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One pot synthesis of benzimidazole derivatives with antimicrobial evaluation

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This study evaluates the antibacterial and antifungal activity of several novel synthesized title benzimidazoles **S2-e**, **S2-g**, **S2-q**, **S2-o** by coupling 3-amino-N,N-dimethyl-4-(methylamino)benzamide) **S2-c** with methoxy amine, 2-(((2,6-dimethylphenyl)glycyl)oxy)acetic acid **S2-f**, (2-methylbenzaldehyde) **S2-p** and ((4-(5-methyl-1,2,4-oxadiazol-3-yl)phenyl)glycine) **S2-n** in presence of carbonyl diimidazole compounds against various bacterial and fungal strains. The compounds have been synthesized using a cost-effective and less hazardous route. ^{1}H and ^{13}C NMR, and mass spectroscopy have been used to characterize the synthesized compounds. The Minimal Inhibition Concentration (MIC) values for the antibacterial and antifungal assays have been determined for each compound and compared with standard drugs such as Gentamycin, Ampicillin, Nystatin, and Griseofulvin. The results show that compound **S2-f** demonstrates notable antibacterial and antifungal properties, making it a candidate for further medicinal development. Molecular docking of **S2-e** has been performed on the binding site of *Candida albicans* CYP 51 (PDB id: 5TZ1).

Keywords: Benzimidazole, MIC, Antimicrobial activity, Molecular docking, Heterocyclic synthesis

According to their structural resemblance, benzimidazole and purine-based nucleic acids are isostere isomers of each other. It has been projected as an important moiety in pharmaceutical studies to show a wide range of pharmaceutical activities, and hence to synthesize its derivatives has become a part of interest for organic and medicinal chemists[1-3]. Looking towards their medicinal aspects, we synthesized new benzimidazole derivatives, and their impact would be advantageous when examining their antibacterial and antifungal properties. In the last few years, a variety of benzimidazole-based derivatives have been discovered. Some of them are mentioned in Fig. 1 along with their natural biological activities. As a result, both the synthetic organic druggist and biologists are concentrating their exploration study on the conflation of benzimidazoles[4,5].

The development of the benzimidazole core has surfaced over recent times as benzimidazole derivatives are bioactive substances, including antihypertensives, anti-inflammatories, antivirals, analgesics, anticancer, proton pump inhibitors, anticonvulsants, antifungals, anticoagulants, antihistaminics, antiparasitics, and antiulcers[6-13]. Also, Benzimidazole derivatives have garnered considerable attention in the medical sector due to their therapeutic properties, demonstrating remarkable efficacy as antimicrobials and antihypertensives[14,15]. Notable examples of drugs featuring a benzimidazole structure include Albendazole (an anthelmintic), Bendamustine (an anticancer agent), Omeprazole (an antiulcer medication), and Astemizole (an antihistamine)[16-18]. They serve as valuable intermediates in the synthesis of numerous biologically active substances, including antibacterial agents[19-23], and antifungal compounds[24-27]. Microbial resistance represents a critical challenge in clinical practice, and a primary focus of contemporary biomedical research is the identification of novel and potent pharmaceuticals capable of addressing multidrug-resistant bacteria. The overuse of antibiotics, coupled with the disinterest of pharmaceutical companies in funding antibiotic development, has rendered the discovery of new classes of antibiotics comprising benzimidazoles[28-30].

Experimental Section

Materials and Methods

All chemicals were purchased from commercial sources (LOBA chem, Spectrochem, Merck, and Sigma-Aldrich). Melting points were determined using the equiptronics model EQ-730 instrument. TLC was carried out using Merck silica gel 60 F254 plates.

