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FULL PAPER

Benzimidazole bearing Pd–PEPPSI complexes catalyzed direct C2-arylation/heteroarylation of *N*-substituted benzimidazoles

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A convenient and highly efficient palladium-catalyzed direct C2-arylation/heteroarylation of *N*-substituted benzimidazole derivatives such as *N*-benzyl/3-chlorobenzyl/2,4,6-trimethylbenzyl/2,4,6-triisopropylbenzyl/aryl benzimidazoles with various aryl/heteroaryl bromides in the presence of Pd–PEPPSI (palladium-pyridine enhanced pre-catalyst preparation stabilization and initiation) complexes is reported. In order to that we have prepared a series of different symmetrical and unsymmetrical *N*,*N*′-diaralkyl benzimidazole-bearing Pd–PEPPSI complexes. Among all of the the prepared complexes, Pd–PEPPSI-**3** effectively tuned the reaction at a relatively higher rate under mild reaction conditions in an ethanol–water system. In addition, the catalytic process avoids the use of external ligand and additives. Further the reactivity was compared with commercially available copper-*N*-heterocyclic carbene catalyst, but the reaction was less successful. With the optimized reaction conditions, a wide range of 2-aryl/heteroaryl-*N*-substituted benzimidazoles were synthesized in good to excellent yields via Csp^2-H/Csp^2-X biaryl cross-coupling.

KEYWORDS

C2-arylation/heteroarylation, *N*-substituted benzimidazole derivatives, palladium, PEPPSI complexes, SEM–EDX and XPS spectra

1 | INTRODUCTION

Benzimidazoles represent a class of medicinally important multi-faceted amalgams with a diverse range of biological and pharmaceutical activities.[1] They possess antifungal,[2] anticancer,[3] antibacterial,[4] antiviral,[5] anti-HIV,[6] anti-inflammatory,[7] antidepressant[8] and antidiabetic[9] properties. Some of the most commonly used drugs with a benzimidazole core are presented in Figure 1.

Owing to their broad application, derivatization (particularly C2-arylated benzimidazoles) is gaining importance in the synthetic field. Importantly, two different approaches are being followed to construct/prepare these biaryl compounds. One is by the condensation of *o*-phenylenediamines with alcohols,[10] aldehydes[11] or carboxylic acids,[12] and the other is by cross de-hydrogenative coupling via C–H activation of benzimidazole,[13] which requires high temperature, strong acids, expensive catalysts and long reaction time. A vast literature is available on C–H functionalizations on simple and highly active nuclei such as oxazole,[14] thiazole,[15] triazoles,[16] indole,[17] benzoxazole,[14b,18] and benzthiazole,[14b,19] while only a few exist for benzimidazole.

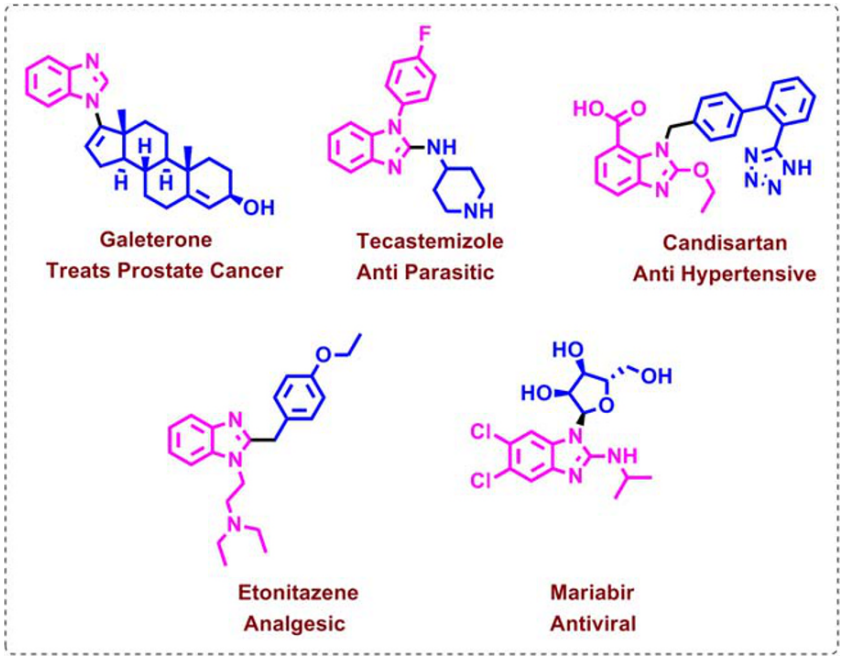


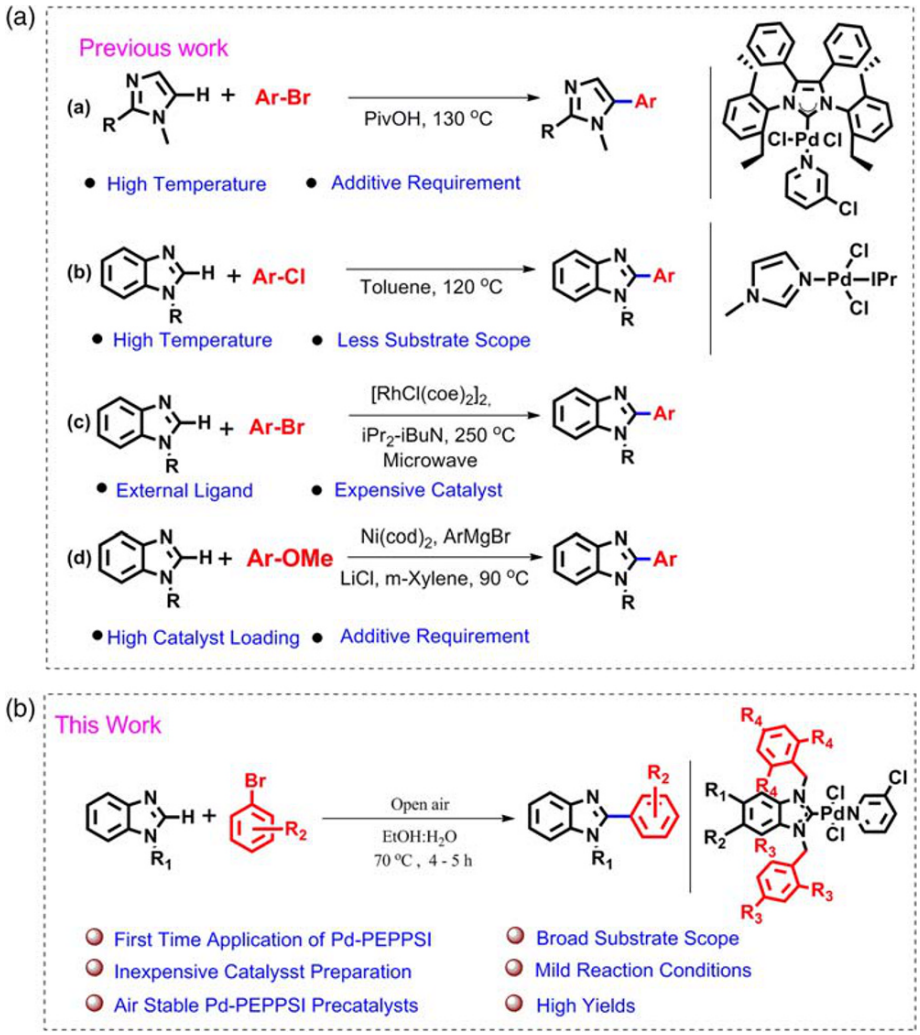
FIGURE 1 Some representative benzimidazole-based drugs

