DE GRUYTER OPEN

ACTA CHEMICA IASI, **25_2**, 163-178 (2017)

DOI: 10.1515/achi-2017-0013

K_2CO_3: A MILD AND EFFICIENT CATALYST FOR THE SYNTHESIS OF PYRAN ANNULATED HETEROCYCLIC SYSTEMS BY GRINDING METHOD UNDER SOLVENT-FREE CONDITIONS

Reza Heydari[a*], Rohollah Rahimi[a], Mehrnoosh Kangani[b], Afshin Yazdani-Elah-Abadi[c] and Mojtaba Lashkari [d*]

[a] *Department of Chemistry, Faculty of Science, University of Sistan and Baluchestan, P. O. Box 98135-674 Zahedan, Iran*

[b] *Young Researchers and Elite Club, Zahedan Branch, Islamic Azad University, Zahedan, Iran*

[c] *Department of Biology, Science and Art University, Yazd, Iran*
[d] *Faculty of Science, Velayat University, Iranshahr, Iran, P. O. Box 9911131311*

Abstract: The potassium carbonate was applied as a green and efficient catalyst for the one-pot synthesis of pyran annulated heterocyclic systems, *via* the condensation between aromatic aldehydes, malononitrile and dimedone/1-naphtole by a grinding method at room temperature and solvent-free conditions. Short reaction times, environmentally friendly procedure and excellent yields are the main advantages of this procedure which makes it more economic than other environmentally synthetic methods.

***Keywords*:** Potassium carbonate; pyran annulated heterocyclic systems; grinding method

* Reza Heydari, Mojtaba Lashkari, *e-mail:* *heydari@chem.usb.ac.ir , m.lashkari@velayat.ac.ir*

Introduction

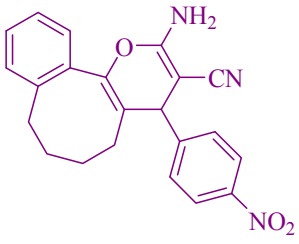
Use of solvents is the major environmentally problematic aspects of organic synthesis. The solvent has to be produced in another chemical process, which also consumes energy and resources. Within the reaction, the vast amount of solvent has to be heated or cooled; consuming large amounts of energy, and has to be removed after completion of the reaction from the reaction mixture. It is believed that solvent-free organic synthesis and transformations are industrially useful and largely green. Green chemistry, also called sustainable chemistry, stimulates researchers to design the products and processes that reduce or eliminate the use and generation of hazardous substances[1]. Avoiding the use of solvents in organic synthesis has led in some cases to improved results and milder synthetic procedures, and the solvent-free reactions are more important for practical synthetic processes in industry[2].

4*H*-Pyrans and 4*H*-pyran-annulated heterocyclic scaffolds represent an outstanding structural motif well distributed in naturally occurring compounds[3-5] with a broad spectrum of considerable biological activities that embrace antimicrobial,[6] anti-inflammatory,[7] antihyperglycemic and antidyslipidemic,[8] anti-HIV[9-11] and antimalarial[12,13].

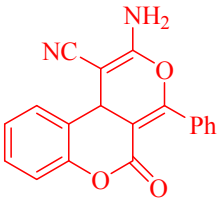
Moreover, functionalized 4*H*-pyran derivatives have played increasing roles in synthetic approaches to promising compounds in the field of medicinal,[14,15] agrochemical, cosmetics, and pigment industries[16] (Figure 1).

The one-pot synthesis of pyran annulated heterocyclic systems from condensation of aromatic aldehydes and malononitrile with dimedone/1-naphtol have been reported in the presence of different catalysts such as: $Fe_3O4@SiO_2$-Imid-PMA^n,[17] [PVPH]HSO_4,[18] $PhB(OH)_2$,[19] [DABCO-

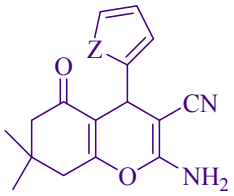
PDO][CH_3COO],[20] $NH_4Al(SO_4)_2.12H_2O$,[21] TFE,[22] CTBr,[23] MW,[24] *(S)*-proline[25] and HAP[26]. Each of these methods has its own merit, with at least one of the limitations of low yields, long reaction time, effluent pollution, harsh reaction conditions and tedious work-up procedures. Thus, in view of the diverse therapeutic activity of pyrans and in continuation to our ongoing endeavor[27-29] aimed at developing environmentally benign methodologies using green catalysts, we report herein the synthesis of tetrahydrobenzopyran and 2-aminobenzochromene derivatives in the presence of K_2CO_3 as a green catalyst by grinding at room temperature (Scheme 1).