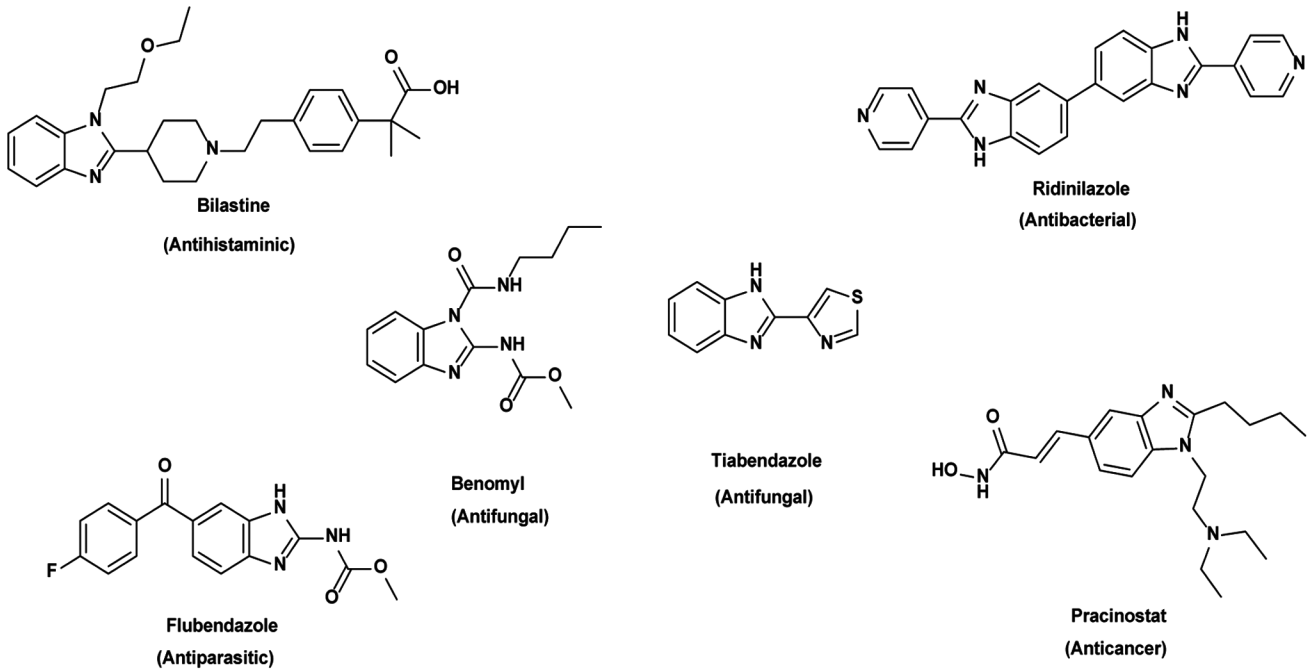


Fig. 1 — The molecular structure of drugs with Benzimidazole ring variations

Visualization of the plates was done using a UV lamp (λmax = 254 or 365 nm). ^{1}H NMR spectra were recorded using Bruker 400MHz NMR spectrometer in DMSO-d_6 solution and TMS as internal standard. IR spectra were recorded using the Bruker alpha FTIR spectrometer. Mass spectral data were recorded using a Shimadzu LC2010 mass analyser and C, H, N analysis using Perkin Elmer PE 2400.

Synthesis of Benzimidazoles

2-Hydroxy-N,N,1-trimethyl-1*H*-benzo[d]imidazole-5-carboxamide, S2-e

In a three-necked RBF immersed in an oil bath, equipped with a water condenser, O-methylhydroxylamine hydrochloride (0.26 g, 1 mol) was taken with MDC (5 ml), CDI (0.5 g, 1 mol) and Diisopropylethylamine (0.77 g, 1 mol) at 25-30°C. Stir for 30 minutes, and 3-amino-N, N-dimethyl-4-(methylamino)benzamide (S2-c) (0.5 g, 1 mol) was then added at 25-30°C and stirred for 1 h. After reaction completion, add water (5 ml) and stir for 10 minutes. The aqueous phase was then saturated with NaCl (0.2 g), and the product was extracted in 2-Butanol. Concentrate the organic phase under vacuum at below 50°C to get the residue. The residue was stripped with toluene (10 mL) and evaporated to get the title S2-e compound.

Yield 78%, brown solid, Rf 0.50. ^{1}H NMR: δ 2.95 (6H, s, CH_3). 3.42 (3H, s, CH_3), 7.00 (1H, d, H_{arom}), 7.10 (2H, d, H_{arom}), 10.98 (1H, s, OH), ^{13}C NMR: δ 26.91, 106.99, 108.78, 120.71, 121.75, 127.92, 129.18, 132.11, 135.05, 155.70, 171.88. Mass, *m/z*: 220.2 $[M + H]^+$; $C_{11}H_{13}N_3O_2$.

