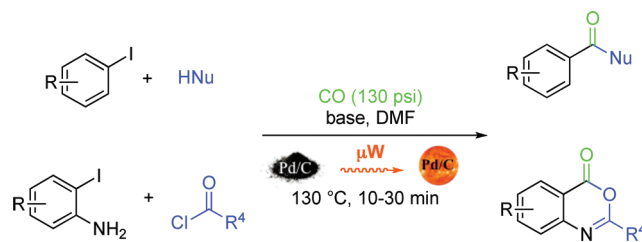# Microwave-Assisted Carbonylation and Cyclocarbonylation of Aryl Iodides under Ligand Free Heterogeneous Catalysis

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Carbonylation reaction is a very effective transformation for the synthesis of esters, amides, and heterocyclic compounds. Heterogeneous catalyzed carbonylation reactions can be carried out using the association of Pd/C and microwave dielectric heating. Alkoxy carbonylation can be performed with stoichiometric amounts of different primary and secondary alcohols in DMF in the presence of DBU as the base. Analogously, iodobenzene, CO, and amines can be transformed into the corresponding amides in good yields after a simple filtration to remove the catalyst. Pd/C was also successfully employed in microwave-assisted cyclocarbonylation of *o*-iodoaniline with acyl chlorides to give benzoxazinones. Pd/C can be recycled two times without a considerable difference in the reaction yields.

## Introduction

Palladium-catalyzed reactions are largely applied to many synthetic transformations for the assembly of a wide range of important molecules in pharmaceutical, agricultural, and natural product chemistry. Using homogeneous palladium catalysis, high reaction rate, turnover numbers (TON), and high selectivities and yields are often possible after addition of opportune ligands, such as phosphines, amines, carbenes, or dibenzylideneacetones (dba).[1] However, the main drawback of homogeneous catalysis is associated with separation and reuse (recycle) of the catalyst. This condition leads to a loss of expensive metal (and ligands) and to the presence of metal impurities in the products. The complete removal of residual metals is a huge problem especially for pharmaceutical products where carryover of metal impurities may cause serious problems in the production of many formulations.[2]

In order to address these problems, heterogeneous Pd catalysis is a promising option. Pd(0) or Pd(II) can be fixed to a solid support such as activated carbon (charcoal), zeolites and molecular sieves, metal oxides (silica, alumina, MgO, ZnO, $TiO_2$, $ZrO_2$), clays, alkali and alkaline earth salts ($CaCO_3$, $BaSO_4$, $BaCO_3$, $SrCO_3$), porous glass, organic polymers, or polymers embedded in porous glass.[3−6] Different Pd nanoparticels are also active catalytic systems due to their large surface area,[7] and some of them have been also used in continuous-flow systems.[7d] Normally, supported Pd

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catalysts require more drastic reaction conditions than homogeneous ones, but this does not cause problems as far as the stability of the catalysts is concerned. The somewhat lower activity can be compensated by using higher temperatures and catalyst loadings. Among heterogeneous Pd sources, palladium activated on carbon (Pd/C) is a commercially available, inexpensive palladium catalyst used only for hydrogenations before the 1990s.[8] More recently, different coupling procedures[5] for carbon−carbon, carbon−oxygen, and carbon−nitrogen bond formation in the presence of Pd/C have been published.[1,9−11] In comparison with other expensive and air-sensitive Pd catalysts, Pd/C is more easily handled and can be recovered from the reaction mixture by simple filtration and reused. It is very stable under acid and basic conditions and has a much higher surface area than alumina- and silica-supported catalysts. It is now the dominant heterogeneous catalyst for industrial application of Pd-catalyzed reactions.

Palladium-catalyzed carbonylation of aryl halides in the presence of nucleophiles is an important atom-economic reaction that can be applied to the synthesis of a wide range of arylcarbonyl compounds[12] such as ketones, carboxylic acids, esters, or amides that can be easily obtained either in solution[12b,13] or in the solid phase.[12e] Most of the carbonylation procedures reported in the literature are based on the use of homogeneous Pd catalysts in the presence of phosphine ligands.[14] However, an excess of phosphine is often required to avoid catalyst deactivation, and its separation from the reaction products and regeneration is usually difficult, limiting the applicability of carbonylation procedures.[15]

