SYNTHESIS AND ANTIMICROBIAL EVALUATION OF NOVEL PYRAZOLE, IMIDAZOLE AND PYRIMIDINE DERIVATIVES POSSESSING IMIDAZO[4,5-B]INDOL MOIETY

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Abstract. In this study, new pyrazole, imidazole, pyrimidine derivatives having imidazo[4,5-b]indol moiety were successfully synthesized, elucidated by spectroscopic techniques, and evaluated as potential antimicrobial agents. The structure-activity relationship was investigated to obtain a better understanding of the relationship between the chemical structure of the synthesized compounds and their corresponding biological activity. Compounds 2b and 3b exhibited potent antibacterial activities against Bacillus subtilis bacteria comparable to that of Ampicillin standard. Structure-activity relationship studies revealed that the presence of withdrawing carbonyl group on 5-position of pyrazole moiety 2b, phenylpyrazole moiety 3b led to an enhancement in the antibacterial activity of pyrazole derivatives. Furthermore, the presence of carbonyl group on 2-position of the pyrimidine ring of compounds 4a, 5a and 6a has a significant effect on their antibacterial activity against Bacillus subtilis. The antifungal studies indicated that compounds 3b, 4b, 7 and 9 have comparable antifungal activity to that of standard Amphotericin B against Candida albicans and Aspergillus flavus fungi.

Keywords: pyrazole, imidazole, pyrimidine, indol, antimicrobial activity.

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Introduction

Pyrazole derivatives are well considered in the literature as significant biologically active heterocyclic compounds [1-4]. Medicinal chemistry studies have shown that pyrazole systems, as biomolecules, display a broad spectrum of pharmacological activities including antimicrobial [5,6], anti-inflammatory [7-9], antitumor [10], anticonvulsant [11] and neuroprotective activity. Synthetic drugs have endured an emergence in recent decades because of the increasing population of multidrug-resistant (MDR) bacteria, particularly the “ESKAPE” pathogens, such as Escherichia coli, Klebsiella pneumoniae, Acinetobacter baumannii and Pseudomonas aeruginosa [12-15].

Further studies showed that imidazole, a five-member heterocyclic aromatic compound, occupied an exclusive position in heterocyclic chemistry and its derivatives have attracted considerable interest in recent years for their ability to cure several diseases [16]. Imidazole derivatives show anti-inflammatory, anticancer [17,18], antibacterial [19], analgesic [20], and anti-tubercular [21-22] activity.

The existence of pyrimidine base in uracil, cytosine, and thymine - the main building blocks of nucleic acids DNA and RNA, is among the reasons for their extensive pharmacological applications [23]. The literature surveys depict that compounds encompassing pyrimidine moiety constitute an important class of natural and non-natural products, many of which display a wide range of biological activity [24,25]. Various pyrimidine derivatives have been found to exhibit remarkable antibacterial [26], antifungal [27], antihypertensive [28], antipyretic [29] and anticancer activity [30].

The recent drug design tendency is to reassemble two or three heterocyclic molecules possessing distinct sites of action to serve as new core structures of molecules towards the obtaining of new biologically active agents. In view of our global interest in the design of new potent antimicrobial agents, the main purpose of our study is to synthesize a new set of antimicrobial...
agents based on pyrazole, imidazole, pyrimidine derivatives bearing the imidazo[4,5-b]indol moiety.

In this study, the identification of the designed compounds was carried out by IR spectroscopy, NMR and mass spectrometry. The biological activity of these compounds was realized to evaluate their antibacterial and antifungal properties against various strains.

Experimental Generalities

Unless otherwise mentioned, reagents were provided from Sigma Aldrich (Bayouni Trading Co. Ltd., Al-Khobar, Saudi Arabia) and used without further purification. Reaction progress was monitored using thin-layer chromatography (TLC) on silica gel pre-coated F254Merck plates (Darmstadt, Germany) and spots were visualized by ultraviolet irradiation.

The melting point values were determined by Gallenkamp electrothermal melting point device (Weiss-Gallenkamp, Loughborough, UK) and are uncorrected.

IR spectra were recorded on φ Bruker-Vector 22 Fourier transform infrared spectrophotometer (Billerica, MA) using potassium bromide disks.

The 1H and 13C NMR spectra were measured on a Varian MercuryVX-300 NMR spectrometer (Palo Alto, CA) at 400 and 125 MHz for using DMSO-d6 as solvents.

