Green and Sustainable Chemistry, **2011, 1, 165-169**
doi:10.4236/gsc.2011.14025 Published Online November 2011 (http://www.SciRP.org/journal/gsc)

Phase-Transfer-Catalyzed Intramolecular Hydroaryloxylation and Hydroamination of C≡C Triple Bonds: An Efficient Synthesis of Benzo[*b*]furan and 3-Methyleneisoindoline-1-one Derivatives

Jie Hu, Lei Liu, Xiangchuan Wang, Yuanyuan Hu, Shangdong Yang*, Yongmin Liang*
State Key Laboratory of Applied Organic Chemistry, *Lanzhou University*, *Lanzhou*, *China*
E-mail: *yangshd@lzu.edu.cn, *liangym@lzu.edu.cn
Received July 20, 2011; *revised August* 30. 2011; *accepted September* 8, 2011

Abstract

Phase-transfer-catalyzed intramolecular cyclization reaction of forming benzo[*b*]furan and 3-methyleneisoindoline-1-one derivatives has been developed. The cyclization reaction of propargylic carbonates was also described under metal-free condition and the reaction was reported by Pd and Ni before. The reaction conditions and the scope of the process are examined. The catalysts are cheap and environmentally friendly and the substrates are readily available and the procedure is simple, rapid, and general. The development of C-O and C-N bond formation processes via an overall structural isomerization represents the most atom-economical approach.

Keywords: PTC, Intramolecular, Cyclization, Metal-Free

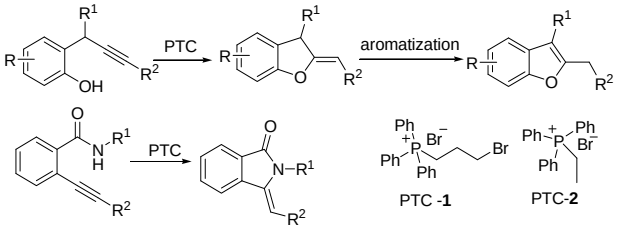
1. Introduction

The addition of heteroatomic nucleophiles to C≡C triple bonds is an important reaction that often requires a high activation energy [1,2]. The transition metal-catalyzed construction of heterocycles is one of the frontier areas in organic chemistry, because of the exceptional ability to activate the triple bond, towards intermolecular and intramolecular nucleophilic attack [3-7]. Oxygen-containing heterocyclic moieties such as benzo[*b*]furan rings represent key structural units of a variety of natural compounds with interesting biological and pharmacological activities [8-10] and a number of routes leading to differently sub- stituted benzo[*b*]furans have been described by metal-catalyzed intramolecular ring closure[11-16]. Meanwhile, nitrogen-containing heterocyclic moiety 3-methyleneisoin-doline-1-one is a core structure of numerous natural products and has also been prepared in the literature.[17,18] Compared with other methods phase-transfer catalysis has long been recognized as a versatile methodology for organic synthesis in both industrial and academic laboratories, featuring its simple reaction procedure, safe, inexpensive, environmentally friendly reagents, absence of anhydrous solvents, ease of scale-up, and metal-free conditions [19-22].

Recently, [23] we have developed a novel and efficient cyclization reaction initiated by phase-transfer catalysis for building carbon-carbon bond. Herein, we report a new mild synthesis of heterocyclic compounds under phase-transfer catalysis by carbon-oxygen or carbon-nitrogen bond formation (**Scheme 1**).

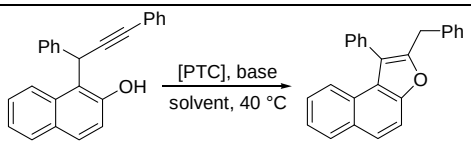
2. Results and Discussion

Initially, we focused on the reaction of 0.20 mmol of 1-(1,3-diphenylprop-2-ynyl)naphthalen-2-ol (**1a**), 5 mol % of PTC-1 and 2 equiv of Na_2CO_3 in DMF at 40˚C in air. To our delight, the desired product benzo[*b*]furan **2a** was formed in 66% yield after 1 h (**Table 1**, entry 1). Encouraged by this result, we further optimized the reaction



Scheme 1. C-O bond and C-N bond formation by PTC.