To our knowledge, a great number of these C–H activations have been reported in the presence of expensive transition metal catalysts like Ni,[14b,20] Pd,[21] Cu[11d,21,22] and Rh.[23] However, these methods have limitations like limited substrate scope, air-sensitivity, a requirement for additional ligands, high catalyst load, elevated temperature and complexity of purification. Hence, the development of alternative catalysts is desired for these conversions. Individual discoveries of Arduengo, Wanzlick and Ofele on the strength and stability of electron-rich σ-donating and weak π-accepting *N*-heterocyclic carbene (NHC) based Pd catalysts has led various research groups to design new and novel mononuclear, dinuclear, trinuclear and expanded cycles bearing M-NHCs for various unsuccessful organic transformations.[24] However, some of them possess shortcomings like expensive and difficult synthesis, moisture sensitivity, the need for an inert atmosphere and non-functional group compatibility, and it is noteworthy that these NHC vehicles are less projected for C–H activations. Hence, to meet the above synthetic challenges, another class of Pd–NHC-Py skeletons (Pd–PEPPSI) was proposed by Organ and other successive research groups.[25] In particular, complexes with bulky NHC ligands were proved to catalyze the Csp^2–Csp^2 bond formations more efficiently than the simpler ones.[26] As a result, the current decade witnessed significant efforts from distinguished teams on the preparation and applications of various nonexistent *N*-benzylbenzimidazolium NHC backbone Pd–PEPPSI complexes. Recently, Boubakri and his group prepared these types of complexes and applied them to Suzuki–Miyaura cross-coupling reactions.[27] Several examples of benzimidazolium Pd–PEPPSI framework synthesis and application to C–C cross couplings were reported by various researchers but no reports are available on C–H activation over benzimidazole skeletons. This study demonstrates a very simple yet general, practical and low-cost preparation of air-stable, easily isolatable, new Pd–PEPPSI complexes. It is the first report of application of this type of benzimidazolium Pd–PEPPSI complex for C2 arylation on *N*-substituted benzimidazoles (Scheme 1).

2 | RESULTS AND DISCUSSION

We prepared nine different *N*,*N*′-diaralkylbenzimidazolium Pd–PEPPSI complexes (**1–9**) from a cheap and readily available benzimidazole nucleus following a simple and high-yielding route. Initially *N*-alkylations were carried out on benzimidazole by utilizing the report of H. Kang and co-workers[28] to acquire various benzimidazolium salts (**5a–i**) with similar and dissimilar *N*,*N*′-aralkyl groups (bearing both electron donating methyl, isopropyl and electron-withdrawing -F and -NO_2 substituents on phenyl rings), which were then converted to corresponding Pd–PEPPSI complexes (**1–9**) upon reaction with 3-chloropyridine in the presence of K_2CO_3 in moderate to good yields (Scheme 2).

All of the prepared catalysts were confirmed by infrared (IR), nuclear magnetic resonance (NMR) and mass spectroscopies (see Supporting Information). Further, the coordination of $PdCl_2$ to NHC and 3-chloropyridine was



SCHEME 1 Previous approach and this work for direct arylation on benzofused heterocycles

demonstrated by scanning electron microscopy–energy dispersive X-ray spectroscopy (SEM–EDX; Figure 2) and X-ray photoelectron spectroscopy (XPS; Figure 3) studies of products are confirmed from NMR and mass spectra products are confirmed from NMR and mass spectra d–PEPPSI-**3.**