2-(2,6-Dimethylphenyl)glycyl)oxy)acetic acid, S2-f

In a three necked RBF immersed in an oil bath, equipped with water condenser, 2-6-Xylidine (5g, 41.26 mmol) was taken with water (75 ml), Bromo acetic acid (11.5 g, 82.76 mmol) at 25-30° C. Stir the reaction mixture for 60 minutes at 90-100°C. Cool reaction mass up to 25-30°C. Filter the separated solid and dried at 50-55°C under vacuum for 6 h to get 1.4 g of S2-f. Yield 19%, white solid, Rf 0.45. ^{1}H NMR: δ 2.50 s (6H, CH_3), 3.82 s (4H, CH_2), 6.89-6.92 m (1H, H_{arom}), 6.98-6.93 m (2H, H_{arom}). ^{13}C NMR: δ 19.26, 55.04, 125.20, 129.16, 136.43, 148.33, 173.62. Mass spectrum, *m/z*: 238.1 $[M + H]^+$; $C_{12}H_{15}N_4O$.

(5-(Dimethylcarbamoyl)-1-methyl-1*H*-benzo[d]-imidazol-2-(2,6-dimethylphenyl)-glycinate, S2-g

In a three-necked RBF immersed in an oil bath, equipped with a water condenser, 2-(2,6-dimethylphenyl)glycyl)oxy) acetic acid (S2-f) (0.7 g, 0.0029 mol) was taken with MDC (5 ml), CDI (0.48 g, 0.029 mol) at 25-30°C. Stir for 30 minutes, and 3-amino-N, N-dimethyl-4-(methylamino)benzamide (S2-c) (0.5 g, 0.0025 mol) was added, and continued stirring for 3 hrs. Concentrate the organic phase under vacuum below 50°C to get the residue. The residue was

stripped with toluene (10 mL) and evaporated to get the title S2-g (0.4 g) compound. Yield 29%, reddish brown solid, Rf 0.70. ^{1}H NMR: δ 3.41 m (10H, CH_3 and CH_2), 3.86 s (3H, CH_3), 7.32-7.34 m (1H, H_{arom}), 7.60-7.69 m (2H, H_{arom}), 8.27 m (1H, H_{arom}), ^{13}C NMR: δ 110.54, 118.71, 122.19, 130.30, 135.57, 142.99, 146.29, 171.23. Mass, *m/z*: 393.6 $[M - H]^-$; $C_{22}H_{26}N_4O_3$.

(4-(5-Methyl-1,2,4-oxadiazol-3-yl)phenyl)glycine, S2-n

In a three necked RBF immersed in an oil bath-magnetic stirrer, equipped with water condenser, a mixture of 4-aminobenzonitrile (10 g, 84 mmol), triethylamine (17 g, 169 mmol), toluene (50 ml) and 0.1 potassium iodide (1% catalyst) were taken and added dropwise methyl chloroacetate (14 g, 129 mmol) at 25-30°C, stirred for 8 h at 80°C, cooled to 25-30°C to get solid by product (TEA. HCl) and filtered and filtrate evaporated to get residue (15 g, 78.8 mmol). To the residue add water (60 ml), hydroxylamine HCl (8.2 g, 118 mmol), and soda ash (12.5 g, 11 mmol). The resulting mass was heated at 65-70°C for 4-6 h under stirring. After reaction completion, cooled to 10°C to get, separated, solid filtered and washed with methanol, dried at 65°C to afford solid (9 g, 20 mmol). This was taken with DMF (30 ml) and added NaOH (2.4 g, 60 mmol). To this mixture added t-butyl acetate (7 g, 60 mmol) dropwise at 25-30°C and stir for 2 hrs. To the resulting mass add water (90 ml) in 1 hr. Cooled to 50°C to get solid, filtered off, washed with water and dried at 70°C to get off white title compound S2-n (5 g). Yield 25%, white solid, Rf 0.30. ^{1}H NMR: δ 2.51 s (3H, CH_3), 3.88 s (2H, CH_2), 6.55 s (1H, NH_{br}), 6.66-6.68 m (2H, H_{arom}), 7.70-7.80 m (2H, H_{arom}), 12.68 s (1H, OH_{br}), ^{13}C NMR: δ 12.40, 112.50, 114.00, 128.57, 151.28, 168.21, 172.64, 176.81, Mass spectrum, *m/z*: 231.9 $[M - H]^-$; $C_{11}H_{11}N_3O_3$.