Table 1. Optimization of the phase-transfer-catalyzed intramolecular cyclization of 1a[a].



1a **2a**

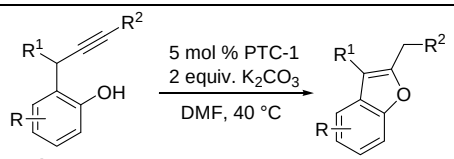
Entry	[PTC]	Base	Solvent	Time (h)	Yield (%)[b]
1	PTC-1	Na_2CO_3	DMF	1	66
2	PTC-1	K_2CO_3	DMF	0.5	85
3	PTC-1	Li_2CO_3	DMF	12	50
4	PTC-1	K_3PO_4	DMF	1	44
5	PTC-1	KOAc	DMF	0.5	65
6	PTC-1	K_2HPO_4	DMF	1	31
7	PTC-1	$KHCO_3$	DMF	0.5	67
8		K_2CO_3	DMF	3	50
9		KO^{t}Bu	DMF	0.5	39
10	PTC-1	K_2CO_3	DMA	1	82
11	PTC-1	K_2CO_3	NMP	1	77
12	PTC-1	K_2CO_3	DMSO	1	68
13	PTC-1	K_2CO_3	THF	3	77
14	PTC-1	K_2CO_3	1,4-dioxane	1.5	53
15	PTC-1	K_2CO_3	CH_3CN	1	83
16	PTC-2	K_2CO_3	DMF	0.5	51
17	TBAI	K_2CO_3	DMF	0.5	56
18	TEAB	K_2CO_3	DMF	0.5	68
19	TBAC	K_2CO_3	DMF	0.5	66
20	TBAF	K_2CO_3	DMF	0.5	64

[a]Reactions were carried out on a 0.2 mmol scale in 2.0 mL of solvent in air at 40˚C with 1.0 equiv of **1a,** 2.0 equiv of base and 5 mol% equiv of PTC. [b]Isolated yield.

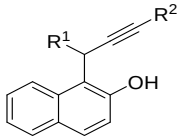
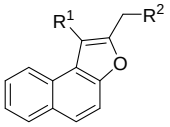
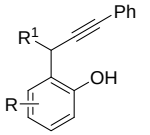
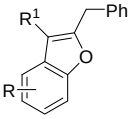
conditions. Other common bases, such as K_2CO_3, Li_2CO_3, K_3PO_4, KOAc, K_2HPO_4, $KHCO_3$ were also tested; K_2CO_3 gave the best yield of 85% (entries 2 - 7), which indicated that base played an important role in the process. In the absence of PTC condition, the product was obtained in low yield (entries 8 and 9). The effect of the solvent was also investigated. Changing solvent to DMA, NMP, DMSO, THF, 1, 4-dioxane, CH_3CN failed to improve the yield of the product **2a** (entries 10 - 15). When different PTCs were examined, the results showed that PTC-2 could also promote this cyclization, but the desired product **2a** was only obtained with 51% yield (entry 16). Tetraalkyl ammonium salts, such as Bu_4NI, Et_4NBr, Bu_4NCl, and Bu_4NF have also been applied to this process, and the yields were not better than PTC-1 (entries 17 - 20). Thus, we chose the following reaction conditions as optimum for subsequent cyclization: 0.20 mmol of **1a**, 5 mol % PTC-1, and 0.40 mmol K_2CO_3 in DMF at 40˚C in air.

With the optimized conditions in hand, the scope of this reaction was then investigated, and the results are summarized in **Table 2**. As depicted in **Table 2**, the

Table 2. Phase-transfer-catalyzed synthesis of disubstituted benzo[b]furan derivatives (2a-m)[a].



