Short communication

$ZrOCl_2$/nano TiO_2 as an Efficient Catalyst for the One Pot Synthesis of Naphthopyranopyrimidines Under Solvent-free Conditions

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Abstract

$ZrOCl_2$/nano-TiO_2 has been used as an efficient catalyst for the preparation of naphtho[1',2':5,6]pyrano[2,3-*d*]pyrimidine derivatives by the three-component reaction of aldehydes, β-naphthol and 1,3-dimethylbarbituric acid. The advantages of the reaction are solvent-free conditions, short reaction times, easy workup, good to excellent yields, and cost-effective and reusable catalyst.

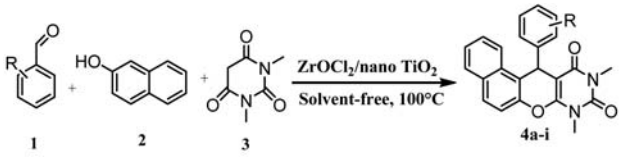
Keywords: $ZrOCl_2$/nano-TiO_2, heterogeneous catalyst, naphtho[1',2':5,6]pyrano[2,3-*d*]pyrimidine, one-pot reaction, solvent-free

1. Introduction

Pyrans belong to an important class of compounds which show a wide range of biological activities.[1] The pyranopyrimidines exhibit important biological properties such as anticancer,[2] antitubercular activity (against *Mycobacterium tuberculosis* $H_{37}Rv$ [ATCC-27294]), antifungal (against *Aspergillus niger* [MTCC-282][3]) and antibacterial[4] activities. Naphthopyranopyrimidines are fused heterocyclic compounds that display antioxidant[5] and antimicrobial[6] activities. Therefore, the development of simple methods for their synthesis is an important challenge. Undoubtedly, the synthesis of naphthopyranopyrimidines through multicomponent reactions (MCRs) has been paid much attention due to excellent synthetic efficiency, inherent atom economy, procedural simplicity and environmental friendliness.[7–11] The eco-friendly, solvent-free multicomponent approach opens up numerous possibilities for environmentally clean synthesis which involves reduction or elimination of the use or generation of hazardous chemicals.[12–13] The possibility of performing multicomponent reactions under solvent-free conditions with a heterogeneous catalyst could improve their cost-effectiveness and ecological acceptability.

Nanoparticles exhibit good catalytic activity due to their high surface-to-volume ratio in comparison to their heterogeneous counterparts. Separation of the catalyst and final product from the reaction mixture is one of the most important aspects of synthetic protocols. Nanoparticles decrease reaction times, impart greater selectivity and can be easily recovered from the reaction mixture by simple filtration.[14–19] Utilizing binary supporting catalysts is a vast challenging necessity for organic chemists due to their expanding surface area. In comparison with conventional supports like solid-phase, nanoparticular matrixes have a higher catalyst loading capacity owing to their very large surface area. Nano-TiO_2 has been extensively used as a heterogeneous catalyst in many reactions due to its high activity, simple availability, nontoxicity, reusability, Lewis acid activity and long-term stability.[20] Meanwhile, $ZrOCl_2.8H_2O$ owing to its low toxicity, commercial availability and moisture stability have gained much attention in organic synthesis.[21] According to the above results we modified nano-TiO_2 surfaces using $ZrOCl_2$ for the synthesis of naphthopyranopyrimidines. Recently, the synthesis of naphthopyranopyrimidines has been reported using MCRs in the presence of diverse catalysts including iodine,[22] $InCl_3$,[23] heteropolya-

cid[24] $Al(H_2PO_4)_3$[25] and P_2O_5.[26] Herein, we report the use of $ZrOCl_2$/nano-TiO_2 as an efficient catalyst for the synthesis of naphthopyranopyrimidines by the three-component reaction of aldehydes, β-naphthol and 1,3-dimethylbarbituric acid under solvent-free conditions at 100 °C (Scheme 1).



