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Research Article

Imidazole: Having Versatile Biological Activities

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Imidazoles have occupied a unique position in heterocyclic chemistry, and its derivatives have attracted considerable interests in recent years for their versatile properties in chemistry and pharmacology. Imidazole is nitrogen-containing heterocyclic ring which possesses biological and pharmaceutical importance. Thus, imidazole compounds have been an interesting source for researchers for more than a century. The imidazole ring is a constituent of several important natural products, including purine, histamine, histidine, and nucleic acid. Being a polar and ionisable aromatic compound, it improves pharmacokinetic characteristics of lead molecules and thus is used as a remedy to optimize solubility and bioavailability parameters of proposed poorly soluble lead molecules. There are several methods used for the synthesis of imidazole-containing compounds, and also their various structure reactions offer enormous scope in the field of medicinal chemistry. The imidazole derivatives possess extensive spectrum of biological activities such as antibacterial, anticancer, antitubercular, antifungal, analgesic, and anti-HIV activities. This paper aims to review the biological activities of imidazole during the past years.

1. Introduction

Imidazole nucleus forms the main structure of some well-known components of human organisms, that is, the amino acid histidine, Vit-B12, a component of DNA base structure and purines, histamine, and biotin. It is also present in the structure of many natural or synthetic drug molecules, that is, cimetidine, azomycin, and metronidazole. Imidazole-containing drugs have a broaden scope in remedying various dispositions in clinical medicine [1]. Imidazole was first synthesized by Heinrich Debus in 1858, but various imidazole derivatives had been discovered as early as the 1840s. His synthesis used glyoxal and formaldehyde in ammonia to form imidazole [2]. This synthesis, while producing relatively low yields, is still used for creating C-substituted imidazoles (see Scheme 1).

Imidazole is a 5-membered planar ring, which is soluble in water and other polar solvents. It exists in two equivalent tautomeric forms because the hydrogen atom can be located on either of the two nitrogen atoms. Imidazole is a highly polar compound, as evidenced by a calculated dipole of 3.61D, and is entirely soluble in water. Imidazole is amphoteric; that is, it can function as both an acid and a base. The compound is classified as aromatic due to the presence of a sextet of π-electrons, consisting of a pair of electrons from the protonated nitrogen atom and one from each of the remaining four atoms of the ring.

Some resonance structures of imidazole are shown in Scheme 2.

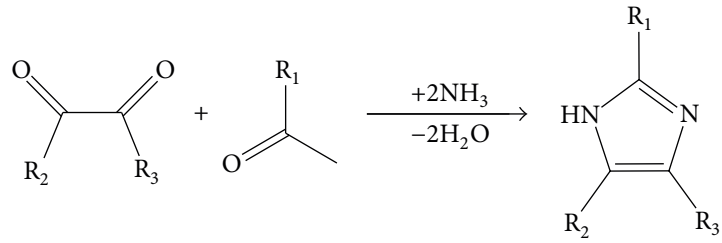
Medicinal chemistry concerns with the discovery, development, interpretation, and identification of the mechanism of action of biologically active compounds at the molecular level [3].

2. Pharmacological Activities

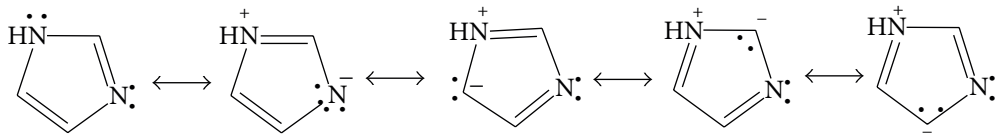
Imidazoles are well-known heterocyclic compounds which are common and have an important feature of a variety of medicinal agents. On the basis of various literature surveys, imidazole derivatives show various pharmacological activities:

(i) antibacterial activity;

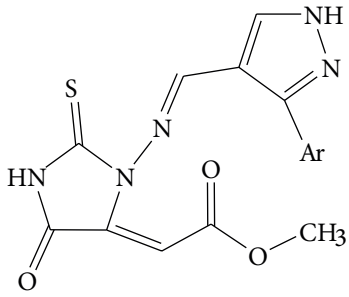
(ii) anticancer activity;



Scheme 1

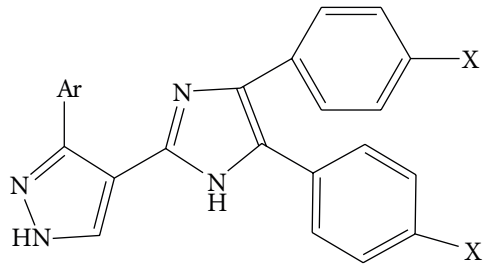


Scheme 2



1a–d

1a	2,4-Dichlorophenyl
1b	2,5-Dichlorothiophene
1c	4-SCH_3-C_6H_4
1d	4-CH_3-C_6H_4



2a–j

	Ar	X
2a	4-SCH_3-C_6H_4	H
2b	2,4-Dichlorophenyl	H
2c	Biphenyl	H
2d	4-CH_3-C_6H_4	H
2e	2,5-Dichlorothiophene	H
2f	4-SCH_3-C_6H_4	Br
2g	2,4-Dichlorophenyl	Br
2h	Biphenyl	Br
2i	4-CH_3-C_6H_4	Br
2j	2,5-Dichlorothiophene	Br

Scheme 3

(iii) antitubercular activity;

(iv) antifungal;

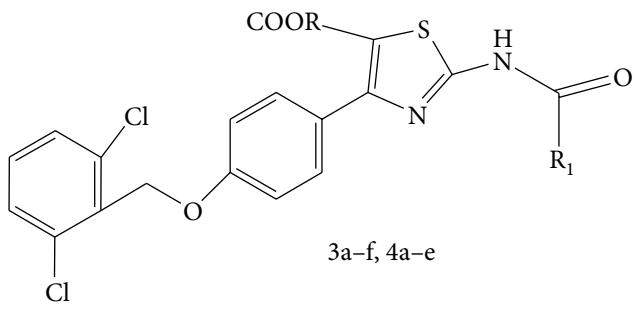
(v) analgesic activity;

(vi) anti-HIV activity.

3. Antibacterial Activity

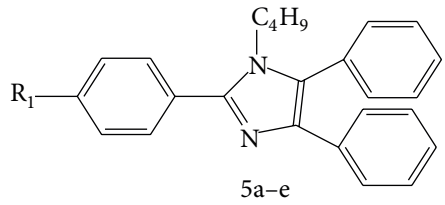
Vijesh et al. carried out the *in vitro* antibacterial activity of newly synthesized compounds 1a–d and 2a–j. *Escherichia coli, Staphylococcus aureus, Bacillus subtilis, Salmonella typhimvrium*, *Clostridium perfringens*, and *Pseudomonas aeruginosa* were used to investigate the activity. The antibacterial screening revealed that some of the tested compounds showed good inhibition against various tested microbial strains. 1c showed excellent activity against *P. aeruginosa* and *C. perfringens* compared to standard drug streptomycin [4] (see Scheme 3).