Only one patent and three papers report the use of Pd/C in the carbonylation of aryl halides for the synthesis of carboxylic acids or esters.[16−18] Sugi and co-workers[18a] first reported the use of Pd/C to obtain aromatic esters. The procedure has been efficiently applied to the synthesis of polymers using 150 psi of carbon monoxide and heating the reaction mixture at 150 °C for 6 h. Moreover, an excess of nucleophile as well as the use of toxic benzene were required to run the reaction to completion. Chen and Xia[18b] recently extended the application of Pd/C to alkoxycarbonylation and carbonylative Sonogashira coupling reactions of aryl iodides in the absence of copper and phosphine ligands. The procedure for alkoxycarbonylation required a pressure of CO from 72 to 300 psi and temperature of 130 °C. Moreover, the nucleophile was used as the solvent, limiting the application of the procedure to nonvolatile alcohols. On the other hand, the use of a more sophisticated heterogeneous catalysts for aminocarbonylation reaction of aryl halide has been recently investigated in a continuous flow reactor by Csajági and co-workers.[19]

Despite its well-known toxicity, CO is a very valuable and convenient reagent for a variety of reasons: (i) it is thermally quite stable and yet chemically reactive, and (ii) it is an inexpensive carbon source, which can be incorporated into a variety of organic compounds in its entirety without producing any undesirable byproduct. Since its toxicity problem can satisfactorily be dealt with in many instances, CO can be considered an environmentally friendly and convenient C source in an overall sense.[12a,20] $Mo(CO)_6$ is a potential alternative source of CO that was applied to the traditional and microwave-assisted synthesis of amides, esters, and carboxylic acids starting from aryl halides or triflates.[21] However, $Mo(CO)_6$ is highly toxic, and its (over)stoichiometric use results in extreme metal waste, a potential problem in scale-up.[22] Recently, Leadbeater and Kormos first reported microwave-promoted hydroxy- and alkoxycarboxylation of aryl iodides using heavy-walled quartz reaction vessels prepressurized with CO in the presence of $Pd(OAc)_2$ as catalyst; in addition, in this procedure the nucleophile of the reaction is the solvent.[23]

Lately, improvements in design of commercial microwave ovens for organic synthesis allowed the controlled introduction of gases inside the reaction tube that can be considered as a potential autoclave. With this kind of apparatus, hydroformylation,[24] hydroaminomethylation,[25] hydrogenation,[26] and hydroxy-,[23a] alkoxy-,[23b] and aminocarbonylation[27] have been performed under mild conditions.[28] Taking

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**TABLE 1.** Temperature of Different Solvents Reached after Microwave Irradiation in the Presence and Absence of Homogeneous and Heterogeneous Palladium Catalysts[a]

| solvent | bp (°C) | tan δ | T (pure solvent) (°C) | T with Pd(OAc)$_2$[b] (°C) | T with Pd/C[b] (°C) | DT (°C) |
|---------|---------|-------|------------------------|-----------------------------|----------------------|---------|
| DMF | 153 | 0.161 | 139 | 140 | 183 | 44 |
| THF | 66 | 0.047 | 89 | 97 | 132 | 43 |
| toluene | 111 | 0.040 | 66 | 70 | 118 | 52 |
| CCl$_4$ | 76 | n.d. | 62 | 67 | 93 | 31 |

[a]Single-mode sealed vessel microwave irradiation, 150 W constant magnetron output power, 1 mL of solvent, sealed 10 mL Pyrex reaction vessel, magnetic stirring, external sensor. Temperature was monitored by an external IR sensor; starting temperature 30 °C. [b]0.05 mmol.

in account that Pd/C efficiently couples with microwave irradiation because of its strong microwave absorbing support (charcoal),[26b,29] the optimization of a methodology for microwave-assisted carbonylation reactions using Pd/C as catalyst was investigated. In fact, during microwave dielectric heating, Pd/C could be consider as a passive heating element allowing very high temperatures to be reached on catalyst surface and, by conduction, in the reaction medium. Its use could be considered particularly favorable regarding the high temperatures usually required for a wide range of heterogeneous catalyzed reactions. Consequently, we decided to investigate the use of Pd/C in the presence of gaseous carbon monoxide under microwave dielectric heating for carbonylation reaction with stoichiometric amount of nucleophile. A wide range of different procedures for the synthesis of carboxylic acids, esters, amides, and heterocyclic compounds was studied using aryl iodides as substrates.

**Results and Discussion**

In order to qualitatively compare the efficiency of heating Pd/C with homogeneous Pd catalyst (i.e., Pd(OAc)$_2$) under microwave dielectric heating, some simple experiments were carried out by irradiating DMF, CCl$_4$, toluene, and THF at 150 W for 1 min in the presence of Pd catalysts and recording the reaction temperature detected by the IR sensor (Table 1).