Scheme 1. Three-component reaction of aldehydes, β-naphthol and 1,3-dimethylbarbituric acid catalyzed by $ZrOCl_2$/nano-TiO_2

2. Results and Discussion

The powder XRD pattern for $ZrOCl_2$ supported nano-TiO2 catalyst is shown in Figure 1. In order to study the morphology and particle size of $ZrOCl_2$ supported nano-TiO_2, SEM image was also obtained (Figure 2), which shows particles with diameters in the range of nanometers.

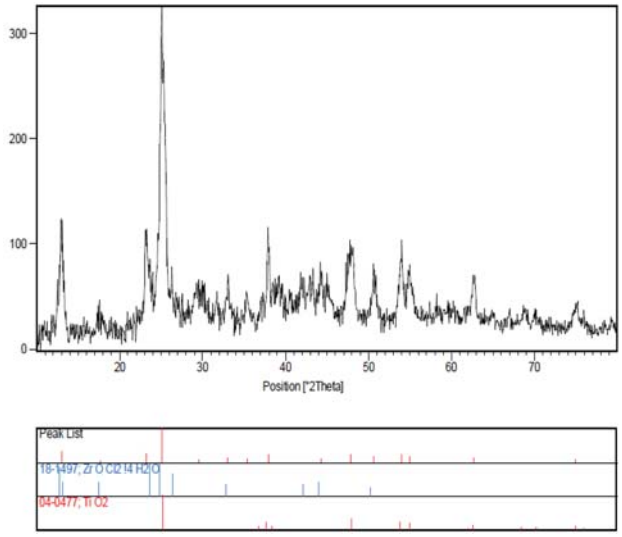


Figure 1. The XRD pattern of $ZrOCl_2$/nano-TiO_2.

Initially, we focused on systematic evaluation of different catalysts in the reaction of 4-nitrobenzaldehyde, β-naphthol and 1,3-dimethylbarbituric acid as a model reaction. Under solvent-free conditions, we were searching for the best reaction conditions in which 3 mol% of $ZrOCl_2$/nano-TiO_2 catalyst gave excellent yields of product and an excessive amount of catalyst did not increase the yields significantly (Table 1).

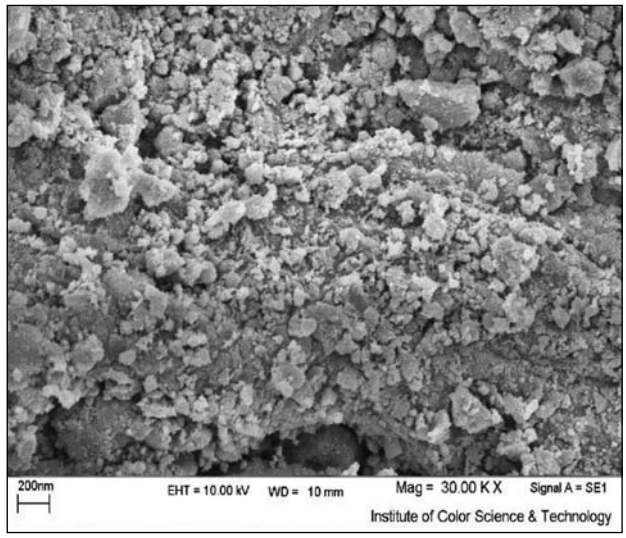


Figure 2. SEM image of $ZrOCl_2$/nano-TiO_2.

