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Microwave Assisted Domino [Pd]-Catalysis in Water: A Diversified Synthesis of 3,3'-Disubstituted Heterocyclic Compounds

Karu Ramesh, [a] Suchand Basuli [a] and Gedu Satyanarayana*[a]

Abstract: An environmentally benign microwave assisted domino [Pd]-catalysis, for the efficient and diversified synthesis of 3,3'-disubstituted indolines, oxindoles and dihydrobenzofurans, was presented. Significantly, water served as the sole green solvent and the strategy displayed an excellent functional group tolerance. Remarkably, the process was also amenable to unmasked functional groups and furnished the products, in very good to near quantitative yields.

Introduction

In the recent past, development of environmentally benign synthetic strategies are in great demand to sustain the ecology of our globe.[1] Green chemistry emerged as an essential alternative to the otherwise very harsh conventional reaction conditions.[2] The use of toxic and volatile organic solvents contributes to the detrimental impact on the environment and may also cause an insufficient E-factor.[3] Therefore, development of chemical processes using green solvents has been one of the main facet of green chemistry.[4] In this context, water is unique, ubiquitous, and renewable polar solvent. Due to its inherently safe, non-flammable nature, it has been regarded as green solvent.

In addition, the use of unconventional strategies, such as, microwave irradiation technique has become evident as an excellent alternative to conventional synthetic processes. The microwave driven chemical strategies are beneficial, as: i) energy efficient; ii) the reaction completes in short span of time; iii) and high products yields and purity. Furthermore, domino processes contribute to the green synthesis by enabling the formation of multiple bonds, in a single pot via minimizing the detrimental impact of step-wise synthesis. Accounting the advantages of multiple bonds formation in an environmentally benign approach, we aimed at the one-pot domino strategy with microwave assistance, under environmentally benign conditions.

Recently, investigations on establishing green chemical processes, for the synthesis of functionalized heterocyclic compounds of biological relevance has become crucial part of organic synthesis. In particular, 3,3'-Disubstituted heterocyclic compounds (indolines[5], oxindoles[6] and dihydrobenzofurans[7]) constitutes chief structural cores of natural products and pharmaceutical compounds [Figure 1 (**A**, **B**, **C**, **E**)[8a] (**D**),[8b] (**F**, **G**)[8c, 8d]]. Among the many classical approaches,[9] particularly, [Pd]-catalyzed domino intramolecular Heck and subsequent C−H functionalization,[10] has proved to be of high significance. The most significant initial results of this sort, were well established by Ronald Grigg and co-workers.[11],[12] Stivala et al and Vachhani et al, respectively, developed Heck and boration strategy, under microwave irradiation. Stivala and co-workers, described synthesis of aza-indolines via Heck and Suzuki coupling. Whereas indolinone-3-methyl boronic esters, were accomplished by the research group Vachhani.[13],[14] Notably, 3,3'-disubstituted indolin-2-ones containing alkynyl moiety, were synthesized by the research groups of Li and Guo, which, in fact, broadens the scope of this concept.[15] To the best of our knowledge, there is no general strategy for the preparation of different 3,3′-disubstituted heterocycles bearing alkynyl functionality, particularly, for the synthesis of indolines. In this context, very recently, we reported an efficient strategy for the synthesis of alkyne substituted dihydrobenzofurans via a domino intramolecular Heck and Sonogashira coupling, under microwave assisting conditions. [16]

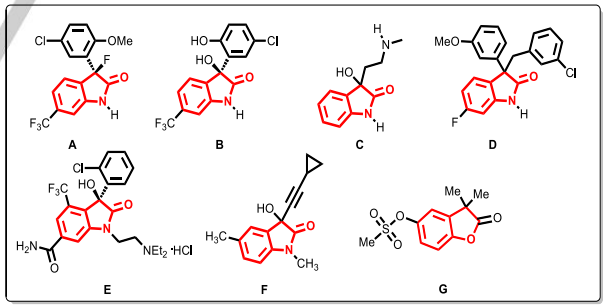

Fig. 1 Natural products and drugs having Indoline, oxindole,dihydrobenzofuran core structure.

In continuation of our ongoing research interests on the development of domino one-pot processes, [17] herein, we present efficient and environmentally benign microwave assisted domino [Pd]-catalysis, for a diversified synthesis of 3,3'-disubstituted indolines, oxindoles and dihydrobenzofurans. Notably, unlike earlier reports, this method is first of its kind on deliberating the synthesis of indolines. Significantly, this strategy is successful using water as the sole green solvent. This greener method involves a domino intramolecular Heck[18] and intermolecular Sonogashira couplings.[19] Remarkably, this process showed excellent functional group tolerance and even successful without protecting the reactive functionalities (e.g. amine, hydroxyl and carboxylic acid groups).

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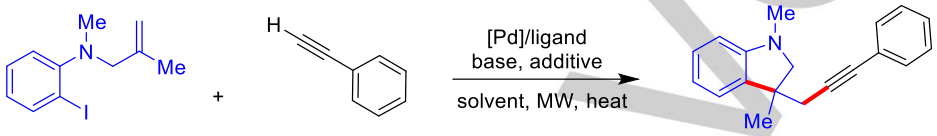
Result and Discussions