These data do not give any information about the temperature on the surface of the heterogeneous catalyst, but they can give an idea of the reaction temperature behavior in the presence of strongly microwave absorbing catalysts.[29,30] It is known that solvents with low tan δ values (CCl$_4$, toluene, or THF) are only slightly heated by microwaves, and in fact, in the absence of the metal, a low heating was observed after long irradiation, probably due to the use of incompletely microwave-transparent vessels. On the other hand, DMF easily reaches higher temperatures after only 1 min of irradiation. Marginally higher temperatures were reached after addition of Pd(OAc)$_2$ (0.05 mmol) to all the solvents investigated, indicating that the presence of the palladium salt itself does not increase the temperature of the reaction mixture under microwaves dielectric heating. When the same amount of Pd/C was added to the solvents, a very high increase of the temperature (from 31 to 52 °C in 1 min depending on the solvent) was observed.

Starting from these data, the possibility of using Pd/C in microwave-assisted carbonylation procedures was evaluated

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**TABLE 2.** Solvent Evaluation on Microwave-Assisted Alkoxycarbonylation of Iodobenzene Using EtOH as Nucleophile
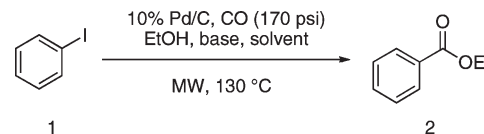
| entry | solvent | base | conversion (%) (yield, %) |
|-------|---------|------|----------------------------|
| 1 | EtOH | K$_2$CO$_3$ | > 99 (90) |
| 2 | THF | K$_2$CO$_3$ | 3 |
| 3 | THF | Cs$_2$CO$_3$ | 6 |
| 4 | THF | DIPEA | 16 |
| 5 | toluene | K$_2$CO$_3$ | |
| 6 | toluene | Cs$_2$CO$_3$ | |
| 7 | toluene | DIPEA | |
| 8 | DCE | K$_2$CO$_3$ | |
| 9 | DCE | Cs$_2$CO$_3$ | 2 |
| 10 | DCE | DIPEA | 33 |
| 11 | DCE | TEA | 32 |
| 12 | DMF | K$_2$CO$_3$ | 93 |
| 13 | DMF | Cs$_2$CO$_3$ | > 99 (88) |
| 14 | DMF | DIPEA | 7 |
| 15 | DMF | TEA | 38 |
| 16 | DMF | DBU | > 99 (95) |

by investigating the transformation of iodobenzene into the corresponding ethyl benzoate (Table 2).[12,18,31]

First, EtOH was used as the solvent, as reported in classical Pd/C and carbonylation reactions,[18,23] using K$_2$CO$_3$ as the base, at 170 psi of CO. Ester **2** was obtained in quantitative yield after 20 min of irradiation by microwaves at 130 °C (entry 1, Table 2). With the aim of using the nucleophile in stoichiometric amounts, the effects on the reaction of different parameters (solvent, base, temperature, and pressure) were examined. In THF and in the presence of inorganic (entries 2 and 3, Table 2) or organic bases (entry 4, Table 2), only a very poor conversion was observed. The reaction did not run at all in toluene (entries 5−7, Table 2) or in 1,2-dichloroethane in the presence of K$_2$CO$_3$ (entry 8, Table 2). Only traces of **2** were detected when Cs$_2$CO$_3$ was used, whereas in the presence of organic bases such as DIPEA and TEA product **2** was obtained in no more than 30% yield (entries 10 and 11, Table 2). Finally, DMF was found to be the best solvent for this transformation. In association with K$_2$CO$_3$, it gave 93% conversion of **1** (entry 12, Table 2), and a higher conversion was observed using Cs$_2$CO$_3$ (entry 13 in Table 2). However, product **2** was recovered only in a 88% yield for the contemporary formation of biphenyl derivative. On the other hand, the association of DMF with DIPEA or TEA gave a decrease in the conversion (entries 14 and 15, Table 2). Finally, the best

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**TABLE 3. Influence of Time, Temperature, And Pressure on Microwave-Assisted Alkoxycarbonylation**

| entry | $T$ (°C) | time (min) | CO (psi) | 1 | 2 | Ph−Ph |
|---|---|---|---|---|---|---|
| | | | | %$^a$ |
| 1 | 140 | 10 | 170 | 61 | 5 | 7 |
| 2 | 140 | 20 | 170 | 35 | 4 | 12 |
| 3 | 130 | 15 | 170 | | 99 | 1 |
| 4 | 130 | 10 | 170 | | >99 | |
| 5 | 130 | 20 | 130 | | 94 | |
| 6 | 130 | 10 | 130 | | 98 | |
| 7 | 130 | 20 | 100 | | 70 | 1 |
| 8 | 130 | 20 | 80 | | 66 | 1 |
| 9 | 130 | 10 | 80 | 84 | 10 | 3 |
| 10 | 130 | 10 | 20 | 98 | 1 | |
| 11 | 130 | 20 | 20 | 95 | 2 | 1 |
| 12 | 120 | 10 | 170 | | 99 | 1 |
| 13 | 120 | 10 | 150 | 7 | 89 | 4 |
| 14 | 120 | 10 | 100 | 76 | 20 | 1 |
| 15 | 120 | 20 | 20 | 98 | 1 | |
| 16 | 100 | 10 | 170 | 89 | 10 | |

$^a$Determined by GC/MS.

