Carbonylative Cyclization of *o*-Halobenzoic Acids for Synthesis of *N*-Substituted Phthalimides Using Polymer-Supported Palladium–N-Heterocyclic Carbene as an Efficient, Heterogeneous, and Reusable Catalyst

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Abstract: The carbonylative cyclization of *o*-iodobenzoic acid with a variety of primary amines and carbon monoxide (1 bar) using a polymer-supported palladium–N-heterocyclic carbene complex (PS-Pd-NHC) as the catalyst gives N-substituted 1*H*-isoindole-1,3(2*H*)-diones (phthalimides) in good to excellent yields with a short reaction time. The catalyst is efficient, heterogeneous, and phosphine-free, it exhibited remarkable activity and it is also recyclable (4 consecutive cycles). The use of methyl *o*-iodobenzoate as the substrate under these conditions also gave N-substituted 1*H*-isoindole-1,3(2*H*)-diones, but with lower yields. Cyclization of *o*-iodobenzyl alcohol with carbon monoxide under these conditions gave isobenzofuran-1(3*H*)-one (phthalide).

Key words: carbonylative cyclization, heterogeneous catalysis, N-heterocyclic carbene, phosphine-free, phthalimides, isoindoles

1*H*-Isoindole-1,3(2*H*)-diones (phthalimides) are a key component of the structure of various natural products and biologically important compounds. They also make a vital contribution in medicinal chemistry due to their application in the treatment of acquired immune deficiency syndrome (AIDS) caused by the human immune deficiency virus (HIV),[1] leprosy,[2] and other diseases.[3] Moreover, phthalimide derivatives are known for their pharmacological properties such as antiviral,[4] anticonvulsant,[5] anti-inflammatory,[6] and analgesic activity.[7] Due to their widespread applications, the synthesis of this privileged structure has attracted considerable attention by organic chemists. Typically, phthalimide derivatives are synthesized via condensation of phthalic anhydride with primary amines.[8] In context, Mori et al. reported the palladium-catalyzed formation of phthalimides from *o*-halobenzamides using carbon monoxide.[9] This seminal work was then followed by other groups, who used this reaction to prepare this useful framework, including the synthesis of phthalimide from *o*-haloaryls,[10] or 1,8-diiodonaphthalene[11] using a homogeneous palladium catalyst. Cao and Alper further extended this reaction using a similar protocol that utilized a phosphonium salt ionic liquid.[12] The carbonylative cyclization of *o*-halobenzoates in the synthesis of phthalimides was explored by Worlikar et al.[13] and Buchwald et al.[14] using a homogeneous palladium catalyst. Both C–H bond activation of aromatic amides[15] and the carbonylation of diols[16] using a ruthenium-metal catalyst have been recently explored for phthalimide synthesis. More recently, Chang and coworkers demonstrated the synthesis of N-substituted phthalimides by intermolecular oxidative C–N bond formation.[17]

The literature reveals that, diiodoaryls, dibromoaryls, *o*-halobenzoates, and substituted benzamide have all been utilized as substrates for carbonylative phthalimide synthesis, however the use of inexpensive *o*-halobenzoic acid has not been well explored. On the other hand, these earlier reported protocols for phthalimide synthesis suffered from one or more drawbacks, such as the use of expensive, air/moisture-sensitive phosphine ligands and difficulties associated with catalyst–product separation, thereby limiting their applications. Also, the catalysts used are homogeneous and are not recyclable. Furthermore, these protocols required longer reaction times and higher carbon monoxide pressures, they had limited substrate applicability and they were unreactivity towards heterocyclic amines, and they required higher catalyst loadings; this invites the development of new general methodologies for phthalimide synthesis. To overcome these issues, heterogeneous catalysts that permit the development of an efficient, economical, and facile protocol with the additional advantage of catalyst recyclability are an emerging alternative to earlier reported homogeneous protocols.