2.1 | SEM–EDX experiment

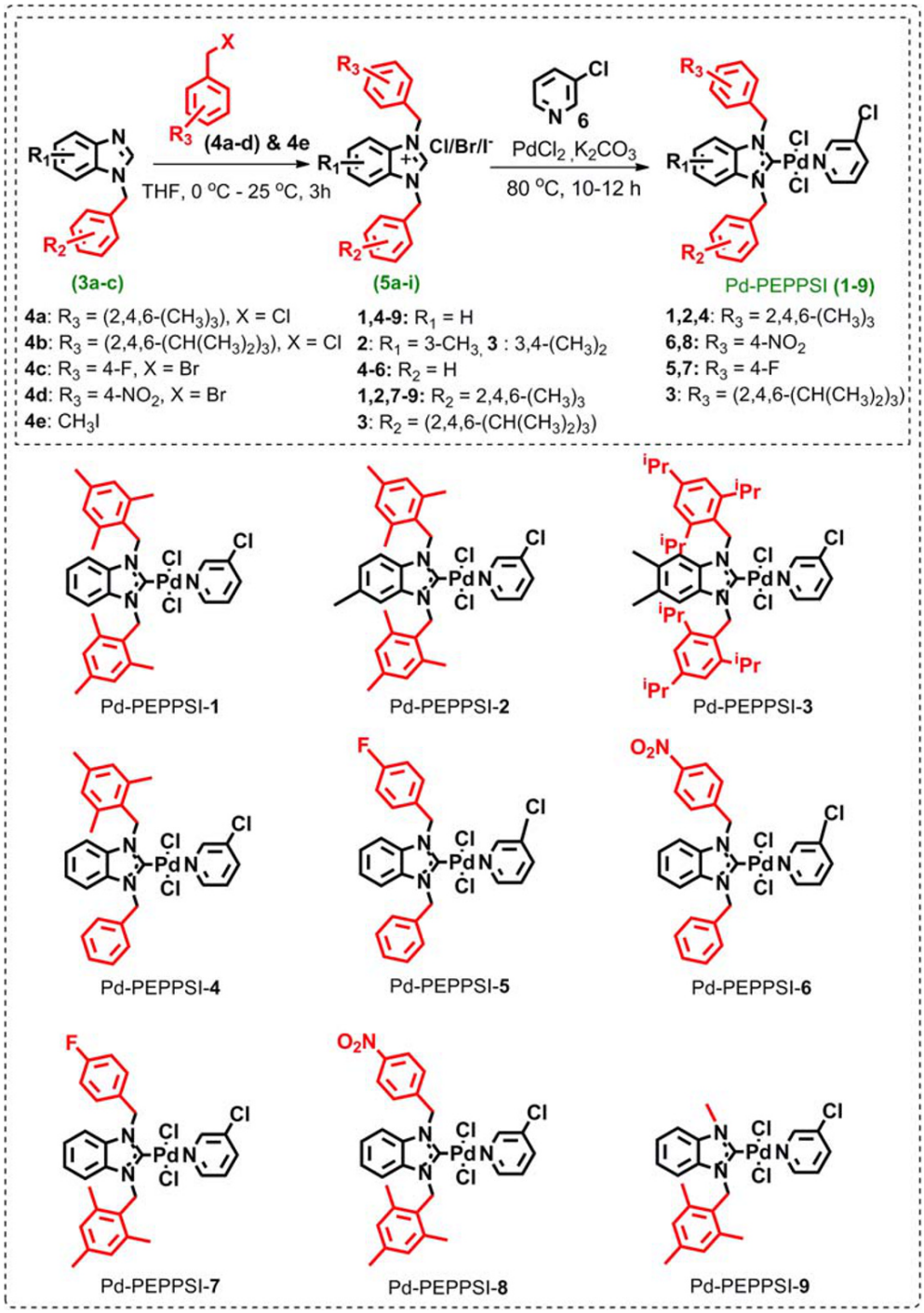
The Smart Quant Analysis of Pd–PEPPSI-**3** from the SEM–EDX experiment showed the corresponding correlated peaks of Pd and Cl with 9.27 and 15.70 wt% and 1.31 and 6.66 atom%, respectively (Figure 2).

2.2 | XPS spectroscopy

The full XPS of Pd–PEPPSI-**3** complex showed two binding energy peaks for $Pd_{3d5/2}$ and $Pd_{3d3/2}$ at 338.1 and 343.4 eV respectively and one peak corresponding to Cl_{2p} was observed at 198.6 eV, which are close to the value for $PdCl_2$ (338.3, 343.0 and 199.2 ev for Pd and Cl, respectively; Figure 3). Slight changes in the binding energy values of Pd support its existence in the +2 state by the ligation to benzimidazolium moiety and 3-chloro pyridine nuclei.

To illustrate the application of the relatively synthesized Pd–PEPPSI precatalysts, experiments were carried out on various organic transformations and it was found that these are direct candidates for the C2 arylation reaction. Hence, we started our investigation to find the active partner for the coupling of aryl bromides and designed a representative class of benzimidazole derivatives (Scheme 3).

In our aspiration towards the synthesis of various C2-arylated/heteroarylated benzimidazoles, initially we prepared **3a–d** following the work of Kang et al.[28] and **3e–f** from Duprac's group[29] and then evaluated the C2 arylation reaction. For this, a model reaction was set between *N*-benzylbenzimidazole and bromobenzene and tested the role of different catalysts and ligands at variable temperatures and solvents to obtain the optimum conditions (Table 1).



SCHEME 2 Synthesis of *N*, *N*′-diaralkyl benzimidazolium Pd–PEPPSI complexes (**1–9**). Reaction conditions: (a) *N*-benzylbenzimidazole **3a–c** (1.0 mmol), benzyl halide (1.0 mmol), THF (3 ml), 0–25 °C, 3 h; (b) compounds **5a–i** (1.0 mmol), $PdCl_2$ (1.0 mmol), K_2CO_3 (3.0 mmol), 3-chloro pyridine (4 ml), 80 °C, 10–12 h

Interested in the work of N.N. Jia and co-workers[13] on C–H activation with copper catalysts, we started to react *N*-benzylbenzimidazole with bromobenzene in the presence of CuI and PPh_3 in DMF at 135 °C for 24 h but noticed only a small amount of product formation (Table 1, entry 1). Later, a similar reaction was repeated with $Cu(OAc)_2$ and PPh_3 in the same reaction conditions and achieved more or less the same yield (Table 1, entry 2). Further, based on our previous investigations on the role of NHC catalysts towards C–C and C–N bond formations,[24f,25a,c,f] we examined the role of a Cu–NHC catalyst for the above conversion but did not observe much change in reactivity (Table 1, entry 3). Owing to the limited success using copper-based catalysts, we next aimed to change the metal center and started conducting experiments with $Pd(OAc)_2$ in the presence of PPh_3 and X-Phos ligands in toluene but unfortunately observed only traces of product (Table 1, entries 4–5). With the

