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Facile Synthesis, and Antimicrobial activity of Imidazole derivatives by Zirconia NPs catalyst

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Abstract

Imidazole derivatives are considered potential chemical compounds that could be therapeutically effective against several harmful pathogenic microbes. In the present study substituted imidazoles via nano zirconia catalyzed multicomponent reaction of isatin derivatives with ammonium acetate and substituted indole-3- aldehydes has been developed. The synthesized imidazole derivatives were characterised using spectral and analytical data viz; nuclear magnetic resonance (NMR) , IR and ^{13} CNMR. The results of antibacterial and antifungal and antioxidant activities showed that some of the synthesized compounds exhibited promising activities.

Key words : nano ZrO_2catalyst, Indole-3-aldehyde, imidazole, Isatin,antimicrobial activity.

Introduction

Heterocycles form the most complicated and fascinating disciplines of chemistry for more than a century. There is an ample collection of various structures of heterocycles and their economic use as drugs. Among the many heterocycles, nitrogen-comprising heterocyclic molecules have piqued the curiosity of researches during periods of organic synthesis advancement [1]. Among the various chemical compounds explored in medicinalchemistry, imidazole derivatives have attracted significant attention due to their versatilepharmacological properties [2].

Immidazole a five membered heterocyclic compound featuring two non adjacent nitrogen atoms act as a versatile building block in chemistry and biology. This 1,3 diazole is a privileged scaffold for designing drugs with broad spectrum activities. It is the basic core of some important biological building blocks such as histidine and the related horomones histamine. The 1,3-diazole and it's containing compounds shows a lot of therapeutic activities such as analgesics, antifungal, antihypertensive, antiobesity, antitumor [3],

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antiviral, anthelmintic, antitubercular [4], antiulcer, antihistaminic [5], anti-inflammatory, antidepressant [6]. antidiabetic [7], anticonvulsant [8], antiallergic [9], antirheumatic [10], antiasthmatic, alpha-blockers [11], antiprotozoal [12], antiaging, anticoagulant, antimalarial [13], and antiamoebic activity [14] etc. Imidazoles and their derivatives are associated with a variety of pharmacological activities. Some of the commercially important imidazolesare1-(1-(2-hydroxy-3-methoxypropyl)-1H-imidazol-2-yl)ethanone (Misonidazole), N-(2,6-dichlorophenyl)-4,5-dihydro-1H-imidazol-2-amine**(**Clonidine),2-(6-chloro-2-(4-chlorophenyl)imidazo[1,2-a]pyridin-3-yl)-N,N-dipropylacetamide(Alpidem)**,**2-(2-methyl-5-nitro-1H-imidazol-1-yl)ethanol(Metronidazole)**,**ethyl8-fluoro-5-methyl-6-oxo-5,6-dihydro-4H-benzo[f]imidazo[1,5-a][1,4]diazepine-3-carboxylate(Fulmazenil)**,**2-(4-(2,4-dichlorophenyl)-1, -dithiolan-2-ylidene)-2-(1H-imidazol-**3**-yl)acetonitrile(Luliconazole)**.**

Due to their impressive significance, various synthetic routes have been designed for the synthesis of imidazole and its derivatives [15]. In recent times, metal nanoparticles are used as heterogeneous catalysts in organic synthesis mainly because they achieve the objectives of green and sustainable chemistry. Recently scientists have done a lot of work to synthesize precise metal nanoparticles(NPs). The easiness of separation, recovery, and reuse of these NPs further enhance their attractiveness as green and sustainable catalysts [16-18]. Recently, nano zirconia (ZrO_2) has attracted considerable attention due to their wide applicability as a heterogeneous catalyst [19-24]. ZrO_2 nanoparticle catalyst is a cheap, moisture stable, safe, reusable, and commercially available white powder is of big curiosity to many researchers. It has been revealed from the literature that numerous parallel applications of nano zirconia, as an effective catalyst in green/sustainable synthetic chemistry, have already been reported [25-30]. but we choose the greener method of synthesizing imidazole using Zirconia nano particles as catalyst.