To begin with, it was intended to explore the reaction with the assistance of microwave irradiation, under different conditions, in order to identify the best optimal conditions. Particularly, it was aimed to conduct the reaction in water as the sole reaction medium. Thus, *ortho*-iodophenyl allyl tertiary amine **1a** and phenylacetylene **2a**, were chosen for this study. Initially, the reaction was carried out under microwave irradiation, in the presence of $Pd_2(dba)_3$ (1 mol%), base K_2CO_3 (3 equiv) in H_2O (0.5 mL), at 100 °C for 20 min. The desired indoline product **5aa** was obtained, in very poor yield (Table 1, entry 1). There was no improvement even by increasing the microwave irradiation time and with other bases (Table 1, entries 2 to 5). Also, $Pd(OAc)_2$ in conjunction with phosphine ligands, showed no improvement (Table 1, entries 6 & 7). While the reaction in the presence of $Pd(OAc)_2$/BINAP and quaternary ammonium salt [benzyltriethylammonium chloride (BTEAC)], as an additive, furnished **5aa**, in moderate yield (Table 1, entry 8). Interestingly, $Pd_2(dba)_3/K_2CO_3$ and additive BTEAC, was found to be suitable and gave the product **5aa**, in 75% yield (Table 1, entry 9). While the reaction with tetrabutylammonium bromide (TBAB) and tetrabutylammonium iodide (TBAI), as additives, gave the product **5aa**, in 62% and 55% yields, respectively (Table 1, entries 10 & 11).

Table 1. Optimization for the formation of indolines **5aa** from 2-iodo-N-alkyl-N-(2-methylallyl)anilines **1a** and phenyl acetylene **2a**.[a,b,c]



1a **2a** **5aa**

entry	catalyst (1 mol%)	ligand (10 mol%)	additive (1 equiv)	base (3 equiv)	Solvent	temp (°C)	time (min)	yield **5aa**[b] (%)
1	$Pd_2(dba)_3$	-	-	K_2CO_3	H_2O	100	20	(10%)
2	$Pd_2(dba)_3$	-	-	K_2CO_3	H_2O	100	40	(15%)
3	$Pd_2(dba)_3$	-	-	Na_2CO_3	H_2O	100	40	trace
4	$Pd_2(dba)_3$	-	-	NaOH	H_2O	100	40	(12%)
5	$Pd_2(dba)_3$	-	-	Cs_2CO_3	H_2O	100	40	trace
6	$Pd(OAc)_2$	PPh_3	-	K_2CO_3	H_2O	100	15	(10%)
7	$Pd(OAc)_2$	Xantphos	-	K_2CO_3	H_2O	100	15	-[c]
8	$Pd(OAc)_2$	BINAP	BTEAC	K_2CO_3	H_2O	100	20	(40%)
9	$Pd_2(dba)_3$	-	BTEAC	K_2CO_3	H_2O	100	20	(75%)
10	$Pd_2(dba)_3$	-	TBAB	K_2CO_3	H_2O	100	20	(62%)
11	$Pd_2(dba)_3$	-	TBAI	K_2CO_3	H_2O	100	20	(55%)
12	$Pd_2(dba)_3$	-	TBACH	K_2CO_3	H_2O	100	20	trace
13	$Pd_2(dba)_3$	-	BTEAC	NEt_3	H_2O	100	15	(40%)
14	$Pd_2(dba)_3$	-	BTEAC	Imidazole	H_2O	100	15	-[c]
15	$Pd_2(dba)_3$	-	BTEAC	Pyridine	H_2O	100	15	-[c]
16	**$Pd_2(dba)_3$**	**-**	**BTEAC**	**DBU**	H_2O	**100**	**15**	**(98%)**
17	$Pd_2(dba)_3$	-	BTEAC	DBU	H_2O	100	10	(50%)
18	$Pd_2(dba)_3$	-	BTEAC	DBU	H_2O	80	20	(62%)
19	$Pd_2(dba)_3$	-	TBAB	DBU	H_2O	100	15	(68%)
20	$Pd_2(dba)_3$	-	TBAI	DBU	H_2O	100	15	(64%)
21	$Pd(PPh_3)_4$	-	BTEAC	DBU	H_2O	100	15	(70%)
22	$PdCl_2$	-	BTEAC	DBU	H_2O	100	10	-[c]
23	$Pd(PPh)_3Cl_2$	-	BTEAC	DBU	H_2O	100	10	-[c]
24	$Pd(TFA)_2$	-	BTEAC	DBU	H_2O	100	10	-[c]
25	$Pd_2(dba)_3$	-	BTEAC	DBU	ETOH	100	10	(62%)

26	$Pd_2(dba)_3$	-	BTEAC	DBU	1,4-Dioxane	100	10	(50%)
27	$Pd_2(dba)_3$	-	BTEAC	DBU	EDC	100	10	(15%)
28	$Pd_2(dba)_3$	-	BTEAC	DBU	Toluene	100	10	(10%)

[a]Unless otherwise mentioned, all the reactions were carried out under microwave irradiation in aqueous medium by using 71.7 mg (0.25 mmol) of 2-iodo-N-methyl-N-(2-methylallyl)aniline **1a**, 39.5 mg (0.37 mmol) of phenylacetylene **2a**, base (0.75 mmol, 3 equiv), [Pd]-catalyst (1 mol%), ligand (10 mol%), and solvent-Water (0.5 mL). [b]Yields in the parentheses are isolated yields of product **5aa**. [c]No significant spot was observed on TLC; neither the starting material was recovered nor any product was isolated.