Table 1. The model reaction carried out by various catalysts under solvent-free conditions at 100 °C [a]

Entry	Catalyst	mol%	Time(min)	Yield[b]%
1	CH_3COOH	10	66	10
2	Na_2SO_4	15	100	35
3	H_2SO_4	3	35	20
4	Montmorillonite	5	60	12
5	*p*-TSA	5	50	60
6	CuO	5	60	30
7	Ethylene glycol	10	60	25
8	$ZrOCl_2$/nano-TiO_2	1	25	80
9	$ZrOCl_2$/nano-TiO_2	**3**	**25**	**85**
10	$ZrOCl_2$/nano-TiO_2	6	25	85

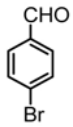
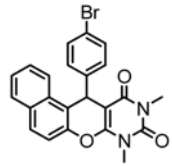
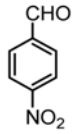
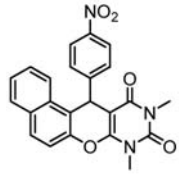
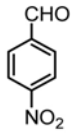
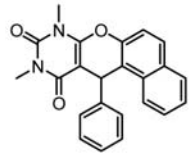
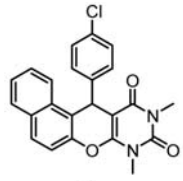
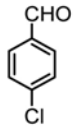
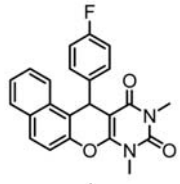
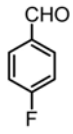
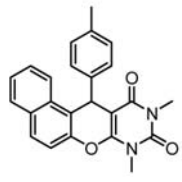
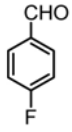
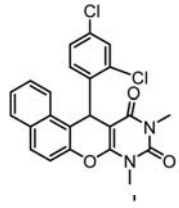
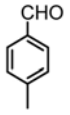
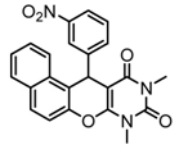
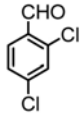
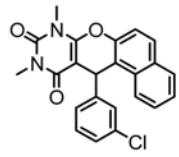
[a] 4-nitrobenzaldehyde (1.1 mmol), β-naphthol (1 mmol) and 1,3-dimethylbarbituric acid (1 mmol) [b] Isolated yield.

Investigations of the reaction scope revealed that various aromatic aldehydes bearing electron-withdrawing and electron-donating groups can be utilized in this protocol (Table 2).

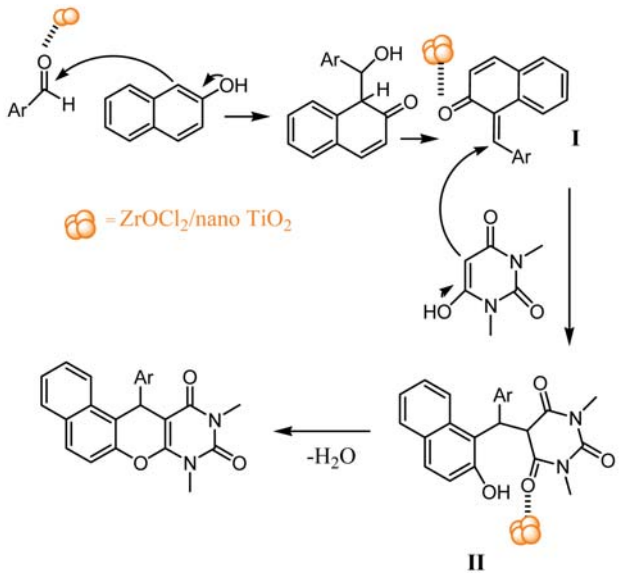
The proposed mechanism for this three-component reaction is outlined in Scheme 2. β-naphthol undergoes condensation with aldehyde in presence of $ZrOCl_2$/nano-TiO_2 to afford α,β-unsaturated carbonyl compound **I.** Michael addition reaction between compounds **I** and 1,3-dimethylbarbituric acid gives intermediate **II** followed by cyclodehydration which gives the desired naphthopyranopyrimidine.

The recycling of $ZrOCl_2$ supported nano-TiO_2 catalyst was also examined and results are summarized in Table 3. The recovered catalyst was washed by hot ethanol (3 × 5 mL) then dried at 80 °C and used in the next run. The results showed that the catalyst could be reused several times without noticeable loss of catalytic activity.