anticancer

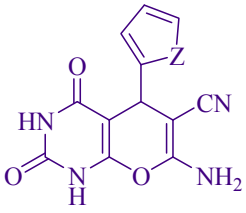


antibacterial



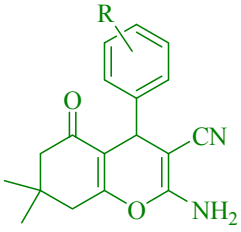
Z= O, S, NH

anticancer and antibacterial

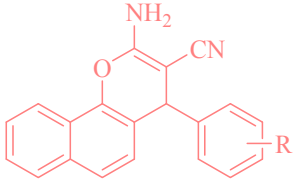


Z= O, S,NH

anticancer and antibacterial

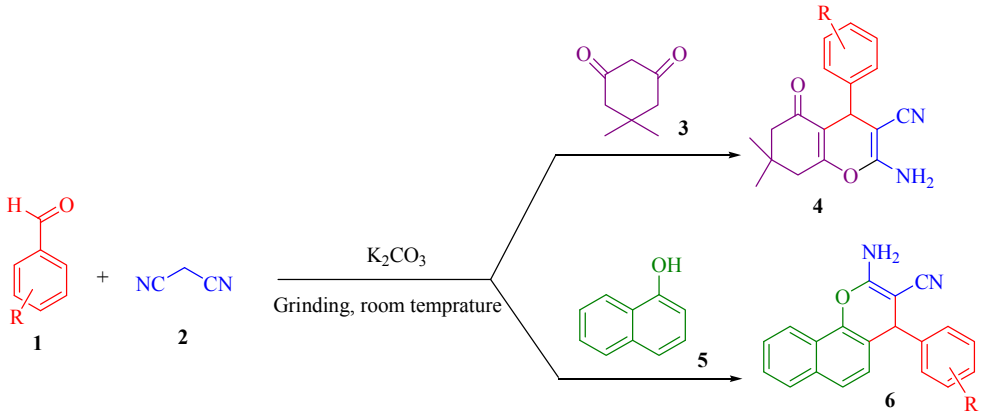


antibacterial



antirheumatic

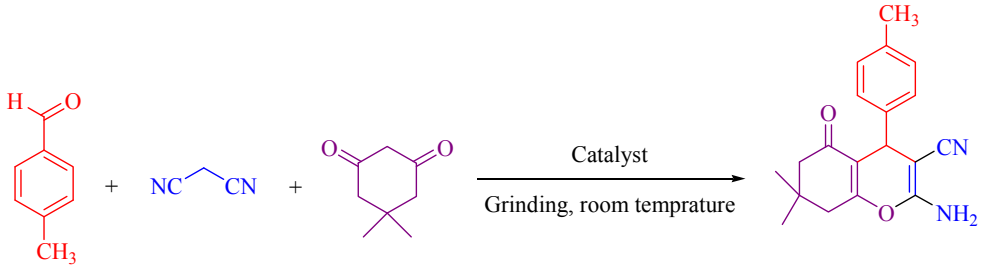
Figure 1. Some important drug-like pyrans heterocycles.



Scheme 1. Synthesis of tetrahydrobenzopyran and 2-aminobenzochromene derivatives in the presence of K_2CO_3 as a green catalyst by grinding at room temperature.

Results and Discussion

Initially, the reaction of 4-methylbenzaldehyde (1.0 mmol), malononitrile (1.0 mmol) and dimedone (1.0 mmol) was chosen as a model system (Scheme 2). The reaction was performed in the presence of different catalysts and different amounts of K_2CO_3 by grinding at room temperature (Table 1). As can be seen in Table 1 the best result was obtained in the presence of 20 mol % of K_2CO_3. Next, the same reaction was repeated with 1-naphtole, in this case 20 mol% of K_2CO_3 was the best result, respectively.



Scheme 2. The optimized reaction conditions for the synthesis of tetrahydrobenzopyrans.

Table 1. Optimization of the reaction conditions for the synthesis of tetrahydrobenzopyrans.

Entry	Catalyst (mol %)	Grinding time (min)	Isolated yields (%)
1	-	60	-
2	K_2HPO_4 (10 mol%)	30	68
3	Na_2CO_3 (10 mol%)	45	65
4	K_2CO_3 (10 mol%)	20	80
5	K_2CO_3 (15 mol%)	12	89
6	K_2CO_3 (20 mol%)	7	94
7	K_2CO_3 (25 mol%)	7	94

Using the optimized reaction condition in the hand (Table 1, Entry 6), a variety of tetrahydrobenzopyran and 2-aminobenzochromene derivatives (Scheme 1) were synthesized and the results are summarized in Table 2. A variety of aromatic aldehydes with *ortho*, *meta* and *para* substituents were examined. In all cases electron donating and electron withdrawing groups were tolerated very well and gave excellent yields in shorter reaction times (Table 2).