Mass spectra were recorded on a Hewlett Packard MS-5988 spectrometer (Palo Alto, CA) at 70 eV.

Elemental analysis was carried out at the Micro-analytical Center of Cairo University, Giza, Egypt.

General synthesis of compounds (1a-c)

A mixture of isatins (1 mmol), urea (1 mmol), and different active methylene reagents (malononitrile, ethylcyanoacetate, ethylacetocacetate) (1 mmol) dissolved in ethanol (10 mL) was stirred under reflux for 2 h until the reaction was completed. Thin-layer chromatography (TLC) on silica gel plates was carried out for reaction monitoring using ethanol : ethyl acetate (1:2). The reaction mixture was left to cool at room temperature and filtered off. The solution was concentrated under vacuum to afford the product 1a-c, which was purified by recrystallization in ethanol to afford the corresponding 1a-c in good yield.

4-(imidazo[4,5-b]indol-2-yl)-pyrazole-3,5-diamine 2a, pale yellow crystals, yield 72%, m.p. 160-162°C. IR (KBr, cm-1): 3491-3229 (NH2), 3236 (NH), 1620 (C=N) cm-1. 1H NMR: δ 4.93 (s, 4H, 2NH2), 7.20-7.41 (m, 4H, C=H), 9.85 (s, H, NH) ppm. 13C NMR: δ 124.81, 128.26, 131.44, 133.23, 150.19, 151.14, 152.17, 164.51, 165.55, 170.22 ppm. MS (EI): m/z 251.25 (M+). Anal. calcd. for C10H8N2O: C, 37.37; H, 2.56; N, 39.02. Found: C, 37.36; H, 2.56; N, 38.98.

3-amino-1,2-dihydro-4-(imidazo[4,5-b]indol-2-yl)pyrazol-5-one 2b, red crystals, yield 74%, m.p. 177-179°C. IR (KBr, cm-1): 3924-3134 (NH2), 3231 (NH), 1679 (C=O), 1619 (C=N) cm-1.
1H NMR: δ 7.24-7.48 (m, 4H, C6H4), 9.34 (s, H, NH), 9.86 (s, H, NH) ppm. 13C NMR: δ 123.24, 125.16, 128.41, 131.22, 133.35, 150.36, 165.55, 166.33, 172.78 ppm. MS (ESI): m/z 252.23 (M+). Anal. calcd. for: C12H10N2O: C, 75.14; H, 3.20; N, 33.26. Found: C, 75.19; H, 3.25; N, 33.39.

1,2-dihydro-4-(imidazo[4,5-b]indol-2-yl)-5-methylpyrazol-3-one 2c, green crystals, yield 68%, m.p. 140-142°C. IR (KBr, cm⁻¹): 3230 (NH), 1676 (C=O), 1616 (C=N) cm⁻¹. 1H NMR: δ 2.35 (s, 3H, CH3), 7.21-7.43 (m, 4H, C6H4), 9.87 (s, H, NH), 10.02 (s, H, NH) ppm. 13C NMR: δ 18.21, 97.51, 123.22, 125.37, 128.42, 131.19, 133.31, 144.32, 150.41, 166.25, 167.22 ppm. MS (ESI): m/z 251.24 (M+). Anal. calcd. for: C12H11NO: C, 62.15; H, 3.61; N, 27.87. Found: C, 62.19; H, 3.67; N, 27.93.

**General procedure for the synthesis of compounds (3a-c)**

A mixture of compounds 1a-c (0.1 mmol), trimethylamine (few drops), and urea or thiourea (0.1 mmol) in ethanol (15 mL) was refluxed for 8 h. After the reaction was completed, the mixture was concentrated by filtration and recrystallized from ethanol.

4.6-diamino-5-(imidazo[4,5-b]indol-2-yl)pyrimidin-2(1H)-one 4a, yellow crystals, yield 60%, m.p. 215-217°C. IR (KBr, cm⁻¹): 3420-3256 (NH3), 3203 (NH), 1673 (C=O), 1618 (C=N) cm⁻¹. 1H NMR: δ 4.86 (s, 4H, 2NH2), 7.23-7.52 (m, 4H, C6H4), 10.35 (s, 2H, NH2) ppm. 13C NMR: δ 123.22, 128.33, 131.32, 133.34, 150.24, 162.23, 164.47, 167.31, 167.51 ppm. MS (ESI): m/z 278.27 (M+). Anal. calcd. for: C9H10N4O: C, 55.97; H, 3.28; N, 35.15. Found: C, 55.91; H, 3.25; N, 35.11.