Almost no progress was observed with tetrabutylammonium chloride hydrate (TBACH) (Table 1, entry 12). On the other hand, the reaction was inferior with nitrogen bases such as, trimethylamine, imidazole and pyridine (Table 1, entries 13 to 15). Gratifyingly, when 1,8-diazabicyclo[5.4.0]undec-7-ene (DBU) was employed as the base, in the presence of 1 mol% of $Pd_2(dba)_3$ and additive BTEAC, under microwave irradiation at 100 °C for 15 min, the desired indoline product **5aa** was obtained, in 98% yield (Table 1, entry 16). The reaction for shorter reaction time (10 min) at 100 °C, gave the product in 50% yield (Table 1, entry 17). However, at slightly low temperature (80 °C), delivered the **5aa**, in 62% yield (Table 1, entry 18). While TBAB and TBAI as additives along with the base DBU, afforded **5aa**, in fair yields (Table 1, entries 19 & 20). On the other hand, the reaction with $Pd(PPh_3)_4$, base DBU and additive BTEAC, gave **5aa**, in 70% yield (Table 1, entry 21). While with other [Pd]-catalysts, the reaction was inconclusive (Table 1, entries 22 to 24). On the other hand, the reaction with organic solvents, gave the product 5aa, in poor to good yields (Table 1, entries 25 to 28).

With these optimal reaction conditions in hand [i.e. $Pd_2(dba)_3$ (1 mol%), DBU (3 equiv), additive BTEAC (1 equiv), microwave irradiation, 100 °C, 15 min (Table 1, entry 16)], to demonstrate the scope of this green method, next, the reaction was tested with different *ortho*-iodophenyl allylic amines **1a-1c** and acetylenes **2a-2o**. To our delight, the method was found to be quite amenable and afforded the corresponding alkyne substituted indolines **5aa-3co**, in very good to near quantitative yields (Table 2). Notably, the reaction was suitable to aryl as well as alkyl acetylenes. Significantly, the reaction was tolerable to protecting group free amine functionality (**5ae, 5be** & **5ce**, Table 2). Gratifyingly, the process was smooth enough with electron withdrawing carboxylic acid group on the aromatic ring of aryl acetylene **2f** (**5af**, Table 2). In addition, the strategy was smoothly amenable to cyclopropyl acetylenes (**5ah** & **5ch**, Table 2). Gratifyingly, the strategy was tolerable with aliphatic acetylenes with protecting group free reactive hydroxyl group (**5an, 5ao, 5bn, 5bo** & **5co**, Table 2). Significantly, the reaction was amenable with testosterone acetylene **2p** and furnished **5bp**, as a diastereomeric mixture. It is worth noting that the reaction is some sort of more selective with *ortho*-iodophenyl allylic amines. Because the reaction with the corresponding *ortho*-bromophenyl allylic amines was sluggish.

Table 2: Synthesis of indolines **5aa-5fa** from 2-iodo-N-alkyl-N-(2-methylallyl)anilines **1a-1f** and terminal alkynes **2a-2p**.[a,b,c]