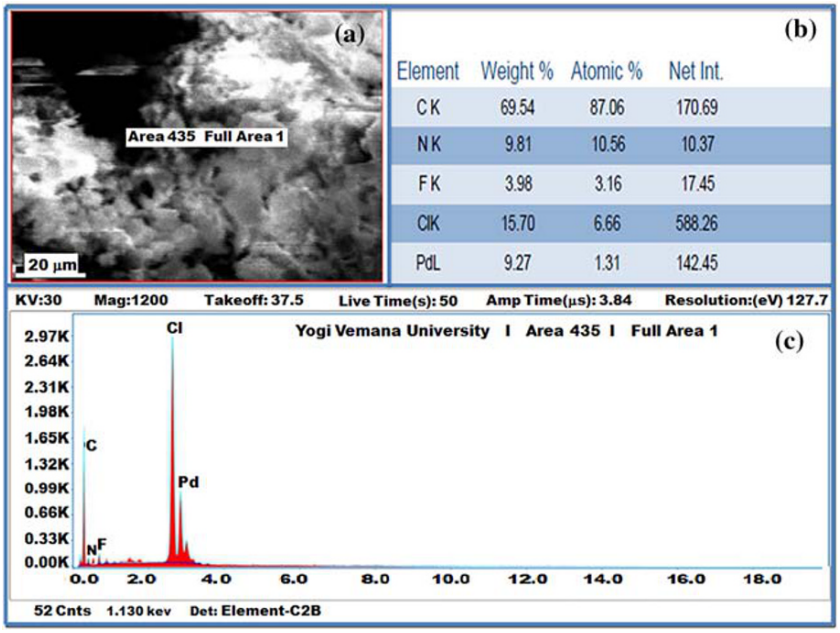


FIGURE 2 (a) Scanning electron microscopy (SEM) image. (B) Energy dispersive X-ray spectroscopy (EDX) smart quant analysis (c) EDX plot for Pd–PEPPSI-**3.** SEM–EDX interpretation

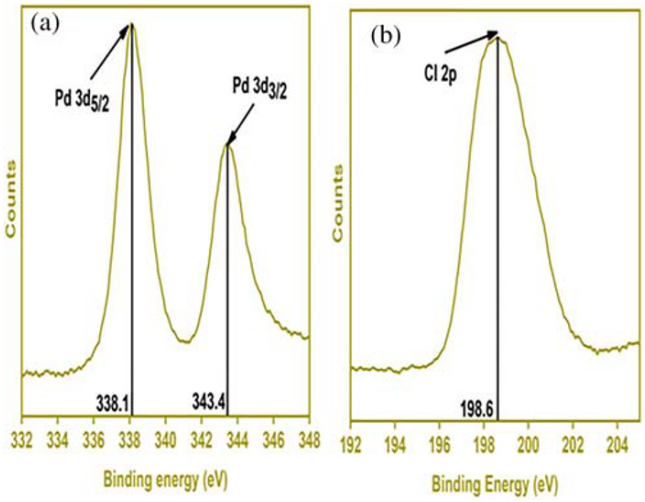
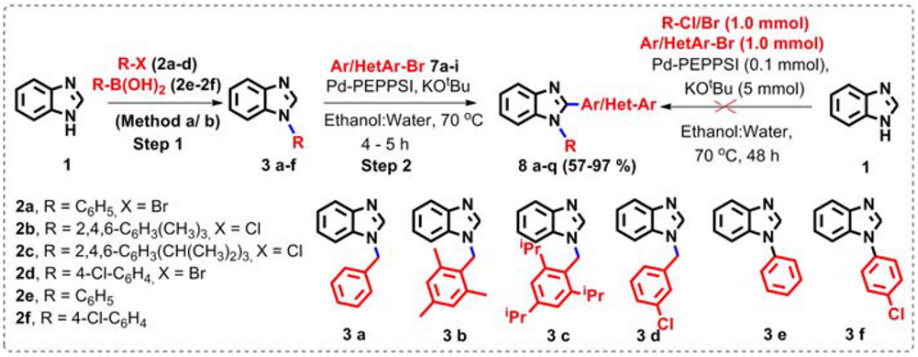


FIGURE 3 Binding energy (eV) plots for (a) palladium and (b) chlorine in Pd–PEPPSI-**3** XPS spectroscopy

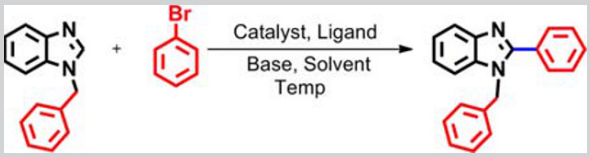
complexity of the reaction in mind, we aimed to examine the role of our prepared Pd–PEPPSI complexes **1–9** for the same reaction. In an initial experiment, Pd–PEPPSI-**1** was applied without using any ligand and gained a moderate yield of product (Table 1, entry 6). Subsequently, other Pd–PEPPSI complexes **2–9** were scrutinized carefully and the steric and electronic profiles were understood to together play a crucial role in the progress of the reaction (Table 1, entries 7–14). Pd–PEPPSI-**3** with bulky, electron-rich *N*,*N*-2,4,6-triisopropylphenyl groups provided better yield compared with all other complexes while Pd–PEPPSI-**6** with an -NO_2 group furnished lower yields despite its lower nucleophilicity (Table 1, entries 8, 11).

Although C2 arylated product was obtained in comparatively good yield with Pd–PEPPSI-**3** in toluene, its reactivity in other solvents like THF, 1,4-dioxane, DMF,



SCHEME 3 Pd–PEPPSI catalyzed C2-arylation/heteroarylation on *N*-substituted benzimdazoles. Reaction conditions: step 1, method a for **3a–d** – benzimidazole (1.0 mmol), benzyl halides (1.0 mmol), 60% NaH (2.0 mmol), THF (3 ml), 0–25 °C, 2 h; method b for **3e–f** – benzimidazole (1.0 mmol), aryl boronic acid (1.0 mmol), copper iminoarylsulfonate (0.05 mmol), MeOH (3 ml), 50 °C, 5 h; step 2, compounds **3a–f** (1.0 mmol), aryl/hetaryl-Br (1.0 mmol), catalyst (0.5 mol%), KO^{t}Bu (3.0 mmol), EtOH–water (3 ml, 1:1), 4.0–5.0 h

TABLE 1 Assessment of reagents and conditions for C2 arylation on *N*-benzylbenzimi-dazole