Table 2. Synthesis of naphtho[1',2':5,6]pyrano[2,3-*d*]pyrimidine by $ZrOCl_2$/nano-TiO_2 under solvent-free conditions at 100 °C.

Entry	4a-i	aldehyde	Product	Time (min)	Yield %[a]	mp °C (ref)
1	**4a**			28	82	243–245[22]
2	**4b**			25	85	291–293 [22]
3	**4c**			30	81	223–225 [22]
4	**4d**			27	83	274–276 [22]
5	**4e**			27	84	305–307 [22]
6	**4f**			31	80	200–202 [22]
7	**4g**			25	84	219–221 [22]
8	**4h**			27	82	310–312 [24]
9	**4i**			28	82	222–224 [22]

[a] Isolated yield.



Scheme 2: The proposed reaction pathway for the synthesis of naphthopyranopyrimidine catalyzed by $ZrOCl_2$/nano-TiO_2.

Table 3. Recycling of $ZrOCl_2$/nano-TiO_2 catalyst in the preparation of **4b.**

Run	1	2	3	4	5
Yield (%)[a]	85	84	84	83	82

[a] Isolated yield.

3. Experimental

3. 1. General

The products were isolated and characterized by physical and spectral data. ^{1}H NMR and ^{13}C NMR spectra were recorded on Bruker Avance-400 MHz spectrometers in the presence of tetramethylsilane as internal standard. The IR spectra were recorded on FT-IR Magna 550 apparatus using KBr plates. Melting points were determined on Electro thermal 9200, and are not corrected. The elemental analyses (C, H, N) were obtained from a Carlo ERBA Model EA 1108 analyzer. X-ray powder diffraction (XRD) was carried out on a Philips diffractometer of X'pert company at λ = 1.5406 Å. Microscopic morphology of products was visualized by SEM LEO 1455VP.

3. 2. Preparation of $ZrOCl_2$ Supported Nano-TiO_2 Catalyst

In a typical procedure, nano-TiO_2 (1 g) and $ZrOCl_2$ (0.3 g) were combined and stirred for 24 h at room temperature in CH_2Cl_2. Afterwards, The solid was dried at 80 °C for 24 h. Then, the solid was calcinated at 300 °C for 30 min.

3. 3. General Procedure for the Synthesis of Naphthopyranopyrimidines (4a–i):

To a mixture of aldehyde (1.1 mmol), β-naphthol (1.0 mmol), and 1,3-dimethylbarbutyric acid (1.0 mmol), 3 mol% of $ZrOCl_2$/nano-TiO_2 were added as the catalyst, and the mixture was stirred for an appropriate time at 100 °C in an oil bath. After completion of the reaction, indicated by TLC, the reaction mixture was dissolved in the appropriate volume of hot ethanol, stirred for 5 min, filtered, and the heterogeneous catalyst recovered. Solution with product was concentrated and recrystallized from ethanol to get pure compound.

3. 4. Analytical Data:

12-(4-Bromophenyl)-8,10-dimethyl-8,12-dihydro-9*H*-naphtho[1',2':5,6]pyrano[2,3-*d*]pyrimidine-9,11-(10*H*)-dione (4a): White solid; mp 243–245 °C; IR (KBr): ν_{max} 2921, 2852, 1665, 1643, 1593, 1483, 1226, 506 cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz): δ (ppm) 3.42 (s, CH_3, 3H), 3.49 (s, CH_3, 3H), 5.88 (s, CH, 1H), 7.04–7.35 (m, 5H), 7.41 (d, *J* = 8.5 Hz, 1H), 7.45–8.04 (m, 4H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ (ppm) 28.3, 29.0, 35.5, 90.8, 116.2, 116.6, 120.6, 123.7, 125.6, 127.5, 128.5, 129.7, 130.0, 130.7, 131.5, 131.7, 142.8, 147.1, 150.5, 152.2, 161.9; Anal.Calcd.for $C_{23}H_{17}BrN_2O_3$: C, 61.48; H, 3.81; N, 6.23. Found C, 61.39; H, 3.75; N, 6.19.