4.6-diamino-5-(imidazo[4,5-b]indol-2-yl)pyrimidin-2-thiol 4b, white crystals, yield 64%, m.p. 225-227°C. IR (KBr, cm⁻¹): 3432-3234 (NH), 3221 (NH), 1678 (C=O), 1623 (C=N) cm⁻¹. 1H NMR: δ 5.32 (s, 4H, 2NH2), 7.03-7.58 (m, 4H, C6H4), 10.35 (s, H, NH) ppm. 13C NMR: δ 123.44, 125.27, 128.41, 131.33, 133.19, 150.31, 167.32, 175.26, 182.41 ppm. MS (ESI): m/z 295.32 (M+). Anal. calcd. for: C7H8N6S: C, 52.87; H, 3.07; N, 33.20; S, 10.86. Found: C, 52.89; H, 3.08; N, 33.24; S, 10.90.

4-amino-5-(imidazo[4,5-b]indol-2-yl)pyrimidin-2(1H)-one 5a, pale yellow crystals, yield 66%, m.p. 234-236°C. IR (KBr, cm⁻¹): 3370-3172 (NH2), 3150 (NH), 1676 (C=O), 1620 (C=N). 1H NMR: δ 5.36 (s, 2H, NH2), 7.15-7.32 (m, 4H, C6H4), 9.78 (s, H, NH) ppm. 13C NMR: δ 99.33, 123.23, 125.22, 127.32, 133.31, 133.35, 150.21, 157.44, 164.41, 167.23, 167.32 ppm. MS (ESI): m/z 264.24 (M+). Anal. calcd. for: C7H8N6S: C, 59.09; H, 3.05; N, 31.80. Found: C, 59.21; H, 3.07; N, 31.84.

4-amino-5-(imidazo[4,5-b]indol-2-yl)pyrimidin-2(1H)-thione 5b, greenish crystals, yield 69%, m.p. 242-244°C. IR (KBr, cm⁻¹): 3437-3233 (NH), 3130 (NH), 1682 (C=O), 1619 (C=N), 1334 (C=S) cm⁻¹. 1H NMR: δ 5.02 (s, 2H, NH2), 6.98-7.21 (m, 4H, C6H4), 10.09 (s, H, NH) ppm. 13C NMR: δ 123.21, 125.22, 128.14, 133.33,
150.42, 146.11, 165.36, 169.51, 181.24 ppm. MS (ESI): m/z 295.32 (M+). Anal. calcd. for C9H9NO2: C, 56.11; H, 3.62; N, 40.27. Found: C, 56.17; H, 3.62; N, 40.32.

2,3-dihydro-5-(imidazo[4,5-b]indol-2-yl)-6-methyl-2-thioxopyrimidin-4(1H)-one 6a, reddish brown crystals, yield 63%, m.p. 170-172°C. IR (KBr, cm⁻¹): 3275 (NH), 1665 (C=O), 1612 (C=N) cm⁻¹. ¹H NMR: δ 7.03-7.58 (m, 4H, C₆H₄). 9.68 (s, H, NH₂), 10.06 (s, H, NH) ppm. ¹³C NMR: δ 128.33, 131.42, 132.17, 134.14, 150.22, 152.15, 153.12, 163.33, 165.17 ppm. MS (ESI): m/z 297.25 (M⁺). Anal. calcd. for C₁₄H₁₀N₂O: C, 60.21; H, 3.25; N, 25.08. Found: C, 60.26; H, 3.31; N, 25.19.

General procedure for the synthesis of compounds 7, 8 and 9

A mixture of compounds 1a-c (10 mmol), guanidine hydrochloride (12.0 mmol), anhydrous K₂CO₃ (15.0 mmol), and absolute ethanol (20 mL) was heated and refluxed for 7 h. After cooling, the mixture was poured into ice water and neutralized with acetic acid. A solid product formed was filtered off and recrystallized from EtOH to afford the corresponding compounds 7, 8 and 9 with good yields.