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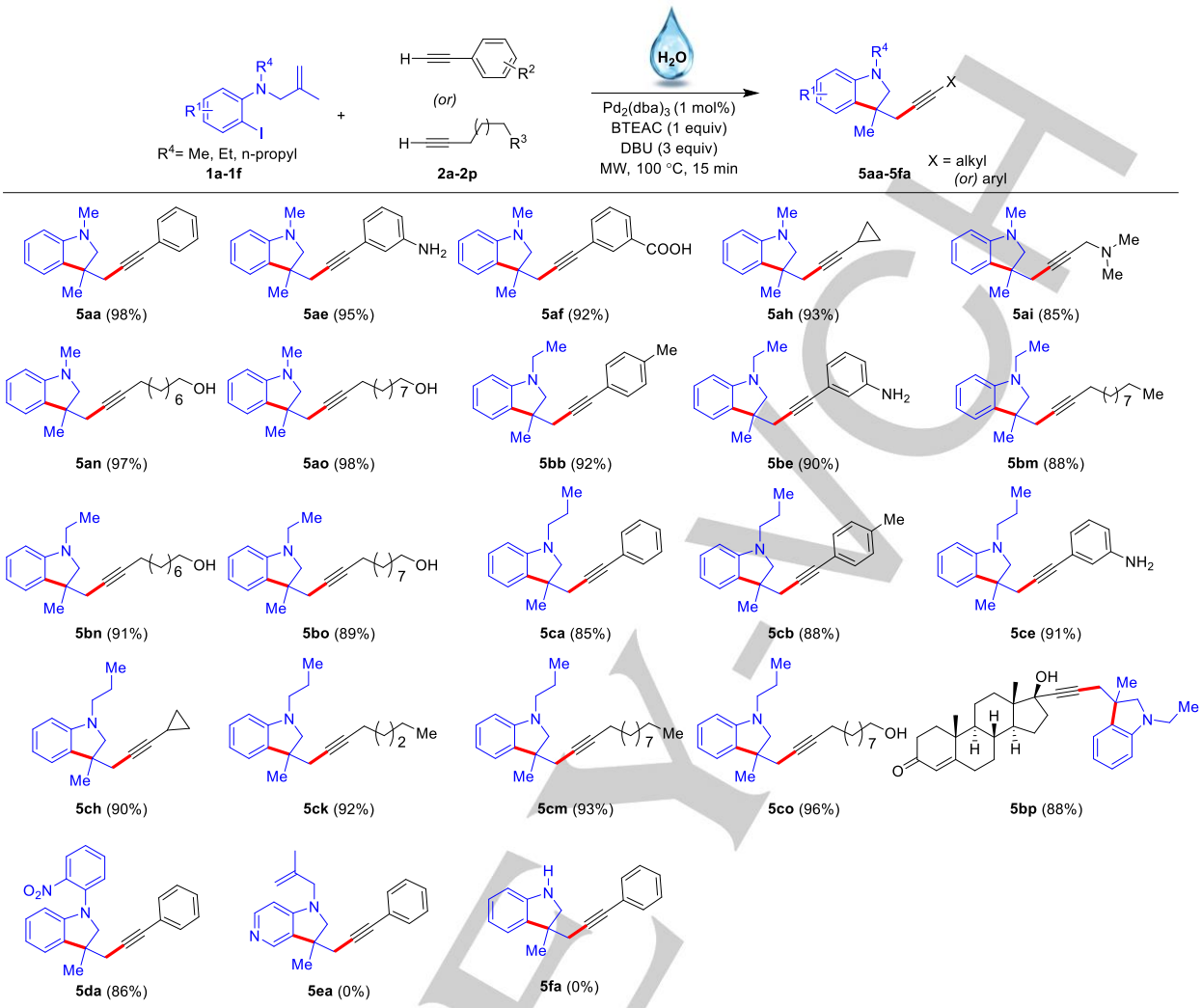
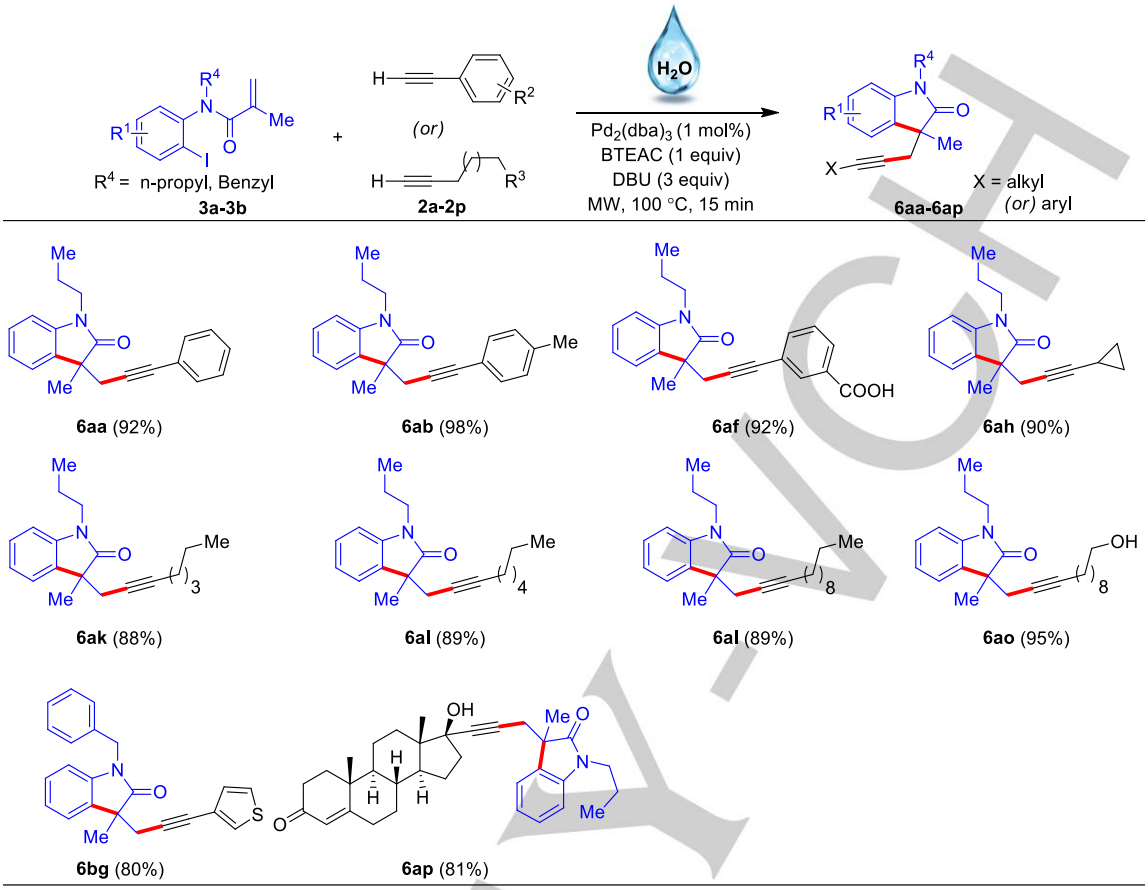


[a]Reaction conditions: 2-iodo-N-alkyl-N-(2-methylallyl)aniline **1a-1f** (0.25 mmol), acetylenes **2a-2p** (0.37 mmol) $Pd_2(dba)_3$ (1 mol%), DBU (1,8-Diazabicyclo[5.4.0]undec-7-ene) (3 equiv), and solvent Water (0.5 mL), 100 °C, 15 minutes. [b]Yields in the parenthesis are chromatographically isolated pure products. [c]The first alphabet of products **5aa-5fa** refers to the 2-iodo-N-alkyl-N-(2-methylallyl)aniline, while the second letter indicates the acetylenes.

It is worth noting that the reaction of N-arylallylamine **1d** with an terminal alkyne **2a** gave the product **5da** with 86% of yield. But, unfortunately, the reaction with 3-iodo-N,N-bis(2-methylallyl)pyridin-4-amine **5e** and 2-iodo-N-(2-methylallyl)aniline **5f** were not successful (neither the starting material nor the product was isolated).

After successful accomplishment of alkyne substituted indolines **5aa-5fa** (Table 2), further to ascertain the applicability of the process, the reaction was examined with *ortho*-iodophenyl enamides **3a-3b** and terminal acetylenes **2a-2p**, under standard microwave irradiation conditions. To our delight, the reaction was quite successful and gave the desired oxindoles **6aa-6ap**, in very good to near quantitative yields (Table 3). Remarkably, the reaction was compatible with different aryl or alkyl acetylenes. Significantly, the reaction was tolerable with protecting group free functional moieties such as amine, hydroxyl and carboxylic acid groups.