A series of substituted 4-(2,6-dichlorobenzyloxy)phenyl thiazole, oxazole, and imidazole derivatives (3a–f, 4a–e) were synthesized by Lu et al. The derivatives were screened for *in vitro* antibacterial activity against *S. aureus, E. coli, S. pneumonia*, and penicillin-*resistant S. pneumonia* [5] (see Scheme 4).



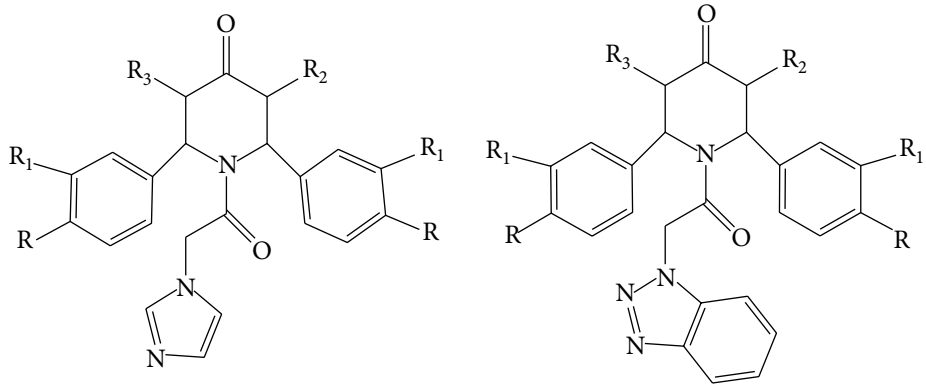
	R	R_1
3a	Et	Ph
4a	H	Ph
3b	Et	4-Cl-Ph
4b	H	4-Cl-Ph
3c	Et	2,4-Cl-Ph
4c	H	2,4-Cl-Ph
3d	Et	4-CH_3O-Ph
4d	H	4-CH_3O-Ph
3e	Et	*n*-Pr
4e	H	*n*-Pr
3f	Et	Ethylene

Scheme 4



5a-*p*-NO_2
5b-*m*-NO_2
5c-*p*-Cl
5d-*o*-Cl
5e-*m*-Br

Scheme 5

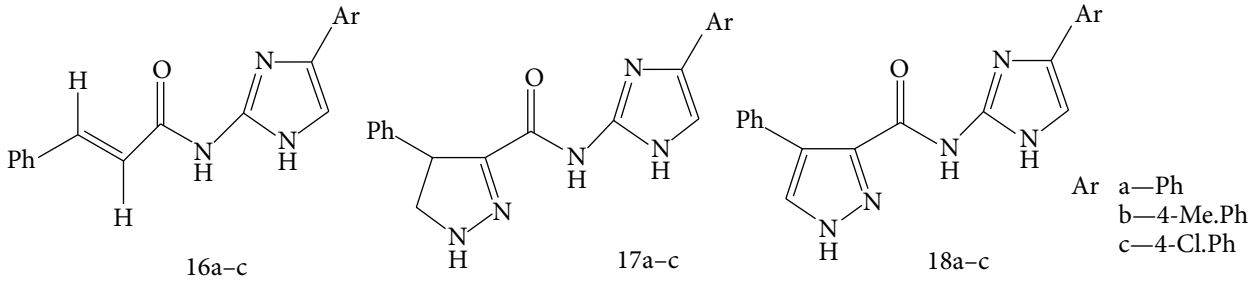


Compounds	R	R_1	R_2	R_3
6	H	H	CH_3	H
7	H	H	CH_3	H
8	H	H	$CH(CH_3)_2$	H
9	H	H	CH_3	CH_3
10	F	H	CH_3	CH_3
11	H	OCH_3	CH_3	CH_3
12	F	H	CH_3	CH_3
13	H	F	CH_3	CH_3
14	H	OCH_3	CH_3	CH_3
15	H	F	CH_2CH_3	H

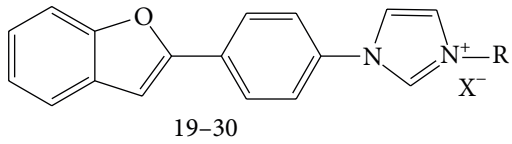
Scheme 6

Jain et al. synthesize 2-substituted-4,5-diphenyl-N-alkyl imidazole derivatives. and evaluate their antibacterial activity. All the synthesized compounds were evaluated for antibacterial activity against *S. aureus, B. subtilis*, and *E. coli.* Out of 5a–e only 5a and 5b showed some short of activity but none of them had considerable activity compared with that of the standard [6] (see Scheme 5).

Ramachandran et al. synthesized imidazole/benzotriazole substituted piperidin-4-one derivatives. Compounds 6–15 were screened for their *in vitro* antibacterial activity against *Staphylococcus aureus, Bacillus subtilis, Salmonella typhi, Escherichia coli*, and *Klebsiella pneumonia*. Among the compounds, 7 and 10 against *B. subtilis*, 9 against *S. aureus*, 8 and 13 against *K. pneumonia*, and 15 against *E. coli* did not