Table 2. Synthesis of tetrahydrobenzopyran and 2-aminobenzochromene derivatives.

Entry	Ar	1,3-dicabonyl	Product	Time (min)	Isolated Yield (%)	M.p observed (°C)	M.p reported (°C)
1	4- Me C_6H_4	3	**4a**	7	94	210-212	212-215 [19]
2	C_6H_5	3	**4b**	20	95	230-232	228-230 [19]
3	2-NO_2 C_6H_4	3	**4c**	15	90	227-230	224-226 [25]
4	3-NO_2 C_6H_4	3	**4d**	13	88	210-212	208-210 [19]
5	2-Cl C_6H_4	3	**4e**	15	82	210-212	208-210 [20]

Table 2. Continued

6	4-NO_2 C_6H_4	3	**4f**	16	87	182-184	183-185 [19]
7	4-Cl C_6H_4	3	**4g**	15	85	208-210	210-212 [25]
10	2,4-$(Cl)_2$ C_6H_3	3	**4h**	15	94	120-122	115-117 [25]
11	4-OMeC_6H_4	3	**4i**	6	95	205-207	213-215 [19]
12	thiophene- 2-carbaldehyde	3	**4j**	20	90	212-214	210-212 [22]
13	4-OH C_6H_4	3	**4k**	10	83	206-208	204-206[25]
14	4-Me C_6H_4	5	**6a**	8	94	210-212	212-215 [26]
15	C_6H_5	5	**6b**	20	95	208-210	210-211 [26]
16	3-NO_2 C_6H_4	5	**6c**	13	88	210-211	212-214 [26]
17	3-Cl C_6H_4	5	**6d**	50	82	227-229	229-230 [24]
18	4-NO_2 C_6H_4	5	**6e**	16	87	238-240	239-241[26]
19	4-Cl C_6H_4	5	**6f**	8	94	229-230	231-232 [26]

Recovery of the catalysts is important in green organic synthesis. Thus, we also for recyclability of the catalysts investigated the recycling of K_2CO_3 under grinding and solvent-free conditions using a selected model reaction of dimedone, 4-methylbenzaldehyde and malononitrile in the presence of K_2CO_3 as homogeneous catalyst (Figure 2).

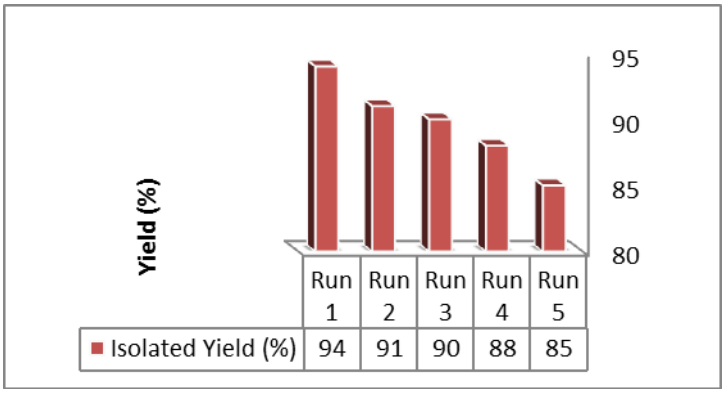
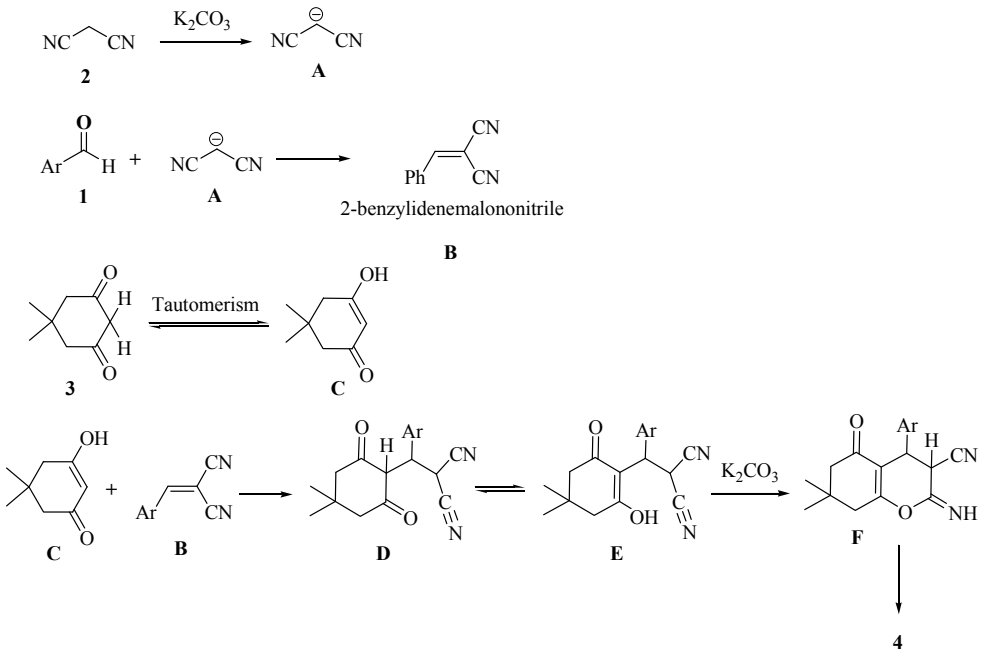