The reaction conditions and several parameters for facile synthesis of substituted imidazole was studied by *Sundaram Singh and Shivam Bajpai* .In view of the above , it was thought worthwhile to synthesize some novel imidazoles fused with indole -3- carboxaldehyde nucleus and isatin derivatives because of their high biological profile to yield novel compounds of lethal interest since the combination of two or more different heterocyclic compounds in a single molecule enhances the biological profile incredibly.

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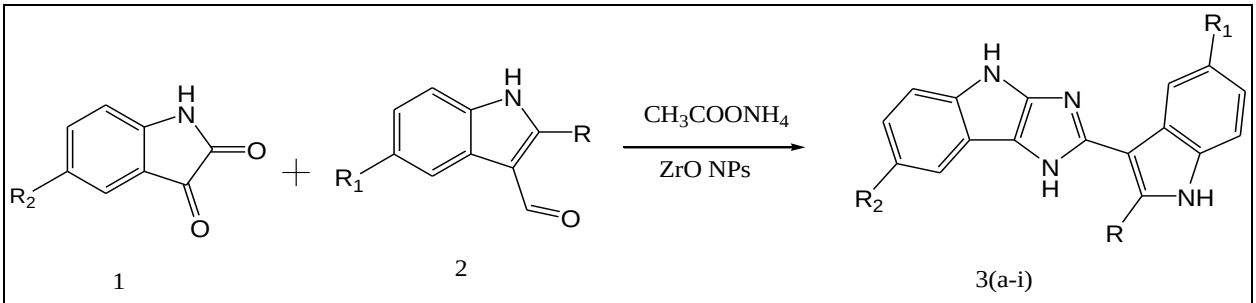
Materials and methods

All the chemicals and solvents were of laboratory reagent grade and used as received from Sigma Aldrich and SD fine. Melting points were determined in open capillaries and are uncorrected. The purity of the compounds was checked by TLC using silica gel-G coated aluminum plates (Merck) and spots were visualized by exposing the dry plates to iodine vapors. The IR(KBr) spectra were recorded on a Perkin-Elmer spectrometer on FT-IR spectrometer. The 1H NMR (DMSO-d6) spectra recorded on a Bruker (400 MHz) and the chemical shifts were expressed in ppm (δ scale) downfield from TMS. Mass spectral data were recorded by electron impact method on JEOL GCMATE II GC-MS mass spectrometer. Elemental analysis was carried out using Flash EA 1112 series elemental analyzer. All the compounds gave C, H and N analysis within±0.5% of the theoretical values.



1 2 3(a-i)

	3a	3b	3c	3d	3e	3f	3g	3h	3i
R	H	C_6H_5	C_6H_5	H	C_6H_5	C_6H_5	H	C_6H_5	C_6H_5
R_1	H	Cl	CH_3	H	Cl	CH_3	H	Cl	CH_3
R_2	H	H	H	Br	Br	Br	Cl	Cl	Cl

Scheme-1

Experimental Procedure

Procedure for the synthesis of ZrO_2NPs

0.075 M solution of $ZrOCl_2.8H_2O$ was prepared and then precipitated with NH_4OH (25%) with continuous stirring on a magnetic stirrer till the PHraises in the range of 10–10.5.This resulted in the formation of precipitate of zirconium hydroxide. The precipitate was filtered and washed with double distilled water until traces of chloride ion were completely removed from the filtrate. Complete removal of chloride ion from filtrate was checked by titrating it with $AgNO_3$solution using potassium chromate as indicator. Now, the

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precipitate was dried in oven at 80–90°C for 24 h and calcinated at 600°C for 3 h in order to formation of white nano zirconia powder[31].

procedure for the synthesis of substituted imidazoles 3(a-i).