Table 3: Synthesis of oxindoles **6aa-6ap** from N-(2-iodophenyl)-N-alkylmethacrylamide **3a-3b** and terminal alkynes **2a-2p**.[a,b,c]

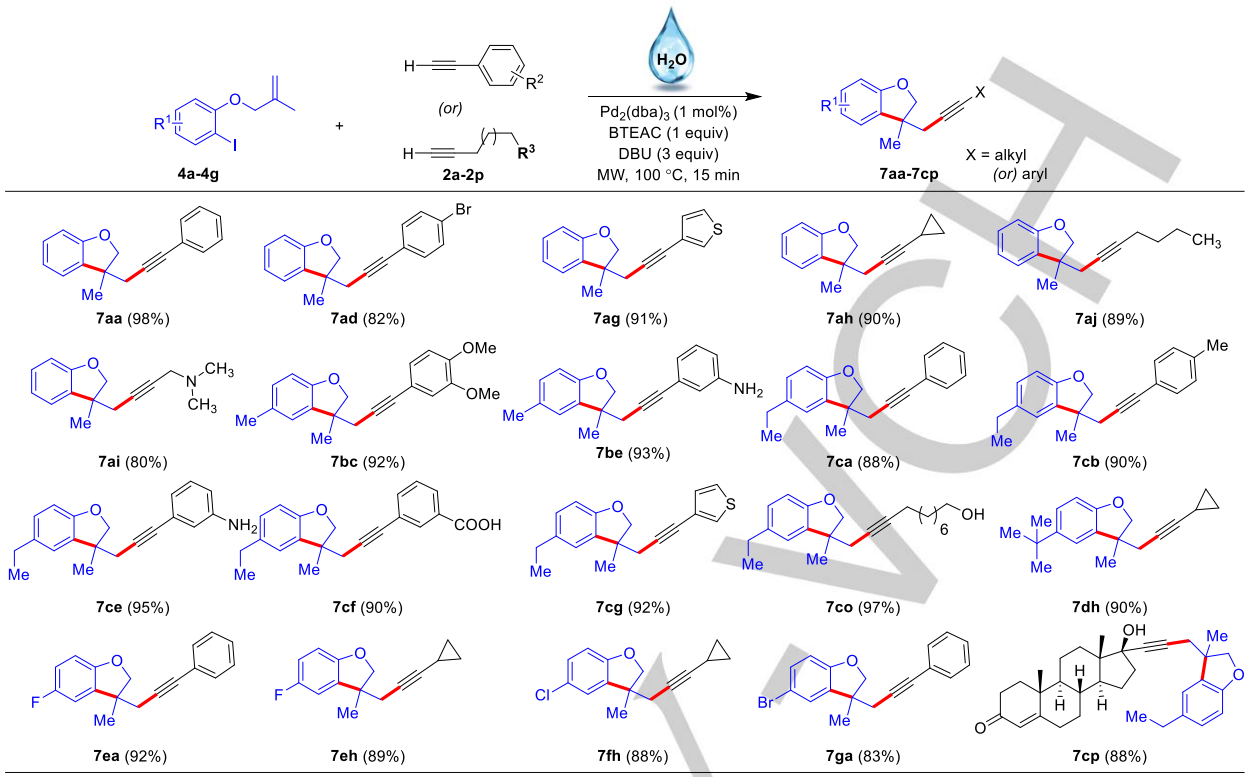


[a]Reaction conditions: N-(2-iodophenyl)-N-alkylmethacrylamide **3a-3b** (0.25 mmol), acetylenes **2a-2p** (0.37 mmol) $Pd_2(dba)_3$ (1 mol%), DBU (1,8-Diazabicyclo[5.4.0]undec-7-ene) (3 equiv), and solvent Water (0.5 mL), 100 °C, 15 minutes. [b]Yields in the parenthesis are chromatographically isolated pure products. [c]The first alphabet of products **6aa-6ap** refers to the N-(2-iodophenyl)-N-methylmethacrylamide, while the second letter indicates the acetylenes.

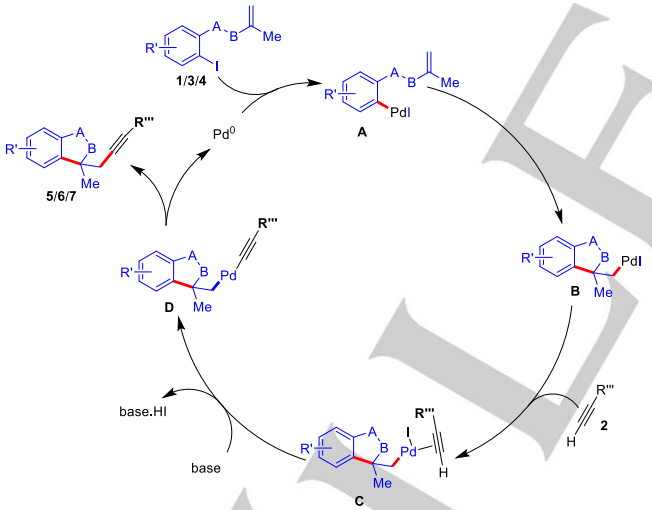
Furthermore, to exemplify the utility and tolerance of this green one-pot domino [Pd]-catalyzed intramolecular Heck and subsequent Sonogashira coupling, it was extended to the reaction between *ortho*-iodophenyl allyl ethers **4a-4g** and terminal acetylenes **2a-2p**, using standard microwave conditions. Delightfully, as anticipated, the protocol was smooth and afforded the desired dihydrobenzofurans **7aa-7cp**, in very good to near quantitative yields (Table 4). Significantly, the method was amenable to a wide range of allyl ethers. For example, suitable for simple to alkyl substituted aromatic rings of allyl ether (**7aa-7dh**, Table 4). Notably, amenable to electron deactivating F, Cl and Br substituents of the allyl ether (**7ea-7ga**, Table 4). On the other hand, the reaction was quite smooth with various aryl acetylenes and showed excellent functional group tolerance. Particularly, the reaction was smooth with acetylenes containing protecting group free reactive $–NH_2$ and –COOH groups on the aromatic ring of the acetylene (**7be**, **7ce** & **7cf**, Table 4). Also, successful with heteroaryl acetylene **2g** and bromoaryl acetylene **2d** (**7ad**, **7ag** & **7cg**, Table 4). In addition, the reaction was quite successful with terminal aliphatic acetylenes. For example, well suited with cyclopropyl acetylenes and furnished the dihydrobenzofuran products, in very good to excellent yields (**7ah**, **7dh**, **7eh** & **7fh**, Table 4). Remarkably, successful with free hydroxyl group containing acetylenes (**7co**, Table 4). In addition, coupling of *ortho*-iodophenyl allyl ether **4c** with steroidal acetylene **2p** was smooth and afforded **7cp**, as a diastereomeric mixture.