Figure 2. Results of recycling over five consecutive recycling experiments.

We propose the possible following mechanism to account for the condensation of **1**, **2**, and **C** (Scheme 3). The step 1 can be regarded as a fast Knoevenagel condensation. In this mechanism, K_2CO_3 is an effective catalyst for the formation of the arylidenemalononitrile (**B**). K_2CO_3 also catalyzes the formation of intermediate (**D**), which affords the products **4** *via* tautomerization.



Scheme 3. Proposed mechanism for the formation of tetrahydrobenzopyrans.

For efficiency of the present work in comparison with the reported results in the literature, some of the results has been accumulated in Table **3**. The results show that K_2CO_3 is a more efficient catalyst with respect to the reaction time and yield.

Table 3. Comparison of the eficiency of $K_2CO_3$with other reported catalysts in literature.

Entry	Product	Catalysts	Conditions	Time	Yield (%)	Ref
1	**4a**	$PhB(OH)_2$	5mol %, $EtOH/H_2O$ Reflux	30 min	65	[19]
2	**4a**	Na_2SO_4	30 mol%, $EtOH/H_2O$	25 min	84	[30]
3	**4a**	NaOAc	5 mol%, EtOH, H_2O, 50°C	20 min	89	[31]
4	**4k**	A-Alum	20 mol%, solvent free or reflux, 100 °C	110 min	85	[32]
5	**4a**	RHPrBPCl	H_2O, reflux	30 min	84	[33]
6	**4a**	$\{[HMIM]C(CN)_3$	0.5 mol%, solvent-free, r.t	8 min	96	[34]
7	**4k**	[DABCO-PDO][CH_3COO]	10 mol%, H_2O, 60 °C	30 min	92	[20]
8	**4a**	$NH_4Al(SO_4)_2.12H_2O$	0.2 g, EtOH, 80 °C	130 min	90	[21]
9	**4a**	TFE	TFE, Reflux	5h	88	[22]
10	**4a**	Pectin	0.05 g, H_2O:EtOH, r.t	35 min	82	[27]
11	**4a**	K_2CO_3	Grinding/ solvent-free/r.t	7 min	93	This work
12	**6b**	*p*-Toluenesulfonic acid	CH_3CN/ Reflux	5 h	90	[35]
13	**6a**	Nano MgO	MeOH/r.t	60 min	96	[8]
14	**6a**	K_2CO_3	Grinding/ solvent-free/r.t.	8	94	This work

Experimental

Chemicals were purchased from Merck (Darmastadt, Germany), and Fluka (Buchs, Switzerland), and used without further purification. Melting points were taken on an Electrothermal 9100 apparatus. IR spectra were obtained on a JASCO FT/IR-460 plus spectrometer. The ^1H NMR spectra

were recorded on a Bruker DRX-400 Avanve instrument with $CDCl_3$ as solvent and using TMS as internal reference at 400 MHz respectively.

General Procedure for the synthesis of tetrahydrobenzopyran and 2-aminobenzochromene derivatives

Aromatic aldehydes **1** (1.0 mmol), malononitrile **2** (1.0 mmol), dimedone or 1-naphtol (1.0 mmol), and K_2CO_3 (20 mol %) are added to a mortar. The mixture is ground by mortar and pestle at room temperature (25 ºC) for 7-20 min (Table 2). The solid product is obtained from an intermediate melt and then is laid up at room temperature. Then, 5 mL of water was added to the mixture and filtered for separation of the crude product. The separated product was washed twice with water (2×5 mL). The solid crude product subsequently recrystallized from hot ethanol to give the pure solid. In order to recover the catalyst, since K_2CO_3 is soluble in water, the filtrate was extracted with diethyl ether. The aqueous layer was separated, and its solvent was evaporated under reduced pressure and K_2CO_3 was recovered and reused. Selected spectroscopic data of some products is given below:

