Makara Journal of Science

Volume 22
Issue 2 *June*

Article 4

6-20-2018

ZnSO4.7H2O Catalyzed One-pot and Facile Synthesis of Highly Substituted Dihydro-2-oxopyrroles at Room Temperature

Farzaneh Mohamadpour
Young Researchers and Elite Club, Shiraz Branch, Islamic Azad University, Shiraz, Iran,
mohamadpour.f.7@gmail.com

Recommended Citation

Mohamadpour, Farzaneh (2018) "ZnSO4.7H2O Catalyzed One-pot and Facile Synthesis of Highly Substituted Dihydro-2-oxopyrroles at Room Temperature," *Makara Journal of Science*: Vol. 22 : Iss. 2 , Article 4.
DOI: 10.7454/mss.v22i2.8792
Available at: https://scholarhub.ui.ac.id/science/vol22/iss2/4

ZnSO4.7H2O Catalyzed One-pot and Facile Synthesis of Highly Substituted Dihydro-2-oxopyrroles at Room Temperature

Cover Page Footnote

We gratefully acknowledge financial support from the Research Council of the Young Researchers and Elite Club of Islamic Azad University of Shiraz.

Makara Journal of Science, 22/2 (2018), 82-88
doi: 10.7454/mss.v22i2.8792

$ZnSO_4.7H_2O$ Catalyzed One-pot and Facile Synthesis of Highly Substituted Dihydro-2-oxopyrroles at Room Temperature

Farzaneh Mohamadpour

Young Researchers and Elite Club, Shiraz Branch, Islamic Azad University, Shiraz, Iran

*E-mail: mohamadpour.f.7@gmail.com

Received December 17, 2017 | Accepted May 9, 2018

Abstract

A mild and facile $ZnSO_4.7H_2O$-catalyzed procedure is developed for the convenient one-pot synthesis of highly substituted dihydro-2-oxopyrroles under mild reaction conditions. In this procedure, dihydro-2-oxopyrroles are synthesized *via* the four-component reactions of amines, dialkyl acetylenedicarboxylates and formaldehyde. The present procedure is an economical and mild approach that offers numerous advantages, including good to high yields, simplicity, inexpensive and readily available catalyst, and high atom economy.

Abstrak

Sintesis Dihidro-2-oksopirol Tersubtitusi Terkatalisis $ZnSO_4.7H_2O$ secara One-pot dan Sederhana pada Suhu Ruang. Prosedur sintesis menggunakan katalis $ZnSO_4.7H_2O$ telah dikembangkan untuk *one-pot* sintesis dari dihydro-2-oxopyrroles pada kondisi reaksi yang sederhana. Dalam prosedur ini, dihydro-2-oxopyrroles disintesis melalui reaksi empat komponen amina, dialkil asetilendikarboksilat dan formaldehida. Prosedur ini adalah pendekatan yang ekonomis dan ringan yang menawarkan banyak keuntungan, termasuk hasil yang tinggi, teknik yang sederhana, katalis yang murah dan mudah tersedia, dan ekonomi atom tinggi.

Keywords: Highly substituted dihydro-2-oxopyrroles, $ZnSO_4.7H_2O$, inexpensive and readily available catalyst, high atom economy

Introduction

Pyrrole rings are an important class of heterocyclic compounds with extensive biological activities. For example, pyrrole rings are present in human cytomegalovirus protease [1] and CD45 protein tyrosinphosphatase [2]. Moreover, these structures are present in compounds with anticancer activities [3]. Pyrrole rings are present in thiomarinol A4, an antibiotic [4]; numerous biologically active alkaloids [5]; UCS1025A [6], Oteromycin [7]; and HIV integrase [8]. They also exhibit herbicidal [9] activities. Numerous protocols have been developed to exploit the biological, pharmacological, and synthetic importance of highly substituted dihydro-2-oxopyrroles. Among these various protocols, the most widely used are the one-pot multi-component condensation of dialkylacetylenedicarboxylate, formaldehyde, and amines. $Cu(OAc)_2.H_2O$ [10], $InCl_3$ [11], I_2 [12], AcOH [13], [n-Bu_4N][HSO_4] [14], $Al(H_2PO_4)_3$ [15], oxalic acid [16], and $ZrCl_4$ [17] are applied as catalysts in the synthesis of dihydro-2-oxopyrroles. However, some of the pathways for the synthesis of pyrrole rings suffer from one or more drawbacks, such as poor yields and long reaction times. In addition, these pathways require the use of toxic catalysts at excessively high loadings. Therefore, the development of a simple and economical procedure for the synthesis of highly substituted dihydro-2-oxopyrroles is necessary. Over the past decades, the use of zinc compounds as environmentally safe catalysts [18-21] in organic synthesis has attracted considerable interest because of the notable advantages of zinc. These advantages include nontoxicity, facile handling, high efficiency, and low cost. In addition, zinc compounds can be successfully used to generate carbon–carbon bonds under mild reaction conditions. Furthermore, the usage of organic solvents under reflux conditions and the need for column chromatography to purify products are sources of environmental pollution. In this present work, products were obtained through simple filtration without the need for column chromatographic separation.