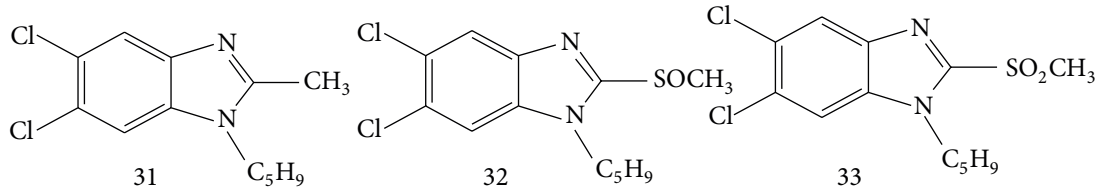


Scheme 7

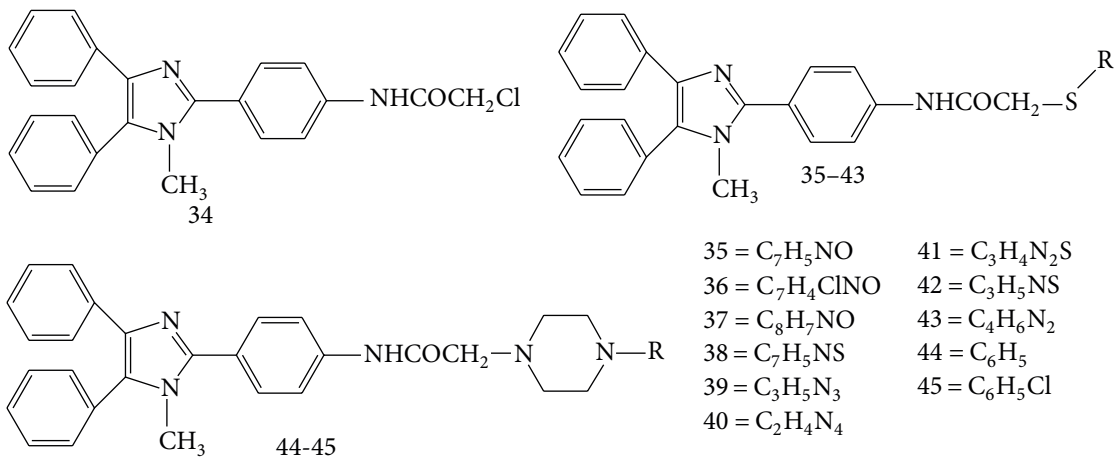


	R	X		R	X
19	—	—	25	4-Hydroxyphenacyl	Br
20	Benzyl	Br	26	4-Methoxyphenacyl	Br
21	2-Bromobenzyl	Br	27	4-Fluorophenacyl	Br
22	Allyl	Br	28	4-Bromophenacyl	Br
23	Butyl	I	29	Naphthylacyl	Br
24	Phenacyl	Br	30	2^1-Phenyl-phenacyl	Br

Scheme 8



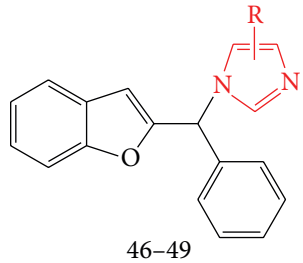
Scheme 9



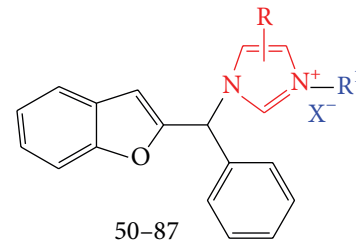
Scheme 10

show any inhibitory activity even at maximum concentration. However, piperidine ring containing compounds 8 against *B. subtilis* and 9 against *E. coli* explored good inhibitory activity. Compound 13 increased the growth inhibition activity against *E. coli*. And compound 15 showed superior inhibition activity against *B. subtilis* [7] (see Scheme 6).

Padmavathi et al. synthesized amido linked imidazoles derivatives and screened antibacterial activity; it was seen that 16c and 18c were more effective against *Pseudomonas aeruginosa*. Amongst bis heterocyclic compounds, the aromatized bis heterocycle 18 was effective than the corresponding nonaromatized compound 17. The compounds 16c and 18c



46–49



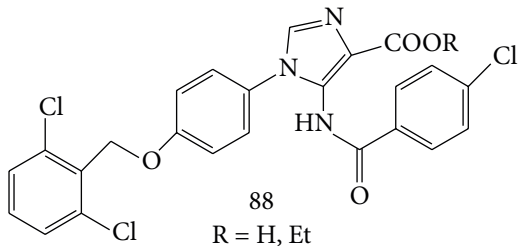
50–87

Imidazole ring
46—imidazole
47—2-methyl-imidazole
48—2-ethyl-imidazole
49—benzimidazole

Imidazole ring
50-59—imidazole
60-68—2-methyl-imidazole
69-77—2-ethyl-imidazole
78-87—benzimidazole

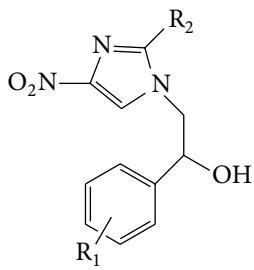
Compounds	R^1	X
50,60,69,78	Propane	Br
51,61,70,79	Butane	I
52,62,71,80	Toluene	Br
53,81	1-Methyl-4-nitro benzene	Br
54,63,72,82	Phenacyl	Br
55,64,73,83	4-Fluorophenacyl	Br
56,65,74,84	4-Bromophenacyl	Br
57,66,75,85	4-Hydroxyphenacyl	Br
58,67,76,86	4-Methoxyphenacyl	Br
59,68,77,87	Napthacyl	Br

Scheme 11



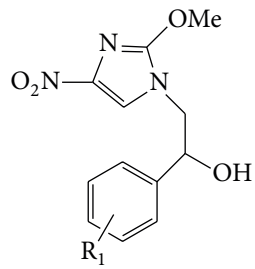
88
R = H, Et

Scheme 12



89a–h

	R_1	R_2
89a	2,4-Dichloro	H
89b	2,4-Dichloro	Br
89c	2,4-Dichloro	Br
89d	4-F	Br
89e	4-Cl	Br
89f	4-NO_2	Br
89g	H	Br
89g	2,4-Dimethyl	Br



90a–h

	R_1
90a	2,4-Dichloro
90b	2,4-Difluoro
90c	4-F
90d	4-Cl
90e	4-NO_2
90f	4-Phenyl
90g	H
90h	2,4-Dimethyl

Scheme 13

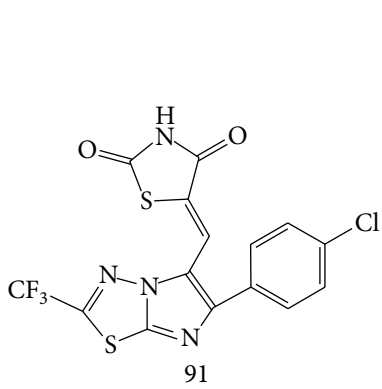
displayed excellent activity particularly against *P. chrysogenum*, almost equivalent to the standard drug Ketoconazole. Amongst the tested compounds, chlorosubstituted imidazolyl cinnamamide 16c showed strong antibacterial activity against *B. subtilis* [8] (see Scheme 7).

4. Anticancer Activities

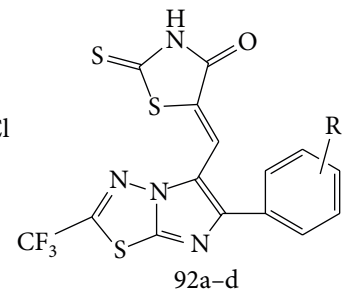
Yang et al. synthesised series of novel hybrid compounds between 2-phenylbenzofuran and imidazole have been prepared and results suggest that substitution of the imidazolyl-3-position with a naphthylacyl or bromophenacyl group, was vital for modulating cytotoxic activity. Compound 21 was the most active compound which displayed similar cytotoxic activity *in vitro* compared with DDP. Compared with alkyl substituent imidazolium salt derivatives 20–23, hybrid compounds 24–30 with phenacyl substituent at position-3 of imidazole ring exhibited higher cytotoxic activity. Compounds 28, 29, and 30 displayed similar cytotoxic activity *in vitro* compared with DDP [9] (see Scheme 8).