Recently, N-heterocyclic carbenes (NHC) have emerged as an attractive alternative to phosphine ligands[18] because of their effective binding ability to transition metals irrespective of their oxidation state. Furthermore, NHC ligands have also shown excellent air/moisture stability and have higher dissociation energies than those of other ligands, which have been quantified by theoretical calculations for different metals.[19] Therefore, the NHC–transition-metal complex is much stronger, as well as being chemically and thermally more inert towards cleavage, than other metal complexes. Therefore researchers are exploring NHC ligands for different organic transformations.[20,21]

Supported transition-metal-complex catalysts are an alternative catalyst system that potentially combine the advantages of homogeneous and heterogeneous catalysts, such as easy separation of the catalyst in large-scale synthesis. The most reasonable technique to support transition-metal

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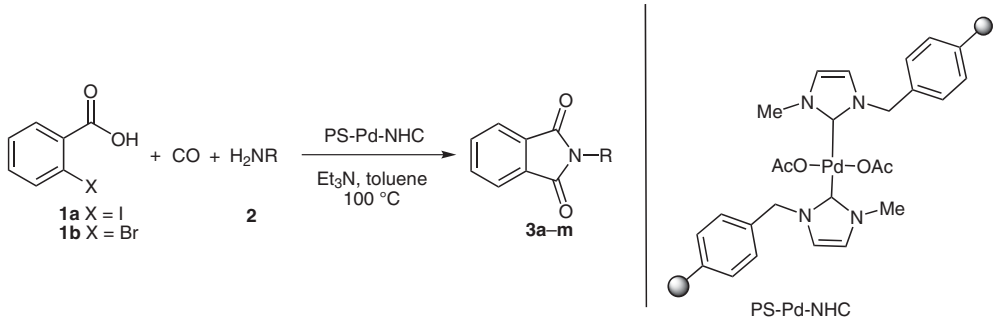


Scheme 1 Carbonylative cyclization of *o*-halobenzoic acid

complexes involves the formation of a chemical bond between the solid support (polymer/resin) and a ligand group in the metal complex. In this way, transition-metal complexes can be attached to the surface of the solid support and this can then be used as heterogeneous catalysts. NHC ligands can bind to the polymer, and polymer-supported N-heterocyclic carbenes (PS-NHC) to form complexes with transition-metal catalysts that have advantages, such as easy recovery, reuse of expensive transition metals and ligands, and the isolation of the product without contamination by metal and ligand impurities. PS-Pd-NHC has been previously used successfully for the Suzuki coupling,[20] carbonylative Suzuki couplings,[21a] and hydrogenation reactions.[21b,c] However, to the best of our knowledge; no such polymer-supported, reusable, catalytic system has yet been explored for the carbonylative cyclization of *o*-halobenzoic acids in the synthesis of phthalimides.

Our continuing interest is in the development of new facile phosphine-free protocols,[22] herein we report a heterogeneous, recyclable protocol for the carbonylative cyclization of *o*-halobenzoic acids using PS-Pd-NHC as the catalyst under atmospheric carbon monoxide pressure (Scheme 1). The methodology permits the synthesis of various aromatic, aliphatic, and heterocyclic *N*-substituted phthalimides in good to excellent yields.

A series of experiments were performed in order to optimize the reaction conditions for the carbonylative cross-coupling reaction using *o*-iodobenzoic acid (**1a**) with aniline (**2a**) as a model system in the presence of PS-Pd-NHC as the catalyst. Various reaction parameters such as the effect of the solvent, catalyst loading, base, temperature, and time were studied (Table 1). The nature of solvent affected the yield of reaction, toluene provided **3a** in an excellent 96% yield, *N*,*N*-dimethylformamide and dimethyl sulfoxide provided lower yields of **3a**, whereas water gave

Table 1 Optimization of Carbonylative Cyclization of *o*-Iodobenzoic Acid[a]

Entry	PS-Pd-NHC (mol%)	Solvent	Base	Temp (°C)	Time (h)	Yield[b] (%)
Effect of solvent						
1	1	DMF	Et_3N	100	4	50
2	1	DMSO	Et_3N	100	4	60
3	1	H_2O	Et_3N	100	4	–
4	1	toluene	Et_3N	100	4	96
5	1.5	toluene	Et_3N	100	4	97
6	0.5	toluene	Et_3N	100	4	89
Effect of base						
7	1	toluene	DBU	100	4	85
8	1	toluene	DABCO	100	4	90
9	1	toluene	K_2CO_3	100	4	50
Effect of temperature and time						
10	1	toluene	Et_3N	80	4	80
11	1	toluene	Et_3N	100	2	90