To a mixture of isatin derivatives **1** (1 mmol), ammonium acetate (5 mmol), substituted indole aldehydes **(2)** (1 mmol), 15 mol% of ZrO_2NPs was added (**Scheme 1**). The mixture was heated and stirred at 110°C for 30 min. The progress of the reaction was monitored by thin layered chromatography (n-hexane:ethyl acetate, 1:1). After completion, 20 ml acetone was added to the reaction mixture; the catalyst was removed by filtration and washed with xylene and acetone. Then, 50 ml of double distilled water is added to the liquid portion. This resulted in the formation of precipitate of products **(3a-i)**. The precipitate was filtered, dried and recrystallized with ethanol.

Experimental

Compound 3a

IR (KBr) (λmax in cm-1): 3427,3297(indoleN-H); 3213(imidazole NH)1278(C=N); 2968 (Ar CH stretch). 1H NMR (400 MHz, $CDCl_3$) δ(ppm):11.70(s,1H,indoleNH);11.20(s, 1H,indoleNH);10.70(s,1H,imidazoleNH);7.20-8.10(m,9H,Ar-H).
LCMS:m/z=193;Analysis:Calcd for:$C_{17}H_{12}N_4$,C(74.98);

H,(4.44);N,(20.58); Found:C,75.12; H,4.40; N,20.67. Brown crystals.

Compound 3b

IR (KBr) (λmax in cm-1): 3431, 3251(indoleN-H); 3224(imidazole NH)1278(C=N); 2968 (Ar CH stretch). 1H NMR (400 MHz, $CDCl_3$) δ(ppm):11.81(s,1H,indoleNH);11.31(s, 1H,indoleNH);10.60(s,1H,imidazoleNH);7.10-8.30(m,12H,Ar-H).
LCMS:m/z=382;Analysis:Calcd for:$C_{23}H_{15}ClN_4$,C(72.16);

H,(3.95);N,(14.63); Found:C,72.08; H,3.91; N,14.73. Dark yellow crystals..

Compound 3c

IR (KBr) (λmax in cm-1): 3481, 3268(indoleN-H); 3254(imidazole NH)1278(C=N); 2968 (Ar CH stretch). 1H NMR (400 MHz, $CDCl_3$) δ(ppm):11.60(s,1H,indoleNH);11.10(s, 1H,indoleNH);10.60(s,1H,imidazoleNH);7.15-8.2(m,12H,Ar-H).
LCMS:m/z=362;Analysis:Calcd for:$C_{24}H_{18}N_4$,C(79.54);

H,(5.01);N,(15.46); Found:C,79.35; H,5.08; N,15.41. Light yellow crystals..

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Compound 3d

IR (KBr) (λmax in cm-1): 3462, 3258(indoleN-H); 3241(imidazole NH)1278(C=N); 2968 (Ar CH stretch). 1H NMR (400 MHz, $CDCl_3$) δ(ppm):12.20(s,1H,indoleNH);11.30(s, 1H,indoleNH);11.10(s,1H,imidazoleNH);7.16-8.40(m,8H,Ar-H).
LCMS:m/z=351;Analysis:Calcd for:$C_{17}H_{11}BrN_4$,C(58.14);

H,(3.16);N,(15.95); Found:C,58.08; H,3.11; N,15.89. Dark brown crystals..

Compound 3e

IR (KBr) (λmax in cm-1): 3438, 3249(indoleN-H); 3232(imidazole NH)1278(C=N); 2968 (Ar CH stretch). 1H NMR (400 MHz, $CDCl_3$) δ(ppm):12.30(s,1H,indoleNH);12(s, 1H,indoleNH);11.40(s,1H,imidazoleNH);7.35-8.20(m,11H,Ar-H).
LCMS:m/z=461;Analysis:Calcd for:$C_{23}H_{14}BrClN_4$,C(59.83);

H,(3..6);N,(12.13); Found:C,59.70; H,3.13; N,12.07. Light yellow crystals..