5-(imidazo[4,5-b]indol-2-yl)pyrimidine-2,4,6-triamine 7, orange crystals, yield 73%, m.p. 286-288°C; IR (KBr, cm⁻¹): 3450-3250 (NH₂), 3200 (NH), 1626 (C=N) cm⁻¹. ¹H NMR: δ 4.75 (s, 4H, 2NH₄), 5.35 (s, 2H, NH₂), 7.01-7.33 (m, 4H, C₆H₄) ppm. ¹³C NMR: δ 107.27, 113.25, 117.55, 119.48, 131.22, 132.34, 156.33, 167.38 ppm. MS (ESI): m/z 295.32 (M⁺). Anal. calcd. for C₁₄H₁₀N₂O: C, 56.11; H, 3.62; N, 40.27. Found: C, 56.21; H, 3.66; N, 40.32.

5-(imidazo[4,5-b]indol-2-yl)pyrimidine-2,4-diamine 8, deep brown, yield 67%, m.p. 246-247°C; IR (KBr, cm⁻¹): 3362-3252 (NH₂), 3150 (NH), 1680 (C=O) cm⁻¹. ¹H NMR: δ 4.32 (s, 2H, NH₂), 5.62 (s, 2H, NH), 7.02-7.32 (m, 4H, C₆H₄), 9.32 (s, 1H, NH) ppm. ¹³C NMR: δ 99.33, 125.33, 125.66, 128.27, 128.32, 131.44, 133.12, 150.17, 157.47, 165.55, 170.11 ppm. MS (ESI): m/z 263.26 (M⁺). Anal. calcd. for C₁₃H₁₀N₂: C, 59.31; H, 3.45; N, 37.24. Found: C, 59.37; H, 3.82; N, 37.29.

Antimicrobial activity assays

Antimicrobial activity (antibacterial and antifungal) of the tested samples was checked out according to a modified Kirby–Bauer disk diffusion method [31]. Briefly, 100 μL of each test bacteria/fungi were grown in 10 mL of fresh media until reaching a count of nearly 108 cells/mL for bacteria and 105 cells/mL for fungi. Subsequently, 100 μL of the microbial suspension was spread out onto Mueller–Hinton agar plates corresponding to the broth in which they were maintained. Plates impregnated with filamentous fungi like Aspergillus flavus at 25°C for 48 h; gram-positive bacteria as Staphylococcus aureus, Bacillus subtilis; gram-negative bacteria as Escherichia coli, Pseudomonas aeruginosa were incubated at 35-37°C for 24-48 h and yeast as Candida albicans was incubated at 30°C for a period varying between 24 and 48 h. Subsequently, the diameters of the inhibition zone were measured in millimeters. The standard disk of ampicillin (antibacterial agent), amphotericin B (an antifungal agent), served as a positive control for antimicrobial activity and filter disks impregnated with 10 μL of solvent (distilled water, chloroform, and DMSO) were used as a negative control. All experiments were repeated and carried out in triplicate in the case of a significant difference in the results and mean values were reported. The mean inhibition zone diameters were measured in mm/mg sample.

Results and discussion

Structure determination

The novel pyrazole, imidazole, and pyrimidine derivatives were synthesized according to the regioselective attack that occurred on the cyano group present in 2-(imidazo[4,5-b]indol-2(4H)-ylidene) derivatives 1a,b. Refluxing of 1a-c derivatives with hydrazine hydrate or phenyl hydrazine in the presence of ethanol gave pyrazole compounds derivatives 2a-c and 3a-c (Schemes 1 and 2).
These reactions involve 1,2-dinucleophile cyclization on CN moiety in compounds 1a-c and concomitant aromatization in the presence of hydrazine and ethanol under reflux.

All reactions were prepared with satisfactory yields varying from 68% to 74% and the obtained products 2a-c were confirmed by spectral data including IR, $^1$H and $^{13}$C NMR. The IR spectra of 4-(imidazo[4,5-b]indol-2-yl)-1H-pyrazole-3,5-diamine 2a showed the characteristic NH$_2$ amine absorption bands in the 3421-3257 cm$^{-1}$ range and the absence of absorption bands corresponding to the cyano group. $^1$H NMR spectrum of compound 2a displayed two different broad signals concentrated at 10.29, 13.25 ppm and attributed to NH$_2$ and NH groups. Furthermore, the $^{13}$C NMR spectrum of this compound showed signals at 146.25 ppm related to CH= N and further signals appeared in the regular regions were mentioned in the experimental data.