Alkahtani et al. synthesized and evaluated benzo[d] imidazole derivatives as potential anticancer agents. 5,6-Dichloro-1-cyclopentyl-1H-benzo[d]imidazoles 31, 32, and 33 possessed potent antiproliferative activity in cancer cell lines [10] (see Scheme 9).

Ozkay et al. synthesized 2-substituted-N-[4-(1-methyl-4,5-diphenyl-1H-imidazole-2-yl)phenyl] acetamide derivatives and evaluated anticancer activity. The 35, 38, 39, 40, and 41 are the most cytotoxic compounds in the series. Cytotoxicity of the 43 was lower than that of the 34. The compounds 36, 37, and 42 showed approximate cytotoxic activity to the 34. Compounds 44 and 45 revealed greater cytotoxic activity than the 34. However, when concentrations were raised, cytotoxic activity of the 34 increased significantly

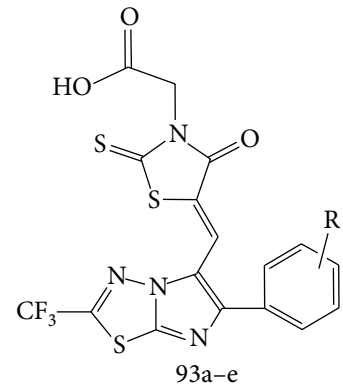


91



92a–d

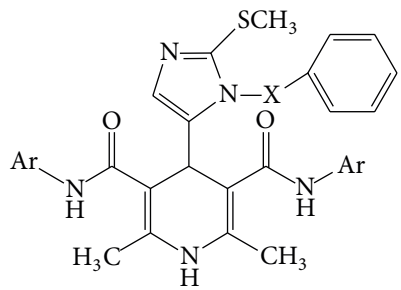
R = 92a-H
92b-Br
92c-F
92d-CH_3



93a–e

R = 93a-Cl
93b-Br
93c-F
93d-CH_3
93e-OCH_3

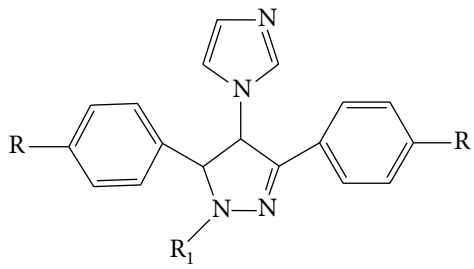
Scheme 14



94a–j

	Ar	X
94a	2-Chlorophenyl	NH
94b	3-Chlorophenyl	NH
94c	4-Chlorophenyl	NH
94d	4-Bromophenyl	NH
94e	2-Pyridyl	NH
94f	3-Pyridyl	NH
94g	2-Chlorophenyl	NH
94h	3-Chlorophenyl	NH
94i	4-Chlorophenyl	NH
94j	3-Pyridyl	NH

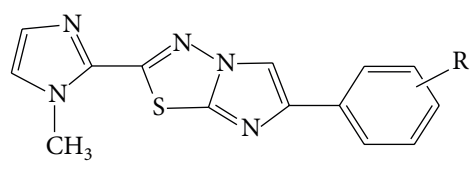
Scheme 15



95a–t

R	R_1	R	R_1
95a—H	H	95k—H	Ph
95b—Br	H	95l—Br	Ph
95c—Cl	H	95m—Cl	Ph
95d—2,4-$(Cl)_2$	H	95n—2,4-$(Cl)_2$	Ph
95e—CH_3	H	95o—CH_3	Ph
95f—H	CH_3	95p—H	4-F-Ph
95g—Br	CH_3	95q—Br	4-F-Ph
95h—Cl	CH_3	95r—Cl	4-F-Ph
95i—2,4-$(Cl)_2$	CH_3	95s—2,4-$(Cl)_2$	4-F-Ph
95j—CH_3	CH_3	95t—CH_3	4-F-Ph

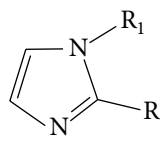
Scheme 16



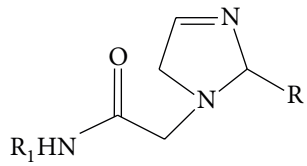
96a–f

	R
96a	3-Nitro
96b	4-Bromo
96c	4-Chloro
96d	4-Fluoro
96e	4-Nitro
96f	2,4-Dichloro

Scheme 17



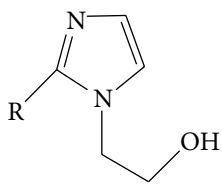
97–99



100–103

97: R = H, R_1 = 3,4-dichlorobenzyl
98: R = H, R_1 = CH_2COOEt
99: R = H, R_1 = CH_2CH_2COOEt

100: R = H, R_1 = *n*-butyl
101: R = H, R_1 = *n*-hexyl
102: R = H, R_1 = *n*-heptyl
103: R = H, R_1 = benzyl



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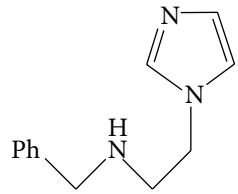

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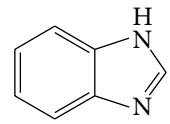
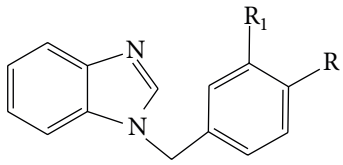
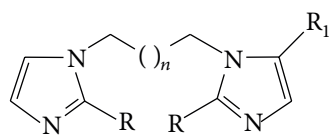


106



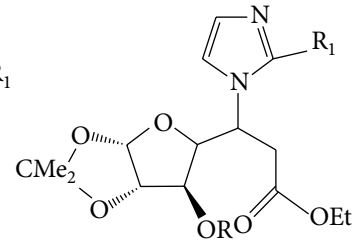
107-108

107: R = R_1 = H
108: R = R_1 = Cl



109–112

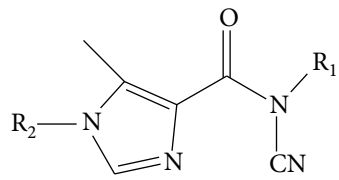
109: *n* = 1, R = R_1 = H
110: *n* = 3, R = R_1 = H
111: *n* = 1, R = propyl, R_1 = H
112: *n* = 1, R = propyl, R_1 = allyl