The plausible reaction mechanism for the synthesis of heterocyclic products **5/6/7** is as depicted in Scheme 1. Insertion of Pd^0 catalyst across the $C(sp^2)$-I bond of iodoarene of **1/3/4**, furnishes the corresponding aryl-Pd^{II} species **A**. Intramolecular Heck reaction of **A**, gives the bicyclic alkyl-Pd^{II} species **B**. Now, the intermediate **B** undergoes π-coordination with terminal acetylene **2** and affords the complex **C**. Then the π-complex **C** transforms into the σ-complex **D** via the elimination of hydroiodic acid (HI). Finally, reductive elimination via Sonogashira coupling, leads to the formation of desired heterocyclic products **5/6/7** and regenerates the Pd^0 catalyst and thus completes the catalytic cycle.

Table 4: Synthesis of dihydrobenzofurans **7aa-7cp** from 1-iodo-2-((2-methylallyl)oxy)benzene **4a-4g** and terminal alkynes **2a-2p**.[a,b,c]



[a]Reaction conditions: 1-iodo-2-((2-methylallyl)oxy)benzene **4a-4g** (0.25 mmol), acetylenes **2a-2p** (0.37 mmol), $Pd_2(dba)_3$ (1 mol%), DBU (1,8-Diazabicyclo[5.4.0]undec-7-ene) (3 equiv), and solvent Water (0.5 mL), 100 °C, 15 minutes. [b]Yields in the parenthesis are chromatographically isolated pure products. [c]The first alphabet of products **7aa-7cp** refers to the *ortho*-iodophenyl allyl ether, while the second letter indicates the acetylenes.



Scheme 1: Plausible mechanism to give products **5/6/7**.

Conclusions

In conclusion, we have developed microwave assisted environmentally benign domino [Pd]-catalyzed intramolecular Heck and intermolecular Sonogashira coupling, for the effective and diversified synthesis of 3,3'-disubstituted indolines, oxindoles and dihydrobenzofurans. Remarkably, this protocol is successful using water as the green solvent. Significantly, protocol showed excellent functional group tolerance comprising protecting group free amino, hydroxyl and carboxylic acid functionalities, and afforded the products, in very good to near quantitative yields.

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Keywords Microwaves. Domino. Pd-catalysis. 3,3'-Disubstituted Heterocycles.

References:

[1] a) C. Bolm, J. Legros, J. L. Paih, J. Zani, *Chem. Rev*. **2004**, *104*, 6217–6254; b) I. Bauer, J. H. Knölker, H. J. *Chem. Rev*. **2015**, *115*, 3170–3387.
[2] V. Satam, R. Rajule, S. Bendre, P. Bineesh, V. Kanetkar, *J. Heterocycl. Chem*. **2009**, *46*, 221-225.
[3] a) B. E. Pinxterhuis, P. Visser, I. Esser, B. J. Gualtierotti, L. B. Feringa, *Angew. Chemie - Int. Ed*. **2017**, *56*, 1–6; b) G. V. Gude, E. Martinez-Guerra, *Environ Chem Lett*. **2017**. doi:10.1007/s10311-017-0680-9.
[4] a) M. F. Kerton, R. Marriott, Alternative Solvents for Green Chemistry, RSC Green Chemistry Series, Cambridge, 2nd edn, **2013**; b) A. Jain, R. Vyas, A. Ameta, B. P. Punjabi, in Green Chemistry: Fundamentals and Applications, ed. S. C. Ameta and R. Ameta, CRC Press, **2013**, pp. 161–198.
[5] a) W. Kong, Q. Wang, J. Zhu, *Angew. Chemie - Int. Ed.* **2016**, *55*, 9714–9718; b) W.W. Ying, W.M. Zhu, Z. Gao, H. Liang, W.T. Wei, *Synlett*

2017, *28*, 1–5; c) J.-S. Li, Y.-J. Liu, G.-W. Zhang, J.-A. Ma, *Org. Lett.* **2017**, *19*, 6364–6367; d) S.-E. Wang, Q. He, R. Fan, *Org. Lett.* **2017**, *19*, 6478–6481; e) W. Fan, N. Li, L. Xu, C. Qiao, X. Wang, *Org. Lett.* **2017**, *19*, 6626–6629; f) R.-R. Liu, T.-F. Xu, Y.-G. Wang, B. Xiang, J.-R. Gao, Y.-X. Jia, *Chem. Commun.* **2016**, *52*, 13664–13667; g) M. B. Zhou, X. C. Huang, Y. Y. Liu, R. J. Song, J. H. Li, *Chem. - A Eur. J.* **2014**, *20*, 1843–1846; h) X. X. Wu, W. L. Chen, Y. Shen, S. Chen, P. F. Xu, Y. M. Liang, *Org. Lett.* **2016**, *18*, 1784–1787.

