromatography (eluent, 3:10 EA/PE) as a white solid (113 mg, 88%) with a 7:1 **2t**:**3t** ratio: ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.07−8.02 (dd, J = 7.2 Hz, 4H), 7.52 (t, J = 7.4 Hz, 2H), 7.42 (d, J = 7.0 Hz, 1H), 7.38 (t, J = 7.8 Hz, 4H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 194.2, 192.5, 188.3, 172.3, 135.4, 134.6, 133.8, 132.1, 130.3, 130.2, 129.4, 129.1, 128.8, 128.5; HRMS (ESI) calcd for $C_{15}H_{10}O_3$ ([M + Na]$^+$) m/z 261.0522, found m/z 261.0517.

*N-(4-Chlorophenyl)-2,3-dioxo-3-(p-tolyl)propanamide (**2u**).* The product was isolated by flash chromatography (eluent, 3:10 EA/PE) as a white solid (129 mg, 81%) with a 3:1 **2u**:**3u** ratio: ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.67 (s, 1H), 7.81 (d, J = 8.4 Hz, 2H), 7.63 (d, J = 8.8 Hz, 2H), 7.35 (dd, J = 8.8, 6.4 Hz, 4H), 2.46 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 192.6, 188.8, 156.5, 147.1, 134.4, 131.0, 129.9, 129.7, 129.5, 129.2, 121.1, 22.1; IR (KBr, neat) ν 3400, 3348, 3072, 1656, 1605, 1551, 1492, 1404, 1307, 1263, 1090, 1013, 830, 765 cm^{-1}; HRMS (ESI) calcd for $C_{16}H_{12}ClNO_3$ ([M + H]$^+$) m/z 302.0578, found m/z 302.0576.

*N-(4-Chlorophenyl)-2,3-dioxo-3-(o-tolyl)propanamide (**2v**).* The product was isolated by flash chromatography (eluent, 3:10 EA/PE) as a white solid (123 mg, 77%) with a >95:5 **2v**:**3v** ratio: ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.64 (s, 1H), 7.62 (dd, J = 14.0, 9.2 Hz, 3H), 7.55 (t, J = 7.4 Hz, 1H), 7.39−7.31 (m, 4H), 2.69 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 195.2, 188.2, 156.5, 141.4, 134.5, 134.4, 132.7, 132.6, 131.0, 130.5, 129.4, 126.1, 121.1, 21.7; IR (KBr, neat) ν 3316, 3189, 3127, 1733, 1683, 1668, 1600, 1545, 1494, 1403, 1290, 1237, 1176, 1084, 1012, 833, 767 cm^{-1}; HRMS (ESI) calcd for $C_{16}H_{12}ClNO_3$ ([M + H]$^+$) m/z 302.0578, found m/z 302.0573.

*N-(4-Chlorophenyl)-2,3-dioxo-3-(m-tolyl)propanamide (**2w**).* The product was isolated by flash chromatography (eluent, 3:10 EA/PE) as a white solid (123 mg, 77%) with a 20:1 **2w**:**3w** ratio: ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.80 (s, 1H), 7.68 (d, J = 12.4 Hz, 2H), 7.62 (d, J = 8.8 Hz, 2H), 7.49 (d, J = 7.2 Hz, 1H), 7.40 (t, J = 7.6 Hz, 1H), 7.31 (d, J = 8.4 Hz, 2H), 2.40 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.4, 188.7, 156.5, 139.2, 136.4, 134.3, 131.9, 131.0, 129.8, 129.3, 129.0, 126.9, 121.2, 21.2; IR (KBr, neat) ν 3308, 3195, 3060, 1734, 1685, 1666, 1602, 1545, 1494, 1404, 1222, 1078, 1014, 937, 870, 833, 748, 725 cm^{-1}; HRMS (ESI) calcd for $C_{16}H_{12}ClNO_3$ ([M + H]$^+$) m/z 302.0578, found m/z 302.0574.