113–116

113: R = CH_3; R_1 = H,
114: R = CH_2Ph; R_1 = H,
115: R = CH_3; R_1 = propyl,
116: R = CH_2Ph; R_1 = propyl

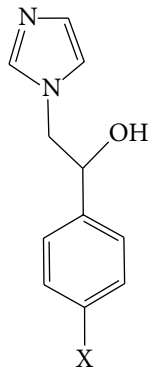
Scheme 18



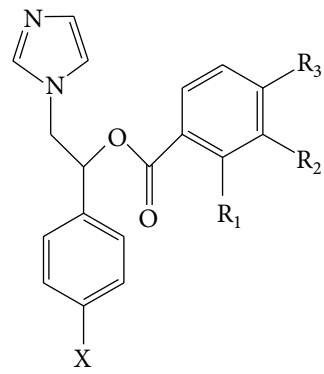
117a–p

R_1	R_2		
117a—$C_6H_5CH_2$	$C_6H_5CH_2$	117i—2-COOMe-$C_6H_5CH_2$	4-F-$C_6H_5CH_2$
117b—2-F-$C_6H_5CH_2$	$CH_3CH_2CH_2CH_2$	117j—4-F-$C_6H_5CH_2$	4-F-$C_6H_5CH_2$
117c—2-F-$C_6H_5CH_2$	4-CH_3-$C_6H_5CH_2$	117k—4-CH_3-$C_6H_5CH_2$	4-CH_3-$C_6H_5CH_2$
117d—2-F-$C_6H_5CH_2$	3-NO_2-$C_6H_5CH_2$	117l—$C_6H_5CH_2$	4-F-$C_6H_5CH_2$
117e—4-F-$C_6H_5CH_2$	4-CH_3-$C_6H_5CH_2$	117m—$CH_3CH_2CH_2CH_2$	$CH_3CH_2CH_2CH_2$
117f—$C_6H_5CH_2CH_2CH_2$	4-CH_3-$C_6H_5CH_2$	117n—$C_6H_5CH_2$	$CH_3CH_2CH_2CH_2$
117g—2-Cl-$C_6H_5CH_2$	4-CH_3-$C_6H_5CH_2$	117o—$C_6H_5CH_2$	4-CH_3-$C_6H_5CH_2$
117h—2,4-F2-C $_6H_5CH_2$	4-F-$C_6H_5CH_2$	117p—4-F-$C_6H_5CH_2$	3-NO_2-$C_6H_5CH_2$

Scheme 19



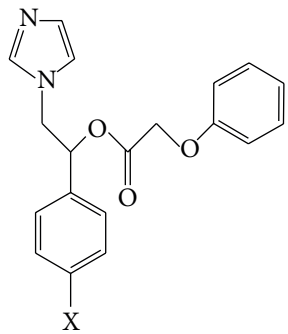
118a–c



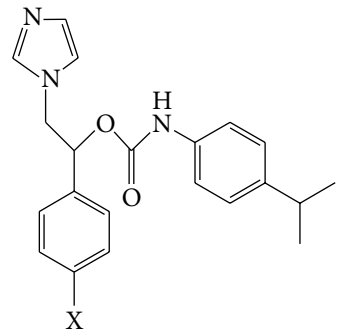
119a–d, 120a, 121a–c

X = H, F, Cl

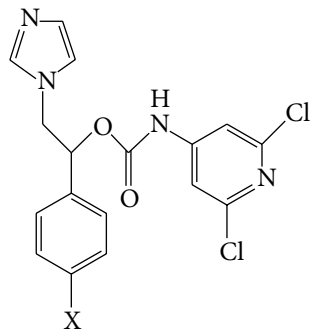
119a—$R_1 = R_3 = H$, $R_2 = CF_3$, X = H
119b—$R_1 = R_3 = H$, $R_2 = CF_3$, X = F
119c—$R_1 = R_3 = H$, $R_2 = CF_3$, X = Cl
119d—$R_1 = R_3 = H$, $R_2 = CF_3$, X = CF_3



122b-c

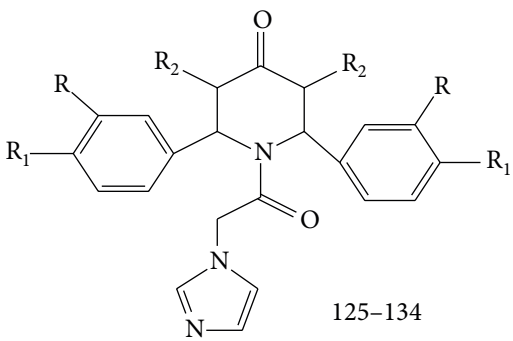


123a–c



124c

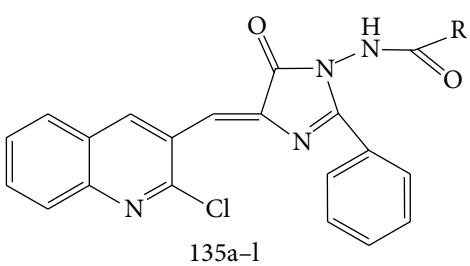
Scheme 20



125–134

	R	R_1	R_2	R_3
125	H	H	CH_3	H
126	H	H	CH_2CH_3	H
127	H	H	$CH(CH_3)_2$	H
128	H	H	CH_3	CH_3
129	F	H	CH_3	CH_3
130	H	OCH_3	CH_3	CH_3
131	F	H	CH_3	CH_3
132	H	F	CH_3	CH_3
133	H	OCH_3	CH_3	CH_3
134	H	F	CH_2CH_3	H

Scheme 21

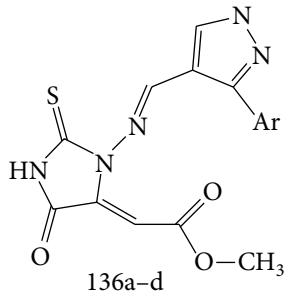


135a–l

-R

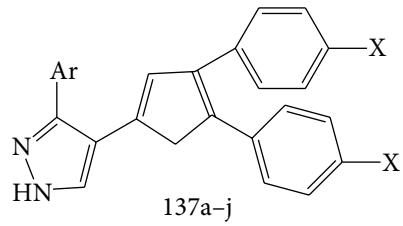
135a	$-C_6H_5$
135b	C_6H_5-CH_2
135c	-3-Cl-C_6H_4
135d	-4-Cl-C_6H_4
135e	-2,5-$(Cl)_2$-C_6H_3
135f	-4-F-C_6H_4
135g	-3-NO_2-C_6H_4
135h	-4-NO_2-C_6H_4
135i	-2-OH-C_6H_4
135j	-3-OH-C_6H_4
135k	-2-OH-4-Cl-C_6H_3
135l	$-C_5H_4N$