N,N,1-Trimethyl-2-(((4-(5-methyl-1,2,4-oxadiazol-3-yl)phenyl)amino)methyl)-1*H*-benzo[d]imidazole-5-carboxamide, S2-o

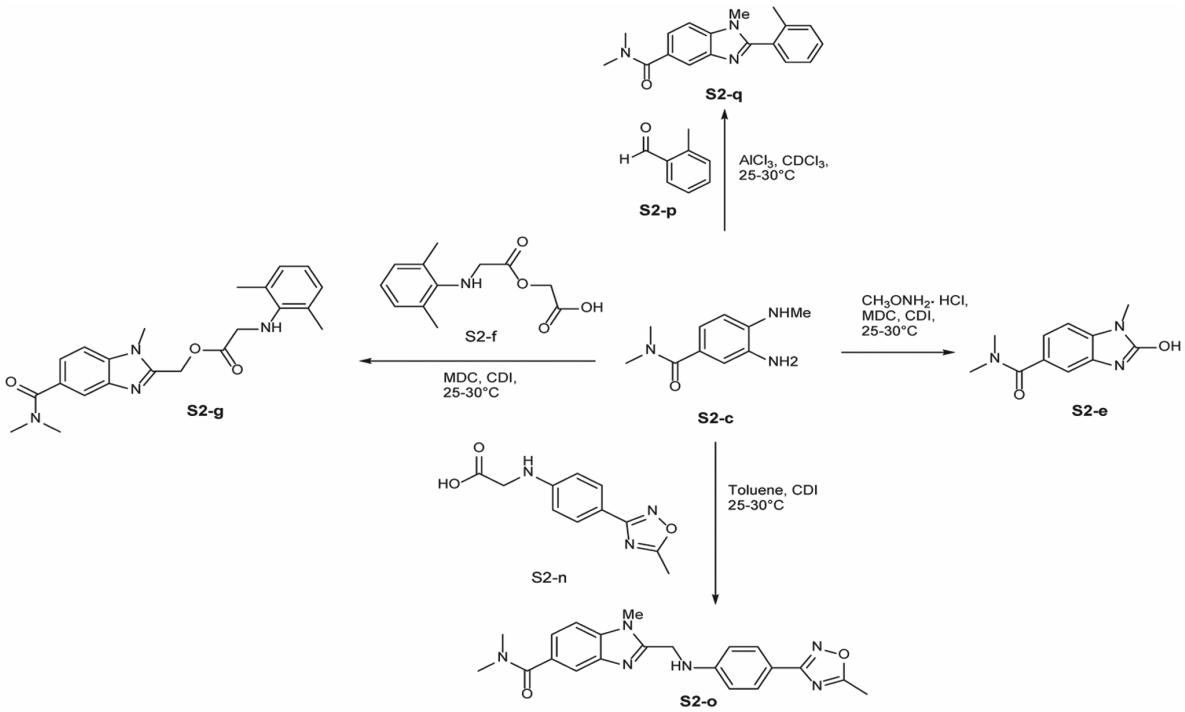
(4-(5-methyl-1,2,4-oxadiazol-3-yl)phenyl)glycine **S2-n** (0.69 g, 2.96 mmol), Toluene (5 ml), CDI (0.48 g 2.96 mmol) taken in a three-necked RBF immersed in an oil bath, equipped with a water condenser at 35-40°C and stirred for 3 Hrs. 3-amino-N, N-dimethyl-4-(methylamino)benzamide S2-c (0.5 g, 2.58 mmol) was then added at 35-40°C and stirred for 3 Hrs. Cool RM to 30-35°C and add 5 ml of water stir for 30 min, filter solid, wash with water and follow with toluene (1 ml). Dried solid and weighed. 400 mg of light brown color powder obtained. Yield 40%, light brown solid, Rf 0.35. ^{1}H NMR: δ 2.62 s (3H, CH_3), 3.15 s (6H, CH_3), 3.84 s (3H, CH_3), 4.62 s (2H, CH_2), 5.12 m (1H, NH_{br}), 7.94-6.82 (7H, m, H_{arom}). ^{13}C NMR: δ 109.23, 112.74, 116.11, 118.38, 122.35, 128.28, 128.74, 130.19, 136.72, 141.22, 149.55, 152.32, 168.21, 171.96, 175.87. Mass, *m/z*: 391.1 $[M + H]^+$; $C_{21}H_{22}N_6O_2$