Entry	Catalyst	Ligand	Base	Solvent	Temperature (°C)	Time (h)	Yield[a] (%)
1	CuI	PPh_3	K_2CO_3	DMF	135	24	10
2	Cu $(OAc)_2$	PPh_3	K_2CO_3	DMF	135	24	12
3	Cu–NHC	None	KO^{t}Bu	Toluene	70	24	<15
4	Pd $(OAc)_2$	PPh_3	KO^{t}Bu	Toluene	70	24	Trace
5	Pd $(OAc)_2$	X-Phos	KO^{t}Bu	Toluene	70	24	Trace
6	Pd–PEPPSI-**1**	None	KO^{t}Bu	Toluene	70	24	75
7	Pd–PEPPSI-**2**	None	KO^{t}Bu	Toluene	70	24	75
8	Pd–PEPPSI-**3**	None	KO^{t}Bu	Toluene	70	24	86
9	Pd–PEPPSI-**4**	None	KO^{t}Bu	Toluene	70	24	73
10	Pd–PEPPSI-**5**	None	KO^{t}Bu	Toluene	70	24	71
11	Pd–PEPPSI-**6**	None	KO^{t}Bu	Toluene	70	24	65
12	Pd–PEPPSI-**7**	None	KO^{t}Bu	Toluene	70	24	72
13	Pd–PEPPSI-**8**	None	KO^{t}Bu	Toluene	70	24	71
14	Pd–PEPPSI-**9**	None	KO^{t}Bu	Toluene	70	24	72
15	Pd–PEPPSI-**3**	None	KO^{t}Bu	Toluene	70	4.5	86
16	Pd–PEPPSI-**3**	None	KO^{t}Bu	THF	70	4.5	79
17	Pd–PEPPSI-**3**	None	KO^{t}Bu	1,4-Dioxane	70	4.5	83
18	Pd–PEPPSI-**3**	None	KO^{t}Bu	DMF	70	4.5	80
19	Pd–PEPPSI-**3**	None	KO^{t}Bu	DMAc	70	4.5	68
20	Pd–PEPPSI-**3**	None	KO^{t}Bu	Ethanol:Water (1:1)	70	4	91
21	Pd–PEPPSI-**3**	None	K_2CO_3	Ethanol:Water(1:1)	70	4	75
22	Pd–PEPPSI-**3**	None	Cs_2CO_3	Ethanol:Water(1:1)	70	4	89
23	Pd–PEPPSI-**3**	None	KO^{t}Bu	Ethanol:Water(1:1)	50	48	64
24	Pd–PEPPSI-**3**	None	KO^{t}Bu	Ethanol:Water(1:1)	25	48	NP

Reaction conditions: *N*-benzylbenzimidazole (1.0 mmol), bromobenzene (1.0 mmol), KO^{t}Bu (3.0 mmol), solvent (3 ml), catalyst (0.5 mol%), ligand (0.5 mol%), Cu–NHC = chloro[1,3-*bis*(2,6-diisoporopylphenyl)imidazole-2-ylidene]copper(I).
[a]Isolated yield. NP, No product.

DMAc and ethanol–water (1:1) was also monitored and the ethanol–water (1:1) system was a better solvent medium for effective reaction conversion (Table 1, entries 16–20). The superior result attained in polar solvent mixtures may be due to the good solubility of the parent molecule and bases that are responsible for proton abstraction on benzimidazoles. In a supplementary action, we examined the role of bases and achieved a superior report with KO^{t}Bu than with other bases like K_2CO_3 and Cs_2CO_3 (Table 1, entries 20–22).

In a further investigation, the effect of temperature on C2 arylation was also monitored and it was identified that 70 °C is a highly reliable reaction condition for the total conversion of *N*-benzylbenzimidazole (Table 1, entry 20). To understand the efficiency of the catalyst, a room temperature (25 °C) reaction was also attempted; however, we did not observe product formation even after 48 h (Table 1, entry 24).

All of the above tests revealed that the optimum conditions for C2 arylation on *N*-benzylbenzimidazole are in

the presence of Pd–PEPPSI-**3**, KO^{t}Bu in ethanol–water at 70 °C for about 4 h.

To minimize the number of steps, a multicomponent approach was also practiced between benzimidazole, benzyl bromide and bromobenzene in the presence of Pd–PEPPSI-**3** catalyst for 48 h but unfortunately obtained only *N*-benzyl product (**3a**), possibly owing to competition among the reactants. Therefore, compound **3a** was once again forced to C2 arylation with bromobenzene and attained **8a** in 85% yield (Scheme 4).

2.3 | Scrutinizing the rate of reactivity of catalyst at different loadings

With the hope of identifying ideal, practical and versatile catalyst conditions, we thoroughly examined another reaction parameter, catalyst load for complete conversion of the starting material to the desired product. Therefore, a similar reaction was taken into consideration and the competence of the catalyst Pd–PEPPSI-**3** was studied. The reaction was started with 0.05 mol% of catalyst and 19% yield of the product obtained in 5 h. Increasing the catalyst load to 0.1, 0.3 and 0.5 mol% resulted in a tremendous rise in yield to 91%. A further increase in load to 0.8 mol% did not produce any variation in yield.

Figure 4 shows that, with an increase in catalyst load from 0.05 to 0.5 mol%, the rate of reactivity increased gradually with time and remained stable thereafter. Based on these observations, we report 0.5 mol% of catalyst to be adequate to surpass the C2-arylation reaction on *N*-substituted benzimidazoles very effectively in just 4 h.

The above investigations substantiated general optimum reaction conditions for the synthesis of a wide variety of C2-arylated benzimidazolium derivatives (**8a–q**). Also, it is apparent that almost all of the reactions proceeded smoothly with negligible variation in yields in 4–5 h at a very low catalyst loading (0.5 mol%). During the course of study, the reactions tolerated a wide range of substituents both on benzimidazole and aryl/heteroaryl bromides and thus the viability of the catalyst for a range of coupling partners is demonstrated. The electronic rationale from Table 2 shows

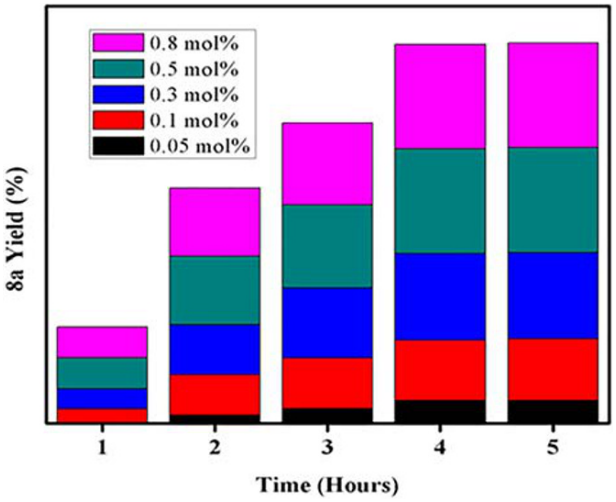
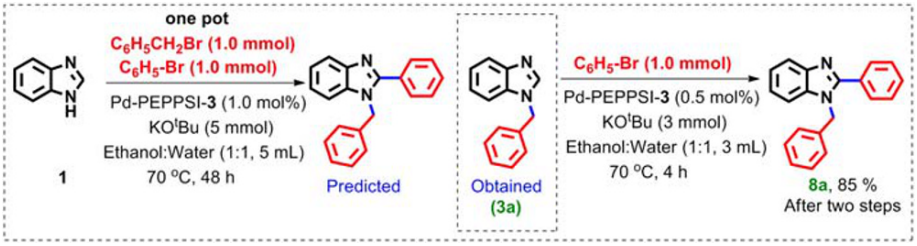