[a] Reaction conditions: *o*-iodobenzoic acid (**1a**, 1 mmol), aniline (**2a**, 1.5 mmol), base (2 mmol), PS-Pd-NHC, solvent (10 mL), CO (1 bar).
[b] Yields based on GC analysis.

no reaction (entries 1–4); hence toluene was used for further study. We also studied the catalyst loading from 0.5–1.5 mol%; at 0.5 mol% the yield of **3a** was 89%, increasing the catalyst loading to 1 mol% increased the yield of **3a** to 96%, while a further increase had no profound effect (entries 4–6). The reaction was examined using various organic and inorganic bases (entries 4 and 7–9) and triethylamine was found to be the best base in this reaction system. In order to examine the effect of temperature, we carried out the reaction at 80 °C and 100 °C; lower yields resulted at 80 °C (entry 4 vs. entry 10). Performing the reaction for two or four hours showed that a lower yield of **3a** was obtained using the shorter reaction time (entry 11 vs. entry 4). Thus, the optimized reaction conditions were: *o*-iodobenzoic acid (**1a**, 1 mmol), aniline (**2a**, 1.5 mmol of **2a**), PS-Pd-NHC (1 mol%), and triethylamine (2 mmol) in toluene (10 mL) at 100 °C under carbon monoxide (1 bar) for four hours.

With the optimized conditions in hand, we examined the scope of the reaction system with various aromatic, aliphatic, and heterocyclic primary amines for the synthesis of diverse N-substituted phthalimides **3** (Table 2). The reaction of *o*-iodobenzoic acid (**1a**) with aniline (**2a**) under the optimized conditions gave 2-phenyl-1*H*-isoindole-1,3(2*H*)-dione (*N*-phenylphthalimide, **3a**) in 92% isolated yield (entry 1). For the first time the use of the unactivated *o*-bromobenzoic acid (**1b**) was explored in phthalimide synthesis, it gave **3a** in a moderate 55% yield after 24 hours (entry 2). Thereafter, various substituted aromatic amines **2b**–**h** containing electron-donating or electron-withdrawing groups were tested and in all cases good to excellent yield of the expected products **3b**–**h** were obtained (entries 3–9). Aliphatic amines such as butylamine and benzylamine furnished **3i**,**j** respectively in excellent yields (entries 10, 11).

To the best of our knowledge *N*-heterocycle-substituted phthalimides have not previously been synthesized from *o*-halobenzoic acids, using 2-aminothiazole (**2k**) and 5-methylfurfurylamine (**2l**) under these reaction conditions we obtained **3k**,**l**, respectively, in good to excellent yields (entries 12, 13). New phthalimide derivatives, 2-(2-bromophenyl)- (**3g**) and 2-[3-(trifluoromethyl)phenyl]-1*H*-isoindole-1,3(2*H*)-dione (**3m**) were successfully synthesized using this protocol (entries 8 and 14).

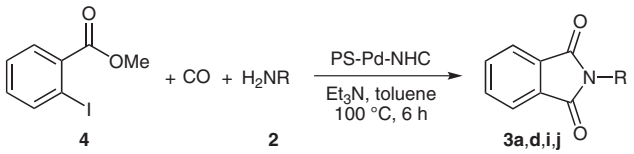
Phthalimide synthesis using *o*-halobenzoates was reported by Worlikar and Larock using palladium(II) acetate with a reaction time of 24 hours.[13] Hence to ensure the applicability of our protocol, we synthesized phthalimides **3a**,**d**,**i**,**j** from methyl *o*-iodobenzoate (**4**) in a short reaction time of six hours, using atmospheric carbon monoxide pressure. In all cases moderate to good yield of the desired products were obtained (Scheme 2, Table 3). Aniline (**2a**) and *p*-toluidine (**2d**) furnished the corresponding products **3a**,**d** in 70% and 75% yields, respectively, whereas aliphatic butylamine (**2i**) and benzylamine (**2j**) provided the corresponding products **3i**,**j** in 79% and 80% yields, respectively.