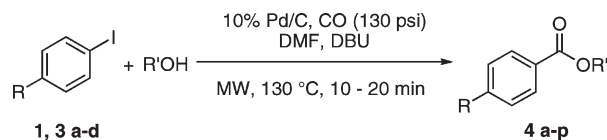conversion and reaction yields were obtained in DMF using DBU as the base (entry 16, table 2).

Fixing DMF/DBU as the best couple solvent/base conditions for stoichiometric alkoxycarbonylation, the influence of time, temperature, and pressure of CO was also investigated (Table 3).

Higher reaction temperatures (140 °C) were tested with the aim to complete the reaction in shorter times, but poor conversions were observed after 10 and 20 min with a growing amount of bipheyl formed together with other byproducts (entries 1 and 2, Table 3). Different attempts were done at 130 °C at different pressures of CO. Using 170 psi, a full conversion was obtained after 10 min of irradiation, and **2** was present as the only reaction product without biphenyl and other byproduct (entries 3 and 4, Table 3). It is interesting to note that also at 130 psi of CO a full conversion is possible in 10 min with high recovery of **2** after a simple acid workup (entry 6, Table 3). When heating was prolonged to 20 min, some products derived from degradation of DBU and DMF were formed lowering the yield of the ester **2** (entry 5, Table 3). Decreasing the pressure (100, 80, and 20 psi), a strong reduction of the conversion was observed (entry 7−11, Table 3). However, lowering the temperature to 120 °C, at 170 psi of CO and irradiating for 10 min, it was possible to obtain compound **2** in good yield. Further reduction of the temperature (entry 16, Table 3) as well as reduction of CO pressure (entries 13−15, Table 3) dramatically lowered the product formed. In conclusion, optimal conditions for alkoxycarbonylation of aryl iodides with stoichiometric amount of EtOH were microwave dielectric heating for 10 min in the presence of 10% Pd/C and DBU in DMF at 130 °C under 130 psi of CO.[33]

The best reaction conditions found on the model substrate were applied to different aryl iodides and alcohols to obtain

**TABLE 4. Generalization of Microwave-Assisted Alkoxycarbonylation Reaction Using Different Alcohols**



| Entry | R'OH | R | Time min | Product (yield) |
|---|---|---|---|---|
| 1 | EtOH | OMe | 10 | **4a** (98%) |
| 2 | EtOH | COOEt | 10 | **4b** (>99%) |
| 3 | EtOH | F | 10 | **4c** (95%) |
| 4 | MeOH | H | 10 | **4d** (>99%) |
| 5 | BuOH | H | 10 | **4e** (95%) |
| 6 | PhCH$_2$OH | H | 10 | **4f** (74%) |
| 7 | CH$_3$(CH$_2$)$_{13}$CH$_2$OH | H | 10 | **4g** (32%) |
| 8 | CH$_3$(CH$_2$)$_{13}$CH$_2$OH | H | 15 | **4g** (74%)$^a$ |
| 9 | $i$-PrOH | H | 15 | **4h** (75%) |
| 10 | $i$-PrOH | OMe | 20 | **4i** (65%) |
| 11 | $i$-PrOH | COOEt | 20 | **4j** (70%) |
| 12 | PhOH | H | 20 | **4k** (75%) |
| 13 | cyclohexyl—OH | H | 10 | **4l** (32%) |
| 14 | cyclohexyl—OH | H | 25 | **4l** (97%)$^a$ |
| 15 | cyclohexylethanol | H | 20 | **4m** (98%) |
| 16 | norborneol | H | 20 | **4n** (96%) |
| 17 | menthol | H | 20 | **4o** (32%)$^b$ |
| 18 | menthol | H | 30 | **4o** (75%) |
| 19 | $t$-BuOH | OMe | 20 | **4p** (20%)$^b$ |

$^a$2 equiv of **1** was used. $^b$No improvement in reaction yields is observed after irradiation for longer times because of dehalogenation of **1**. See reference 32.

the corresponding ester derivatives **4a−p** (Table 4). EtOH, MeOH, and BuOH gave **4a−e** in almost quantitative yields (entries 1−5, Table 4) as phenol, cyclohexylethanol, and norborneol that gave esters **4k−n** in very good yield. It is interesting to note that using menthol as starting material longer reaction times are required in order to obtain **4o** in satisfactory yields (entries 17 and 18, Table 4).