As a part of our research on the identification and development of efficient and economical catalysts for multicomponent reactions [22-29] and in consideration of the above, herein, we report an efficient and simple procedure for the synthesis of highly substituted dihydro-2-oxopyrroles *via* a one-pot four-condensation domino reaction among amines (aromatic or aliphatic **1** and **3**), dialkyl acetylenedicarboxylate **2**, and formaldehyde **4** in the presence of $ZnSO_4.7H_2O$ at room temperature. Compared with some of the earlier reported methods, our protocol, which requires the use of a nontoxic catalyst, is more efficient, facile, inexpensive, and environmentally friendly. Moreover, it provides good to high yields and requires a short reaction time.

Materials and Methods

General. The melting points of all compounds were determined by using an Electro thermal 9100 apparatus. Nuclear magnetic resonance and ^{1}H NMR spectra were recorded on a Bruker DRX-400 Avance instrument with $CDCl_3$ as a solvent. All reagents and solvents were purchased from Merck, Fluka, and Acros chemical companies and were used without further purification.

General procedure for the preparation of highly substituted dihydro-2-oxopyrroles (5a–q). A mixture of amine **1** (1.0 mmol) and dialkyl acetylenedicarboxylate **2** (1.0 mmol) was stirred in MeOH (3 mL) for 15 min. Next, amine **3** (1.0 mmol), formaldehyde **4** (1.5 mmol), and $ZnSO_4.7H_2O$ (20 mol %) were added to the mixture, and the reaction was stirred for the appropriate duration. After the reaction was completed, the mixture was separated through filtration with thin layer chromatography (TLC). The recovered solid was washed with ethanol (3 times × 2 mL) to obtain the pure compounds **5a–q** without the need for column chromatographic separation [12, 14]. The catalyst is soluble in ethanol and removable from the reaction mixture. The products were characterized through the comparison of spectroscopic data (^{1}HNMR). The spectral data of the products are presented below.

Methyl4-(4-fluoroyphenylamino)-1-(4-fluorophenyl)-2,5-dihydro-5-oxo-1H-pyrrole-3-carboxylate (5e). Yield: 89%; M.p. 164 °C–166 °C; ^{1}H NMR (400 MHz, $CDCl_3$): 3.79 (3H, s, OCH_3), 4.52 (2H, s, $C\underline{H_2}$–N), 7.04 (2H, t, *J* = 8.4 Hz, ArH), 7.08–7.16 (4H, m, ArH), 7.73–7.76 (2H, m, ArH), 8.05 (1H, s, NH).

Methyl4-(4-methoxyphenylamino)-1-(4-methoxyphenyl)-2,5-dihydro-5-oxo-1H-pyrrole-3-carboxylate (5i):. Yield: 82%; M.p. 172 °C–174 °C; ^{1}H NMR (400 MHz, $CDCl_3$): 3.77 (3H, s, CH_3), 3.83 (6H, s, $2OCH_3$), 4.50 (2H, s, $C\underline{H_2}$–N), 6.89 (4H, d, *J* = 17.6 Hz, ArH), 7.13 (1H, s, ArH) ,7.68 (1H, s, ArH), 8.03 (1H, s, NH).

Ethyl4-(4-methoxyphenylamino)-1-(4-methoxyphenyl)-2,5-dihydro-5-oxo-1H-pyrrole-3-carboxylate (5j): Yield: 85%; M.p. 150 °C –152 °C; ^{1}H NMR (400 MHz, $CDCl_3$): 1.26 (3H, t, *J* = 7.2Hz, $CH_2\underline{CH_3}$), 3.83 (6H, s, $2OCH_3$), 4.23 (2H, q, *J* = 7.2 Hz, $\underline{CH_2}CH_3$), 4.50 (2H, s, $C\underline{H_2}$–N), 6.87 (2H, d, *J* = 8.8 Hz, ArH), 6.93 (2H, d, *J* = 8.8 Hz, ArH), 7.12 (2H, d, *J* = 8.8 Hz, ArH), 7.69 (2H, d, *J* = 8.8 Hz, ArH), 8.02 (1H, s, NH).