To expand the scope of this protocol, we investigated the synthesis isobenzofuran-1(3*H*)-one (phthalide, **6**) via a

Table 2 Reaction of *o*-Halobenzoic Acid with Different Aromatic, Aliphatic, and Heterocyclic Amines (Scheme 1)[a]

Entry	*o*-Halobenzoic acid	Amine	R	Product	Yield[b] (%)
1	**1a**	**2a**	Ph	**3a**	92
2[c]	**1b**	**2a**	Ph	**3a**	55
3	**1a**	**2b**	2-naphthyl	**3b**	89
4	**1a**	**2c**	1-naphthyl	**3c**	75
5	**1a**	**2d**	4-MeC_6H_4	**3d**	89
6	**1a**	**2e**	4-$MeOC_6H_4$	**3e**	90
7	**1a**	**2f**	2-MeC_6H_4	**3f**	76
8	**1a**	**2g**	2-BrC_6H_4	**3g**	81
9	**1a**	**2h**	4-AcC_6H_4	**3h**	80
10	**1a**	**2i**	Bu	**3i**	91
11	**1a**	**2j**	Bn	**3j**	90
12	**1a**	**2k**	1,3-thiazol-2-yl	**3k**	80
13	**1a**	**2l**	5-methylfurfuryl	**3l**	85
14	**1a**	**2m**	3-$F_3CC_6H_4$	**3m**	80

[a] Reaction conditions: *o*-halobenzoic acid **1** (1 mmol), amine **2** (1.5 mmol), PS-Pd-NHC (1 mol%), Et_3N (2 mmol), toluene (10 mL), CO (1 bar) 100 °C, 4 h.
[b] Isolated yield.
[c] Reaction time 24 h.



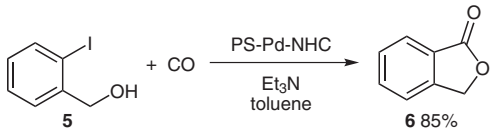
Scheme 2 Carbonylative cyclization of methyl *o*-iodobenzoate

Table 3 Reaction of Methyl *o*-Iodobenzoate (**4**) with Different Aromatic and Aliphatic Amines (Scheme 2)[a]

Entry	Amine	R	Product	Yield[b] (%)
1	**2a**	Ph	**3a**	70
2	**2d**	4-MeC_6H_4	**3d**	75
3	**2i**	Bu	**3i**	79
4	**2j**	Bn	**3j**	80

[a] Reaction conditions: methyl *o*-iodobenzoate (**4**, 1 mmol), amine **2** (1.5 mmol), PS-Pd-NHC (1 mol%), Et_3N (2 mmol), toluene (10 mL), CO (1 bar), 100 °C, 6 h.
[b] Isolated yield.

cyclization reaction of *o*-iodobenzyl alcohol with carbon monoxide under the optimized reaction conditions (Scheme 3). This gave isobenzofuran-1(3*H*)-one (**6**) in excellent yield (up to 85% yield). This observation, and the obtained results, thus suggests that varying the *ortho* substituent on the *o*-haloaryls would lead to the synthesis of various heterocycles, thus highlighting the potentially wide applicability of this protocol.



Scheme 3 Carbonylative cyclization in the synthesis of isobenzofuran-1(3*H*)-one

To confirm that the catalysis was due to the PS-Pd-NHC complex, we performed a hot filtration test.[21a] The carbonylative cyclization reaction of *o*-iodobenzoic acid with aniline was carried under the optimized reaction conditions. Then the PS-Pd-NHC complex was hot-filtered before completion of the reaction, and the filtrate was allowed to react further. We found that, after this hot filtration, no further reaction occurred. This experimental result suggests that the palladium metal did not leach out of polymer support during the reaction. Thereafter ICP-AES analysis of the reaction mixture was also carried and palladium in solution was estimated to be below the detectable level (below 0.01 ppm).

In order to make the catalytic system more economical, we focused on the reusability of the PS-Pd-NHC catalyst using the model system of the carbonylative cyclization of *o*-iodobenzoic acid (**1a**) with aniline (**2a**) in the presence of triethylamine as a base in toluene at atmospheric carbon monoxide pressure. The catalyst exhibited remarkable activity and recyclability for four consecutive cycles without decreasing the activity of the catalyst (Figure 1).