Using benzyl alcohol, the corresponding ester **4f** was obtained in only 74% yield (entry 6, Table 4). In the case of substrates like tatradodecanol, $i$-PrOH, and cyclohexanol, no full conversion was possible (entries 7−11, Table 4). As these substrates may be different from EtOH, the reaction

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(33) (a) The catalyst can be used two times without changing in the reaction yield. A decrease in the reaction yield was observed using Pd/C four times: 2 was in fact isolated in 40% yield. (b) Similar results were obtained using bis-(dibenzyldeneacetone)Pd(0) as homogeneous catalyst, but 15 min of irradiation by microwaves is necessary to obtain full conversion. Using Pd(OAc)$_2$, as previously reported by Leadbeater and Kormos,[23] a large excess of nuclephile is necessary to obtain comparable yields as well as higher pressures of CO (160 psi) and longer reaction times (20 min).

**TABLE 5. Microwave-Assisted Aminocarbonylation Reaction**
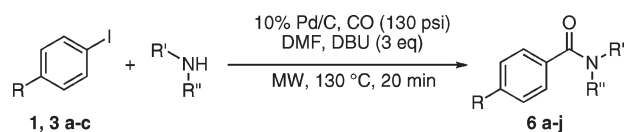


| Entry | amine | R | Product (yield) |
|---|---|---|---|
| 1 | morpholine | H | **6a** (80%) |
| 2 | morpholine | OMe | **6b** (89%) |
| 3 | morpholine | COOEt | **6c** (90%) |
| 4 | MeO–benzylamine | H | **6d** (75%) |
| 5 | MeO–benzylamine | OMe | **6e** (60%) |
| 6 | MeO–benzylamine | COOEt | **6f** (75%) |
| 7 | MeO–benzylamine | F | **6g** (74%) |
| 8 | aniline | H | **6h** (95%) |
| 9 | aniline | F | **6i** (93%) |
| 10 | 5-chloro-2-nitroaniline | H | **6j** (2%)[a] |

[a]Conversion detected by GC–MS.

**TABLE 6. Microwave-Assisted Pd/C-Catalyzed Cyclocarbonylation**
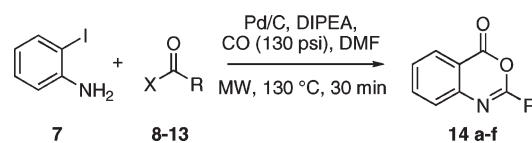


| Entry | XCOR | Product | Yield |
|---|---|---|---|
| 1 | **8** | **14a** | 82% |
| 2 | **9** | **14b** | 80% |
| 3 | **10** | **14c** | 46% |
| 4 | **11** | **14d** | 78% |
| 5 | **12** | **14e** | 45% |
| 6 | **13** | **14f** | 70% |

was also tried using $Cs_2CO_3$ in the place of DBU but with insufficient results. However, a good conversion of tetra-dodecanol and cyclohexanol into esters **4g** and **4l** was observed when 2 equiv of iodobenzene were employed as dehalogenation reaction appeared to be faster than alkoxylation reaction (entries 8 and 14, Table 4). Acceptable yields of 2-propanol esters **4h**−**j** were finally obtained after 15−20 min of irradiation (entries 9−1,1 Table 4). When *t*-BuOH was used, the corresponding ester was obtained only in 20% yield (entry 20, Table 4).

Compared to alkoxycarbonylation,[12a] there are only a few reports on aminocarbonylation reactions even if the conditions for both transformations are similar, reflecting the similarity in their mechanism. Therefore, the use of amines as nuclephiles was investigated as well. Starting from **1** and **3a**−**c**, aryl amides **6a**−**j** were obtained in good yields after only 15 min of irradiation by microwaves using Pd/C as catalyst, in the presence of DBU in DMF at 130 °C (Table 5).