Scheme 22



136a–d

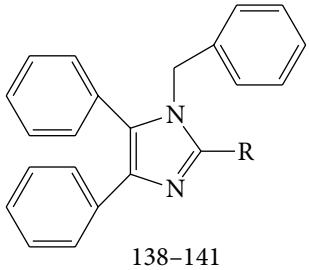
136a	2,4-Dichlorophenyl
136b	2,5-Dichlorothiophene
136c	4-SCH_3-C_6H_4
136d	4-CH_3-C_6H_4



137a–j

	Ar	X
137a	4-SCH_3-C_6H_4	H
137b	2,4-Dichlorophenyl	H
137c	Biphenyl	H
137d	4-CH_3-C_6H_4	H
137e	2,5-Dichlorothiophene	H
137f	4-SCH_3-C_6H_4	Br
137g	2,4-Dichlorophenyl	Br
137h	Biphenyl	Br
137i	4-CH_3-C_6H_4	Br
137j	2,5-Dichlorothiophene	Br

Scheme 23



138–141

R = 138-Ph-*o*-Br.
139-Ph-M-OCH_3, *p*-OH
140-Ph-*o*-OH.
141-Ph-*o*-NO_2

Scheme 24

and seemed as higher than those of the 44 and 45 [11] (see Scheme 10).

Wang et al. evaluated the cytotoxic potential of all newly synthesized hybrid compounds. 2-Benzylbenzofurane imidazole hybrids 47–49 lacked activities against all tumor cell lines. In terms of the imidazole ring (imidazole, 2-methyl-imidazole or 2-ethyl-imidazole, and benzimidazole), imidazolium salt hybrids 50–59 with imidazole ring displayed weak cytotoxic activities. Only compounds 55 and 58 showed medium cytotoxic activities, and compound 59 with a naphthylacyl substituent at position-3 of the imidazole ring displayed higher cytotoxic activity *in vitro*. Imidazolium salt hybrids 60–68 with 2-methyl-imidazole ring and 69–77 with 2-ethyl-imidazole ring exhibited medium cytotoxic activities. However, imidazolium salt hybrids 78–87 with benzimidazole ring exhibited powerful cytotoxic activities. Among them, compounds 86 and 87 showed potent cytotoxic activities [12] (see Scheme 11).

5. Antitubercular Activity

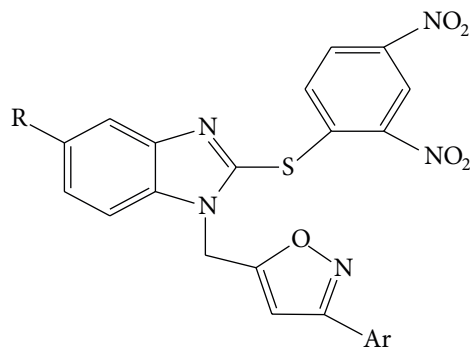
Lu et al. synthesised a series of substituted 4-(2,6-dichlorobenzyloxy)phenyl thiazole, oxazole and imidazole derivatives. The derivatives were screened for *in vitro* antitubercular activities against *Mycobacterium tuberculosis* H37Rv [13] (see Scheme 12).

Lee et al. synthesised monocyclic nitroimidazole derivatives, and the antitubercular activity of the synthesized compounds against Mtb H37Rv was determined by the microdilution Alamar blue assay. Compounds 89a, 89b, and 89d were moderately active. In case of 90a, 90d, 90e, and 90g, the activity was increased 4-fold, compared with 89b, 89e, 89f, and 89g, respectively. While 90c and 90h were 8-fold more active than 89d and 89h, respectively, 90b was 16-fold more active than 90c [14] (see Scheme 13).

Alegaon et al. synthesized imidazo[2,1-b][1, 3, 4]thiadiazole derivatives, and the antitubercular activities have been assessed against *M. tuberculosis* H37Rv (ATCC 27294) and found that compounds (91, 92a, 92b, 92c, 92d, 93a, 93b, 93c, 93d, and 93e) are active against *M. tuberculosis* [15] (see Scheme 14).

According to Fassihi et al. a series of 4-substituted imidazolyl-2,6-dimethyl-N3,N5-bisaryl-1,4-dihydropyridine-3,5-dicarboxamides (94a–j) were prepared and tested *in vitro* against *M. tuberculosis* H37RV strain ATCC 27294 which is susceptible to rifampicin and isoniazid [16] (see Scheme 15).

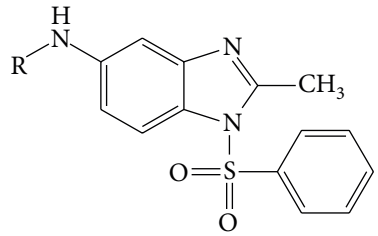
According to Zampieri et al. a series of 1-(3,5-diaryl-4,5-dihydro-1H-pyrazol-4-yl)-1H-imidazole and 1-[(1-aralkyl)-3,5-diaryl-4,5-dihydro-1H-pyrazol-4-yl]-1H-imidazole derivatives were synthesized and evaluated for antimycobacterial activities. Compounds 95a–t were tested against a strain of



142a–1

Compounds	R	Ar
a	H	4-$OCH_3C_6H_4$
b	H	4-FC_6H_4
c	H	4-CNC_6H_4
d	Br	4-$OCH_3C_6H_4$
e	Br	4-FC_6H_4
f	Br	4-CNC_6H_4
g	OCH_3	4-$OCH_3C_6H_4$
h	OCH_3	4-FC_6H_4
i	OCH_3	4-CNC_6H_4
j	NO_2	4-$OCH_3C_6H_4$
k	NO_2	4-FC_6H_4
l	NO_2	4-CNC_6H_4

Scheme 25



143a–c

R
a = *p*-$NH_2C_6H_4$
b = *o*-$NH_2C_6H_4$
c = *p*-$NH_2C_7H_6$

Scheme 26

M. tuberculosis H37Rv and showed a good antimycobacterial activity [17] (see Scheme 16).

Imidazo[2,1-b][1, 3, 4]thiadiazole derivatives were synthesised by Patel et al. and evaluated for *in vitro* antitubercular activity against *M. tuberculosis* strain H37Rv. Among the imidazo[2,1-b][1, 3, 4]thiadiazole series the compounds 96a–f exhibited significant antitubercular activities but not as good as that of the nitro phenyl substituent 96e [18] (see Scheme 17).