N,N,1-Trimethyl-2-(((4-(5-methyl-1,2,4-oxadiazol-3-yl)phenyl)amino)methyl)-1H-benzo[d]imidazole-5-carboxamide, S2-q

In a three necked RBF immersed in an oil bath, equipped with water condenser, *o*-methyl benzaldehyde (S2-p) (0.25 g, 2 mmol) was added over the stirred solution of 3-amino-N, N-dimethyl-4-(methylamino)benzamide (S2-c) (0.4 g, 2 mmol), Ammonium chloride (0.44 g, 8.2 mmol) in Chloroform (5 ml), at 25-30°C and stir for 4 Hrs, the solvent was removed under reduced pressure and extracted with ethyl acetate (20ml); the organic layer was washed with water (10 ml). Layers were separated, and the organic layer was dried over sodium sulfate. The solvent was removed under reduced pressure to get crude oily mass, which was subjected to column chromatography using Cyclohexane: ethyl acetate to get S2-q, a light brown gummy mass of 0.5 g (Yield: 82.23%). Yield 82%, brown oil, Rf 0.50. ^{1}H NMR: δ 2.26 s (3H, CH_3), 3.06-3.24 (6H, m, CH_3), 3.72 (3H, s, CH_3), 7.26 – 7.90 (7H, m, H_{arom}), ^{13}C NMR: δ 20.76, 30.79, 40.19, 109.25, 110.00, 118.72, 122.66, 125.88, 128.72, 129.80, 130.06, 130.31, 130.56, 136.21, 137.92, 141.34, 155.11, 172.72. Mass , *m/z*: 294.5 $[M + H]^+$; $C_{18}H_{19}N_3O$.

Results and Discussion

As illustrated in Scheme 1, 3-amino-N, N- dimethyl-4-(methylamino)benzamide S2-C was used as starting materials which reacted with Methoxy amine, S2-f (2-(((2,6-dimethyl phenyl)glycyl)-oxy)acetic acid), S2-p (2-methyl benzaldehyde) and S2-n ((4-(5-methyl-1,2,4-oxadiazol-3-yl)phenyl)-glycine) in presence of Carbonyl diimidazole to give substituted benzimidazole derivatives S2-e, S2-g, S2-o, S2-q. Formation of benzimidazoles (S2-e, S2-g, S2-o and S2-q) are confirmed by disappearance of -NH2 protons of 3-amino-N,N-dimethyl-4-(methylamino)benzamide (S2-C) from 1H NMR spectrum. Synthesis of 2-hydroxy-N,N,1-trimethyl-1H-benzo[d]imidazole-5-carboxamid (S2-e) Confirmed by appearance of -OH proton at δ 10.98 ppm. 2-(2,6-



Scheme 1 — Synthesis of Benzimidazoles

Table 1 — The MIC values for the *in vitro* antibacterial activity of the compounds are summarized below

S. No.	Compd	The MIC values for the antibacterial activity of the compounds are summarized below			
		E. coli (MTCC 443)	*P. aeruginosa* (MTCC 1688)	*S. aureus* (MTCC 96)	*S. pyogenes* (MTCC 442)
1	**S2-e**	125	100	200	125
2	**S2-f**	62.5	125	100	100
3	**S2-g**	200	200	65.5	100
4	**S2-o**	100	125	100	200
5	**S2-q**	100	100	125	100
		Standard Drugs for Antibacterial Activity			
S. No.	Compd	*E. coli* (MTCC 443)	*P. aeruginosa* (MTCC 1688)	*S. aureus* (MTCC 96)	*S. pyogenes* (MTCC 442)
1	Gentamycin	0.05	1	0.25	0.5
2	Ampicillin	30	–	40	25
3	Chloramphenicol	50	50	50	50
4	Ciprofloxacin	25	25	50	50
5	Norfloxacin	10	10	10	10

dimethyl phenyl)glycyl)oxy)acetic acid (S2-g) formation concluded through the appearance of two methylene protons at δ 3.41 and 3.86 ppm respectively. N,N,1-trimethyl-2-(((4-(5-methyl-1,2,4-oxadiazol-3-yl)phenyl)-amino)methyl)-1H-benzo[d]-imidazole-5-carboxamide (S2-q) formation confirmed by appearance of aromatic protons at δ 7.26 and 7.90 ppm. Synthesis of N,N,1-trimethyl-2-(((4-(5-methyl-1,2,4-oxadiazol-3-yl)phenyl)-amino)methyl)-1H-benzo-[d]imidazole-5-carboxamide (S2-o) confirmed by appearance of methylene protons at δ 4.62 ppm and aromatic protons at δ 6.82 -7.94 ppm. Intermediate S2-f was synthesized from 2, 6-Xylidine by acid amine coupling with Bromo acetic acid in water with less hazardous conditions. Intermediate S2-n was synthesized from one pot coupling of 4-aminobenzonitrile and methyl chloroacetate with hydroxylamine HCl. Benzimidazole acted as a model to investigate the range of reactions.