Primary and secondary amines are good substrates for this transformation as well as aniline (entries 1−9, Table 5). However, using deactivated 2-nitro-5-chloroaniline only traces of expected amide **6j** were obtained.[27]

Another interesting application of Pd-catalyzed insertion of CO is the cyclocarbonylation of *o*-iodoanilines with acid chlorides reported by Alper and co-workers;[34−37] this one-pot procedure yielding 2-substituted 4*H*-3,1-benzoxazin-4-ones was achieved using $Pd(OAc)_2$ as the catalyst, at 300 psi of CO and in the presence of DIPEA, heating at 130 °C for 24 h. A good conversion was also possible at lower reaction temperatures (100 °C), but the addition of an opportune ligand appeared to be necessary. We were pleased to observe that when 2-iodoaniline was irradiated with benzoyl chloride for 30 min, at 130 °C in the presence of CO (130 psi) Pd/C and

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DIPEA in DMF, the expected compound **14a** was obtained in 82% yield (entry 1, Table 6).

It is interesting to note that the use of homogeneous palladium sources like Pd(OAc)$_2$ or Pd(PPh$_3$)$_2$Cl$_2$ under our reaction conditions gave only traces of product **14a** with the formation of *N*-phenylbenzamide as the main product.

Cyclocarbonylation with different acyl chlorides or acid activated as hydroxysuccinimido derivatives gave compounds **14a–f** in good yields (Table 6). It is worth noting that when activated acid **11** was the starting material a complete isomerization of double bond in the final product was observed (entry 4, Table 6).

In conclusion, the association of Pd/C and microwave dielectric heating allowed the rapid alkoxy and amino carbonylation of aryl iodides in the presence of a heterogeneous catalyst. Different alcohols and amines can be used in stoichiometric amounts, increasing the potential of the reaction limited until now to the use of the alcohol as the reaction solvent. The versatility of Pd/C as heterogeneous catalyst for carbonylation reaction is also confirmed by the possibility to carry out cyclohydrocarbonylation producing benzoxazinones. The catalyst can be reused at least two times without changing in the reaction yields.[61]

## Experimental Section

**General Remarks.** $^1$HNMR and $^{13}$C NMR spectra were recorded on a 400 MHz instrument at 400 and at 200 MHz, respectively. GC/MS analysis was performed using a CP 8944 column (30 m × 0.250 mm × 0.39 mm). After 5 min at 90 °C, the temperature was increased in 10 °C/min steps up to 280 °C and kept at 300 °C for 4 min. All reactions are performed in a CEM Discover microwave oven equipped with a 10 mL tube for reactions under pressure and an external IR sensor to the detect the reaction temperature during the irradiation (CEM Corporation). This glass vial, tested for resisting up to 250 psi (17 bar, 1723 KPa), is provided with a tube connection to an external pressure controlling system equipped with a valve and an exit tube for venting the vial at the end of the reaction. The exit tube was connected to a cylinder containing CO through a three-way connector equipped with two taps to pressurized the system before microwave irradiation. All products synthesized in this study have been characterized by $^1$H NMR and MS analysis.

**General Procedure for the Synthesis of Esters 2 and 4a–o and Amides 6a–i.** A solution of the aryl iodide (0.50 mmol) and the alcohol or amine (0.50 mmol) in DMF (1 mL) was placed in a 10 mL tube for microwave reactions. DBU (224 μL, 1.50 mmol) and Pd/C 10% (10 mg, 0.01 mmol) were added, and the solution was submitted to pressurized CO (130 psi) and inserted in the cavity of a Discover System (CEM Corp.). After being heated for 20 min at 130 °C at 150 W (value previously settled on the microwave oven), the tube was cooled and the internal gas pressure released. The reaction mixture was filtered, diluted with 1 N HCl, and extracted with EtOAc. The organic layer were washed several times with H$_2$O, dried over anhydrous Na$_2$SO$_4$, and evaporated in vacuo after filtration. The product obtained was purified by flash chromatography (eluent: PE/AcOEt 9:1, esters; PE/AcOEt 6:1 amides).

**Ethyl Benzoate (2).** See ref 38.

**Ethyl 4-Methoxybenzoate (4a).** See ref 39.

**Diethyl Terephthalate (4b).** See ref 40.

**Ethyl 4-Fluorobenzoate (4c).** See ref 41.

**Methyl Benzoate (4d).** See ref 42.

**Butyl Benzoate (4e).** See ref 43.

**Benzyl Benzoate (4f).** See ref 44.

**Pentadecyl Benzoate (4g).** See ref 45.

**Isopropyl Benzoate (4h).** See ref 46.

**Isopropyl 4-Methoxybenzoate (4i).** See ref 47.

**Ethyl Isopropyl Terephthalate (4j).** $^1$H NMR (400 MHz, CDCl$_3$) δ: 8.03 (m, 4H); 5.21 (q, 1H, *J* = 7 Hz); 4.34 (q, 2H, *J* = 7.2 Hz); 1.35 (m, 9H). $^{13}$C NMR (400 MHz, CDCl$_3$) δ: 165.8; 165.2; 134.6; 134.0; 129.1; 68.93; 61.32; 21.2; 14.25. Purification by column chromatography (eluent: petroleum ether/AcOEt 9:1). Yield: 70%. Anal. Calcd for C$_{13}$H$_{16}$O$_4$: C, 66.09; H, 6.83; O, 27.09. Found: C, 66.12; H, 6.78; O, 27.02.