8,10-Dimethyl-12-(4-nitrophenyl)-8,12-dihydro-9*H*-naphtho[1',2':5,6]pyrano[2,3-*d*]pyrimidine-9,11-(10*H*)-dione (4b): Cream solid; mp 290–292 °C, IR (KBr): ν_{max} 2921, , 1667, 1595, 1513, 1342, 1229, 1175 cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz): δ (ppm) 3.48 (s, CH_3, 3H), 3.63 (s, CH_3, 3H), 5.91 (s, CH, 1H), 7.26 (m, 5H), 7.60 (m, 2H), 8.07 (d, *J* = 8.8 Hz, 1H), 8.32 (d, *J* = 8.6 Hz, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ (ppm) 28.3, 29.1, 36.0, 90.0, 115.7, 116.3, 123.3, 123.7, 125.8, 127.8, 128.7, 129.2, 130.2, 130.5, 131.8, 146.5, 147.1, 150.4, 150.8, 152.4, 161.8; Anal.Calcd.for $C_{23}H_{17}N_3O_5$: C, 66.50; H, 4.12; N, 10.12; Found C, 66.41; H, 4.02; N, 10.20.

8,10-Dimethyl-12-phenyl-8,12-dihydro-9*H*-naphtho[1',2':5,6]pyrano[2,3-*d*]pyrimidine-9,11-(10*H*)-dione (4c): White solid; mp 223–225 ° C, IR (KBr): ν_{max} 2921, 2849, 1669, 1645, 1593, 1485, 1234, 1175 cm^{-1}, ^{1}H NMR ($CDCl_3$, 400 MHz): δ (ppm) 3.34 (s, CH_3, 3H), 3.59 (s, CH_3, 3H), 5.77 (s, CH, 1H), 7.12–7.50 (m, 8H), 7.82 (m, 2H), 7.96 (m, 1H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ (ppm) 28.2, 29.1, 35.9, 91.4, 116.2, 117.3, 123.9, 125.4, 126.7, 127.4, 128.2, 128.4, 129.0, 129.5, 130.9, 131.7, 143.8, 147.1, 150.6, 152.2, 161.9; Anal.Calcd.for $C_{23}H_{18}N_2O_3$: C, 74.58; H, 4.90; N, 7.56; Found C, 74.62; H, 4.96; N, 7.48.

12-(4-chlorophenyl)-8,10-dimethyl-8,12-dihydro-9*H*-naphtho[1',2':5,6]pyrano[2,3-*d*]pyrimidine-9,11-

(10*H*)-dione (4d): White solid; mp 275–277 °C; IR (KBr): ν_{max} 2961, 1668, 1622, 1358, 1205 cm^{-1}, ^{1}H NMR ($CDCl_3$, 400 MHz): δ (ppm) 3.33 (s, CH_3, 3H), 3.60 (s, CH_3, 3H), 5.75 (s, CH, 1H), 7.18 (d, *J* = 8Hz, 2H), 7.28 (d, *J* = 8Hz, 2H), 7.32 (m, 1H), 7.48 (m, 2H), 7.75–7.90 (m, 2H), 8.12 (d, *J* = 8Hz, 1H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ (ppm) 28.2, 29.0, 35.4, 90.8, 116.3, 116.7, 123.7, 125.6, 127.5, 128.5, 129.6, 129.7, 130.7, 131.7, 132.5, 142.3, 147.1, 150.5, 152.2, 161.9; Anal.Calcd.for $C_{23}H_{17}ClN_2O_3$: C, 68.23; H, 4.23; N, 6.92; Found C, 68.16; H, 4.16; N, 6.96.