Antibacterial activity of synthesised compounds

Results exhibit that compound **S2-f** and compound **S2-g** shows the most promising efficacy, with low MIC values across all tested bacterial strains (Table 1) , particularly against *E. coli* (62.5 µg/mL) and against

S.aureus (65.5 µg/mL). **S2-f** compound was also set up to have moderate antifungal activity, with MIC values of 1000 µg/mL against *C. albicans* and 500 µg/mL against *A. niger*. When compared to standard drugs, the synthetic compounds had advanced MIC values, indicating lower potency. Gentamycin, for case, displayed an MIC as low as 0.05 µg/mL against *E. coli*, whereas **S2-f** showed 62.5 µg/mL.

Antifungal activity for synthesised compound

Nystatin showed the highest potency, with MIC values of 100 µg/mL against both *C. albicans* and *A. niger*. In comparison, **S2-e** and **S2-q** demonstrated moderate inhibition (500 µg/mL), showing some potential for antifungal applications (Table 2). The results suggest that structural variations to the tested compounds, particularly **S2-f,** could improve their efficacy. Additionally, **S2-q** also displayed moderate antifungal antibacterial activity, particularly against *A. niger*.

Molecular docking

The synthesis of imidazole-5-carboxamide derivatives has been conducted, with the docking position of compound **S2-e** (highlighted in yellow) identified within the binding site of *Candida albicans* CYP 51 (PDB ID: 5TZ1). Table 3 showed the docking scores for synthesized compound within the binding site of *Candida albicans* CYP 51, detailing the following results: the reference compound achieved a score of -12.25 and an RTCNN score of -28.26, while compound **S2-e** recorded a score of -11.97 and an RTCNN score of -9.33. Docking pose of **S2-e** (yellow) in the binding site of *Candida albicans* CYP 51 (PDB id: 5TZ1)(Score: -11.97, RTCNN Score: -: –9.33) (Fig. 2).

Antibacterial Test Procedures

All the Synthesized medicines Were Used for Antibacterial Test Procedures. All Necessary Controls Like Drug Control, Vehicle Control, Agar Control Organism Control, Given Antibacterial medicines Control. All MTCC societies Were Tested Against Above Mentioned Given and Unknown medicines. Mueller Hinton Broth Was Used as Nutrient Medium to Grow and Adulterate the medicine suspense for the Test bacteria. Inoculum Size for Test Strain Was Acclimate to 108 Cfu (Colony Forming Unit) per milliliter by comparing the turbidity. Following common standard strains were used for webbing of antibacterial and antifungal conditioning the strains were carried from Institute of Microbial Technology, Chandigarh. DMSO was used as diluents vehicle to get asked attention of medicines to test upon Standard bacterial strains.

Table 2 — The MIC values for the *in vitro* antifungal activity of the compounds are summarized below

The antifungal activity of the compounds is shown in the following table

S. No.	Compd	*C. albicans* (MTCC 227)	*A. niger* (MTCC 282)
1	**S2-e**	500	500
2	**S2-f**	500	500
3	**S2-g**	300	500
4	**S2-o**	>1000	>1000
5	**S2-q**	500	500