**Phenyl Benzoate (4k).** See ref 48.

**Cyclohexyl Benzoate (4l).** See ref 49.

**2-Cyclohexylethyl Benzoate (4m).** See ref 50.

**Bicyclo[2.2.1]heptan-2-yl Benzoate (4n).** $^1$H NMR (400 MHz, CDCl$_3$) δ: 8.10 (d, 2H, *J* = 7.6 Hz); 7.49−7.58 (m, 3H); 5.15 (m, 1H); 1.63 (m, 2H); 1.39 (m, 4H); 1.26 (m, 1H); 1.12 (m, 1H); 0.33 (m 2H). GC/MS: *m/z* 105. $t_R$: 16.4 min. Yield: 96%. Anal. Calcd for C$_{14}$H$_{16}$O$_2$: C, 77.75; H, 7.46; O, 14.80. Found: C, 77.69; H, 7.42; O, 14.82.

**4-Isopropyl-2-methylcyclohexyl Benzoate (4o).** $^1$H NMR (400 MHz, CDCl$_3$) δ: 8.02 (d, 2H, *J* = 7.6 Hz); 7.50−7.52 (m, 1H); 7.39−7.40 (m, 2H); 4.89−4.92 (m, 1H); 1.72−1.72 (m, 2H); 1.65 (m, 2H); 1.23 (m, 1H); 1.09−1.12 (m, 2H); 0.89−0.91 (m, 9H). Yield: 75%. Anal. Calcd for C$_{17}$H$_{24}$O$_2$: C, 78.42; H, 9.29; O, 12.29. Found: C, 78.48; H, 9.31; O, 12.25.

***tert*-Butyl Benzoate (4p).** See ref 60.

**Morpholino(phenyl)methanone (6a).** See ref 51.

**(4-Methoxyphenyl)(morpholino)methanone (6b).** See ref 52.

**Ethyl 4-(morpholine-4-carbonyl)benzoate (6c).** $^1$H NMR (400 MHz, CDCl$_3$) δ: 8.02 (d, 2H, *J* = 7.5 Hz); 7.39 (d, 2H, *J* = 7.5 Hz); 4.31 (q, 2H, *J* = 7.2 Hz); 3.21−3.70 (m, 8H); 1.32 (t, 3H, *J* = 7.5 Hz). $^{13}$C NMR (400 MHz, CDCl$_3$) δ: 169.3; 165.7; 139.4; 131.6; 129.8; 127.0; 66.7; 61.2; 14.2. Yield: 90%. Anal. Calcd for C$_{14}$H$_{17}$NO$_4$: C, 63.87; H, 6.51; N, 5.32; O, 24.31. Found: C, 63.82; H, 6.57; N, 5.39; O, 24.38.

**N-(4-Methoxybenzyl)benzamide (6d).** See ref 53.

**4-Methoxy-N-(4-methoxybenzyl)benzamide (6e).** $^1$H NMR (400 MHz, CDCl$_3$) δ: 8.39 (d, 2H, *J* = 7.2 Hz); 7.48 (bs, 1H); 7.21−7.25 (m, 2H); 6.80−6.92 (m, 4H); 4.49 (d, 2H, *J* = 6 Hz); 3.86 (s, 3H); 3.76 (s, 3H). Yield: 60%. Anal. Calcd for C$_{16}$H$_{17}$NO$_3$: C, 70.83; H, 6.32; N, 5.16; O, 17.69. Found: C, 70.88; H, 6.39; N, 5.13; O, 17.74.

**Ethyl 4-(4-methoxybenzylcarbamoyl)benzoate (6f).** $^1$H NMR (400 MHz, CDCl$_3$) δ: 7.97 (d, 2H, *J* = 8.4 Hz); 7.78 (d, 2H, *J* = 8.4 Hz); 7.16−7.20 (m, 2H); 6.74−6.85 (m, 2H); 4.51 (d, 2H, *J* = 5.6 Hz); 4.32 (q, 2H, *J* = 7.2 Hz); 3.71 (s, 3H); 1.35 (t, 3H, *J* = 5.6 Hz). $^{13}$C NMR (400 MHz, CDCl$_3$) δ: 166.7; 165.8; 159.9; 139.5; 138.1; 132.9; 129.7; 129.6; 127.1; 120.0; 113.5; 112.8; 61.3; 55.1; 44.1; 14.2. Yield: 75%. Anal. Calcd for C$_{18}$H$_{19}$NO$_4$: C,

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68.99; H, 6.11; N, 4.47; O, 20.42. Found: C, 68.91; H, 6.19; N, 4.39; O, 20.48.