Pandey et al. synthesized and screened a series of imidazole-based compounds (97–116) for their antitubercular efficacy against *M. tuberculosis* [19] (see Scheme 18).

6. Antifungal Activities

Yang et al. synthesized various N-cyano-1H-imidazole-4-carboxamides derivatives, and the fungicidal activities were screened against six kinds of fungi, *Fusarium oxysporum, Rhizoctonia solani, Botrytis cinerea Pers, Gibberella zeae, Dothiorella gregaria,* and *Colletotrichum gossypii,* at a concentration of 50 lg/mL. The newly synthesized compounds have good antifungal activity selectively against *Rhizoctonia solani* among the six fungi tested. Particularly, compound 117h was identified as the most promising candidate with an EC50 of 2.63 lg/mL against *R. Solani* [20] (see Scheme 19).

The *in vitro* antifungal activity of imidazole derivatives 118a–c, 119a–d, 120a, 121a–c, 122b-c, 123a–c, and 124c was evaluated by Vita et al. against four strains of *C. albicans* and seven strains of nonalbicans Candida species [21] (see Scheme 20).

Ramachandran et al. synthesised various imidazole derivatives and evaluated fungicidal activity against *A. niger*, *C. neoformans*, Rhizopus sp., *C. albicans*, and *A. flavus* [7] (see Scheme 21).

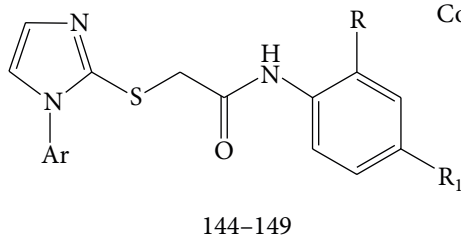
Desai et al. synthesised N-(4-((2-chloroquinolin-3-yl)methylene)-5-oxo-2-phenyl-4,5-dihydro-1H-imidazol-1-yl)(aryl) amides (135a–l). The compounds were tested for antifungal activity in six sets against *C. albicans, Aspergillus niger* and *A. clavatus* at various concentrations. Among these compounds 135c, 135d, 135f, 135h, and 135j showed significant potency against different microbial strains [22] (see Scheme 22).

Vijesh et al. synthesized and screened compounds 136a–d and 137a–j for their antifungal activity against *Aspergillus flavus, Aspergillus niger, Candida albicans, Microsporum gypseum,* and *Trichophyton rubrum.* Among the tested compounds, the compound 136c has emerged as active against *T. rubrum* compared with standard, fluconazole [4] (see Scheme 23).

7. Analgesic Activity

Ucucu et al. reported the synthesis of some 1-benzyl-2-substituted-4,5-diphenyl-1H-imidazole derivatives. Swiss albino mice were used to carry out analgesic activity of both sexes weighing 23–36 g. All derivatives show poor response; only compounds 138 and 139 exhibited a moderate activity, and compounds 140 and 141 ranged not far from morphine [23] (see Scheme 24).

According to Kankala et al. synthesis of isoxazole-mercaptobenzimidazole hybrids and the analgesic activity of the synthesized compounds (142a–l) was assessed by hot plate method. Almost all the compounds have shown very potent analgesic activity when compared with standard drug pentazocine. Amongst all the compounds, 142e and 142f with potent analgesic activity, the compounds 142k and 142l have shown moderate activity and were found to be more potent than the standard pentazocine. The remaining



144–149

Compounds	Ar	R	R_1
144	Naphthalen-1-yl	F	H
145	Naphthalen-1-yl	Cl	H
146	Naphthalen-1-yl	Br	H
147	Naphthalen-1-yl	Br	Me
148	Naphthalen-1-yl	NO_2	H
149	*p*-Tolyl	NO_2	H

Scheme 27

compounds 142a–d and 142g–j had shown poor activity [24] (see Scheme 25).

A series of novel 5-substituted-1-(phenylsulfonyl)-2-methylbenzimidazole derivatives have been synthesized and evaluated for analgesic activity. Derivatives 143a–c exhibited moderate to good analgesic activity [25] (see Scheme 26).

8. Anti-HIV Evaluation

A series of 2-(1-aryl-1H-imidazol-2-ylthio)acetamide [imidazole thioacetanilide (ITA)] derivatives were synthesized and evaluated as potent inhibitors of human immunodeficiency virus type-1 (HIV-1). All of the newly synthesized imidazole thioacetanilides were first evaluated for their anti-HIV activity. The most potent HIV-1 inhibitors were 148 and 145. Other compounds, 146, 147, 149, and 144, also showed higher anti-HIV-1 potency [26] (see Scheme 27).

9. Conclusion

The above study about various imidazole derivatives is the significant class of heterocyclic compounds, showed promising results in most of the pharmacological activities, and also has fascinating results including antibacterial, anticancer, antitubercular, antifungal, analgesic, and anti-HIV activities. It has been noticed so far that modifications on imidazole nucleus displayed promising biological activities. It will be interesting to observe that in the future many new pharmacological profiles will be added to it as it is still unrevealed and can be taken as a lead for future development to get safer and more effective compounds.

Conflicts of Interests

Authors declare that there is no conflict of interests regarding the publication of this article.

References

[1] A. Kleeman, J. Engel, B. Kutscher, and D. Reichert, *Pharmaceutical Substances: Syntheses, Patents, Applications of the Most Relevant APIs*, Thieme Medical, New York, NY, USA, 3rd edition, 1999.

[2] H. Debus, "Ueber die Einwirkung des Ammoniaks auf Glyoxal," *Annalen der Chemie und Pharmacie*, vol. 107, no. 2, pp. 199–208, 1858.

[3] H. Singh and V. K. Kapoor, *Medicinal and Pharmaceutical Chemistry*, vol. 2, Vallabh Prakashan, Delhi, India, 2008.

[4] A. M. Vijesh, A. M. Isloor, S. Telkar, S. K. Peethambar, S. Rai, and N. Isloor, "Synthesis, characterization and antimicrobial studies of some new pyrazole incorporated imidazole derivatives," *European Journal of Medicinal Chemistry*, vol. 46, no. 8, pp. 3531–3536, 2011.

[5] X. Lu, X. Liu, B. Wan et al., "Synthesis and evaluation of anti-tubercular and antibacterial activities of new 4-(2,6-dichlorobenzyloxy)phenyl thiazole, oxazole and imidazole derivatives," *European Journal of Medicinal Chemistry*, vol. 49, pp. 164–171, 2012.

[6] A. K. Jain, V. Ravichandran, M. Sisodiya, and R. K. Agrawal, "Synthesis and antibacterial evaluation of 2-substituted-4,5-diphenyl-N-alkyl imidazole derivatives," *Asian Pacific Journal of Tropical Medicine*, vol. 3, no. 6, pp. 471–474, 2010.