Standard Drugs for Antifungal Activity

The MIC values for the standard antifungal drugs are as follows

S. No.	Drug	*C. albicans* (MTCC 227)	*A. niger* (MTCC 282)
1	Nystatin	100	100
2	Griseofulvin	500	100

Table 3 — Docking score in the binding site of *Candida albicans* CYP 51

S. No.	Drug	Score	RTCNN Score
1	Reference	–12.25	–28.26
2	**S2-e**	–11.97	–9.33

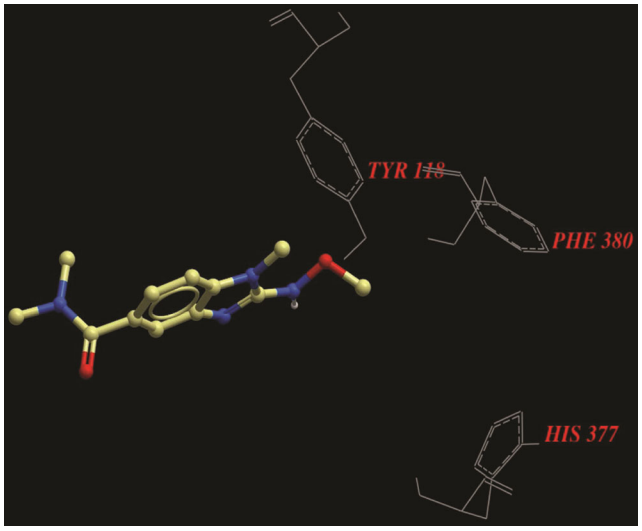


Fig. 2 — Benzimidazole derivatives: Docking pose of mol3 (yellow) in the binding site of *Candida albicans* Cyp 51 (PDB id: 5TZ1)

Calculation of the median inhibitory concentration (IC50) value

The value (%) of the bacterial growth inhibition is determined as [(Ac–At)/Ac] × 100, where Ac is a normal of six replicates of light immersion values at wavelength nm of the negative controls, and at was a normal of six replicates of light immersion values at

wavelength of the samples. The IC50 value is calculated using the direct relation between the inhibitory probability and attention logarithm according to the system of Sakuma. The IC50 value is expressed as the mean ± standard divagation of three independent trials.

Minimal Inhibition Concentration (MIC)

The main advantage of the 'Broth Dilution system' for MIC determination lies in the fact that it can readily be converted to determine the MIC as well. periodical dilutions were prepared in primary and secondary webbing. The control tube containing no antibiotic is incontinently sub dressed (before inoculation) by spreading a loopful unevenly over a quarter of plate of medium suitable for the growth of the test organism incubation at 37 °C for 12 hrs. The tubes are also incubated overnight. The MIC of the control organism is read to check the delicacy of the medicine attention. The lowest value attention inhibiting growth of the organism is recorded as the MIC. The quantum of growth from the control tube before incubation (which represents the original inoculum) is compared.

Methods used for primary and secondary screening

Each synthesized medicine was adulterated obtaining 2000 microgram /ml concentration, as a stock solution.

Primary screen

Primary screen in primary webbing 1000 micro/ ml, 500 micro/ ml, and 250 micro/ ml attention of the synthesized medicines were taken. The active synthesized medicines set up in this primary webbing were further tested in an alternate set of dilution against all microorganisms.

Secondary screen

Secondary screen the medicines set up active in primary webbing were also adulterated to gain 200 micro/ ml 100 micro/ ml, 50 micro/ ml, 25 micro/ ml, 12.5 micro/ ml, 6.250 micro/ ml, and attention.

Reading Result

The maximum dilution resulted at least 99% inhibition zone is taken as MIC. Inoculum size is very important in result. The test admixture should contain 108 organism/ ml.

Conclusion

Synthesized derivations of benzimidazole have been successfully carried out in good yield according to the designed response, outlined in Scheme 1. The conformation of target composites were verified by their ^{1}H NMR, ^{13}C NMR, Mass spectral data, and essential analyses. The mass of compounds displayed a molecular ion peak at applicable m/z values, which corresponded to the desired structure concerning molecular formula. This research has shown that the antibacterial and antifungal activity of benzimidazole derivatives and S2-f exhibits the most promising antibacterial and antifungal properties. Although less potent than standard drugs like Gentamycin and Nystatin, the novel compounds, especially S2-f and S2-q, could serve as leads for further development of new antibacterial and antifungal agents. A molecular docking study supports that compound S2-e recorded a score of -11.97 and an RTCNN score of -9.33 against the binding site of *Candida albicans* CYP 51 (PDB ID: 5TZ1).

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References

1 Alzhrani Z M M, Alam M M & Nazreen S, *Mini-Rev Med Chem*, 22 (2022) 365.

2 Faheem M, Rathaur A, Pandey A, Singh V K & Tiwari A K, *Chem Sel*, 5 (2020), 3981.

3 Patel A, Shah D, Patel N, Patel K, Soni N, Nagani A, Parikh V, Shah H & Bambharoliya T, *Mini-Rev Org Chem*, 18 (2021) 1064.