**4-Fluoro-*N*-(4-methoxybenzyl)benzamide (6g).** See ref 54.

***N*-Phenylbenzamide (6h).** See ref 55.

**4-Fluoro-*N*-phenylbenzamide (6i).** See ref 56.

**General Procedure for the Synthesis of Cycles 14a–f.** A solution of the *o*-iodoaniline (0.50 mmol) and acyl chloride (0.75 mmol) in DMF (1 mL) was placed in a 10 mL tube for microwave reactions. DIPEA (261 $\mu$L, 1.50 mmol) and Pd/C 10% (10 mg, 0.01 mmol) were added, and the solution was submitted to pressurized CO (130 psi) and inserted in the cavity of a Discover System (CEM Corp.). After being heated for 30 min at 130 °C at 150 W (value previously settled on the microwave oven), the tube was cooled and the internal gas pressure released. The reaction mixture was filtered, diluted with 1 N HCl, and extracted with $CH_2Cl_2$. The organic layer were washed several times with $H_2O$, dried with dry $Na_2SO_4$, and evaporated in vacuo after filtration. The product obtained was purified by flash chromatography using a 3:2 mixture of PE/AcOEt as eluent.

**2-Phenyl-4*H*-benzo[*d*][1,3]oxazin-4-one (14a).** See ref 57.

**2-Neopentyl-4*H*-benzo[*d*][1,3]oxazin-4-one (14b).** $^1$H NMR (400 MHz, CDCl$_3$) $\delta$: 8.15 (d, *J* = 8.4 Hz, 1H); 7.73 (t, *J* = 6.8 Hz, 1H); 7.48 (d, *J* = 8.4 Hz, 1H); 7.15 (t, *J* = 6.8 Hz, 1H); 2.54 (s, 2H); 1.09 (s, 9H). GC/MS: *m/z* 128. $t_R$: 16.5 min. Yield:

80%. Anal. Calcd for C$_{13}$H$_{15}$NO$_2$: C, 71.87; H, 6.96; N, 6.45; O, 14.73. Found: C, 71.82; H, 6.92; N, 6.50; O, 14.78.

**2-Benzyl-4*H*-benzo[*d*][1,3]oxazin-4-one (14c).** See ref 58.

**(*E*)-2-(Prop-1-enyl)-4*H*-benzo[*d*][1,3]oxazin-4-one (14d).** See ref 59.

**(*E*)-2-Styryl-4*H*-benzo[*d*][1,3]oxazin-4-one (14e).** $^1$H NMR (400 MHz, CDCl$_3$) $\delta$: 8.15 (d, *J* = 8.4 Hz, 1H); 7.61−7.73 (m, 2H); 7.21−7.59 (m, 7H); 6.73−6.69 (m, 2H). LC/MS: 271 [M + 1]$^+$ (yield 78%). Anal. Calcd for C$_{16}$H$_{11}$NO$_2$: C, 77.10; H, 4.45; N, 5.62; O, 12.84. Found: C, 77.06; H, 4.51; N, 5.57; O, 12.89.

**2-*tert*-Butyl-4*H*-benzo[*d*][1,3]oxazin-4-one (14f).** $^1$H NMR (400 MHz, CDCl$_3$) $\delta$: 8.25 (d, 1H, *J* = 8 Hz); 7.35 (m, 1H); 7.21 (d, 1H, J = 7.2); 7.04 (m, 1H); 1.32 (s, 3H). $^{13}$C NMR (400 MHz, CDCl$_3$) $\delta$: 169.3; 162.7; 136.8; 130.2; 127.1; 123.6; 122.2; 37.8; 27.77 (yield 70%). Anal. Calcd for C$_{12}$H$_{13}$NO$_2$: C, 70.92; H, 6.45; N, 6.89; O, 15.74. Found: C, 70.99; H, 6.37; N, 6.92; O, 15.78.

**Supporting Information Available:** NMR spectra and GC/MS. This material is available free of charge via the Internet at http://pubs.acs.org.

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(61) The catalyst was recovered by filtration using membrane filter after the carbonylation of iodobenzene. Recovered catalyst was used for the reaction under the same condition; the conversions determined by GC−MS were as follows (see the Supporting Information for more details): >99% (first time), 98% (second time), and 7% (third time).