FIGURE 4 Rate of reaction

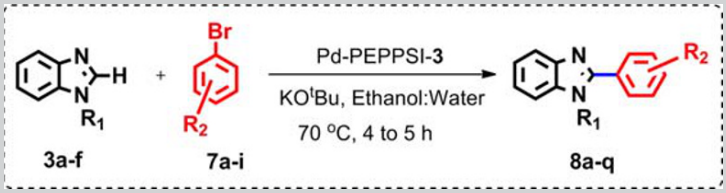
that electron donating groups like -OCH_3 on aryl bromides afforded somewhat better yields than those bearing electron-withdrawing atoms/groups like Cl/CF_3 (Table 2, **8b**, **8i**, **8 k**, **8n**, **8c**, **8d**, **8 l**). 1-Bromo-2-chloro benzene coupled with *N*-benzylbenzimidazole by undergoing substitution of bromine at a faster rate than chlorine (Table 2, **8c**). Interestingly, the sterically demanding cohort 9-bromophenanthrene also reacted efficiently with moderate yields (Table 2, **8f**, **8j**). Heteroaryl bromides like 3-bromo thiophene and 3-bromo quinoline also cope with the reaction; however, with an extended reaction time and comparatively low yields (Table 2, **8e**, **8 m**). Bulky *N*-benzyl-6-bromo carbazole also reported smooth conversion of imidazole to result in the desired product, nevertheless with low quantifying yield (Table 2, **8 g**). Surprisingly, a remarkable variation in the C2 arylation on different *N*-benzyl substituted benzimidazoles with various aryl/heteroaryl bromides was not detected. Electron-donating substituents like -CH_3 and -$CH(CH_3)_2$ on benzyl groups gave fairly good yields compared with those with electron-withdrawing substituents like -Cl (Table 2, **8 h–o**).

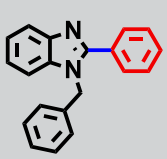
Having completed the substrate scope on *N*-benzylbenzimidazoles, we continued our efforts at recognizing the substitution effect by *N*-aryl groups for C2



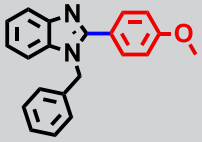
SCHEME 4 Exploration of one-pot tandem coupling of benzylbromide and bromobenzene to benzimidazole

TABLE 2 Pd–PEPPSI-**3** catalyzed direct C_2-arylation of *N*-aralkylbenzimidazoles with aryl/heteroaryl bromides

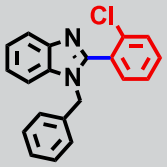




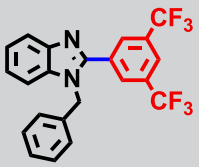
8a, 91%, 4h



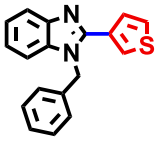
8b, 97%, 4h



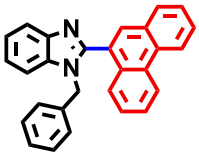
8c, 82%, 4h 20 min



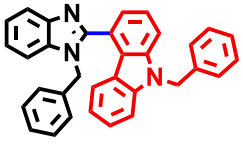
8d, 80%, 4h 15min



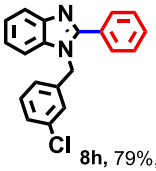
8e, 83%, 4h 45min



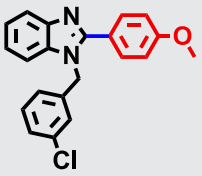
8f, 79%, 5h



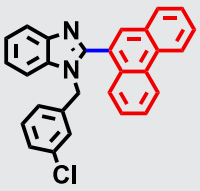
8g, 84%, 4h 50min



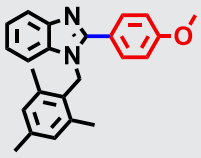
8h, 79%, 4h 50min



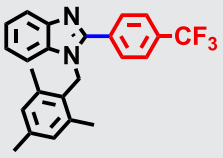
8i, 89%, 4h 45min



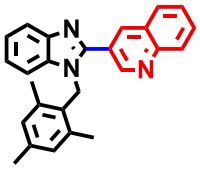
8j, 75%, 5h



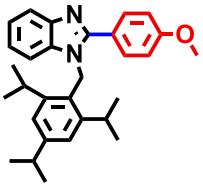
8k, 93%, 4h 40min



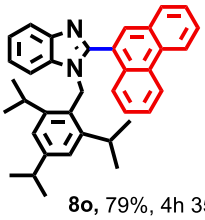
8l, 89%, 4h 35min



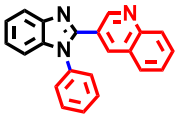
8m, 76%, 4h 40min



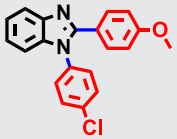
8n, 95%, 4h 15min



8o, 79%, 4h 35min



8p, 57%, 05h 10min



8q, 72%, 05h 05min

Reaction conditions: *N*-benzylbenzimidazole (1.0 mmol), aryl/heteroaryl bromides (1.0 mmol), KO^{t}Bu (3.0 mmol), EtOH:H_2O (1:1, 3 ml), Pd–PEPPSI-**3** (0.5 mol%).

arylation/heteroarylation and performed two more experiments between different *N*-arylbenzimidazoles and aryl/heteroaryl bromides and achieved fair yields of products (Table 2, **8p–q**). *N*-Aryl groups on benzimidazole are thus shown to limit the reactivity compared with aralkyl groups. All of the experiments clearly show better catalyst activity for C2-arylation on a diverse set of *N*-substituted benzimidazoles with different aryl/heteroaryl bromides. The results are compiled in Table 2 and the products are confirmed from NMR and mass spectra (see Supporting Information).