Methyl4-(4-methylphenylamino)-1-(4-methylphenyl)-2,5-dihydro-5-oxo-1H-pyrrole-3-carboxylate (5k): Yield: 88%; M.p. 178 °C–180 °C; ^{1}H NMR (400 MHz, $CDCl_3$): 2.36 (6H, s, $2CH_3$), 3.77 (3H, s, OCH_3), 4.52 (2H, s, $C\underline{H_2}$–N), 7.06 (2H, d, *J* = 8.4 Hz, ArH), 7.14 (2H, d, *J* = 8.4 Hz, ArH), 7.21(2H, d, *J* = 8.4 Hz, ArH), 7.68 (2H, d, *J* = 8.8 Hz, ArH), 8.03 (1H, s, NH).

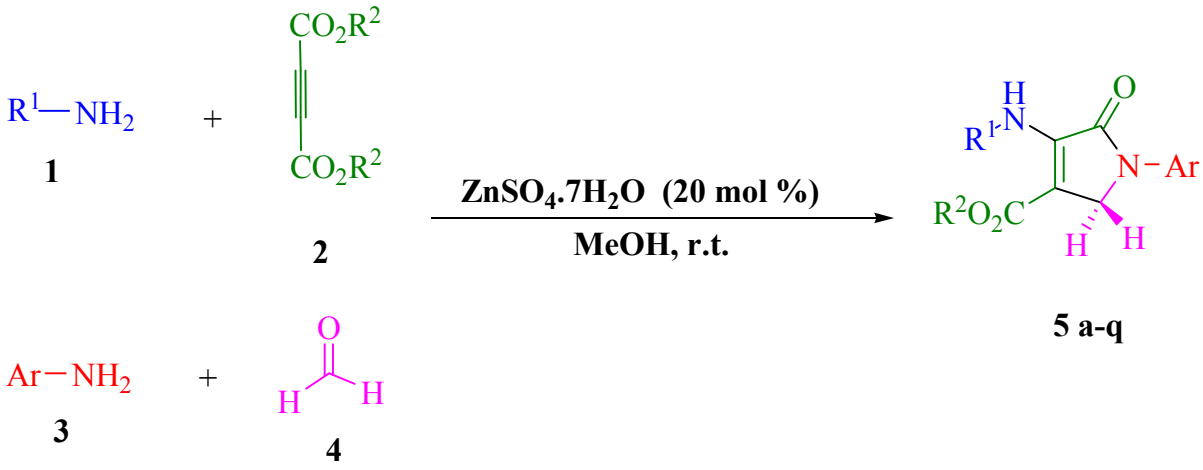
Ethyl4-(4-methylphenylamino)-1-(4-methylphenyl)-2,5-dihydro-5-oxo-1H-pyrrole-3-carboxylate (5l): Yield: 86%; M.p. 131 °C -133 °C; ^{1}H NMR (400 MHz, $CDCl_3$): 1.25 (3H, t, *J* = 7.2 Hz, $CH_2\underline{CH_3}$), 2.37 (6H, s, $2CH_3$), 4.23 (2H, q, *J* = 7.2 Hz, $2\underline{CH_2}CH_3$), 4.53 (2H, s, $C\underline{H_2}$–N),7.06 (2H, d, *J* = 8.4 Hz, ArH), 7.14 (2H, d, *J* = 8.4 Hz, ArH), 7.21 (2H, d, *J* = 8.4 Hz, ArH), 7.69 (2H, d, *J* = 8.4 Hz, ArH), 8.01 (1H, s, NH).