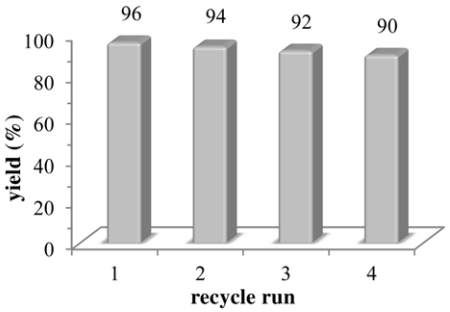
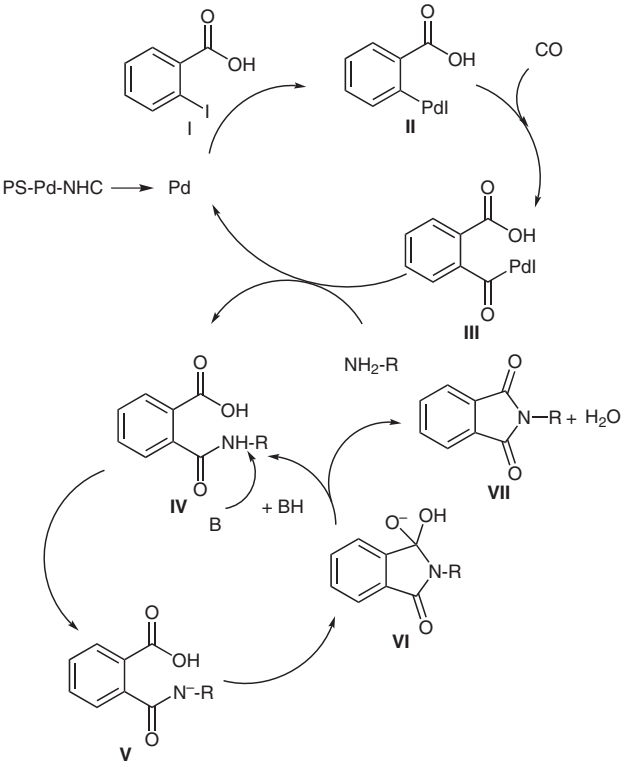


Figure 1 Catalyst recyclability study. *Reaction conditions*: *o*-iodobenzoic acid (**1a**, 1 mmol), aniline (**2a**, 1.5 mmol), PS-Pd-NHC (1 mol%), Et_3N (2 mmol), toluene (10 mL), CO (1 bar), 100 °C, 4 h. Yield based on GC analysis.

A plausible reaction mechanism is presented in Scheme 4. Palladium undergoes oxidative insertion into the carbon–halogen bond of **I** to give intermediate **II**, which then inserts carbon monoxide to form the acylpalladium complex **III**. The acylpalladium complex then reacts with the amine to give intermediate **IV**, which in the presence of base gives intermediate **V**, this is then cyclized to produce intermediate **VI**, which can reductively eliminate to give the corresponding phthalimide product **VII**.[13]



Scheme 4 Plausible reaction mechanism

In conclusion, we have explored the carbonylative cyclization of *o*-halobenzoic acids using polymer-supported palladium–N-heterocyclic carbene complex as a heterogeneous, phosphine-free, and recyclable catalyst for the synthesis of 2-substituted 1*H*-isoindole-1,3(2*H*)-diones (*N*-substituted phthalimides). In this study, the reaction conditions were milder with the additional advantage of easy product isolation. Moreover, the developed protocol was applicable to the synthesis of various 2-substituted 1*H*-isoindole-1,3(2*H*)-diones from different aromatic, aliphatic, and heterocyclic amines with appreciable yields. Catalyst reusability and palladium leaching were also examined, and the catalyst was effectively recyclable for four consecutive runs without any significant loss in catalytic activity. Furthermore, isobenzofuran-1(3*H*)-one was also synthesized using the optimized reaction conditions, which is an additional advantage to this protocol.