12-(4-fluorophenyl)-8,10-dimethyl-8,12-dihydro-9*H*-naphtho[1',2':5,6]pyrano[2,3-*d*]pyrimidine-9,11-(10*H*)-dione (4e): White solid; mp 300–303 °C, IR (KBr): ν_{max} 2955, 1664, 1631, 1342, 1203, 1164 cm^{-1}, ^{1}H NMR ($CDCl_3$, 400 MHz): δ (ppm) 3.33 (s, CH_3, 3H), 3.62 (s, CH_3, 3H), 5.75 (s, CH, 1H), 6.88 (m, 2H), 7.25–7.37 (m, 3H), 7.41 (m, 2H), 7.75–7.89 (m, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ (ppm) 28.2, 29.1, 35.3, 91.2, 115.4, 116.3, 117.0, 123.8, 125.6, 127.5, 128.6, 129.6, 129.7, 129.8, 130.7, 131.8, 139.6, 147.1, 150.6, 152.2, 161.9; Anal.Calcd.for $C_{23}H_{17}FN_2O_3$: C, 71.13; H, 4.41; N, 7.21; Found C, 71.19; H, 4.35; N, 7.16.

8,10-Dimethyl-12-*p*-tolyl-8,12-dihydro-9*H*-naphtho[1',2':5,6]pyrano[2,3-*d*]pyrimidine-9,11-(10*H*)-dione (4f): White solid; mp 200–202 °C, IR (KBr): ν_{max} 2919, 2853, 1700, 1638, 1486, 1229, 1172 cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz): δ (ppm) 2.24 (s, 3H), 3.32 (s, CH_3, 3H), 3.58 (s, CH_3, 3H), 5.71 (s, CH, 1H), 6.96 (d, *J* = 8Hz, 2H), 7.15 (d, *J* = 8Hz, 2H), 7.45 (m, 3H), 7.66 (m, 2H), 7.94 (m, 1H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ (ppm) 21.1, 28.1, 29.0, 35.5, 91.6, 116.2, 117.7, 124.3, 125.4, 127.4, 128.1, 128.4, 129.2, 129.3, 130.1, 131.7, 136.0, 140.9, 147.1, 150.3, 151.8, 161.5; Anal.Calcd.for $C_{24}H_{20}N_2O_3$: C, 74.98; H, 5.24; N, 7.29; Found C, 75.05; H, 5.31; N, 7.21.

12-(2,4-dichlorophenyl)-8,10-dimethyl-8,12-dihydro-9*H*-naphtho[1',2':5,6]pyrano[2,3-*d*]pyrimidine-9,11-(10*H*)-dione (4g): White solid; mp 219–221 °C, IR (KBr): ν_{max} 2923, 1642, 1582, 1484, 1174, 743, 718 cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz): δ (ppm) 3.30 (s, CH_3, 3H), 3.64 (s, CH_3, 3H), 5.98 (s, CH, 1H), 7.1 (m, 1H), 7.22 (s, 1H), 7.33 (m, 2H), 7.53 (m, 2H), 7.80 (m, 2H), 8.10 (m, 1H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ (ppm) 28.1, 29.0, 33.8, 89.9, 116.2, 123.7, 125.5, 127.4, 127.6, 128.6, 129.6, 129.9, 130.9, 131.5, 132.3, 133.0, 133.7, 139.7, 146.8, 150.4, 152.4, 161.5; Anal.Calcd.for $C_{23}H_{16}Cl_2N_2O_3$: C, 62.88; H, 3.67; N, 6.38; Found C,62.79; H, 3.61; N, 6.29.

8,10-Dimethyl-12-(3-nitrophenyl)-8,12-dihydro-9*H*-naphtho[1',2':5,6]pyrano[2,3-*d*]pyrimidine-9,11-(10*H*)-dione (4h): Cream solid; mp 307–309 °C, IR (KBr): ν_{max} 2953, 1688, 1645, 1583, 1545, 1483 cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz): δ (ppm) 3.39 (s, CH_3, 3H), 3.71 (s, CH_3, 3H), 5.95 (s, CH, 1H), 7.55–7.85 (m, 8H), 8.10 (m, 1H), 8.14 (s, 1H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ (ppm) 28.2, 29.1, 36.0, 90.0, 115.5, 116.1, 123.2, 123.7, 125.4, 127.6, 128.4, 128.7, 129.0, 130.1, 130.3, 131.5, 143.2, 146.4, 147.0, 150.2, 150.8, 152.3, 161.5; Anal.Calcd.for $C_{23}H_{17}N_3O_5$: C, 66.50; H, 4.12; N, 10.12; Found C, 66.41; H, 4.07; N, 10.20.