Aiming to determine the sensitivity of catalysts for other functional groups, a simple reaction was conducted between *N*-benzylbenzimidazole and 3-bromophenylboronic acid but unanticipated product **8a** was obtained, merely by chopping up the boronic acid (Scheme 5).

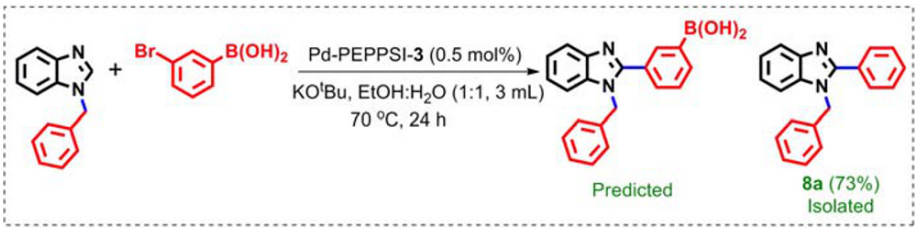
Abdellaoui et al. reported extended arylation reactions on C2-arylbenzoxazole/benzothiazoles.

using palladium catalyst.[30] In a similar vein, a test for extended arylation and regioselectivity on 1-benzyl-2-[5-*bis*(trifluoromethyl)phenyl]-1*H*-benzo[*d*]imidazole **8d** was practiced with 4-bromoanisole but no conversion of the starting material was observed, possibly owing to the suppression of reactivity by the electronic properties of -CF_3 groups present on either side of the active -CH carbon. Instead, Pd–PEPPSI-3 catalyzed homocoupling of bromoanisole yielded **8aa** (Scheme 6).

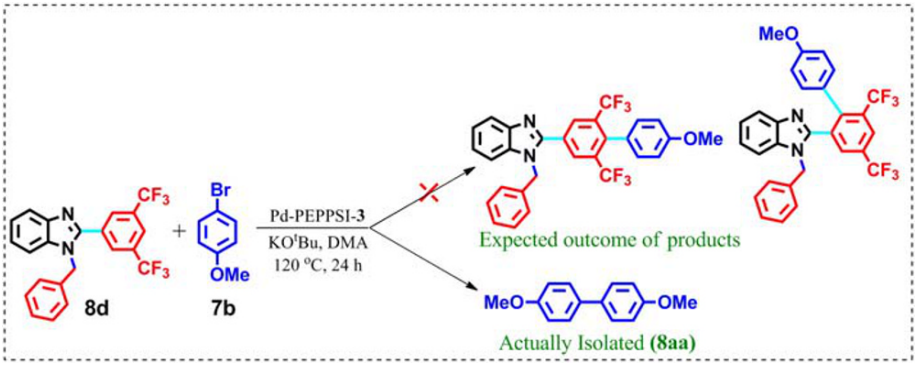
To obtain a concrete report on the utility of the catalyst, a gram-scale synthesis of 1-benzyl-2-phenyl-1*H*-benzo[*d*]imidazole was performed. Hence the reaction between *N*-benzylbenzimidazole and bromobenzene was repeated using 0.5 mol% of Pd–PEPPSI-**3** and nearly 90% of the product was achieved in just 4 h. Thus the methodology can be used even for bulk-scale synthesis of C2-arylated products, which is essential for industrial applications.

2.4 | Conclusions

In summary, we disclosed a new catalytic approach for the C2 arylation on *N*-substituted benzimidazoles with different newly synthesized Pd–PEPPSI complexes and one commercially available Cu–NHC chloro[1,3-bis(2,6-diisopropylphen-yl)imidazol-2-ylidene] copper(I)complex. Of all of the investigated catalysts, Pd–PEPPSI-**3** showed outstanding reactivity over a library of compounds by virtue of its bulky and steric factors of *bis*-1,3-(2,4,6-triisopropyl benzyl) groups on benzimidazolium nucleus (yields reported upto 97%). Besides this, Cu–NHC complex, although almighty bears *N*,*N*-2,6-diisopropylphenyl groups on imidazole core stood as a poor vehicle which clearly put forth the real role of Pd–PEPPSI complexes for this conversion. Hence, this protocol explains the steric demand



SCHEME 5 Investigation on functional groups tolerance of Pd–PEPPSI-**3** for halide partner. Reaction conditions: benzimidazole (1.0 mmol), 3-bromo phenylboronic acid (1.0 mmol), KO^{t}Bu (3.0 mmol), Pd–PEPPSI-**3** (0.5 mol%), EtOH–water (1:1, 3 ml), 70 °C, 24 h



SCHEME 6 Identification of possibility of regio-isomer formation. Reaction conditions: compound **8d** (1.0 mmol), 4-bromo anisole (1.0 mmol), KO^{t}Bu (3.0 mmol), Pd–PEPPSI-**3** (0.5 mol%), DMA (3 ml), 120 °C, 24 h

and importance of the metal in the C2 arylation reaction. The particular strength of this strategy is finding a broad substrate scope for the preparation of a diverse set of benzimidazole derivatives with complex mesityl, triisopropyl, trifluoromethyl substituents by newly synthesized catalysts and evidently this is the opening report for such types of reaction with moderate to high yields of products in enivronmentally friendly solvent medium at a low loading of 0.5 mol%. Also, all of the prepared compounds are new to the best of our knowledge and biological activity studies in under progress.

3 | EXPERIMENTAL SECTION

3.1 | General experimental section

All of the reactions were carried out in noninert atmosphere in tetrahydrofuran, toluene, dimethylformamide, 1,4-dioxane, *N*,*N*-dimethylformamide, dimethylacetamide and ethanol–water. Reactions were monitored through thin-layer chromatography (TLC) analysis using Merck silica gel 60 F_{254} plates by visualizing under a UV lamp. All of the commercially available reagents such as benzimidazole, aryl halides, bases and palladium reagents were procured from Aldrich, Acros organics, TCI, Merck Scientific and Avra Synthesis companies and used as received without further purification. Cu–NHC was procured from Sigma Aldrich Company.