All chemicals and reagents were purchased from firms of repute with their highest purity available and were used without further purification. The progress of reaction was monitored by gas chromatography (Perkin Elmer Clarus 400 GC) equipped with capillary column (Elite-1, 30 m × 0.25 mm × 0.25 μm) and a flame ionization detector (FID). Products were purified by column chromatography on silica gel (100–200 mesh). The products are well known in the literature and were confirmed by ^{1}H NMR and GC-MS analysis. Newly synthesized compounds were characterized by ^{1}H NMR, ^{13}C NMR, IR, GC-MS, and HRMS. Polymer-supported palladium–N-heterocyclic carbene complex (PS-Pd-NHC) used was prepared according to the reported procedure in the literature.[19] Loading of palladium catalyst on chloromethyl polystyrene resin support was evaluated by ICP-AES analysis and was found to about 0.29 mmol·g^{-1} of support.[21]

2-Substituted 1*H*-Isoindole-1,3(2*H*)-diones 3; General Procedure

To a 100-mL stainless steel autoclave, *o*-halobenzoic acid **1** or methyl *o*-iodobenzoate (**4**) (1 mmol), **2** amine (1.5 mmol), PS-Pd-NHC (1 mol%), toluene (10 mL), and Et_3N (2 mmol) were added. The autoclave was closed, purged with CO (4 ×), pressurized with 1 atm of CO and then heated at 100 °C for 4 h. After completion of the reaction, the reactor was cooled to r.t. and the remaining CO gas was carefully vented. The reactor was opened and the mixture was filtered, and the vessel was thoroughly washed with EtOAc (2 × 5 mL) to remove any traces of product and catalyst if present. The filtrate obtained was evaporated under vacuum to give the crude product which was purified by column chromatography (silica gel, 100–200 mesh, petroleum ether–EtOAc, 95:5) to afford the desired product **3** with high purity.

Recycling of PS-Pd-NHC Catalyst

The catalyst obtained after filtration was thoroughly washed with distilled H_2O (3 × 5 mL) and then with MeOH (3 × 5 mL) to remove any traces of organic material if present, and dried under reduced pressure. The dried catalyst was then used for catalyst recyclability experiment.

2-Phenyl-1*H*-isoindole-1,3(2*H*)-dione (3a)[22a]
White solid; yield: 205 mg (92%).

IR (KBr): 3079, 1700, 1590, 1489, 1390, 1119, 768, 717 cm^{-1}.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.99 (dd, *J* = 5.5, 3.3 Hz, 2 H), 7.82 (dd, *J* = 5.4, 3.5 Hz, 2 H), 7.43–7.55 (m, 5 H).

GC-MS (EI, 70 eV): *m/z* (%) = 223 (M$^+$, 100), 179 (75), 104 (20), 76 (48), 50 (10).

2-Naphthalen-2-yl-1*H*-isoindole-1,3(2*H*)-dione (3b)[23a]
White solid; yield: 242 mg (89%).

IR (KBr): 3030, 1720, 1600, 1479, 1379, 1075, 852, 722 cm^{-1}.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.00–7.81 (m, 8 H), 7.56–7.53 (m, 3 H).

1-Naphthalen-2-yl-1*H*-isoindole-1,3(2*H*)-dione (3c)[23a]
White solid; yield: 204 mg (75%).

IR (KBr): 3055, 1721, 1569, 1375, 1105, 856, 726 cm^{-1}.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.02–7.83 (m, 6 H), 7.62–7.25 (m, 5 H).

2-(4-Methylphenyl)-1*H*-isoindole-1,3(2*H*)-dione (3d)[13]
Colorless solid; yield: 211 mg (89%).

IR (KBr): 2929, 1706, 1616, 1520, 1380, 1222, 1118, 825, 725 cm^{-1}.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.95 (dd, *J* = 5.1, 3 Hz, 2 H), 7.78 (dd, *J* = 5.1, 3 Hz, 2 H), 7.54–7.26 (m, 4 H), 2.24 (s, 3 H).

GC-MS (EI, 70 eV): *m/z* (%) = 238 (M$^+$, 100), 193 (45), 104 (29), 76 (39).

2-(4-Methoxyphenyl)-1*H*-isoindole-1,3(2*H*)-dione (3e)[10]
White solid; yield: 227 mg (90%).

IR (KBr): 3470, 2955, 1779, 1501, 1475, 1382, 1130, 790, 712 cm^{-1}.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.94 (m, 2 H), 7.78 (m, 2 H), 7.33 (d, *J* = 8.5 Hz, 2 H), 7.02 (d, *J* = 8.5 Hz, 2 H), 3.85 (s, 3 H).