Results and Discussion

The reaction conditions of this four-condensation reaction were optimized. The reaction among aniline, dimethyl acetylenedicarboxylate (DMAD), and formaldehyde was investigated as the model reaction. Then, the effects of different amounts of catalyst in MeOH solvent on the protocol were investigated. A trace amount of the product was detected after 10 h in the absence of the catalyst (Table 1, entry 1), and good yields were obtained in the presence of the catalyst. The optimal amount of the catalyst was 20 mol% (Table 1, entry 5). Increasing the amount of the catalyst did not increase product yields (Table 1, entry 14). The results are summarized in Table 1. In addition, the effect of various solvents, namely, H_2O, EtOH, H_2O/EtOH, CH_2Cl_2, $CHCl_3$, CH_3CN and DMF, on the protocol was investigated, and MeOH was identified as the optimal solvent for this methodology (Table 1, entry 5). Finally, a convenient, expedient, and efficient procedure for the synthesis of highly substituted dihydro-2-oxopyrroles *via* the one-pot four-condensation of amines (aromatic or aliphatic **1** and **3**), dialkyl acetylenedicarboxylate (**2**), and formaldehyde (**4**) under ambient temperature in the presence of $ZnSO_4.7H_2O$ (Scheme 1) was described. The results are summarized in Table 2.

The proposed mechanism for the synthesis of highly substituted dihydro-2-oxopyrroles in the presence of $ZnSO_4.7H_2O$ is illustrated in scheme **2**. First, an

amine (**1**) reacts with dialkyl acetylenedicarboxylate (**2**) to yield intermediate **A**. Second, condensation between amine **3** and formaldehyde **4** in the presence of $ZnSO_4.7H_2O$ produces imine **B**. Intermediate **A** possesses an enamine character and can thus readily react with imine **B** to in the presence of $ZnSO_4.7H_2O$ to generate intermediate **C**. The cyclization of intermediate **C** yields intermediate **D**, which tautomerizes to the corresponding highly substituted dihydro-2-oxopyrrole (**5**) in the final step.



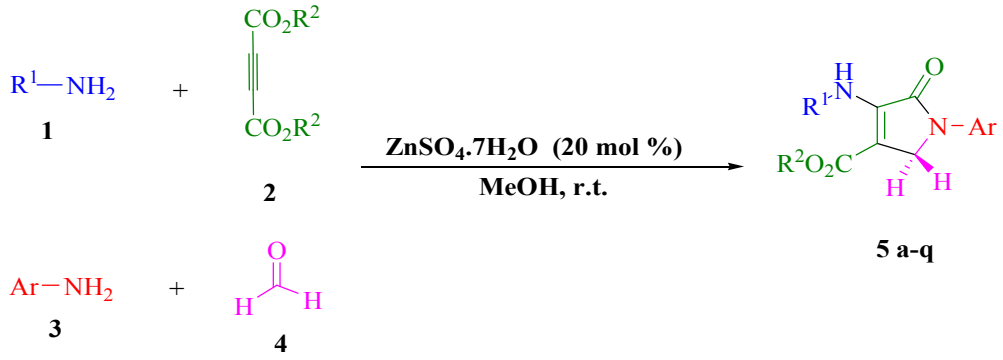
Scheme 1. Synthesis of Highly Substituted Dihydro-2-oxopyrroles

Table 1. Optimization of Reaction Conditions for the Synthesis of 5a in the Presence of Different Amounts of $ZnSO_4.7H_2O$ and Different Solvents[a]

Entry	$ZnSO_4.7H_2O$ (mol %)	Solvent	Time (h)	Isolated Yields (%)
1	Catalyst free	MeOH	10	trace
2	5	MeOH	8	34
3	10	MeOH	8	51
4	15	MeOH	5	73
5	**20**	**MeOH**	**4**	**86**
6	20	Solvent free	10	27
7	20	H_2O	7	24
8	20	EtOH	4	61
9	20	H_2O/EtOH	6	45
10	20	CH_2Cl_2	12	11
11	20	$CHCl_3$	12	16
12	20	CH_3CN	6	47
13	20	DMF	6	43
14	25	MeOH	4	88