1a-m **2a-m**

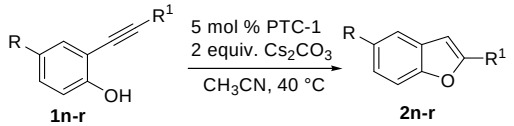
Entry	Substrate (**1**)/Time (h)	Product (**2**)	Yield[b]
			
1	**1a** R^1 = Ph, R^2 = Ph (0.5)	**2a** R^1 = Ph, R^2 = Ph	85
2	**1b** R^1 = *o*-$CH_3OC_6H_4$, R^2=Ph (1.5)	**2b**R^1 = *o*-$CH_3OC_6H_4$, R^2 = Ph	80
3	**1c** R^1 = *m*-$CH_3C_6H_4$, R^2 = Ph (0.5)	**2c** R^1 = *m*-$CH_3C_6H_4$, R^2 = Ph	95
4	**1d** R^1 = *p*-$CH_3C_6H_4$, R^2 = Ph (0.5)	**2d** R^1 = *p*-$CH_3C_6H_4$, R^2 = Ph	81
5	**1e** R^1 = 2,4-diClC_6H_4, R^2 = Ph (0.5)	**2e** R^1 =2,4-diClC_6H_4, R^2 =Ph	60
6	**1f** R^1 = Ph, R^2 = TMS (0.5)	**2f** R^1 = Ph, R^2 = H	75
7	**1g** R^1 = Ph, R^2 = $CH_3CH_2CH_2$ (1)	**2g** R^1 = Ph, R^2 = $CH_3CH_2CH_2$	20
8	**1h** R^1 = $CH_3(CH_2)_2$, R^2 = Ph (2)	**2h** R^1 = $CH_3(CH_2)_2$, R^2 = Ph	51
			
9	**1i** R = 4-$CH_3C_6H_4$, R^1 = Ph (0.5)	**2i** R = 4-$CH_3C_6H_4$, R^1 = Ph	76
10	**1j** R = 5-$CH_3C_6H_4$, R^1 = Ph (0.5)	**2j** R = 5-$CH_3C_6H_4$, R^1 = Ph	87
11	**1k** R = 4-^{t}BuC_6H_4, R^1 = Ph (0.5)	**2k** R = 4-^{t}BuC_6H_4, R^1 = Ph	64
12	**1l** R = 5-$CH_3C_6H_4$, R^1 = *m*-$CH_3C_6H_4$ (1)	**2l** R = 5-$CH_3C_6H_4$, R^1 = *m*-$CH_3C_6H_4$	72
13	**1m** R = 5-$CH_3C_6H_4$, R^1= *o*-$CH_3OC_6H_4$(2)	**2m** R = 5-$CH_3C_6H_4$, R^1 = *o*-$CH_3OC_6H_4$	62

[a]Reactions were carried out on a 0.2 mmol scale in 2.0 mL of DMF in air at 40˚C with 1.0 equiv of 1a, 2.0 equiv of K2CO3 and 5 mol% equiv of PTC-1. [b]Isolated yield (%).

reaction was application to various propargylnaphthols and phenols, and for the most tested substrates, good results have also been obtained. Naphthols with an electron-donating aryl group at propargylic position cyclized smoo- thly to give the products in high yields, no matter sub- stituents appeared in *ortho*, *meta* or *para* positions (Table 2, entries 2 - 4), while the electron-withdrawing aryl group naphthol (**1e**) apparently lowered yield (entry 5). The trimethylsilyl-substituted naphthol, **1f**, reacted to produce the respective naphthofuran in a moderate (75%) yield and the TMS group happened to undergo desilylation at the same time (entry 6). When a propargylnaphthol with a butyl group at the triple bond was used, the desired product **2g** was obtained in a poor yield (entry 7). On employing naphthol with a propyl group at the propargylic position, cyclization product **2h** was obtained in moderate yield (entry 8). Furthermore, the propargylphenols were also examined. The presence of electron-donating group on the aromatic ring gave moderate to good yields (entries 9 - 11). Introducing an electron-donating aryl group at the propargylic position, the reaction proceeded smoothly to give the corresponding cyclization products (entries 12 and 13).

Furthermore, to expand the scope of this reaction, we also investigated the ethynylphenol **1n-r**. As depicted in **Table 3**, for all the tested substrates, the phase-transfer-catalysts intramolecular cyclization of ethynylphenol could prove to be a very effective method for the synthesis of a variety of monosubstituted benzo[*b*]furans and the reaction can be tolerant of the substitution groups in aromatic ring (**Table 3**, entries 1 - 4). It is noteworthy that when R^1 was replaced by an alkyl group, the reaction proceeds smoothly to give the corresponding product in good yield (entry 5).