*2-amino-5,6,7,8-tetrahydro-4-(4-methyl)-7,7-dimethyl-5-oxo-4H-chromene-3-carbonitrile (**4a**)*

mp 210-212 IR (KBr) ν/cm^{-1} 3467, 3325, 2955, 2190, 1676, 1247; ^{1}H NMR (400 MHz, DMSO-d_6): δ 1.06 (s, 3H, CH_3), 1.12 (s, 3H, CH_3), 2.26 (dd, 2H, CH_2, *J*= 16.4 Hz, *J*= 22.0), 2.38 (s, 3H), 2.46 (s, 2H, CH_2), 4.37 (s, 1H, CH), 4.59 (s, 2H, NH_2), 7.10 (d, 2H, Ar, *J*= 8.0 Hz), 7.17 (d, 2H, Ar, *J*= 8.0 Hz).

*2-amino-5,6,7,8-tetrahydro-7,7-dimethyl-5-oxo-4-phenyl-4H-chromene-3-carbonitrile (**4b**)*

mp 230-232 IR (KBr) ν/cm^{-1} 3360, 3285, 2960, 2190, 1686, 1209; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.07 (s, 3H, CH_3), 1.14 (s, 3H, CH_3), 2.23 (dd, 2H, CH_2, J= 16.4, J= 22.0 Hz), 2.78, (s, 2H, CH_2), 4.43 (s, 1H, CH), 4.55 (s, 2H, NH_2), 7.21, 7.35 (m, 5H, Ar).

*2-amino-5,6,7,8-tetrahydro-4-(4-nitrophenyl)-7,7-dimethyl-5-oxo-4H-chromene-3-carbonitrile (**4f**)*

mp 182-184 IR (KBr) ν/cm^{-1} 3285, 3160 , 2960 , 2185 , 1675, 1209; ^{1}H NMR (300 MHz, DMSO-d_6): δ 0.98 (s, 3H, CH_3) , 1.029 (s, 3H, CH_3), 2.12 (d, 1H, CH_2, J= 16.0 Hz), 2.27 (d, 1H, CH_2, J = 16.0 Hz), 2.51 (d, 2H, CH_2, J= 12.0 Hz), 4.36 (s, 1H,CH), 7.14 (s, br, NH_2), 7.44 (d, 2H, Ar, J=8.0 Hz), 8.12 (d, 2H, Ar, J= 8.0 Hz).

*2-amino-5,6,7,8-tetrahydro-4-(4-methoxyphenyl)-7,7-dimethyl-5-oxo-4H-chromene-3-carbonitrile (**4i**)*

mp 205-207 IR (KBr) ν/cm^{-1} 3465, 3320, 2955, 2190, 1676, 1247; ^{1}H NMR (300 MHz, DMSO-d_6): δ 0.95 (s, 3H,CH_3), 1.04 (s, 3H,CH_3), 2.09 (d, 1H, CH_2, J= 18.0 Hz), 2.25 (d, 1H, CH_2, J= 18.0 Hz), 3.37 (s, 1H,CH_2), 3.72 (s, 3H,OCH_3), 4.13 (s, 1H,CH), 6.85 (d, 2H, Ar, J= 8.0 Hz), 6.97 (br, NH_2), 7.06 (d, 2H, Ar, J= 8.0 Hz).

*2-amino-5,6,7,8-tetrahydro-4-(4-hydroxyphenyl)-7,7-dimethyl-5-oxo-4H-chromene-3-carbonitrile (**4k**)*

IR (KBr, cm^{-1}): 3275, 3170 , 2950 , 2285, 1675, 1219; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) : 1.07 (s, 3H, CH_3) , 1.18 (s, 3H, CH_3), 2.21-2.27 (dd, 2H, CH_2, J= 16.0 Hz, 20.0), 2.42-2.53 (dd, 2H, CH_2, J= 16.0 Hz, J= 20.0 Hz) , 4.36 (s, 1H,CH), 4.55 (s, 2H, NH_2), 5.27 (s, 1H,OH), 6.71- 7.29 (m, 4H, Ar).

*2-amino-4-phenyl-4H-benzo[h]chromene-3-carbonitrile (**6b**)*

IR (KBr, cm^{-1}): 3454, 3318, 2205, 1656, 1600, 1572; ^{1}H NMR (400 MHz, $CDCl_3$): 4.90 (s, 1H, CH), 7.10 (s 2H, NH_2), 7.07-7.12 (m, 6H, Ar), 7.56-7.66 (m, 3H, Ar), 7.94 (d, *J*= 8.4 Hz, 1H, Ar), 8.23 (d, *J*= 8.4 Hz, 1H, Ar).