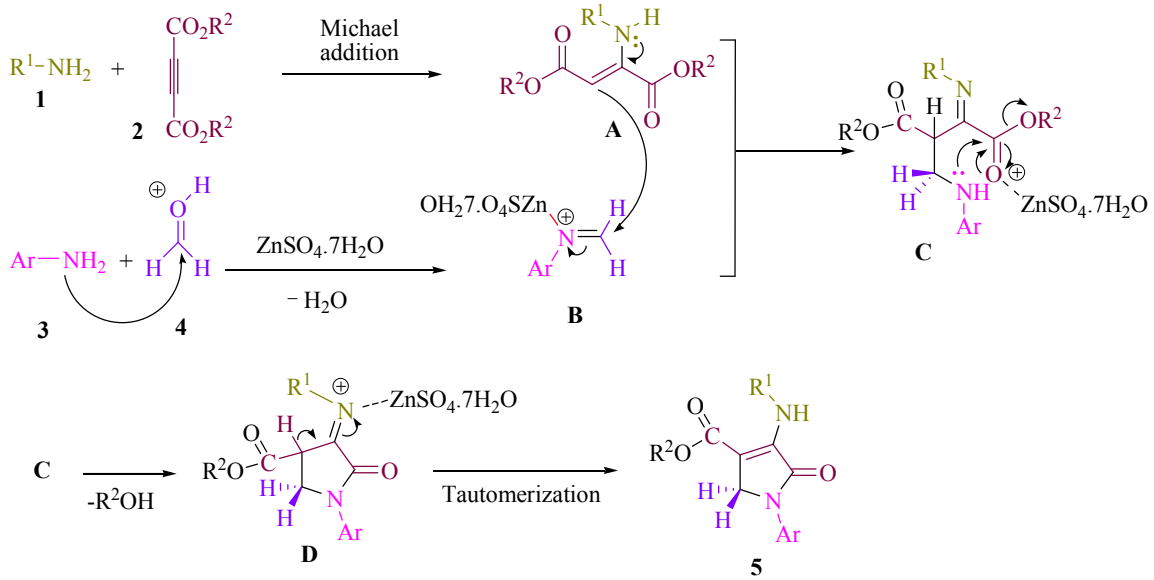
[a]Reaction conditions: aniline (2.0 mmol), dimethyl acetylenedicarboxylate (1.0 mmol) and formaldehyde (1.5 mmol), and catalyst in various solvents at room temperature.

Table 2. Synthesis of Highly Substituted Dihydro-2-oxopyrroles



Entry	R^1	R^2	Ar	Product	Time (h)	Yield (%)[a]	M.p. °C	Lit. M.p. °C
1	Ph	Me	Ph	**5a**	4	86	156–158	155–156[12]
2	Ph	Et	Ph	**5b**	4	85	139–141	138–140[13]
3	4-Cl-C_6H_4	Me	4-Cl-C_6H_4	**5c**	5	78	170–172	171–173[14]
4	4-Cl-C_6H_4	Et	4-Cl-C_6H_4	**5d**	5	76	168–170	168–170[14]
5	4-F-C_6H_4	Me	4-F-C_6H_4	**5e**	3	89	164–166	163–165[16]
6	4-F-C_6H_4	Et	4-F-C_6H_4	**5f**	3	88	173–175	172–174[14]
7	4-Br-C_6H_4	Me	4-Br-C_6H_4	**5g**	5	75	177–179	175–177[14]
8	4-Br-C_6H_4	Et	4-Br-C_6H_4	**5h**	5	73	167–170	169–171[13]
9	4-OMe-C_6H_4	Me	4-OMe-C_6H_4	**5i**	4	82	172–174	172–175[14]
10	4-OMe-C_6H_4	Et	4-OMe-C_6H_4	**5j**	4.5	85	150–152	152–154[15]
11	4-Me-C_6H_4	Me	4-Me-C_6H_4	**5k**	3	88	178–180	177–178[12]
12	4-Me-C_6H_4	Et	4-Me-C_6H_4	**5l**	3.5	86	131–133	131–132[13]
13	$PhCH_2$	Me	Ph	**5m**	4.5	82	138–140	140–141[13]
14	$PhCH_2$	Et	Ph	**5n**	5.5	79	132–134	130–132[13]
15	$PhCH_2$	Me	4-F-C_6H_4	**5o**	4	84	167–169	166–168[15]
16	n-C_4H_9	Me	Ph	**5p**	4.5	80	60–62	60[12]
17	n-C_4H_9	Me	3,4-Cl_2-C_6H_3	**5q**	5	75	99–101	97–99[15]

[a] Isolated yield



Scheme 2. Proposed Mechanistic Route for the Synthesis of Highly Substituted Dihydro-2-oxopyrroles

Table 3. Comparison of the Catalytic ability of Some Previously Reported Catalysts for the Synthesis of Highly Substituted Dihydro-2-oxopyrroles