[7] R. Ramachandran, M. Rani, S. Senthan, Y. T. Jeong, and S. Kabilan, "Synthesis, spectral, crystal structure and in vitro antimicrobial evaluation of imidazole/benzotriazole substituted piperidin-4-one derivatives," *European Journal of Medicinal Chemistry*, vol. 46, no. 5, pp. 1926–1934, 2011.

[8] V. Padmavathi, C. P. Kumari, B. C. Venkatesh, and A. Padmaja, "Synthesis and antimicrobial activity of amido linked pyrrolyl and pyrazolyl-oxazoles, thiazoles and imidazoles," *European Journal of Medicinal Chemistry*, vol. 46, no. 11, pp. 5317–5326, 2011.

[9] X. Yang, W. Wan, X. Deng et al., "Design, synthesis and cytotoxic activities of novel hybrid compounds between 2-phenylbenzofuran and imidazole," *Bioorganic and Medicinal Chemistry Letters*, vol. 22, no. 8, pp. 2726–2729, 2012.

[10] H. M. Alkahtani, A. Y. Abbas, and S. Wang, "Synthesis and biological evaluation of benzo[d]imidazole derivatives as potential anti-cancer agents," *Bioorganic and Medicinal Chemistry Letters*, vol. 22, no. 3, pp. 1317–1321, 2012.

[11] Y. Özkay, I. Işikdağ, Z. Incesu, and G. Akalin, "Synthesis of 2-substituted-N-[4-(1-methyl-4,5-diphenyl-1H-imidazole-2-yl) phenyl] acetamide derivatives and evaluation of theiranti-cancer activity," *European Journal of Medicinal Chemistry*, vol. 45, no. 8, pp. 3320–3328, 2010.

[12] X. Wang, L. Liu, Y. Li et al., "Design, synthesis and biological evaluation of novel hybrid compounds of imidazole scaffold-based 2-benzylbenzofuran as potent anticancer agents," *European Journal of Medicinal Chemistry*, vol. 62, pp. 111–121, 2013.

[13] X. Lu, X. Liu, B. Wan et al., "Synthesis and evaluation of anti-tubercular and antibacterial activities of new 4-(2,6-dichlorobenzyloxy)phenyl thiazole, oxazole and imidazole derivatives," *European Journal of Medicinal Chemistry*, vol. 49, pp. 164–171, 2012.

[14] S. Lee, S. Kim, M. Yun et al., "Synthesis and antitubercular activity of monocyclic nitroimidazoles: insights from econazole,"

Bioorganic and Medicinal Chemistry Letters, vol. 21, no. 5, pp. 1515–1518, 2011.

[15] S. G. Alegaon, K. R. Alagawadi, P. V. Sonkusare, S. M. Chaudhary, D. H. Dadwe, and A. S. Shah, "Novel imidazo[2,1-b][1,3,4]thiadiazole carrying rhodanine-3-acetic acid as potential antitubercular agents," *Bioorganic and Medicinal Chemistry Letters*, vol. 22, no. 5, pp. 1917–1921, 2012.

[16] A. Fassihi, Z. Azadpour, N. Delbari et al., "Synthesis and antitubercular activity of novel 4-substituted imidazolyl-2,6-dimethyl-N3,N5-bisaryl-1,4-dihydropyridine-3,5-dicarboxamides," *European Journal of Medicinal Chemistry*, vol. 44, no. 8, pp. 3253–3258, 2009.

[17] D. Zampieri, M. G. Mamolo, E. Laurini, G. Scialino, E. Banfi, and L. Vio, "Antifungal and antimycobacterial activity of 1-(3,5-diaryl-4,5-dihydro-1H-pyrazol-4-yl)-1H-imidazole derivatives," *Bioorganic and Medicinal Chemistry*, vol. 16, no. 8, pp. 4516–4522, 2008.

[18] H. M. Patel, M. N. Noolvi, N. S. Sethi, A. K. Gadad, and S. S. Cameotra, "Synthesis and antimicrobial evaluation of novel 1,3,4-thiadiazole derivatives of 2-(4-formyl-2-methoxyphenoxy) acetic acid," *Arabian Journal of Chemistry*, pp. 1–22, 2013.

[19] J. Pandey, V. K. Tiwari, S. S. Verma et al., "Synthesis and antitubercular screening of imidazole derivatives," *European Journal of Medicinal Chemistry*, vol. 44, no. 8, pp. 3350–3355, 2009.

[20] W. C. Yang, J. Li, J. Li, Q. Chen, and G. F. Yang, "Novel synthetic methods for N-cyano-1H-imidazole-4-carboxamides and their fungicidal activity," *Bioorganic and Medicinal Chemistry Letters*, vol. 22, no. 3, pp. 1455–1458, 2012.

[21] D. de Vita, L. Scipione, S. Tortorella et al., "Synthesis and antifungal activity of a new series of 2-(1H-imidazol-1-yl)-1-phenylethanol derivatives," *European Journal of Medicinal Chemistry*, vol. 49, pp. 334–342, 2012.

[22] N. C. Desai, A. S. Maheta, K. M. Rajpara, V. V. Joshi, H. V. Vaghani, and H. M. Satodiya, "Green synthesis of novel quinoline based imidazole derivatives and evaluation of their antimicrobial activity," *Journal of Saudi Chemical Society*, 2011.

[23] Ü. Uçucu, N. G. Karaburun, and I. Işikdag, "Synthesis and analgesic activity of some 1-benzyl-2-substituted-4,5-diphenyl-1H-imidazole derivatives," *Farmaco*, vol. 56, no. 4, pp. 285–290, 2001.

[24] S. Kankala, R. K. Kankala, G. Prasad et al., "Regioselective synthesis of isoxazole-mercaptobenzimidazole hybrids and their in vivo analgesic and anti-inflammatory activity studies," *Bioorganic & Medicinal Chemistry Letters*, vol. 23, pp. 1306–1309, 2013.

[25] M. Gaba, D. Singh, S. Singh, V. Sharma, and P. Gaba, "Synthesis and pharmacological evaluation of novel 5-substituted-1-(phenylsulfonyl)-2-methylbenzimidazole derivatives as anti-inflammatory and analgesic agents," *European Journal of Medicinal Chemistry*, vol. 45, no. 6, pp. 2245–2249, 2010.

[26] P. Zhan, X. Liu, J. Zhu et al., "Synthesis and biological evaluation of imidazole thioacetanilides as novel non-nucleoside HIV-1 reverse transcriptase inhibitors," *Bioorganic and Medicinal Chemistry*, vol. 17, no. 16, pp. 5775–5781, 2009.