GC-MS (EI, 70 eV): *m/z* (%) = 253 (M$^+$, 100), 238 (65), 210 (18), 209 (16), 130 (12), 106 (20), 76 (35).

2-(2-Methylphenyl)-1*H*-isoindole-1,3(2*H*)-dione (3f)[22a]
White solid; yield: 180 mg (76%).

IR (KBr): 3078, 1727, 1612, 1507, 1383, 1222, 1110, 874, 776, 715 cm^{-1}.

^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.97 (dd, *J* = 5.7, 3 Hz, 2 H), 7.80 (dd, *J* = 5.4, 3 Hz, 2 H), 7.39–7.22 (m, 4 H), 2.22 (s, 3 H).

GC-MS *m/z* (%) = 238 (M$^+$, 100), 191 (25), 104 (26), 76 (45).

2-(2-Bromophenyl)-1*H*-isoindole-1,3(2*H*)-dione (3g)
White solid; yield: 243 mg (81%).

IR (KBr): 2924, 1721, 1478, 1381, 1223, 1110, 888, 719, 529 cm^{-1}.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.98 (dd, *J* = 5.5, 2.5 Hz, 2 H), 7.82 (dd, *J* = 5.5, 2.5 Hz, 2 H), 7.75 (d, *J* = 8 Hz, 1 H), 7.47 (t, *J* = 7.5 Hz, 1 H), 7.38–7.34 (m, 2 H).

^{13}C NMR (125 MHz, $CDCl_3$): δ = 166.61, 135.14, 134.22, 133.86, 132.89, 130.25, 129.13, 127.75, 124.68, 123.33.

GC-MS (EI, 70 eV): *m/z* (%) = 301 (2), 222 (M$^+$, 100), 164 (5), 166 (8), 111 (7), 76 (25).

HRMS (ESI): *m/z* [M + H]$^+$ calcd for $C_{14}H_9NO_2Br$: 301.9817; found: 301.9823.

2-(4-Acetylphenyl)-1*H*-isoindole-1,3(2*H*)-dione (3h)[22a]
Pale yellow solid; yield: 212 mg (80%).

IR (KBr): 2927, 1716, 1596, 1513, 1380, 1221, 829, 720 cm^{-1}.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.13 (d, *J* = 8.5 Hz, 2 H), 8.01 (dd, *J* = 5.5, 3.5 Hz, 2 H), 7.85 (dd, *J* = 5.5, 3.5 Hz, 2 H), 7.65 (d, *J* = 8.5 Hz, 2 H), 2.67 (s, 3 H).

GC-MS (EI, 70 eV): *m/z* (%) = 265 (25), 250 (M$^+$, 100), 222 (29), 166 (20), 104 (28), 76 (20).

2-Butyl-1*H*-isoindole-1,3(2*H*)-dione (3i)[22a]
Colorless liquid; yield: 184 mg (91%).

IR (neat): 3323, 2922, 1765, 1691, 1430, 1335, 1327, 1190, 969, 719 cm^{-1}.

^1H NMR (300 MHz, $CDCl_3$): δ = 7.84–7.83 (m, 2 H), 7.72–7.71 (m, 2 H), 3.69 (t, *J* = 7.5 Hz, 2 H), 1.66 (qt, *J* = 7.5 Hz, 2 H), 1.36 (qt, *J* = 7.5 Hz, 2 H), 0.95 (t, *J* = 7.5 Hz, 3 H).

GC-MS (EI, 70 eV): *m*/*z* (%) = 203 (40), 161 (50), 160 (M^+, 100), 133 (20), 130 (22), 105 (14), 77 (29).

2-Benzyl-1*H*-isoindole-1,3(2*H*)-dione (3j)[22a]
White solid; yield: 213 mg (90%).

IR (KBr): 3555, 2965, 1753, 1716, 1660, 1389, 1189, 1081, 1018, 918, 716 cm^{-1}.

^1H NMR (500 MHz, $CDCl_3$): δ = 7.86–7.87 (m, 2 H), 7.72–7.73 (m, 2 H), 7.45 (d, *J* = 7.5 Hz, 2 H), 7.32–7.34 (m, 3 H), 4.87 (s, 2 H).

GC-MS (EI, 70 eV): *m*/*z* (%) = 237 (M^+, 100), 219 (50), 208 (21), 104 (60), 91 (10), 77 (35).