Entry	Compound	Catalyst	Conditions	Time/Yield (%)	References
1	**5a**	$Cu(OAc)_2.H_2O$	MeOH, r.t.	6h/91	[10]
2	**5a**	$InCl_3$	MeOH, r.t.	3h/85	[11]
3	**5a**	I_2	MeOH, r.t.	1 h/82	[12]
4	**5a**	$[n\text{-}Bu_4N][HSO_4]$	MeOH, r.t.	4 h/88	[14]
5	**5a**	$Al(H_2PO_4)_3$	MeOH, r.t.	5 h/81	[15]
6	**5a**	$ZrCl_4$	MeOH, r.t.	4 h/84	[17]
7	**5a**	$ZnSO_4.7H_2O$	MeOH, r.t.	4 h/86	This work
8	**5b**	$Cu(OAc)_2.H_2O$	MeOH, r.t.	5h/85	[10]
9	**5b**	$InCl_3$	MeOH, r.t.	3h/85	[11]
10	**5b**	I_2	MeOH, r.t.	1 h/81	[12]
11	**5b**	$[n\text{-}Bu_4N][HSO_4]$	MeOH, r.t.	4 h/86	[14]
12	**5b**	$Al(H_2PO_4)_3$	MeOH, r.t.	5 h/80	[15]
13	**5b**	$ZrCl_4$	MeOH, r.t.	3.5 h/83	[17]
14	**5b**	$ZnSO_4.7H_2O$	MeOH, r.t.	4 h/85	This work

The comparison of the catalytic ability of some previously reported catalysts in the synthesis of highly substituted dihydro-2-oxopyrroles is shown in Table 3. $ZnSO_4.7H_2O$ has extraordinary potential as an alternative, inexpensive, readily available, and efficient catalyst for the one-pot synthesis of biologically active heterocyclic compounds. Good to high yields and short reaction times are the notable advantages of the present methodology.

Conclusion

$ZnSO_4.7H_2O$ was used as a readily available, economical, and efficient catalyst in the simple synthesis of highly substituted dihydro-2-oxopyrroles under mild reaction conditions. Results showed that the efficiency of $ZnSO_4.7H_2O$ is higher than those of other reported catalysts, especially in the terms of reaction times and yields. The important aspects of this protocol are simplicity, environmental friendliness, and ease while requiring the use of an inexpensive and readily available catalyst.

Acknowledgments

We gratefully acknowledge financial support from the Research Council of the Young Researchers and Elite Club of Islamic Azad University of Shiraz.

References

[1] Borthwick, A.D., Crame, A.J., Ertl, P.F., Exall, A.M., Haley, T.M., Hart, G.J., Mason, A.M., Pennell, M.K., Singh, O.M.P., Weingarten, G.G., Woolven, J.M. 2002. Design and synthesis of pyrrolidine-5,5-trans-lactams (5-oxohexahydropyrrolo [3,2-b]pyrroles) as novel mechanism-based inhibitors of human cytomegalovirus protease. 2. Potency and chirality. J. Med. Chem. 45(1): 1-18, doi: 10.1021/jm0102203.

[2] Li, W.R., Lin, S.T., Hsu, N.M., Chern, M.S. 2002. Efficient total synthesis of pulchellalactam, a CD45 protein tyrosine phosphatase inhibitor. J. Org. Chem. 67 (14): 4702-4706, doi: 10.1021/jo010828j.

[3] Lampe, Y.L., Chou, R.G., Hanna, R.G., DiMeo, S.V., Erhardt, P.W., Hagedorn, A.A., Ingebretsen, W.R., Cantor, E. 1993. (Imidazolylphenyl) pyrrol-2- one inhibitors of cardiac cAMPphosphodiesterase. J. Med. Chem. 36 (8): 1041-1047, doi: 10.1021/jm00060a012.

[4] Shiozawa, H., Takahashi, S. 1994. Configurational studies on thiomarinol. J. Antibiot. 47(7): 851-853.

[5] Chen, Y., Zeng, D.X., Xie, N., Dang, Y.Z. 2005. Study on photochromism of diarylethenes with a 2, 5-dihydropyrrole bridging unit: a convenient preparation of 3, 4-diarylpyrroles from 3,4-diaryl-2,5-dihydropyrroles. J. Org. Chem. 70(13): 5001-5005. doi: 10.1021/jo050236r.

[6] Grunwald, C., Rundfeldt, C., Lankau, H.J., Arnold, T., Hofgen, N., Dost, R., Egerland, U., Hofmann, H.J., Unverferth, K. 2006. Synthesis, pharmacology, and structure-activity relationships of novel Imidazolones and Pyrrolones as modulators of GABAA receptors. J. Med. Chem. 49(6): 1855-1866. doi: 10.1021/jm0509400.

[7] Singh, S.B., Goetz, M.A., Jones, E.T., Billes, G.F., Giacobbe, R.A., Herranz, L., Stevens Miles, S., Williams, D.L., Stevens-Miles, S., Williams, D.L.