Compound 3f

IR (KBr) (λmax in cm-1): 3435, 3259(indoleN-H); 3232(imidazole NH)1278(C=N); 2968 (Ar CH stretch). 1H NMR (400 MHz, $CDCl_3$) δ(ppm):12.30(s,1H,indoleNH);12(s, 1H,indoleNH);11.40(s,1H,imidazoleNH);7.35-8.20(m,11H,Ar-H).
LCMS:m/z=461;Analysis:Calcd for:$C_{24}H_{17}BrN_4$,C(65.32); H,(3..88);N,(12.70); Found:C,65.40; H,3.81; N,12.62. Light yellow crystals..

Compound 3g

IR (KBr) (λmax in cm-1): 3457, 3254 (indoleN-H); 3239(imidazole NH)1278(C=N); 2968 (Ar CH stretch). 1H NMR (400 MHz, $CDCl_3$) δ(ppm): 12.30 (s,1H,indoleNH); 11.40,(s,1H,indoleNH);11.10(s,1H,imidazoleNH);7.20-8.40(m,11H,Ar-H).
LCMS:m/z=306; Analysis: Calcd for: $C_{17}H_{11}ClN_4$,C(66.56); H,(3.61);N,(18.26); Found:C,66.41; H,3.67; N,18.20 Light yellow crystals..

Compound 3h

IR (KBr) (λmax in cm-1): 3438, 3262 (indoleN-H); 3223(imidazole NH)1278(C=N); 2968 (Ar CH stretch). 1H NMR (400 MHz, $CDCl_3$) δ(ppm): 12.40 (s,1H,indoleNH); 12.10,(s,1H,indoleNH);11.60(s,1H,imidazoleNH);7.30-8.(m,11H,Ar-H).
LCMS:m/z=417,Analysis:Calcd for:$C_{23}H_{14}Cl_2N_4$,C(66.20); H,(3.38);N,(13.43); Found:C,66.35; H,3.31; N,13. 37 Light yellow crystals..

Compound 3i

IR (KBr) (λmax in cm-1): 3419, 3257 (indoleN-H); 3231(imidazole NH)1278(C=N); 2968 (Ar CH stretch). 1H NMR (400 MHz, $CDCl_3$) δ(ppm): 12.35(s,1H,indoleNH); 11.50,(s,1H,indoleNH);11.25(s,1H,imidazoleNH);7.36-8.01(m,11H,Ar-H).

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LCMS:m/z=396, Analysis:Calcd for:$C_{24}H_{17}$ Cl N_4 ,C(72.63); H,(4.32);N,(14.12); Found:C,72.55; H,4.35; N,14.03 Light yellow crystals..

Biological Activity

Antimicrobial activity

The antibacterial activities of compounds **(4a-l)**,were carried out using Cup plate diffusion method**[25]** . This method depends on the diffusion of the antibiotic from a cavity through the solidified agar layer in a petri dish to an extent such that the growth of the added microorganism is prevented in a circular zone around the cavity containing a solution of the antibiotic. For antibacterial activity , antibacterial species used are two Gram negative species *Escherichia coli*(ATCC 9637),*Salmonella typhi* (ATCC 6539)and two Gram-positive species *Bacillus subtilis(*ATCC 6633), *Staphylococcus aureus*(ATCC 29737).Two fungal strains *Aspergillus niger* (ATCC 16509), *Aspergillus fumigates (*ATCC 16406).are used for antifungal activity. Solution of each compound at a concentration of 1000µg/ml in DMSO was prepared and the inhibition zone diameter in millimeter was used as the criterion for measuring the microbial activity after 24h for bacteria and 72h for fungi. Ciprofloxacin is used as bacterial standards and amphotericin B is used as fungal standards for references. to evaluate the efficacy of the tested compounds under the same conditions. DMSO used as control and solvent to prepare compound solutions. Measurements of results are shown in **Table 1**