*2-Oxo-N^1,N^3-diphenylmalonamide (**2x**).* The product was isolated by flash chromatography (eluent, 3:10 EA/PE) as a white solid (76 mg, 53%) with a >95:5 **2x**:**3x** ratio: ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.08 (s, 2H), 7.57 (d, J = 7.6 Hz, 4H), 7.37 (t, J = 7.8 Hz, 4H), 7.17 (t, J = 7.4 Hz, 2H), 4.85 (d, J = 2.8 Hz, 1H), 4.75 (d, J = 2.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 166.4, 136.5, 129.2, 125.3, 120.0, 70.6; IR (KBr, neat) ν 3355, 3307, 3055, 1694, 1599, 1536, 1443, 1312, 1196, 1123, 983, 930, 897 cm^{-1}; HRMS (ESI) calcd for $C_{15}H_{12}N_2O_3$ ([M + Na]$^+$) m/z 291.0740, found m/z 291.0743.

*3-Methyl-N-phenylquinoxaline-2-carboxamide (**4y**).*[32] The product was isolated by the precipitate filtered and washed with ethyl acetate and ether to give a yellow solid (92 mg, 70%): mp 177−179 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.02 (s, 1H), 8.16−8.08 (m, 2H), 7.86 (m, 1H), 7.82−7.78 (m, 3H), 7.42 (t, J = 8.0 Hz, 2H), 7.19 (t, J = 7.4 Hz, 1H), 3.22 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 162.2, 154.6, 143.1, 142.8, 138.9, 137.7, 131.9, 130.0, 129.2, 128.6, 124.7, 120.0, 25.1; IR (KBr, neat) ν 3349, 3055, 2991, 1694, 1595, 1526, 1482, 1441, 1423, 1373, 1315, 1137, 1067, 1008, 912, 881, 779, 758 cm^{-1}; HRMS (ESI) calcd for $C_{16}H_{13}N_3O$ ([M + Na]$^+$) m/z 286.0951, found m/z 286.0940.

*3-Methylquinoxaline-2-carboxamide (**4z**).*[33] The product was isolated by the precipitate filtered and washed with ethyl acetate and ether to give a yellow solid (38 mg, 41%): mp 192−194 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.09−8.05 (m, 2H), 7.89 (d, J = 6.8 Hz, 1H), 7.86−7.81 (m, 1H), 7.74−7.78 (m, 1H), 5.70 (s, 1H), 3.14 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 167.2, 154.3, 143.1, 142.7, 139.2, 131.8, 129.7, 129.3, 128.5, 24.8; IR (KBr, neat) ν 3449, 3264, 3180, 1703, 1583, 1566, 1467, 1412, 1369, 1342, 1211, 1139, 1030, 956, 821, 787, 754 cm^{-1}; HRMS (ESI) calcd for $C_{10}H_9N_3O$ ([M + H]$^+$) m/z 188.0818, found m/z 188.0817.

*N,N,3-Trimethylquinoxaline-2-carboxamide (**4a′**).*[34] The product was isolated by flash chromatography (eluent, 1:2 EA/PE) as a yellow liquid (89 mg, 83%): ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.04 (m, 2H), 7.80−7.70 (m, 2H), 3.22 (s, 3H), 2.94 (s, 3H), 2.76 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 167.5, 151.3, 149.7, 141.6, 139.7, 130.8, 129.7, 129.0, 128.4, 38.2, 34.9, 21.9; IR (KBr, neat) ν 3449, 3068, 2995, 1642, 1502, 1485, 1410, 1321, 1260, 1184, 1123, 1061, 1007, 886, 765 cm^{-1}; HRMS (ESI) calcd for $C_{12}H_{13}N_3O$ ([M + H]$^+$) m/z 216.1131, found m/z 216.1127.