1995. a novel antagonist of endothelin receptor. J. Org. Chem. 60(21): 7040-7042. doi: 10.1021/jo00126a071.

[8] Kawasuji, T., Fuji, M., Yoshinaga, T., Sato, A., Fujiwara, T., Kiyama, R. 2007. 3-Hydroxy-1, 5-dihydro-pyrrol-2-one derivatives as advanced inhibitors of HIV integrase. J. Bioorg. Med. Chem. 15(16): 5487-5492, doi: https://doi.org/10.1016/j.bmc.2007.05.052.

[9] Zhang, L., Tan, Y., Wang, N.X., Wu, Q.Y., Xi, Z., Yang, G.F. 2010. Design, syntheses and 3D-QSAR studies of novel N-phenyl pyrrolidin-2-ones and N-phenyl-1H-pyrrol-2-ones as protoporphyrinogen oxidase inhibitors. J. Bioorg. Med. Chem. 18(22): 7948-7956, doi: https://doi.org/10.1016/j.bmc.2010.09.036.

[10] Lv, L., Zheng, S., Cai, X., Chen, Z., Zhu, Q., Liu, S. 2013. Development of four-component synthesis of tetra- and pentasubstituted polyfunctional dihydropyrroles: Free permutation and combination of aromatic and aliphatic amines. J. Acs. Comb. Sci. 15(4): 183-192, doi: 10.1021/co300148c.

[11] Sajadikhah, S.S., Maghsoodlou, M.T., Hazeri, N. 2014. A simple and efficient approach to one-pot synthesis of mono- and bis-N-aryl-3-aminodihidropyrrol-2-one-4-carboxylate catalyzed by $InCl_3$. J. Chin. Chem. Lett. 25(1): 58-60, doi: https://doi.org/10.1016/j.cclet.2013.10.010.

[12] Khan, A.T., Ghosh, A., Musawwer Khan, M. 2012. One-pot four-component domino reaction for the synthesis of substituted dihydro-2-oxypyrrole catalyzed by molecular iodine. Tetrahedron Lett. 53(21): 2622-2626, doi: https://doi.org/10.1016/j.tetlet.2012.03.046.

[13] Zhu, Q., Jiang, H., Li, J., Liu, S., Xia, C., Zhang, M. 2009. Concise and versatile multicomponent synthesis of multisubstituted polyfunctional dihydropyrroles. J. Comb. Chem. 11(4): 685-696, doi: 10.1021/cc900046f.

[14] Sajadikhah, S.S., Hazeri, N. 2014. Coupling of amines, dialkyl acetylenedicarboxylaes and formaldehyde promoted by $[n\text{-}Bu_4N][HSO_4]$: an efficient synthesis of highly functionalized dihydro-2-oxopyrrols and bis-dihydro-2-oxopyrroles. Res. Chem. Intermed. 40(2): 737-748.

[15] Sajadikhah, S.S., Hazeri, N., Maghsoodlou, M.T., Habibi Khorasani, S.M., Beigbabaei, A., Willis. A.C. 2013. $Al(H_2PO_4)_3$ as an efficient and reusable catalyst for the multi-component synthesis of highly functionalized piperidines and dihydro-2-oxypyrroles. J. Iran. Chem. Soc. 10(5): 863-871.

[16] Sajadikhah, S.S., Hazeri, N., Maghsoodlou, M.T. 2013. A one-pot multi-component synthesis of N-aryl-3-aminodihydropyrrl-2-one-4-carboxylate catalyzed by oxalic acid dehydrate. J. Chem. Res. 37(1): 40-42, doi: https://doi.org/10.3184/174751912X13547952669204.

[17] Sajadikhah, S.S., Maghsoodlou, M.T., Hazeri, N., Mohamadian-Souri, S. 2016. $ZrCl_4$ as an efficient catalyst for one-pot four-component synthesis of polysubstituted dihydropyrrol-2-ones. Res. Chem. Intermed. 42(4): 2805-2814.

[18] Dake, S.S., Tekale, S.U., Sarda, S.R., Jadhav, W.N., Bhusare, S.R., Pawar, R.P. 2008. Anhydrous Zinc Chloride: An efficient catalyst for one pot synthesis of 2,3,4,12-tetrahydro-benzo-[4,5]-thiazolo-[2,3b]-quinazolin-1-ones. ARKIVOC. 17 (xvii): 241-247, doi: http://dx.doi.org/10.3998/ark.5550190.0009.h23.