12-(3-chlorophenyl)-8,10-dimethyl-8,12-dihydro-9*H*-naphtho[1',2':5,6]pyrano[2,3-*d*]pyrimidine-9,11-(10*H*)-dione (4i): White solid; mp 222–224 °C, IR (KBr): ν_{max} 2921, 1639, 1588, 1478, 1424 cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz): δ (ppm) 3.33 (s, CH_3, 3H), 3.61 (s, CH_3, 3H), 5.75 (s, CH, 1H), 7.15–7.60 (m, 7H), 7.81–7.92 (m, 3H); ^{1}H NMR ($CDCl_3$, 400 MHz): δ (ppm); 28.2, 29.1, 35.8, 90.8, 116.3, 116.5, 123.7, 125.6, 126.7, 127.0, 127.6, 128.2, 128.6, 129.5, 129.8, 130.7, 131.8, 134.3, 145.7, 147.1, 150.5, 152.3, 161.8; Anal.Calcd.for $C_{23}H_{17}ClN_2O_3$: C, 68.23; H, 4.23; N, 6.92; Found C, 68.18; H, 4.12; N, 6.85.

4. Conclusions

In summary, we have developed the synthesis of naphtho[1',2':5,6]pyrano[2,3-*d*]pyrimidines in the presence of $ZrOCl_2$/nano-TiO_2 as an efficient catalyst under solvent-free conditions. The procedure offers several advantages including easy workup, the employment of a cost-effective catalyst, short reaction times, excellent yields and reusability of the catalyst. Furthermore, synthesized compounds provide promising candidates for chemical biology and drug discovery.

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6. References

1. D. Kumar, V. B. Reddy, S. Sharad, U. Dube, S. Kapur, *Eur. J. Med. Chem*. **2009**, *44*, 3805–3809. http://dx.doi.org/10.1016/j.ejmech.2009.04.017
2. X. Jiang, Y. Sun, J. Yao, Y. Cao, M. Kai, N. He., X. Zhang, Y. Wang, R. Wang. *Adv. Synth. Catal*. **2012**, *354*, 917–925. http://dx.doi.org/10.1002/adsc.201100792
3. N. R. Kamdar, D. D. Haveliwala, P. T. Mistry, S. K. Patel, *Eur. J. Med. Chem*. **2010**, *45*, 5056–5063. http://dx.doi.org/10.1016/j.ejmech.2010.08.014
4. A. H. Bedair, N. A. El-Hady, M. S. A. El-Latif, A. H. Fakery, A. M. El-Agrody., *Il Farmaco,* **2000**, *55*, 708–714. http://dx.doi.org/10.1016/S0014-827X(00)00097-5