*3-(tert-Butyl)-N-phenylquinoxaline-2-carboxamide (**4b′**).* The product was isolated by the precipitate filtered and washed with ether to give a yellow solid (78 mg, 85%): mp 217−219 °C; ^{1}H NMR (600 MHz, DMSO) δ 10.82 (s, 1H), 8.14 (d, J = 7.8 Hz, 1H), 8.10 (d, J = 7.8 Hz, 1H), 7.94−7.86 (m, 2H), 7.73 (d, J = 7.8 Hz, 2H), 7.40 (t, J = 7.8 Hz, 2H), 7.16 (t, J = 7.5 Hz, 1H), 1.52 (s, 9H); ^{13}C NMR (150 MHz, DMSO) δ 167.1, 160.4, 149.7, 140.8, 139.2, 138.8, 131.5, 130.8, 129.5, 129.2, 128.8, 124.6, 120.0, 39.2, 30.0; IR (KBr, neat) ν 3283, 3254, 1655, 1607, 1561, 1445, 1330, 1166, 1113, 1057, 767, 756 cm^{-1}; HRMS (ESI) calcd for $C_{19}H_{19}N_3O$ ([M + H]$^+$) m/z 306.1601, found m/z 306.1600.

*3-Butyl-N-phenylquinoxaline-2-carboxamide (**4c′**).* The product was isolated by flash chromatography (eluent, 3:10 EA/PE) as a white solid (133 mg, 87%): mp 119−121 °C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 10.00 (s, 1H), 8.12 (t, J = 7.5 Hz, 2H), 7.85 (t, J = 7.5 Hz, 1H), 7.79 (t, J = 8.7 Hz, 3H), 7.42 (t, J = 7.8 Hz, 2H), 7.19 (t, J = 7.5 Hz, 1H), 3.62 (t, J = 7.8 Hz, 2H), 1.91−1.83 (m, 2H), 1.54 (m, 2H), 0.99 (t, J = 7.2 Hz, 3H); ^{13}C NMR (150 MHz, CDC_{l3}) δ 162.2, 158.5, 143.2, 142.8, 138.7, 137.7, 131.7, 129.9, 129.2, 129.1, 128.8, 124.6, 120.0, 36.8, 31.8, 23.0, 14.1; IR (KBr, neat) ν 3349, 2956, 1689, 1599, 1531, 1446, 1361, 1315, 1131, 1070, 913, 777, 755 cm^{-1}; HRMS (ESI) calcd for $C_{19}H_{19}N_3O$ ([M + H]$^+$) m/z 306.1601, found m/z 306.1588.

*Methyl 3-Butylquinoxaline-2-carboxylate (**4d′**).* The product was isolated by flash chromatography (eluent, 3:10 EA/PE) as a colorless oil (92 mg, 75%): ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.17 (d, J = 8.4 Hz, 1H), 8.07 (d, J = 8.4 Hz, 1H), 7.83 (t, J = 7.5 Hz, 1H), 7.76 (t, J = 7.5 Hz, 1H), 4.08 (s, 3H), 3.25 (t, J = 7.8 Hz, 2H), 1.85−1.77 (m, 2H), 1.48 (m, 2H), 0.98 (t, J = 7.2 Hz, 3H); ^{13}C NMR (150 MHz, $CDCl_3$)

DOI: 10.1021/acs.joc.6b03062
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δ 166.2, 156.6, 144.2, 142.7, 139.7, 131.7, 129.8, 129.7, 128.7, 53.3, 35.8, 31.5, 22.8, 13.9; IR (KBr, neat) ν 3443, 2957, 2872, 1732, 1560, 1483, 1465, 1438, 1324, 1263, 1235, 1193, 1125, 1080, 850, 762 cm^{-1}; HRMS (ESI) calcd for $C_{14}H_{16}N_2O_2$ ($[M + H]^+$) m/z 245.1285, found m/z 245.1274.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.joc.6b03062.

^1H and ^{13}C NMR spectra for all compounds (PDF)
Crystallographic data (CIF)

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Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

We thank the NSFC (21272057, 21372065, and U1604285), the Young Backbone Teachers Fund of Henan (2014GGJS-049), the Key Project of Henan Educational Committee (14A150019, 14B150042, 15B610005, and 15A150015), Science & Technology Innovation Talents in Universities of Henan Province (17HASTIT002), the Program of Foundation and Frontier Technology Research of Henan Province (122300410296), and Outstanding Young Talent Cultivation Project Funding of Henan Normal University (14YR002).

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DOI: 10.1021/acs.joc.6b03062
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