The reaction between ethyl 2-cyano-2-(imidazo[4,5-b]indol-2(4H)-ylidene)acetate 1b and hydrazine hydrate in ethanol was carried out under reflux and gave compound 3-amino-1,2-dihydro-4-(imidazo[4,5-b]indol-2-yl)pyrazol-5-one 2b. The data obtained from the IR spectrum of compound 2b confirmed the presence of an absorption band at 1687 cm$^{-1}$ ascribed to C=O. Its $^1$H NMR spectrum showed a signal at 9.45 ppm corresponding to NH and a singlet signal peak at 2.35 ppm for (CH$_3$).

![Scheme 1. Synthetic routes for the compounds 2a-c.](image-url)
In this study, 1,2-dihydro-4-(imidazo[4,5-b]indol-2-yl)-5-methylpyrazol-3-one 2c was prepared by reaction of diethyl 2-(imidazo[4,5-b]indol-2(4H)-ylidene) malonate 1c with hydrazine hydrate in ethanol under reflux. Its IR spectrum showed the characteristic absorption band of (C=O) at 1673 cm$^{-1}$ and another absorption band at 3421, 3232 cm$^{-1}$ corresponding to NH$_2$ group. The $^1$H NMR spectrum of compound 2c exhibited two singlets; the first appeared at 8.25 ppm and the second at 11.25 ppm. Another singlet peak was observed at 4.27 ppm and assigned to NH$_2$ group. The data further ascertain the chemical structures of the synthesized compounds.

As an extension of our work that aims to obtain novel 2-(imidazole)[4-b] indole derivatives possessing different substituents with significant bioactive properties, additional experiments were conducted by reacting compounds 1a-c with adequate amount of phenylhydrazine in ethanol under reflux to yield compounds 3a-c as presented in (Scheme 2). IR spectrum of compound 3,2-(5-methyl-1-phenyl-1H-pyrazol-4-yl)imidazo[4,5-b]indole 3a showed the characteristic absorption bands due to the NH$_2$ stretching. The corresponding $^1$H NMR spectrum showed a multiplet at $\delta$ 7.20-7.36 ppm due to aromatic protons of phenyl ring (C$_6$H$_5$). The IR spectrum of compound 3-amino-1,2-dihydro-4-(imidazo[4,5-b]indol-2-yl)-2-phenylpyrazol-5-one 3b showed absorption at 3431-3156 cm$^{-1}$, which is due to the NH stretching vibrations. The observed bands at 1679 and 1624 cm$^{-1}$ were attributed to C=O and C=N respectively. The $^1$H NMR spectrum of compound 3b showed a multiplet at $\delta$ 7.20-7.36 due to the phenyl ring and singlets at 6.86 and 9.23 ppm related to NH$_2$.

![Scheme 2. Synthetic routes for the compounds 3a-c.](image-url)
The appearance of bands between 3420-3256 (NH$_2$), 3203 (NH), 1673 (C=O) and 1618 (C=N) cm$^{-1}$ in the IR spectrum; a multiplet at $\delta$ value 7.20-7.36 ppm for phenyl ring support the formation of 2-(5-methyl-1-phenyl-1$H$-pyrazol-4-yl)imidazo[4,5-b]indole 3c. Compounds 1a-c were subjected to condensation reactions with urea and thiourea under reflux to give pyrimidine derivatives 4a, 5a, and 6a as shown in (Scheme 3). The chemical structures of these compounds were confirmed by spectral data (see experimental section). The IR spectrum of all compounds displayed the characteristic absorption bands of C=C and C=N stretching frequencies at 1475 and 1620 cm$^{-1}$ corresponding to pyrimidine moiety. The absorption of C=O at 1673 cm$^{-1}$ was observed in the IR spectrum of compound 4a. The $^1$H NMR spectrum of compounds 4a, b displayed a multiplet at $\delta$ value 7.20-7.36 ppm for C$_6$H$_4$, two singlets at 10.35 and 4.86 ppm for NH$_2$ groups. Moreover, the $^1$H NMR spectrum of compounds 5a, b exhibited two singlets for each NH of pyrimidine ring in the range of 11.25 and 9.26 ppm. The IR spectrum of compounds 8a, b revealed the presence of absorption bands at 1673 cm$^{-1}$ due to (C=O). The absence of the CN group in compounds 6a, b (IR spectrum) and the singlet at 7.23 ppm related to NH$_2$ ($^1$H NMR) ascertain their formation.