5. J. M. Khurana, A. Lumb, A. Chaudhary, B. Nand, *RSC Adv* . **2013**, *3*, 1844–1854.
6. A. H. Bedair, H. A. Emam, N. A. El-Hady, K. A. R. Ahmed, A. M. El-Agrody, *Il Farmaco*, **2001**, *56*, 965–973. http://dx.doi.org/10.1016/S0014-827X(01)01168-5
7. J. Safaei-Ghomi, F. Eshteghal, M. A. Ghasemzadeh, *Acta Chim. Slov*. **2014**, *61*, 703–708.
8. J. P. Wan, Y. Liu, *RSC Adv*. **2012**, *2*, 9763–9777.
9. B. Jiang, T. Rajale, W, Wever, S. J. Tu, G. Li. *Chem. Asian J.* **2010**, *5*, 2318–2335. http://dx.doi.org/10.1002/asia.201000310
10. J. Safaei-Ghomi, H, Shahbazi-Alavi, E, Heidari-Baghbahadorani, *RSC Adv*. **2014**, *4*, 50668–50677. http://dx.doi.org/10.1039/C4RA04769A
11. F. Yu, R. Huang, H. Ni, J. Fan, S. Yan, J. Lin, *Green Chem*, **2013**, *15*, 453–462. http://dx.doi.org/10.1039/C2GC36552A
12. S. Tao, S. Xia, L. Rong, C. Cao, S. Tu, *Res Chem Intermed*. **2012**, *38*, 2065–2073. http://dx.doi.org/10.1007/s11164-012-0526-9
13. A. Hasaninejad, A. Zare, M. Shekouhy, *Tetrahedron* **2011**, *67*, 390–400. http://dx.doi.org/10.1016/j.tet.2010.11.029
14. J. Safaei-Ghomi, H. Shahbazi-Alavi, M. R. Saberi-Moghadam, A. Ziarati, *Iran. J. Cat.* **2014**, *4*, 289–294.
15. D. Damodara, R. Arundhathi, P. R. Likhar, *Adv. Synth. Catal*. **2014**, *356*, 189–198. http://dx.doi.org/10.1002/adsc.201300453
16. K. Chanda, S. Rej, M. H. Huang, *Chem. -Eur. J*. **2013**, *19*, 16036–16043. http://dx.doi.org/10.1002/chem.201302065
17. M. Kidwai, A. Jain, S. Bhardwaj, *Mol Divers* **2012**, *16*, 121–128. http://dx.doi.org/10.1007/s11030-011-9336-z
18. M. Niederberger, G. Garnweitner, *Chem. Eur. J*. **2006**, *12*, 7282–7302. http://dx.doi.org/10.1002/chem.200600313
19. C. W. Lim, I. S. Lee, *Nano Today* **2010**, *5*, 412–434. http://dx.doi.org/10.1016/j.nantod.2010.08.008
20. M. Haghighi, K. Nikoofar, *J. Saudi. Chem. Soc*. . http://dx.doi.org/10.1016/j.jscs.2014.09.002
21. S. Mishra, R. Ghosh, *Tetrahedron Lett*. **2011**, *52*, 2857–2861. http://dx.doi.org/10.1016/j.tetlet.2011.03.116
22. K. Praveen Kumar, S. Satyanarayana, P. Lakshmi Reddy, G. Narasimhulu, N. Ravirala, B. V. Subba Reddy, *Tetrahedron Lett*. **2012**, *53*, 1738–1741. http://dx.doi.org/10.1016/j.tetlet.2012.01.096
23. G. C. Nandi, S. Samai, M. S. Singh, *Synlett* **2010**, *7*, 1133–1137.
24. S. S. Jalde, H. V. Chavan, L. K. Adsul, V. D. Dhakane, B. P. Bandgar. *Synth. React. Inorg., Met.-Org., Nano-Met. Chem.* **2014**, *44*, 623–626.
25. S. S. Sajadikhah, *RSC Adv*. **2015**, *5*, 28038–28043.
26. G. C. Nandi, S. Samai, R. Kumar, M. S. Singh, *Tetrahedron* **2009**, *65*, 7129–7134. http://dx.doi.org/10.1016/j.tet.2009.06.024

Povzetek

V prispevku je opisana uporaba $ZrOCl_2$/nano-TiO_2 kot učinkovitega katalizatorja za pripravo nafto[1',2':5,6]pirano[2,3-*d*]pirimidinskih derivatov v trikomponentni reakciji med aldehidi, β-naftolom in 1,3-dimetilbarbiturno kislino. Prednosti tako izvedenih reakcij so izključitev topila med potekom reakcije, kratki reakcijski časi, enostavna izolacija produkta, dobri izkoristki reakcij ter možnost reciklaže relativno cenenega katalizatorja.