4 Narasimhan B, Sharma D & Kumar P, *Med Chem Res*, 21 (2012) 269.

5 Venugopal S, Kaur B, Verma A, Wadhwa P & Sahu S K, *Curr Org Synth,* 20 (2023) 595.

6 Bansal Y & Silakari O, *Bioorg Med Chem*, 20 (2012) 6208.

7 Narasimhan B, Sharma D & Kumar P, *Med Chem Res*, 21 (2012) 269.

8 Rossignol J, Maisonneuve H, *Ann Trop Med Parasitol,* 78 (1984) 135.

9 McKellar Q & Scott E, *J Vet Pharmacol Ther*, 13 (1990) 223.

10 Dubey A & Sanyal P, *Online Vet Med J*, 5 (2010) 63.

11 Spasov A, Yozhitsa I, Bugaeva L & Anisimova V, *Pharm Chem J*, 33 (1999) 232.

12 Boiani M & González M, *Mini Rev Med Chem*, 5 (2005) 409.

13 Patil A, Ganguly S & Surana S, *Rasayan J Chem*, 1 (2008) 447.

14 Cole D C, Gross J L, Comery T A, Aschmies S, Hirst W D, Kelley C, Kim J I, Kubek K, Ning X, Platt B J, Robichaud A J, Solvibile W R, Stock J R, Tawa G, Williams M J & Ellingboe J W, *Bioorg Med Chem Lett*, 20 (2010) 1237.

15 Ouattara M, Sissouma D, Koné M W, Menan H E, Touré S A, Ouattara L, *Trop J Pharm Res*, 10 (2011) 767.

16 Abdel-Motaal M, Almohawes K, Tantawy M A, *Bioorg Chem*, 101 (2020) 103972.

17 Alzahrani H A, Alam M M, Elhenawy A A, Nazreen S S, *Biointerface Res Appl Chem*, 13 (2022) 298.

18 Işık Ayşen, Çevik U A, Karayel A, Ahmad I, Patel H, Çelik İ, Gül Ü D, Bayazıt G, Bostancı H E, Koçak A, Özkay Y & Kaplancıklı Z A, *ACS Omega*, 9 (2024) 18469.

19 Mahalakshmi C M & Chidambaranathan V, *Int J Chem Sci,* 13 (2015) 205.

20 Madalageri P M & Kotresh O, *J Chem Pharm Res*, 4 (2012) 2697.

21 Lingala S, Nerella R & Rao K R S S, *Int J Pharm Sci Rev Res*, 10 (2011) 100.

22 Vaidehi B N B, Deepika K G, Satya R V, Bangaramma R R, Kumar R H, Sudha Y R & Kumar T R, *Int J Res Pharm Chem*, 2 (2012) 322.

23 Gowda J, Khader A M A, Kalluraya B & Hidayathulla S, *Indian J Chem*, 50B (2011) 1491.

24 Petkar K, Parekh P, Mehta P, Kumari A & Baro A, *Int J Pharm Pharm Sci*, 5 (2013) 115.

25 Madkour H M F, Farag A A, Ramses S S & Ibrahiem N A A, *Phosphorus Sulfur Silicon Rel Elem*, 181 (2006) 255.

26 Madkour H M F, Farag A A, Ramses S S & Ibrahiem N A A, *Egyptian J Chem*, 49 (2006) 35.

27 Upadhyay D P & Somaiya C P, *Russ J Org Chem*, 60 (2024) 1777.

28 Hjouji M Y, Almehdi A M, Elmsellem H, Seqqat Y, Ouzidan Y, Tebbaa M, Lefakir N A, Rodi Y K, Chahdi F O, Chraibi M, Benbrahin K F, Al-Omar M A, Almehizia A A, Naglah A M & El-Mowafi S A, *Molecules*, 28 (2023) 3197.

29 Abdelgalil M M, Ammar Y A, Ali G A E, Ali A K, Ragab A, *J Mol Struc*, 1274 (2023) 134443.

30 Kus C, Ozer E, Osman H M, Sozudonmez F, Simsek D, Altanlar N, Basaran R, Guven N M, Kocyigit A, Can-Eke B, *Chem Sel*, 8 (2023) e202203651.