Table:1, Antimicrobial activity results of synthesized compounds. Scheme 1

	Antibacterial Activity				Antifungal Activity	
compound	Gram Positive		Gram negative			
	B.Subtilis	***S.aureus***	***E. Coli***	***S.Typhi***	*A.fumigatus*	*A.niger*
3a	**15**±.471	**11**±.313	**14**±253268.	14±.	**13**±.341	**12**±252.
3b	**15**±.272	**14**±.360	**13**±.27	**13**±273.	**16**±.381	**16**±.135
3c	13±.54	12±256.	**12**±.15	**13**±.361	**13**±227.	11±.272
3d	13±.136	12±.272	13±243.	12±.123	12±.136	13±.361
3e	**17**±.143	**15**±163	14±.326	16±.241	**16**±.341	15±.143
3f	12±.28	13±.362	13±.361	12±14.	12±.272	12±.236
3g	11±.471	10±.271	10±.139	11±.27	10±.213	12±.251
3h	**16**±.362	**16**±.136	**15**±.212	14±.263	**17**±.361	**17**±.214
3i	13±272	13±.324	12±.238	12±.153	12±.258	14±.321
Ciproflaxcin	19	21	19	20		

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Amphotericin.B					20	20

Values are expressed in mean±SD(n=3)

RESULTS AND DISCUSSION

Chemistry

Compounds2-(2,5-disubstituted-1H-indol-3-yl)-7-substituted-1,4-dihydroimidazo [4,5-b] indole **(3a-I)** are obtained by cyclocondensation of various 2,5-disubstituted indole-3-carboxaldehydes **(2)**with substituted isatin **(1)** using ZrO_2 NPs as catalyst in the presence ammonium acetate under reflux condition heated at 110°C for 30 minutes. The IR spectrumof2-(5-chloro-2-phenyl-1H-indol-3-yl)-1,4-dihydroimidazo[4,5-b]indole(**3b)** showed characteristic absorption at 3431 cm^{-1} and 3251 cm^{-1} corresponding to indole NH, absorption at 3224 cm^{-1} corresponds to the imidazole NH. The ^1H NMR spectrum of compound **3b** has shown a singlet at down field δ11.81(s,1H,NH) and δ11.31(s, 1H, NH) integrating for single proton each due to deshielded indole NH and asinglet at δ10.6(s,1H,NH)integrated for a single protonis due to the imidazole NH, which are D_2O exchangeable. A multiplet from δ 7.10-8.30 (m, 12H, Ar-H)integrating for twelve aromatic protons. The ^{13}C NMR Spectrum of **3b** has shown peaks at δ 151 ,149, 147, 142, 141, 134, 133, 132,131,127,124,119 and 106 integrated for different carbon atoms in the molecule. The most deshielded carbon appeared at δ 151 is due to imidazole ring carbon (C_2) flanked between two nitrogens.The peak at δ 149 is due the indole carbon attached to–NH. Peak at δ147 is due to carbon flanked between indole–NH and imidazole nitrogen. Peak at δ142 is due to 2,5-disubstituted indole carbon attached to–NH.

Biological activity

All the final synthesized derivatives were taken for preliminary screening to evaluate antibacterial activity by cup plate method, in the nutrient agar medium against two gram positive and two gram-negative bacterial strains at concentration of 1000µg/ml. The zone of inhibition (mm) of each derivative was ascertained and compared with Ciprofloxacin taken as standard drug for anti-bacterial activity. DMSO was used to prepare stock solutions of test compounds. The findings of antibacterial evaluation revealed that most of the compounds have variable activity against bacterial strains. Compounds **3b,3e and 3h** are the active compounds which present excellent activity against the bacteria in comparison to

standard drug Ciproflaxcin .**3e** is found to exhibit excellent activity against bacterial strains. All the final compounds were examined for antifungal activity using cup plate method, in the agar medium against two pathogenic fungal strains . The area of inhibition (mm) of each derivative was ascertained and compared with Amphotericin B standard drug. The compounds **3b,3e and 3h** were found active compounds against the fungal strains used. All the synthesized products were found to be active against A. fumigatus than A. Niger. However none of the compounds exhibited zone of inhibition more than that of standard.