[6] a) M. Petrini, E. Chiurchiù, F. V. Rossi, A. Palmieri, *Synth.* **2017**, *49*, 4–8; b) C. Sivasankara, L. Satham, I. N. N. Namboothiri, *J. Org. Chem.* **2017**, *82*, 12939–12944; c) D. Y. Seo, H. J. Roh, B. K. Min, J. N. Kim, *Bull. Korean Chem. Soc.* **2017**, *38*, 1519–1522; d) H. Wang, S. Sun, J. Cheng, *Org. Lett.* **2017**, *19*, 5844–5847; e) H. Xu, H. W. Liu, H. S. Lin, G. W. Wang, *Chem. Commun.* **2017**, *53*, 12477–12480; f) J.-H. Zhang, R.-B. Wang, D.-F. Li, L.-M. Zhao, *ACS Omega* **2017**, *2*, 7022–7028.

[7] W. Wang, R. Zhou, J. Z. Jiang, X. Wang, Y. H. Fu, L. X. Zheng, H. Chen, X. R. Li, *European J. Org. Chem*. **2015**, 2579– 2584.

[8] a) P. Hewawasam, M. Erway, L. S. Moon, J. Knipe, H. Weiner, G. C. Boissard, J. D. Post-Munson, Q. Gao, S. Huang, K. V. Gribkoff, A. N. Meanwell, *J. Med. Chem*. **2002**, *45*, 1487; b) T. Bleith, H. Q. Deng, H. Wadepohl, H. L. Gade, *Angew. Chem., Int. Ed.* **2016**, *55*, 7852; c) T. Tokunaga, E. W. Hume, T. Umezome, K. Okazaki, Y. Ueki, K. Kumagai, S. Hourai, J. Nagamine, H. Seki, M. Taiji, H. Noguchi , R. Nagata, *J. Med. Chem*. **2001**, *44*, 4461; d) P. Hewawasam, M. Erway, L. S. Moon, J. Knipe, H. Weiner, G. C. Boissard, J. D. Post-Munson, Q. Gao, S. Huang, V. K. Gribkoff, A. N. Meanwell, *J. Med. Chem*. **2002**, *45*, 1487.

[9] a) B. M. Trost, Y. Zhang, T. Zhang, *J. Org. Chem.* **2009**, *74*, 5115–5117; b) A. A. Akaev, E. V. Villemson, N. S. Vorobyeva, A. G. Majouga, E. M. Budynina, M. Y. Melnikov, *J. Org. Chem.* **2017**, *82*, 5689–5701; c) L. A. Galliamova, M. V. Varaksin, O. N. Chupakhin, P. A. Slepukhin, V. N. Charushin, *Organometallics* **2015**, *34*, 5285–5290; d) A. P. Ilyn, A. S. Trifilenkov, *J. Org. Chem.* **2005**, *70*, 1478–1481; e) J. P. MacDonald, J. J. Badillo, G. E. Arevalo, A. Silva-García, A. K. Franz, *ACS Comb. Sci.* **2012**, *14*, 285–293; f) H. Sharghi, J. Aboonajmi, M. Mozaffari, M. M. Doroodmand, M. Aberi, *Appl. Organomet. Chem.* **2017**, e4124.

[10] a) I. Franzoni, H. Yoon, J.-A. García López, A. I. Poblador-Bahamonde, M. Lautens, *Chem. Sci.* **2017**, asap; b) K. SiLarbi, H. Y. Fu, N. Laidaoui, K. Beydoun, A. Miloudi, D. ElAbed, S. Djabbar, H. Doucet, *ChemCatChem* **2012**, *4*, 815–823; c) Y. J. Jang, E. M. Larin, M. Lautens, *Angew. Chemie - Int. Ed.* **2017**, *56*, 11927–11930; d) M. Pérez-Gómez, L. Navarro, I. Saura-Llamas, D. Bautista, M. Lautens, J.-A. García-López, *Organometallics* **2017**, *36*, 4465–4476; e) Y. Wu, J. Wang, F. Mao, F. Y. Kwong, *Chem. - An Asian J.* **2014**, *9*, 26–47; f) J. N. Desrosiers, L. Hie, S. Biswas, O. V. Zatolochnaya, S. Rodriguez, H. Lee, N. Grinberg, N. Haddad, N. K. Yee, N. K. Garg, et al., *Angew. Chemie - Int. Ed.* **2016**, *55*, 11921–11924; g) J. Roger, A. L. Gottumukkala, H. Doucet, *ChemCatChem* **2010**, *2*, 20–40.

[11] P. Fretwell, R. Grigg, M. J. Sansano, J. V. Sridharan, S. Sukirthalingam, J. Redpath, J. *Tetrahedron*. **2000**, *56*, 7525–7539.

[12] G. Grigg, V. Sridharan, *J. Organomet. Chem*. **1999**, *576*, 65–87.

[13] T. T. Schempp, E. B. Daniels, B. T. S. Staben, E. S. Stivala, *Org. Lett*. **2017**, *19*, 3616–3619.

[14] D. D. Vachhani, H. H. Butani, N. Sharma, C. U. Bhoya, K. A. Shah, V. E. Van der Eycken, *Chem. Commun*. **2015**, *51*, 14862–14865.