[19] Nagvenkar, A., Naik, S., Fernandes, J. 2015. Zinc oxide as a solid acid catalyst for esterification reaction. Catal. Commun. 65(1): 20-23, doi: 10.1016/j.catcom.2015.02.009.

[20] Ravi Sankar Arigala, U., Matcha, C., Yoon, K.R. 2012. $Zn(OAc)_2.2H_2O$-catalyzed synthesis of α-aminophosphonates under neat reaction. Hetero Chem. 23(2): 160-165, doi: 10.1002/hc.20765.

[21] Ramu, E., Varala, R., Sreelatha, N., Adapa, S.R. 2007. $Zn(OAc)_2 \cdot 2H_2O$: a versatile catalyst for the one-pot synthesis of propargylamines. Tetrahedron Lett. 48(40): 7184-7190, doi: 10.1016/j.tetlet.2007.07.196.

[22] Mohamadpour, F., Maghsoodlou, M.T., Heydari, R., Lashkari, M. 2016. Saccharin: a green, economical and efficient catalyst for the one‐pot, multi‐component synthesis of 3,4‐dihydropyrimidin‐2‐(1H)‐one derivatives and 1H‐pyrazolo [1,2‐b] phthalazine‐5,10‐dione derivatives and substituted dihydro‐2‐oxypyrrole. J. Iran. Chem. Soc. 13(8): 1549-1560, doi:10.1007/s13738-016-0871-5.

[23] Mohamadpour, F., Maghsoodlou, M.T., Heydari, R., Lashkari, M. 2016. Copper(II) acetate monohydrate: an efficient and ecofriendly catalyst for the one-pot multi-component synthesis of biologically active spiropyrans and 1Hpyrazolo[1,2-b]phthalazine-5,10-dione derivatives under solvent-free conditions. Res. Chem. Intermed. 42(12): 7841-7853, doi: 10.1007/s11164-016-2565-0.

[24] Mohamadpour, F., Maghsoodlou, M.T., Heydari, R., Lashkari, M. 2017. Tartaric acid: A naturally green and efficient di-functional brønsted acid catalyst for the one-pot four-component synthesis of polysubstituted dihydropyrrol-2-ones at ambient temperature. Iran. J. Sci. Technol. Trans. Sci. 41(3): 843-849, doi: 10.1007/s40995-016-0049-0.

[25] Lashkari, M., Mohamadpour, F., Hazeri, N., Heydari, R. 2017. Clean and facile synthesis of 1H-pyrazolo [1, 2-b] phthalazine-5, 10-dione derivatives catalyzed by Neodymium (III) chloride hexahydrate as an efficient Lewis acidic catalyst under solvent-free conditions. Biointerface Res. Appl. Chem. 7(5): 2151-2157.

[26] Lashkari, M., Heydari, R., Mohamadpour, F. 2016. Chromium (III) nitrate nonahydrate: as an envi-

ronmentally benign nature and efficient heterogeneous catalyst for facile one-pot Biginelli synthesis of 3,4-dihydropyrimidin-2-(1H)-ones/thiones derivatives under solvent-free conditions. acta chemica iasi. 24(1): 29-42, doi: 10.1515/achi-2016-0003.

[27] Mohamadpour, F., Heydari, R., Lashkari, M. 2016. Clean, facile and eco-friendly synthesis of biologically active N-aryl-3-aminodihydropyrrol-2-one-4-carboxylates at present of maleic acid as an environmental friendly, readily and efficient catalyst under ambient temperature. Biointerface Res. Appl. Chem. 6(5): 1469-1470.

[28] Lashkari, M., Heydari, R., Mohamadpour, F. 2016. A facile approach for one-pot Synthesis of 1H-pyrazolo [1,2-b]phthalazine-5,10-dione Derivatives Catalyzed by $ZrCl_4$ as an efficient catalyst under solvent-free conditions. Iran. J. Sci. Technol. Trans. Sci. doi: 10.1007/s40995-016-0122-8.

[29] Maghsoodlou, M.T., Heydari, R., Lashkari, M., Mohamadpour, F. 2017. Clean and one-pot synthesis of 3, 4-dihydropyrimidin-2-(1H)-ones/tiones derivatives using maleic acid as an efficient and environmentally benign nature di-functional Brønsted acid catalyst under solvent-free conditions. Indian. J. Chem. 56B(02): 160-164.