2-(1,3-Thiazol-2-yl)-1*H*-isoindole-1,3(2*H*)-dione (3k)[22a]
White solid; yield: 184 mg (80%).

IR (KBr): 3082, 1730, 1625, 1501, 1448, 1335, 1190, 751, 714 cm^{-1}.

^1H NMR (500 MHz, $CDCl_3$): δ = 8.03 (dd, *J* = 5.5, 2 Hz, 2 H), 7.85 (dd, *J* = 5.5, 2 Hz, 2 H), 7.83 (d, *J* = 3.5 Hz, 1 H), 7.27 (d, *J* = 3.5 Hz, 1 H).

GC-MS (EI, 70 eV): *m*/*z* (%) = 230 (M^+, 100), 76 (51), 50 (10).

2-(5-Methylfuran-2-ylmethyl)-1*H*-isoindole-1,3(2*H*)-dione (3l)[22a]
Pale yellow solid; yield: 204 mg (85%).

IR (KBr): 3086, 1772, 1616, 1566, 1396, 1334, 1187, 1052, 914, 719, 529 cm^{-1}.

^1H NMR (500 MHz, $CDCl_3$): δ = 7.86–7.85 (m, 2 H), 7.71–7.70 (m, 2 H), 6.23 (d, *J* = 3 Hz, 1 H), 5.87 (d, *J* = 2.1 Hz, 1 H), 4.80 (s, 2 H), 2.24 (s, 3 H).

GC-MS *m*/*z* (%) = 241 (M^+, 100), 226 (18), 198 (70), 170 (26), 95 (39), 78 (56).

2-[3-(Trifluoromethyl)phenyl]-1*H*-isoindole-1,3(2*H*)-dione (3m)
White solid; yield: 203 mg (80%).

IR (KBr): 2921, 1711, 1610, 1456, 1384, 1115, 1069, 877, 715 cm^{-1}.

^1H NMR (500 MHz, $CDCl_3$): δ = 7.98 (dd, *J* = 5.5, 3.5 Hz, 2 H), 7.83 (dd, *J* = 5.5, 3.5 Hz, 2 H), 7.78 (s, 1 H), 7.63–7.70 (m, 3 H).

^{13}C NMR (125 MHz, $CDCl_3$): δ = 166.80, 135.36, 134.09, 132.36, 131.51, 130.32, 129.00, 125.34, 124.68, 124.07, 123.32.

GC-MS (EI, 70 eV): *m*/*z* (%) = 291 (M^+, 100), 247 (92), 104 (32), 76 (72), 50 (20).

HRMS (ESI): *m*/*z* $[M + H]^+$ calcd for $C_{15}H_9NO_2F_3$: 292.0585; found: 292.0584.

Isobenzofuran-1(3*H*)-one (6)
To a 100-mL stainless steel autoclave, *o*-iodobenzyl alcohol (**5**, 1 mmol), PS-Pd-NHC (1 mol%), toluene (10 mL), and Et_3N (2 mmol) were added. The autoclave was closed and pressurized with 1 atm of CO and then heated at 100 °C for 4 h. After completion of the reaction, the reactor was cooled to r.t. and the remaining CO gas was carefully vented. The reactor was opened and the mixture was filtered, and the vessel was thoroughly washed with EtOAc (2 × 5 mL) to remove any traces of product and catalyst if present. Column chromatography (silica gel, 100–200 mesh; petroleum ether–EtOAc, 95:5) gave **6**[23b] as a white solid; yield: 113 mg (85%).

IR (KBr): 3491, 1767, 1713, 1596, 1313, 1289, 1200, 1062, 743, 661, 474 cm^{-1}.

^1H NMR (500 MHz, $CDCl_3$): δ = 7.94 (d, *J* = 7.5 Hz, 1 H), 7.7 (t, *J* = 7 Hz, 1 H), 7.51–7.57 (m, 2 H), 5.35 (s, 2 H).

^{13}C NMR (125 MHz, $CDCl_3$): δ = 171.49, 146.49, 133.89, 129.00, 125.71, 122.07, 69.62.

GC-MS (EI, 70 eV): *m*/*z* (%) = 134 (31), 105 (M^+, 100), 77 (55), 51 (20).

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