Table 3. Phase-transfer-catalyzed synthesis of monosubstituted benzo[*b*]furan derivatives (2n-s)[a].



1n-r **2n-r**

Entry	Substrate (**1**)/Time (h)	Product (**2**)	Yield (%)[b]
1	**1n** R=H, R^1= h (1)	**2n** R=H, R^1=Ph	90
2	**1o** R H_3, R^1 h (1)	**2o** R=CH_3, R^1=Ph	95
3	**1p** R= l, R^1=h (1)	**2p** R=Cl, R^1=Ph	90
4	**1q** R=*t*-Bu, R^1=Ph (1.5)	**2q** R=*t*-Bu, R^1=Ph	86
5	**1r** R=H, R^1=$CH_3(CH_2)_4$ (1.5)	**2r** R=H, R^1=$CH_3(CH_2)_4$	84

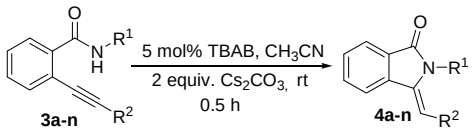
[a]Reactions were carried out on a 0.2 mmol scale in 2.0 mL of CH_3CN in air at 40°C with 1.0 equiv of **1a,** 2.0 equiv of Cs_2CO_3 and 5 mol% equiv of PTC-**1**. [b]Isolated yield.

The addition of nitrogen nucleophiles to triple bonds were also investigated and results are summarized in **Table 4**. On introducing aryl groups on the amide moiety, the desired products were generated in good to excellent yields irrespective of the presence of electron-withdrawing or electron-donating groups (entries 2 - 6). Functional groups, such as methyl, methoxyl and bromo were well tolerated in the reaction. When R^1 was the benzyl or substituted benzyl, good results still were obtained in our system (entries 7 - 9). Furthermore, we investigated the effect of various substituents on the remote end of the alkyne moiety. These substrates all worked well and gave moderate yields (entries 10 - 14).

When the substrates **5a** was investigated, to our surprising, 2-phenyl-1H-indole was obtained in good yield (**Scheme 2**).

For the substrates **7aa**, **7ba** and **7ca**, we have reported via Pd [24] and Ni [25,26] catalyzed reaction. To our delight, the same good result could also been obtained in our system under metal-tree condition (**Scheme 3**).

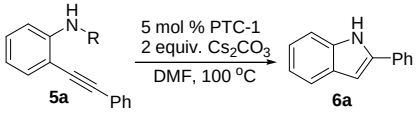
Table 4. Cyclization reaction catalyzed by TBAB[a,b].



3a-n **4a-n**

Entry	R^1	R^2	**3**	**4**	Isolated Yield (%)
1	CH_3	Ph	**3a**	**4a**	98
2	Ph	Ph	**3b**	**4b**	91
3	m-$CH_3C_6H_4$	Ph	**3c**	**4c**	84
4	p-$CH_3C_6H_4$	Ph	**3d**	**4d**	80
5	p-$CH_3OC_6H_4$	Ph	**3e**	**4e**	94
6	m-BrC_6H_4	Ph	**3f**	**4f**	80
7	$PhCH_2$	Ph	**3g**	**4g**	90
8	p-CH_3OPhCH_2	Ph	**3h**	**4h**	91
9	p-$ClPhCH_2$	Ph	**3i**	**4i**	87
10	Ph	p-$CH_3C_6H_4$	**3j**	**4j**	65
11	Ph	p-BrC_6H_4	**3k**	**4k**	64
12	Ph	m-$CH_3C_6H_4$	**3l**	**4l**	63
13	Ph	o-$CH_3C_6H_4$	**3m**	**4m**	67
14[c]	Ph	$CH_2CH_2CH_3$	**3n**	**4n**	70