**Scheme 3. Synthetic routes for the compounds 4a,b, 5a,b and 6a,b.**
In this work, another procedure was adopted to design novel substituted pyrimidines having imidazo[4,5-b]indol moiety (Scheme 4). For this purpose, compounds 1a-c were treated with guanidine hydrochloride anhydrous K$_2$CO$_3$ in ethanol (20 mL) under reflux to give novel pyrimidine derivatives 7-9. All spectral data confirmed the formation of these compounds. $^1$H NMR spectrum of compounds 7-9 displayed three singlets in different positions ranging from 4.83 to 5.62 for NH$_2$ groups. Compound 9 showed a singlet peak at 2.36 ppm for CH$_3$ group and a singlet peak at 4.25 ppm corresponding to NH$_2$.

**Antimicrobial activity assays**

**Antibacterial activity**

After successful synthesis and elucidation of the chemical structures of the newly synthesized compounds, the *in vitro* screening for their antibacterial activity against *Bacillus subtilis*, *Staphylococcus aureus*, *Escherichia coli*, and *Pseudomonas aeruginosa* bacteria was performed. The obtained results are presented in Table 1. Structure-activity relationship (SAR) studies allowed a better understanding of the relationship between the chemical structure of the synthesized compounds and their corresponding biological activity against the tested bacteria.
Most of the synthesized compounds displayed moderate to good activities and the SARs of these compounds were discussed. Among these compounds, compounds 2b and 3b showed comparable efficacy as ampicillin against Bacillus subtilis strains (d= 25 mm/mg sample). Firstly, the introduction of carbonyl group on the 5-position of pyrazole moiety of compound 2b and phenylpyrazole moiety of compound 3b afforded more potent antibacterial activities against the tested strains than compounds 2a,c and 3a,c containing amino and methyl groups on the 5-position (Table 1, Figure 1). Meanwhile, the relationship between various substituents on the 5-position of pyrazole ring were investigated, the presence of electron-donating groups such as amino 2a and methyl 2c showed lower activities against the bacterial strains compared to compound 2b having a carbonyl withdrawing group in 5-position of the pyrazole ring.

Secondly, compounds 4a and 5a with C=O group on the 2-position of pyrimidine moiety exhibited higher activity against Bacillus subtilis, Staphylococcus aureus, Escherichia coli and Pseudomonas aeruginosa bacteria strains compared to compounds 4b and 5b containing C=S group on the 2-position. The substitution of amino groups on 4-position in compounds 4a,b, and 5a,b with a carbonyl group in 6a,b improved the antibacterial activity against Bacillus subtilis, Escherichia coli and Pseudomonas aeruginosa bacteria. It is also noteworthy to indicate that compound 6a bearing a carbonyl group on 2-position of pyrimidine ring exhibited higher antibacterial properties against Bacillus subtilis, Staphylococcus aureus and Escherichia coli strains than compound 6b possessing a thiol (C=S) group on the same position.

These finding ascertain that the presence of more withdrawing groups on the 5-position of pyrazole moiety 2b, 3b and on 2-position of pyrimidine ring 4a, 5a and 6a of the synthesized compounds enhanced their antibacterial activities against the tested bacterial strains. Compound 9 exhibited better antibacterial activity against Escherichia coli, this finding was assigned to the absence of electro-donating amino group on 6-position and to the presence of methyl group in 6-position of the pyrimidine ring. Furthermore, compound 7 exhibited higher antibacterial activity against Bacillus subtilis compared to 8 and 9.