[15] a) M. L. N. Rao, D. N. Jadhav, P. Dasgupta, *Org. Lett.* **2010**, *12*, 2048–2051; b) H. Wang, Y. Liu, M. Li, H. Huang, H. M. Xu, R. J. Hong, H. Shen, *Optoelectron. Adv. Mater. Rapid Commun.* **2013**, *15*, 3170–3175; c) J. Li, J. Zhang, H. Qu, J. Liu, J. Li, L. Zhou, *Org. Lett.* **2009**, *11*, 3318–3321; d) D. Ye, J. Wang, X. Zhang, Y. Zhou, X. Ding, E. Feng, H. Sun, G. Liu, H. Jiang, H. Liu, *Green Chem.* **2009**, *11*, 1201–1208; e) Z. L. Palchak, D. J. Lussier, C. J. Pierce, C. H. Larsen, *Green Chem.* **2015**, *17*, 1802–1810.

[16] K. Ramesh, G. Satyanarayana, *Green Chem*. **2018**, *20*, 369–374.

[17] a) L. Mahendar, J. Krishna, A. G. K. Reddy, B. V. Ramulu, G. Satyanarayana, *Org. Lett.* **2012**, *14*, 628–631; b) L. Mahendar, G. Satyanarayana, *J. Org. Chem.* **2014**, *79*, 2059–2074; c) D. R. Kumar, G. Satyanarayana, *Org. Lett.* **2015**, *17*, 5894–5897; d) J. Krishna, A. G. K. Reddy, G. Satyanarayana, *Adv. Synth. Catal*. **2015**, *357*, 3597–3610; e) A. G. K. Reddy, G. Satyanarayana, *J. Org. Chem*. **2016**, *81*, 12212-12222; f) K. Ramesh, G. Satyanarayana, *J. Org. Chem*. **2017**, *82*, 4254-4264; g) B. Suchand, G. Satyanarayana, *Eur. J. Org. Chem.* **2017**, *26*, 3886–3895; h) B. Suchand, G. Satyanarayana, *J. Org. Chem*. **2016**, *81*, 6409-6423; i) B. Suchand, G. Satyanarayana, *J. Org. Chem*. **2017**, *82*, 372-381.

[18] a) A. Balanta, C. Godard, C. Claver, *Chem. Soc. Rev.* **2011**, *40*, 4973–4985; b) E. L. Cropper, A. J. P. White, A. Ford, K. K. Hii, *J. Org. Chem.* **2006**, *71*, 1732–1735; c) A. B. Dounay, K. Hatanaka, J. J. Kodanko, M. Oestreich, L. E. Overman, L. A. Pfeifer, M. M. Weiss, *J. Am. Chem. Soc.* **2003**, *125*, 6261–6271; d) R. Lasch, S. K. Fehler, M. R. Heinrich, *Org. Lett.* **2016**, *18*, 1586–1589; e) L. Firmansjah, G. C. Fu, *J. Am. Chem. Soc.* **2007**, *129*, 11340–11341; f) M. R. Harris, M. O. Konev, E. R. Jarvo, *J. Am. Chem. Soc.* **2014**, *136*, 7825–7828; g) E. P. Kündig, H. Ratni, B. Crousse, G. Bernardinelli, *J. Org. Chem.* **2001**, *66*, 1852–1860.

[19] a) H. Abe, K. Ohtani, D. Suzuki, Y. Chida, Y. Shimada, S. Matsumoto, M. Inouye, *Org. Lett.* **2014**, *16* (3), 828–831; b) W. M. Carson, W. M. Giese, J. M. Coghlan, *Org. Lett.* **2008**, *10* (13), 2701–2704; c) C. Che, H. Zheng, G. Zhu, *Org. Lett.* **2015**, *17* (6), 1617–1620; d) J. Santandrea, C. A. Bédard, K. S. Collins, *Org. Lett.* **2014**, *16* (15), 3892–3895; e) H. Kinoshita, H. Takahashi, K. Miura, K. *Org. Lett.* **2013**, *15* (12), 2962–2965; f) E. Ramesh, M. Shankar, S. Dana, A. K. Sahoo, *Org. Chem. Front.* **2016**, *3* (9), 1126–1130; g) N. Ramkumar, R. Nagarajan, *Org. Biomol. Chem.* **2015**, *13* (45), 11046–11051.

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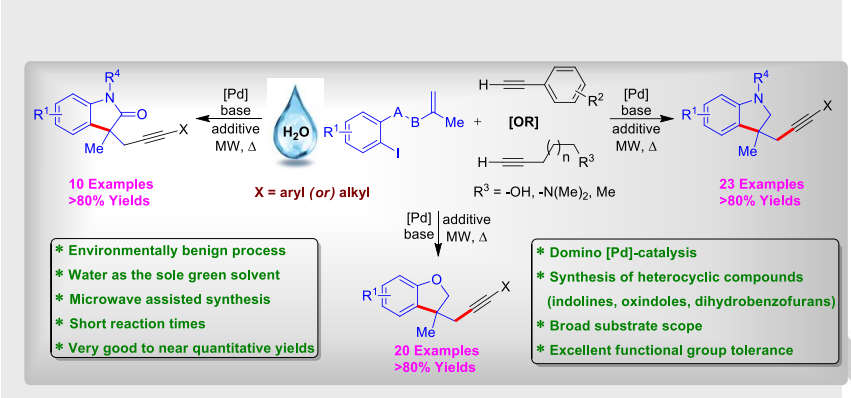

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Microwave Assisted Domino [Pd]-Catalysis in Water: A Diversified Synthesis of 3,3'-Disubstituted Heterocyclic Compounds