Conclusion

ZrO_2nanoparticles have been synthesized and a novel synthetic route has been developed for the condensation reaction of isatin derivatives with ammonium acetate and substituted indole-3-carboxaldehyde using ZrO_2nanoparticles under ethanol conditions to yield compound comprising fused two to three heterocycles.. The yields of the products obtained were up to 93% at 110°C. The advantage of the proposed method is its facile reaction conditions; the product can be isolated very easily without the use of column chromatography and the catalyst can be recycled. The obtained catalyst is expected to contribute to the development of environmentally benign methods and forms a part of nanomaterial chemistry.

Refrences

1. Kerru N, Bhaskaruni SV, Gummidi L, et al. Recent advances in heterogeneous catalysts for the synthesis of imidazole derivatives. Synthetic Commun. 2019;49(19):2437-2459.

2. Alghamdi, S.S.; Suliman, R.S.; Almutairi, K.; Kahtani, K.; Aljatli, D. Imidazole as a Promising Medicinal Scaffold: Current Status and Future Direction. Drug Des. Devel Ther. **2021**, 15, 3289–3312. [CrossRef

3. Reyes-Arellano A, Gómez-García O, Torres-Jaramillo J (2016) Synthesis of azolines and imidazoles and their use in drug design. Med Chem (Los Angeles) 6:561–570

4. Verma A, Joshi S, Singh D (2013) Imidazole: having versatile biological activities. New J Chem. https://doi.org/10.1155/2013/329412

5. Srestha N, Banerjee J, Srivastava S (2014) A review on chemistry and biological significance of benzimidazole nucleus. IOSR J Pharm 4(12):28–41

6. Romero DH, Heredia VET, García-Barradas O, López MEM, Pavón ES (2014) Synthesis of imidazole derivatives and their biological activities. J Chem Biochem 2(2):45–83

7. Anand K, Wakode S (2017) Development of drugs based on benzimidazole heterocycle: recent advancement and insights. J Chem Biol 5(2):350–362

8. Verma BK, Kapoor S, Kumar U, Pandey S, Arya P (2017) Synthesis of new imidazole derivatives as effective antimicrobial agents. Indian J Pharm Biol Res 5(01):1–9

9. Kumar M, Kumar D, Raj V (2017) Studies on Imidazole and its derivatives with particular emphasis on their chemical/biological applications as bioactive molecules/intermediated to bioactive molecule. Curr Synth Syst Biol 5(01):1–10

10. Sharma GK, Pathak D (2010) Microwave-assisted, solvent-free and parallel synthesis of some novel substituted imidazoles of biological interest. Chem Pharm Bull 58(3):375–380

11. Bhade MW, Rajput PR (2016) Design and synthesis of some imidazole derivatives containing 4-(3, 5-dichloro-2-hydroxyphenyl) imidazole moiety as antibacterial agents. Int J Appl Pure Sci Agric 2(11):80–84

12. Salman AS, Abdel-Aziem A, Alkubbat MJ (2015) Design, synthesis of some new thio-substituted imidazole and their biological activity. Am J Org Chem 5:57–72

13. Behmaram B, Foroughifar N, Foroughifar N, Hallajian S (2017) Synthesis of some derivatives of 4-phenyl-1, 3-dihydro-2H-imidazole-2-thion using ionic liquid as catalyst and evaluation of their antimicrobial activity. Int J Chem 9(2):45–51