Melting points of the synthesized compounds are uncorrected. Infrared spectra for the final compounds were recorded on a Bruker Alpha-Eco ATR-FTIR (attenuated total reflection–Fourier transform infrared) interferometer with a single reflection sampling module equipped with KBr crystals. ^{1}H- and ^{13}C-NMR were recorded on Bruker top-spin 400 and 100 MHz spectrometers using tetramethylsilane (TMS) as an internal standard. Chemical shifts (δ) are reported in ppm. Multiplicities in the ^{1}H-NMR spectra are described as: s, singlet; d, doublet; t, triplet; q, quartet; dd, doublet of doublet; td, triplet of doublet; m, multiplet. Coupling constants are reported in Hz. High-resolution mass spectra were recorded on a microTOF-Q II-Bruker compass mass spectrometer operating at 70 eV. SEM-EDX was recorded using a Jeol SEM-EDX instrument to characterize the elemental composition of the analyzed volume in Pd–PEPPSI complexes. An XPS system (Omicron ESCA+, Oxford Instruments, Germany) operated with an Argus analyzer (mean radius of 124 mm) was used to identify the chemical state of Pd in PEPPSI complexes. Resolution was confirmed using a full width at half maximum (FWHM) of ~0.60 eV.

3.2 | General procedure for the synthesis of Pd–PEPPSI complexes 1–9

3.2.1 | Common procedure for the preparation of *N*-benzyl benzimidazole (3a–d)

To a freshly dried 25 ml round-bottom flask containing benzimidazole 1 (1.0 mmol) in anhydrous THF (3 ml), was added 60% NaH in paraffin oil (2.0 mmol) slowly under ice-cold conditions and allowed to stir for 5 min. To that was added benzylhalide **2a–d** (1.0 mmol) and the reaction mixture was continued to stir for another 1–2 h at the same temperature. After the reaction was completed as monitored by TLC, the reaction mixture was quenched with ice cold-water and the THF evaporated under vacuum. The obtained aqueous mixture was then extracted with ethyl acetate twice (2 × 5ml) and the combined organics were dried under vacuum to obtain the crude mass which was triturated with 2 × 5 ml of hexane and again dried under reduced pressure to afford white solids (**3a–d**).

3.2.2 | Common procedure for the preparation of *N*-phenyl benzimidazole (3e–f)

To a freshly dried 25 ml round-bottom flask containing benzimidazole **1** (1.0 mmol) in anhydrous MeOH (3 ml) was added copper iminoarylsulfonate (0.05 mmol) and aryl boronic acid **2e–f** (1.0 mmol) and allowed to stir at 50°C for 5 h. After the completion of the reaction from TLC, the solvent was distilled off, 5 ml of water added and then extracted with ethyl acetate twice (2 × 5ml). The combined organics were dried under vacuum to obtain the crude mass which was triturated with 2 × 5 ml of hexane and dried under reduced pressure to obtain white solids (**3e–f**).

3.2.3 | Systematic procedure for the preparation of *N*,*N*′-diaralkylbenzmidazolium salts (5a–i)

To compounds **3a–c** (1.0 mmol) in anhydrous THF, corresponding aralkylchlorides or bromides **4a–e** (1.0 mmol) were added slowly at 0°C and then allowed to stir for 1–2 h at the same temperature. The solvent was filtered through a Buchner funnel and the white solids were washed with ethyl acetate (5 ml) and dried under high vacuum to acquire pure compounds **(5a–i)**. Overall yields for two steps were 93–98%.

3.2.4 | Typical procedure for the synthesis of Pd–PEPPSI complexes (1–9)

In air, an equipped 25 ml round-bottom flask and a stir bar was charged with benzimidazolium salts **5a–i** (1 mmol), $PdCl_2$ (1 mmol), K_2CO_3 (3 mmol) and 3-chloro-pyridine (4.0 ml) and the reaction mixture was allowed to stir for 10–12 h at 80 °C. Reaction progress was monitored through TLC and after successful completion the reaction mixture was cooled to room temperature, 5 ml of water added and extracted with ethyl acetate (2 × 10 ml). The combined organics were dried over anhydrous Na_2SO_4, evaporated under reduced pressure, and purified through short pad of silica using hexane and ethyl acetate as an eluent. Solids formed were washed with hexane to afford pure yellow solids and characterized by SEM-EDX (Figure 2), XPS (Figure 3), IR, NMR and mass spectroscopies (see Supporting Information).

3.3 | Common procedure for the C2-arylation on *N*-aralkyl/arylbenzimidazoles (8a–q)

A dry 25 ml round-bottom flask with a stir bar was charged with ethanol–water (1:1, 3 ml), and *N*-benzyl/phenyl benzimidazole **3a–f** (1 mmol), Pd–PEPPSI-**3** (0.5 mol%), KO^tBu (3 mmol) and aryl/heteroarylbromides **7a–i** (1 mmol) added at room temperature. The mixture was then allowed to stir vigorously for 4–5.5 h at 70 °C in open air. Reaction progress was monitored through TLC, cooled to room temperature and the solvent removed under reduced pressure to get crude mass. To that was added 5 ml of water and extracted with ethyl acetate (2 × 5 ml). The combined organics were dried over anhydrous Na_2SO_4, evaporated under reduced pressure and purified by flash column chromatography (eluent, petroleum ether–ethyl acetate) to offer pure products **8a–q** (yield up to 97%). The identity and purity of the compounds were confirmed by NMR, IR and mass spectroscopic analyses (see Supporting Information).

3.3.1 | Gram-scale synthesis of 1-benzyl-2-phenyl-1*H*-benzo[*d*]imidazole

To a fresh, dry 25 ml RBF containing *N*-benzylbenzimidazole (1.05 g, 5 mmol) in ethanol–water (5 ml:5 ml) were added Pd–PEPPSI-3 (21 mg, 0.5 mol%), KO^tBu (1.69 g, 15 mmol) and bromobenzene (0.79 g, 5 mmol) at room temperature and the mixture was allowed to stir vigorously at 70 °C for about 4 h. The reaction mixture was then cooled to room temperature, and the solvent removed under reduced pressure to get crude mass. To that was added 10 ml of water and extracted with ethyl acetate twice (2 × 20 ml). The combined organics were dried over anhydrous Na_2SO_4, evaporated under reduced pressure and purified through column chromatography (eluent, petroleum ether–ethyl acetate) to obtain pure product **8a** (yield 1.28 g, 89.32%). The identity and purity of the compound were confirmed by NMR spectroscopy.

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CONFLICT OF INTEREST

All authors declare no conflicts of interest.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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