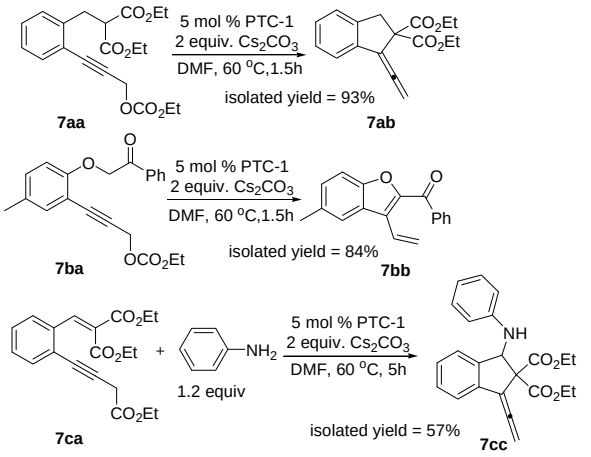
[a]Reactions were carried out on a 0.2 mmol scale in 2.0 mL of solvent in air at r.t. with 1.0 equiv of 1a, 2 equiv of base and 5 mol% equiv of TBAB for 0.5 h. [b]TBAB: Tetrabutylammonium bromide. [c]The reaction was carried out for 5 h.



5a **6a**

R= Ac **(5aa)**, isolated yield**(6a)** = 80 %, 45 h;
R= Ts **(5ab)**, isolated yield**(6a)** = 71 %, 30 h.

Scheme 2. Phase-transfer-catalyzed intramolecular cyclization of 5a.



Scheme 3. Phase-transfer-catalyzed intramolecular cyclization of propargylic carbonates.

3. Experimental Part

Typical procedure for the preparation of disubstituted benzo[*b*]furan derivatives **2a**. To a solution of **1a** (65.2 mg, 0.20 mmol) in 2.0 mL of DMF was added K_2CO_3 (55.2 mg, 0.40 mmol). The mixture was allowed to stir at room temperature for 1 minute and PTC-**1** (4.74 mg, 5 mol%) was added. The resulting mixture was then heated under air at 40˚C. When the reaction was considered complete as determined by TLC analysis, the reaction was allowed to cool to room temperature and quenched with a saturated aqueous solution of ammonium chloride, and the mixture was extracted with EtOAc. The combined organic extracts were washed with water and saturated brine. The organic layers were dried over Na_2SO_4, filtered. Solvents were evaporated under reduced pressure. The residue was purified by chromatography on silica gel to afford 2,3-disubstitution benzo[*b*]furans **2a.**

Typical procedure for the preparation of 3-methyleneisoindoline-1-one derivatives **4a** to a solution of **3a** (0.20 mmol) in 2.0 mL of CH_3CN was added Cs_2CO_3 (130.4 mg, 0.40 mmol). The mixture was allowed to stir at room temperature when TBAB (3.22 mg, 5 mol%) was added. When the reaction was considered complete as determined by TLC analysis, the reaction was allowed to quench with a saturated aqueous solution of ammonium chloride, and the mixture was extracted with EtOAc. The combined organic extracts were washed with water and saturated brine. The organic layers were dried over Na_2SO_4, filtered. Solvents were evaporated under reduced pressure. The residue was purified by chromatography on silica gel to afford 3-methyleneisoindoline-1-one derivatives **4a**.

4. Conclusions

In conclusion, phase-transfer-catalyzed intramolecular hydroaryloxylation and hydroamination reaction of corresponding O/N-containing substrates is a novel and efficient method for synthesis of heteroatomic compounds. We also described the cyclization reaction of propargylic carbonates under metal-free condition. These reactions are run under mild conditions, tolerate various functional groups, and generally a wide range of substrates undergo this process in good to excellent yields. Compared to the expensive and toxic transition-metal catalyzed reaction, this methodology showed considerable synthetic advantages in terms of mild reaction conditions, environmentally friendly catalysts and simple experimental operations. The scope and synthetic application of these reactions are currently under investigation.

5. Acknowledgements

We are grateful for the National Science Foundation (NSF-21072080) for financial support. We acknowledge National Basic Research Program of China (973 Program), 2010CB833203.