14.Katikireddy R, Kakkerla R, Krishna MM, Durgaiah G, Reddy YN, Satyanarayana M (2019) Synthesis and biological evaluation of (E)-N'-benzylidene7-methyl-2-propyl-1H-benzo [d] imidazole-5-carbohydrazides as antioxidant, anti-inflammatory and analgesic agents. Heterocycl Commun 25(1):27–38

15. Banerjee *et al*., World J Pharm Sci 2015; 3(8): 1668-1681

16.Grunes J, Zhu J, Somorjai GA. Catalysis and nanoscience. Chemical Communications. 2003;**18**:2257-2260

17. Reetz MT, Westermann E. Phosphane-free palladium-catalyzed coupling reactions: The decisive role of Pd nanoparticles. Angewandte Chemie, International Edition. 2000;**39**:165-168

18.Ramarao C, Ley SV, Smith SC, Shirley IM, DeAlmeida N. Encapsulation of palladium inpolyurea microcapsules. Chemical Communications. 2002:1132-1133

19. Liu G, Lin Y. Electrochemical sensor for organophosphate pesticides and nerve agents using zirconia nanoparticles as selective sorbents. Analytical Chemistry. 2005;**77**:5894-5901

20. Liu S, Han MY. Silica-coated metal nanoparticles. Chemistry - An Asian Journal. 2010;**5**:36-45

21.Lu J, Zang J, Shan S, Huang H, Wang Y. Synthesis and characterization of core− shell structural MWNT− zirconia nanocomposites. Nano Letters. 2008;**8**:4070-4074

22.Sholklapper TZ, Radmilovic V, Jacobson CP, Isco SJ, De Jonghe LC. Synthesis and stability of a nanoparticle-infiltrated solid oxide fuel cell electrode. Electrochemical and Solid-State Letters. 2007;**10**:B74-B76

23.Luo X, Morrin A, Killard AJ, Smyth MR. Application of nanoparticles in electrochemical sensors and biosensors. Electroanalysis. 2006;**18**:319-326

24.Steiner SA, Baumann TF, Bayer BC, Blume R, Worsley MA, MoberlyChan WJ, et al. Nanoscale zirconia as a nonmetallic catalyst for graphitization of carbon and growth of single-and multiwall carbon nanotubes. Journal of the American Chemical Society. 2009;**131**:12144-12154

25. Yamaguchi T, Tanabe K, Kung YC. Preparation and characterization of ZrO2 and SO42−-promoted ZrO2. Materials Chemistry and Physics. 1987;**16**:67-77

26. Yamaguchi T. Application of ZrO2 as a catalyst and a catalyst support. Catalysis Today. 1994;**20**:199-217

27. Asakura K, Aoki M, Iwasawa Y. Selective isopentane formation from CH3OH on a new one-atomic layer ZrO2/ZSM-5 hybrid catalyst. Catalysis Letters. 1988;**1**:395-403

28. Li W, Liu H, Iglesia E. Structures and properties of zirconia-supported ruthenium oxide catalysts for the selective oxidation of methanol to methyl formate. The Journal of Physical Chemistry B. 2006;**110**:23337-23342

29. He D, Ding Y, Luo H, Li C. Effects of zirconia phase on the synthesis of higher alcohols over zirconia and modified zirconia. Journal of Molecular Catalysis A: Chemical. 2004;**208**:267-271

30. Mercera PDL, Ommen VJG, Doesburg EBM, Burggraat AJ, Ross JRH. Zirconia as a support for catalysts: Evolution of the texture and structure on calcination in air. Applied Catalysis. 1990;**57**:127-148.

31Sundaram Singh and Shivam Bajpai Eco-Friendly and Facile Synthesis of Substituted Imidazoles via Nano Zirconia Catalyzed One-Pot Multicomponent Reaction of Isatin Derivatives with Ammonium Acetate and Substituted Aromatic Aldehydes under Solvent Free Conditions.DOI: http://dx.doi.org/10.5772/intechopen.82720

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