Table 1

| Sample | Gram-positive | Gram-negative | Mean inhibition zone diameter (mm/mg sample) (n=3) |
|--------|---------------|---------------|-------------------------------------------------|
|        | Bacillus subtilis | Staphylococcus aureus | Escherichia coli | Pseudomonas aeruginosa |
| 1a     | 15             | 14             | 14               | 12               |
| 1b     | 13             | 12             | 14               | 11               |
| 1c     | 12             | 13             | 13               | 11               |
| 2a     | 18             | 15             | 15               | 13               |
| 2b     | 25             | 19             | 18               | 15               |
| 2c     | 19             | 14             | 15               | 15               |
| 3a     | 18             | 17             | 14               | 16               |
| 3b     | 25             | 18             | 14               | 15               |
| 3c     | 19             | 15             | 13               | 12               |
| 4a     | 17             | 15             | 12               | 11               |
| 4b     | 16             | 14             | 13               | 15               |
| 5a     | 15             | 13             | 13               | 14               |
| 5b     | 14             | 13             | 11               | 13               |
| 6a     | 18             | 15             | 13               | 12               |
| 6b     | 12             | 11             | 10               | 12               |
| 7      | 19             | 14             | 13               | 16               |
| 8      | 17             | 14             | 12               | 14               |
| 9      | 16             | 14             | 15               | 13               |
| Control (DMSO) | 0             | 0             | 0               | 0               |
| Ampicillin | 27           | 23             | 25               | 26               |
Antifungal activity

Antifungal properties of the synthesized compounds were tested against Aspergillus flavus and Candida albicans fungi using the standard Amphotericin B antifungal agent. The obtained results are summarized in Table 2. Antifungal data of targeted compounds have obviously shown that distinct electronic varieties are responsible for wide spectrum activity.

Table 2

| Sample | Aspergillus flavus | Candida albicans |
|--------|-------------------|------------------|
| Mean inhibition zone diameter (mm/mg sample) (n=3) |
| Control (DMSO) | 0 | 0 |
| Amphotericin B | 15 | 19 |
| 1a | 12 | 15 |
| 1b | 11 | 15 |
| 1c | 10 | 12 |
| 2a | 14 | 13 |
| 2b | 14 | 15 |
| 2c | 12 | 10 |
| 3a | 13 | 17 |
| 3b | 16 | 18 |
| 3c | 12 | 17 |
| 4a | 13 | 16 |
| 4b | 14 | 17 |
| 5a | 13 | 14 |
| 5b | 11 | 12 |
| 6a | 13 | 14 |
| 6b | 12 | 11 |
| 7 | 15 | 18 |
| 8 | 13 | 14 |
| 9 | 14 | 18 |

Compounds 3b, 4b, 7 and 9 displayed similar antifungal activities as that of standard Amphotericin B against Candida albicans and Aspergillus flavus fungi. Compound 3b afforded more important antifungal activity against the tested fungi compared to compounds 3a and 3c, this finding was attributed to the presence of the carbonyl withdrawing group on the 5-position of the phenylpyrazole moiety of compound 3b. On the other hand, the antifungal activity of compound 4b against Candida albicans was associated with the presence of the C=S group on the 2-position of the pyrimidine ring. SARs studies also indicated that the introduction of the electron releasing groups such as amino (2,4,6-position) in compound 7 and methyl (4-position) in compound 9 enhanced their antifungal activity against Candida albicans fungi.

Conclusions

In this study, novel pyrazole, imidazole, pyrimidine derivatives bearing imidazo[4,5-b]indol moiety were successfully synthesized and their chemical structures were identified and confirmed by different spectral techniques. All the synthesized compounds were assessed for their antibacterial activities against four bacterial strains (Bacillus subtilis, Staphylococcus aureus, Escherichia coli, and Pseudomonas aeruginosa) and antifungal activities against two fungi (Aspergillus flavus and Candida albicans).

Structure-activity relationship studies revealed that the introduction of the electron-withdrawing group contributes substantially to the antibacterial activity of the synthesized compounds. It was interesting to note that the compounds bearing a carbonyl group on 5-position of pyrazole moiety 2b, phenylpyrazole moiety 3b displayed outstanding antibacterial activity against Bacillus subtilis bacteria and are almost similar to the Ampicillin standard. Furthermore, the presence of carbonyl group in 2-position of the pyrimidine ring of compounds 4a, 5a and 6a has significantly improved their antibacterial activity against Bacillus subtilis bacteria and the other tested bacterial strains.

The antifungal studies indicated that compounds 3b, 4b, 7 and 9 displayed comparable antifungal activity to that of standard Amphotericin B against Candida albicans and Aspergillus flavus fungi. Structure-activity relationship studies indicated that the presence of electron donating groups such as amino (2,4,6-position) in compound 7 and methyl (4-position) in compound 9 enhanced their antifungal activity against Candida albicans fungi. These synthesized compounds could find fruitful applications as antibacterial and antifungal agents in pharmaceutical chemistry and additional studies are currently conducted by our group to evaluate their anti-inflammatory and anti-cancer activity.

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