*2-amino-4-(3-chlorophenyl)-4H-benzo[h]chromene-3-carbonitrile (**6d**)*

IR (KBr, cm^{-1}): 3465, 3340, 2220, 1644,1660, 1580, ^{1}H NMR (400 MHz, $CDCl_3$): 5.13 (s, 1H, CH), 7.10 (s, 2H, NH_2), 7.13 (d, *J*= 8.4 Hz, 1H, Ar), 7.32-7.35 (m, 4H, Ar), 7.23 (s, 1H, Ar), 7.56-7.67 (m, 3H, Ar), 7.90 (d, *J*= 8.4 Hz, 1H, Ar), 8.25 (d, *J*= 8.4 Hz, 1H, Ar).

*2-amino-4-(4-nitrophenyl)-4H-benzo[h]chromene-3-carbonitrile (**6e**)*

IR (KBr, cm^{-1}): 3450, 3325, 2196, 1645, 1575, ^{1}H NMR (400 MHz, $CDCl_3$): 5.14 (s, 1H, CH), 7.11 (s, 2H, NH_2), 7.15 (d, *J*= 8.4 Hz, 1H, Ar), 7.50-7.71 (m, 3H, Ar), 7.52 (d, 2H, Ar), 7.90 (d, 1H, *J*= 8.4 Hz, Ar), 8.15 (d, 2H, Ar), 8.27 (d, 1H, *J*= 8.4, Ar).

Conclusions

In conclusion, we have described a highly efficient procedure for the preparation of pyran annulated heterocyclic systems by a three-component condensation *via* a one-pot grinding method using K_2CO_3 as catalyst under solvent-free conditions. Moreover, the procedure offers several advantages including operational simplicity, high yields, minimal environmental impact, cleaner reaction, and low cost, which make it a useful and attractive process for the synthesis of these compounds.

Acknowledgements

We are thankful to the University of Sistan and Baluchestan Research Council for the partial support of this research.

References

1. Sheldon, R.A. Selective catalytic synthesis of fine chemicals: opportunities and trends *J. Mol. Catal.* **1996**, *107*, 75-83.
2. Tanaka, K.; Toda, F. Solvent-Free Organic Synthesis. *Chem. Rev.* **2000**, *100*, 1025-1074.
3. Wu, J.Y.; Fong, W.F.; Zhang, J.X.; Leung, C.H.; Kwong, H.L.; Yang, M. S.; Li, D; Cheung, H.Y. Reversal of multidrug resistance in cancer cells by pyranocoumarins isolated from Radix Peucedani. *Eur. J. Pharmacol.* **2003**, *473*, 9-17.
4. Raj, T.; Bhatia, R.K.; Sharma, M.; Saxena, A.K.; Ishar, M.P. Cytotoxic activity of 3-(5-phenyl-3H-[1,2,4]dithiazol-3-yl)chromen-4-ones and 4-oxo-4*H*-chromene-3-carbothioic acid N-phenylamides. *Eur. J. Med. Chem.* **2010**, *45*, 790-794.
5. Rueping, M.; Sugiono, E.; Merino, E. Asymmetric Organocatalysis: An Efficient Enantioselective Access to Benzopyranes and Chromenes. *Chem. A. Eur. J.* **2008**, *14*, 6329-6332.
6. Morgan, L.R.; Jursic, B.S.; Hooper, C.L.; Neumann, D.M.; Thangaraj, K.; LeBlanc, B. Anticancer activity for 4,4′-Dihydroxybenzophenone-2,4-dinitrophenylhydrazone (A-007) analogues and Their abilities to interact with lymphoendothelial cell surface markers. *Bioorg. Med. Chem. Lett.* **2002**, *12*, 3407-3411.
7. Moon, D.O.; Kim, K.C.; Jin, C.Y.; Han, M.H.; Park, C.; Lee, K.J.; Park, Y.M.; Choi, Y.H.; Kim, G.Y. Inhibitory effects of eicosapentaenoic acid on lipopolysaccharide-induced activation in BV2 microglia. *Int. Immunopharmacol.* **2007**, *7*, 222-229.
8. Kumar, A.; Maurya, R.A.; Sharma, S.; Ahmad, P.; Singh, A.B.; Bhatia, G.; Srivastava, A.K. Pyranocoumarins: A new class of anti-hyperglycemic and anti-dyslipidemic agents. *Bioorg. Med. Chem. Lett.* **2009**, *19*, 6447-6451.
9. Konkoy, C.S., Fick, D.B., Cai, S.X., Lan, N.C. Keana, J.F.W. (2001). PCT Appl. WO 0075123; Chem. Abstr. (**2000**), 134, 29313a.