6. References

[1] T. E. Müller and M. Beller, "Metal-Initiated Amination of Alkenes and Alkynes," *Chemical Reviews*, Vol. 98, No. 2, 1998, pp. 675-704. doi:10.1021/cr960433d

[2] J. H. Teles, S. Brode and M. Chabanas, "Cationic Gold(I) Complexes Highly Efficient Catalysts for the Addition of Alcohols to Alkynes," *Angewandte Chemie International Edition*, Vol. 37, No. 10, 1998, pp. 1415-1418. doi:10.1002/(SICI)1521-3773(19980605)37:10<1415::AID-ANIE1415>3.0.CO;2-N

[3] Y. Yamamoto and U. Radhakrishnan, "Palladium Catalysed Pronucleophile Addition to Unactivated Carbon-Carbon Multiple Bonds," *Chemical Society Reviews*, Vol. 28, No. 3, 1999, pp. 199-207. doi:10.1039/a806581k

[4] F. Pohlki and S. Doye, "The Catalytic Hydroamination of Alkynes," *Chemical Society Reviews*, Vol. 32, No. 2, 2003, pp. 104-114. doi:10.1039/b200386b

[5] F. Alonso, I. P. Beletskaya and M. Yus, "Transition-Metal-Catalyzed Addition of Heteroatom-Hydrogen Bonds to Alkynes," *Chemical Reviews*, Vol. 104, No. 6, 2004, pp. 3079-3160. doi:10.1021/cr0201068

[6] D. K. Barange, T. C. Nishad, N. K. Swamy, V. Bandameedi, D. Kumar, B. R. Sreekanth, K. Vyas and M. Pal, "A Remarkable Accelerating Effect of Ag-Salt on Intramolecular Cyclization of ***o***-(1-Alkynyl)benzenesulfonanmides," *The Journal of Organic Chemistry*, Vol. 72, No. 22, 2007, pp. 8547-8550. doi:10.1021/jo701470h

[7] Y. Yu, A. Gregory, G. A. Stephenson and D. Mitchell, "A Regioselective Synthesis of 3-Benzazepinones via Intramolecular Hydroamidation of Acetylenes," *Tetrahedron Letters,* Vol. 47, No. 23, 2006, pp. 3811-3814. doi:10.1016/j.tetlet.2006.03.198

[8] X. L. Hou, Z. Yang, K. S. Yeung and H. N. C. Wong, "In Progress in Heterocyclic Chemistry," In: G. W. Gribble and J. A. Joule, Eds., Elsevier, Oxford, 2008, Vol. 19, pp. 176-207.

[9] B. Carlsson, B. N. Singh, M. Temciuc, S. Nilsson, Y.-L. Li, C. Mellin and J. Malm, "Synthesis and Preliminary Characterization of a Novel Antiarrhythmic Compound (KB130015) with an Improved Toxicity Profile Compared with Amiodarone" *Journal of Medicinal Chemistry*, Vol. 45, No. 3, 2002, pp. 623-630. doi:10.1021/jm001126+

[10] B. L. Flynn, E. Hamel and M. K. Jung, "One-Pot Synthesis of Benzo[*b*]furan and Indole Inhibitors of Tubulin Polymerization," *Journal of Medicinal Chemistry*, Vol. 45, No. 12, 2002, pp. 2670-2673. doi:10.1021/jm020077t

[11] F. Alonso, I. P. Beletskaya and M. Yus, "Transition-Metal-Catalyzed Addition of Heteroatom-Hydrogen Bonds to Alkynes," *Chemical Reviews*, Vol. 104, No. 6, 2004, pp. 3079-3160. doi:10.1021/cr0201068

[12] G. Zeni and R. C. Larock, "Synthesis of Heterocycles via Palladium-Catalyzed Oxidative Addition," *Chemical Reviews*, Vol. 106, No. 11, 2006, pp. 4644-4680.

[13] A. S. K. Hashmi, T. M. Frost and J. W. Bats, "Gold Catalysis: On the Phenol Synthesis," *Organic Letters*, Vol. 3, No. 23, 2001, pp. 3769-3771. doi:10.1021/ol016734d

[14] M. Carril, R. SanMartin, I. Tellitu and E. Dominguez, "On-Water Chemistry: Copper-Catalyzed Straightforward Synthesis of Benzo[*b*]furan Derivatives in Neat Water," *Organic Letters*, Vol. 8, No. 7, 2006, pp. 1467-1470. doi:10.1021/ol060274c.