10. Hanna L. Calanolide A: a natural non-nucleoside reverse transcriptase inhibitor. *BETA: bulletin of experimental treatments for AIDS: a publication of the San Francisco AIDS Foundation.* 12, 8. (**1999**).

11. Flavin, M.T.; Rizzo, J.D.; Khilevich, A.; Kucherenko, A.; Sheinkman, A.K.; Vilaychack, V.; Lin, L.; Chen, W.; Greenwood, E.M.; Pengsuparp, T.; Pezzuto, J.M. Synthesis, Chromatographic Resolution, and Anti-Human Immunodeficiency Virus Activity of (±)-Calanolide A and Its Enantiomers. *J. Med. Chem.* **1996**, *39*, 1303-1313.

12. De Andrade-Neto, V.F.; Goulart, M.O.; MJ Da silva, MDCFR Pinto, AV Pinto, MG Zalis, LH Carvalho and AU Krettli. Antimalarial activity of phenazines from lapachol, β-lapachone and its derivatives against Plasmodium falciparum in vitro and Plasmodium berghei in vivo. *Bioorg. Med. Chem. Lett.* **2004**, *14*, 1145-1149.

13. Agarwal, A.; Srivastava, K.; Puri, S.K.; Chauhan, P.M.S. Synthesis of 4-pyrido-6-aryl-2-substituted amino pyrimidines as a new class of antimalarial agents. *Bioorg. Med. Chem.* **2005**, *13*, 6226-6232.

14. Shaabani, A.; Ghadari, R.; Sarvary, A.; Rezayan, A.H. Synthesis of Highly Functionalized Bis(4*H*-chromene) and 4*H*-Benzo[*g*]chromene Derivatives *via* an Isocyanide-Based Pseudo-Five-Component Reaction. *J. Org. Chem.* **2009**, *74*, 4372-4374.

15. Elinson, M.N.; Dorofeev, A.S.; Miloserdov, F.M.; Ilovaisky, A.I.; Feducovich, S.K.; Belyakov, P.A.; Nikishin, G.I. Catalysis of Salicylaldehydes and Two Different C—HAcids with Electricity: First Example of an Efficient Multicomponent Approach to the Design of Functionalized Medicinally Privileged 2-Amino-4*H*-Chromene Scaffold. *Adv. Synth. Catal.* **2008**, *350*, 591-601.

16. Hafez, E.A.A.; Elnagdi, M.H.; Elagamey, A.G.A.; El-taweel, F.M.A.A. Nitriles in Heterocyclic Synthesis: Novel Synthesis of Benzo[c]coumarin and of Benzo[c]pyrano[3,2-c]quinoline Derivatives. *Heterocycles*, **1987**, *26*, 903-907.

17. Esmaeilpour, M.; Javidi, J.; Dehghani, F.; Dodeji, F.N. A green one-pot three-component synthesis of tetrahydrobenzo[b]pyran and 3,4-dihydropyrano[c]chromene derivatives using a Fe_3O_4@SiO_2–imid–PMA^n magnetic nanocatalyst under ultrasonic irradiation or reflux conditions. *RSC Adv*. **2015**, *5*, 26625-26633.

18. Shirini, F.; Abedini, M.; Zarrabzadeh, S.; Seddighi, M. Efficient synthesis of 4*H*-pyran derivatives using a polymeric catalyst based on PVP. *J. Iran. Chem. Soc.* **2015**, *12*, 2105-2113.

19. Nemouchi, S.; Boulcina, R.; Carboni, B.; Debache, A. Phenylboronic acid as an efficient and convenient catalyst for a three-component synthesis of tetrahydrobenzo[b]pyrans. *C. R. Chimie.* **2012**, *15*, 394-397.

20. Yang, J.; Liu, S.; Hu, H.; Ren, S.; Ying, A. One-pot three-component synthesis of tetrahydrobenzo[b]pyrans catalyzed by cost-effective ionic liquid in aqueous medium. *Chin. J. Chem. Eng.* **2015**, *23*, 1416-1420.

21. Mohammadi AA, Asghariganjeh MR, Hadadzahmatkesh A. Synthesis of tetrahydrobenzo[b]pyran under catalysis of $NH_4Al(SO_4)_2 \cdot 12H_2O$ (Alum). *Arab. J.Chem.,* **2017**, *10*, S2213-S2216.

22. Khaksar, S.; Rouhollahpour, A.; Talesh, S.M. A facile and efficient synthesis of 2-amino-3-cyano-4*H*-chromenes and tetrahydrobenzo[b]pyrans using 2,2,2-trifluoroethanol as a metal-free and reusable medium. *J. Fluor. Chem.* **2012**, *141*, 11-15.

23. Jin, T.S.; Xiao, J.C.; Wang, S.J.; Li, T.S. Ultrasound-assisted synthesis of 2-amino-2-chromenes with cetyltrimethylammonium bromide in aqueous media. *Ultrason. Sonochem.* **2004**, *11*, 393-397.

24. Santra, S.; Rahman, M.; Roy, A.; Majee, A.; Hajra, A. Microwave-Assisted Three-Component "Catalyst and Solvent-Free" Green Protocol: A Highly Efficient and Clean One-Pot Synthesis of Tetrahydrobenzo[b]pyrans. *Org. Chem. Int.*, **2014**, ID 851924, 1-8.

25. Balalaie, S.; Bararjanian, M.; Amani, A.M.; Movassagh, B. (S)-Proline as a Neutral and Efficient Catalyst for the One-Pot Synthesis of

Tetrahydrobenzo[b]pyran Derivatives in Aqueous Media. *Synlett,* **2006**, 263-266.

26. Essamlali, Y.; Amadine, O.; Maati, H.; Abdelouahdi, K.; Fihri, A.; Zahouily, M.; Varma, R.S.; Solhy, A. Highly Efficient One-Pot Three-Component Synthesis of Naphthopyran Derivatives in Water Catalyzed by Phosphates. *ACS Sustainable Chem. Eng.,* **2013**, *1*, 1154-1159.

27. Kangani, M.; Hazeri, N.; Maghsoodlou, M.T. A Mild and Environmentally Benign Synthesis of Tetrahydrobenzo[*b*]pyrans and Pyrano[*c*]chromenes Using Pectin as a Green and Biodegradable Catalyst. *J. Chin. Chem. Soc,* **2016**, *63*, 896-901.

28. Hazeri, N.; Maghsoodlou, M.T.; Mir, F.; Kangani, M.; Saravani, H.; Molashahi, E. An efficient one-pot three-component synthesis of tetrahydrobenzo[b]pyran and 3,4-dihydropyrano[c]chromene derivatives using starch solution as catalyst. *Chin. J. Catal.* **2014**, *35*, 391-395.

29. Noori Sadeh, F.; Maghsoodlou, M.T.; Hazeri, N.; Kangani, M. A facile and efficient synthesis of tetrahydrobenzo[b]pyrans using lactose as a green catalyst. *Res. Chem. Intermed.* **2015**, *41*, 5907-5914.

30. Maghsoodlou, M. T.; Masoumnia, A.; Mousavi, M. R.; Hazeri, N.; Aboonajmi, J.; Habibi-Khorasani, S. M.; Kiaee, S. A green protocol for synthesis of pyran annulated heterocyclic systems using Na_2SO_4 as an efficient catalyst. *Iran. J. Catal.* **2015**, *2*, 169-174.

31. Maghsoodlou, M.T.; Safarzaei, M.; Mousavi, M.R.; Hazeri, N.; Aboonajmi, J.; Shirzaei, M. A green and novel three-component one-pot synthesis of tetrahydrobenzopyran, pyrano[2,3-d]pyrimidine, and 3,4-dihydropyrano[c]chromene derivatives using sodium acetate. *Iran J. Org. Chem.* **2014**, *6*, 1197-1202.

32. Bodaghifard, M.A.; Ahadi, N. One pot synthesis of tetrahyrobenzo[b]pyran and dihydropyrano[c]chromene derivatives using ammonium Alum in green media. *Bulg. Chem, Commun*. **2015**, 47, 603-606.

33. Kiasat, A.R.; Hamid, S.; Saghanezhad, S.J. Synthesis and Characterization of a Novel Nanosilica Supported Bipyridinium Chloride Nanocomposite and its Application as a Basic Catalyst in the One-pot Preparation of Tetrahydrobenzo[b]pyran, Dihydropyrano[3,2-c]chromene and Dihydropyrano[4,3-b]pyran Derivatives. Nanochem Res., **2016**, 1, 157-165.

34. Zolfigol, M.A.; Bahrami-Nejad, N.; Afsharnadery, F.; Baghery, S. 1-Methylimidazolium tricyanomethanide {[HMIM]C$(CN)_3$} as a nano structure and reusable molten salt catalyst for the synthesis of tetrahydrobenzo[b]pyrans *via* tandem Knoevenagel-Michael cyclocondensation and 3,4-dihydropyrano[c]chromene derivatives. *J. Mol. Liq.,* **2016**, *221*, 851-859.

35. Baghernejad, B.; Heravi, M.M.; Oskooie, H.A. A Novel and Efficient Catalyst to One-Pot Synthesis of 2-Amino-4*H*-chromenes by *p*-Toluenesulfonic Acid**.** *J. Korean Chem. Soc*., **2009**, *53*, 631-634.