[15] B. Zhao and X. Lu, "Cationic Palladium(II)-Catalyzed Addition of Arylboronic Acids to Nitriles. One-Step Synthesis of Benzofurans from Phenoxyacetonitriles," *Organic Letters*, Vol. 8, No. 26, 2006, pp. 5987-5990.

[16] J. Hu, X.-C. Wang, L.-N. Guo, Y.-Y. Hu, X.-Y. Liu and Y.-M. Liang, "Pd/C-Catalyzed Cyclization/Isomerization: A New Route to 2-Aroyl-3-vinyl benzo[b]furans via Carbon-Carbon Bond Formation," *Catalysis Communications*, Vol. 5, No. 25, 2010, pp. 346-350. doi:10.1016/j.catcom.2009.10.028

[17] G. Blaskó, D. J. Gula and M. Shamma, "The Phthalide-isoquinoline Alkaloids," *Journal of Naturral Products*, Vol. 45, No. 2, 2010, pp. 105-122.

[18] N. G. Kundu and M. W. Khan, "Palladium-Catalysed Heteroannulation with Terminal Alkynes: a Highly Regio- and Stereoselective Synthesis of (Z)-3-Aryl(alkyl) idene Isoindolin-1-ones," *Tetrahedron Letters*, Vol. 56, No. 27, 2000, pp. 4777-4792.

[19] E. V. Dehmlow and S. S. Dehmlow, "Phase Transfer Catalysis," 3rd Edition, VCH, Weinheim, 1993.

[20] C. M. Starks, C. L. Liotta and M. Halpern, "Phase-Transfer Catalysis" Chapman & Hall, New York, 1994. doi:10.1007/978-94-011-0687-0

[21] Y. Sasson and R. Neumann, "Handbook of Phase- Transfer Catalysis" Blackie Academic & Professional, London, 1997. doi:10.1007/978-94-009-0023-3

[22] M. E. Halpern, "Phase-Transfer Catalysis; ACS Symposium Series 659," American Chemical Society, Washington, D.C., 1997.

[23] J. Hu, L.-Y. Wu, X.-C. Wang, Y.-Y. Hu, Y.-N. Niu, X.-Y. Liu, S. Yang and Y.-M. Liang, "Phase-Transfer-Catalyzed Intramolecular Cyclization of ortho-Alkynyl Phenyl Ether Derivatives for Synthesis of 2,3-Disubstituted Benzo[b]furans," *Advanced. Synthesis and Catalysis*, Vol. 352, No. 2-3, 2010, pp. 351-356.

[24] H.-P. Bi, X.-Y. Liu, F.-R. Gou, L.-N. Guo, X.-H., Duan and Y.-M. Liang, "Highly Regioselective Synthesis of Indene Derivatives Including an Allene Functional Group via Pd/C-Catalyzed Cyclization Reaction in Air," *Organic. Letters*, Vol. 9, No. 18, 2007, pp. 3527-3529. doi:10.1021/ol071385u

[25] F.-R. Gou, H.-P. Bi, L.-N. Guo, Z.-H. Guan, X.-Y. Liu and Y.-M. Liang, "New Insight into Ni(II)-Catalyzed Cyclization Reactions of Propargylic Compounds with Soft Nucleophiles: Novel Indenes Formation," *The Journal of Organic Chemistry*, Vol. 73, No. 10, 2008, pp. 3837-3841. doi:10.1021/jo800155a

[26] Y. Shi, J. Huang, Y.-F. Yang, L.-Y. Wu, Y.-N. Niu, P.-F. Huo, X.-Y. Liu and Y.-M. Liang, "One-Pot Synthesis of Highly Substituted Allenylidene Derivatives via Palladium- or Nickel-Catalyzed Tandem Michael Addition–Cyclization Reaction," *Advanced. Synthesis &. Catalysis*, Vol. 351, No. 1-2, 2009, pp. 141-146.

