Synthesis and characterization of some novel coumarin based 2-pyridone heterocycles with their broad spectrum antimicrobial potency

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Abstract: The synthesis of a novel series of 6-((arylidene)amino)-2-oxo-1-((1-(2-oxo-2H-chromen-3-yl)ethylidene)amino)-4-phenyl-1,2-dihydropyridine-3,5-dicarbonitriles 4a-o were synthesized and structures of compounds have been elucidated by IR, 1H NMR, 13C NMR and mass spectral data. Antimicrobial activity was measured against certain strains of bacteria and fungi by serial broth dilution. Evaluation of antimicrobial activity shown that the compounds (4g, 4j, 4k and 4o) were found to be most active against selected bacterial strains and compounds (4d, 4m and 4n) were found to be most active against selected fungal strains.

1. Introduction

Coumarin and 2-pyridone derivatives play a vital role in the theoretical development of heterocyclic chemistry along with being used extensively in organic synthesis. The action of bacterial infections still remains a significant therapeutic problem. It led to develop infectious diseases and the increasing number of multidrug-resistant microbial pathogens. Therefor since the past few decades much attention has been given to the design and synthesis of new types of pharmacologically diverse structural hybrid molecules [1]. The present work is dealing with the synthesis of novel series of 6-((arylidene)amino)-2-oxo-1-((1-(2-oxo-2H-chromen-3-yl)ethylidene)amino)-4-phenyl-1,2 dihydropyridine-3,5-dicarbonitriles 4a-o. It is well known that coumarin derivatives possess a wide range of medicinal indications, such as anthelmintic, anticoagulant, hypnotic and insecticidal properties [2]. The antimicrobial activity of coumarin derivatives is reported in the literature [3,4,5,6,7]. Potential of various natural and synthetic coumarin derivatives proved its importance as anti-inflammatory [8] antioxidant properties [9] anticancer [10,11] and monoamine oxidase inhibitors [12]. Novobiocin and chlorobiocin have reported as antimicrobials containing a coumarin skeleton [13].

Pyridone and their derivatives play a vital role in some biological processes and have significant chemical and pharmacological importance [14,15,16]. 2-Pyridone motifs found to possess useful pharmacological activities, such as analgesic [17], antimalarial [18], anti-HIV [19], phytotoxic [20], and antitumoral [21] properties. The versatility of 2-pyridone and its potential to yield derivatives with a wide range of biological activities has made it a useful structure for further molecular investigation. Moreover, 2-pyridones are a class of newly exposed potent antibacterial agents that are of specific concern due to their in vitro and in vivo antibacterial potencies against the bacterial type II DNA topoisomerases, which consist of two highly homologous enzymes-DNA gyrase and topoisomerase IV [22,23]. In accordance with our previous work [24,25,26] and medicinal importance of coumarin and 2-pyridone motifs we report herein the synthesis of a new class of 6-((arylidene)amino)-2-oxo-1-((1-(2-oxo-2H-chromen-3-yl)ethylidene)amino)-4-phenyl-1,2-dihydropyridine-3,5-dicarbonitriles 4a-o as potential antimicrobial agents.
2. Results and discussion

2.1. Chemistry

The synthetic route to the proposed compounds is shown in Scheme 1. The synthesis of 6-((arylidene)amino)-2-oxo-1-((1-(2-oxo-2H-chromen-3-yl)ethylidene)amino)-4-phenyl-1,2-dihydropyridine-3,5-dicarbonitriles 4a-o have carried out as follows: 3-acetyl-2H-chromen-2-one (1) was prepared by Salicylaldehyde (A) (0.01 mol) and equimolar amount of ethyl acetoacetate (B) in dry methanol using 1 mL piperidine as a catalyst. Reaction mixture was stirred at room temperature for 30 mins and after the stirring, crystals were observed at the bottom of the RBF. In the first step, compound (2) was prepared by mixture of 3-acetyl-2H-chromen-2-one (0.01 mol) (1) and 2-cyanoacetohydrazide (0.01 mol) in presence of glacial acetic acid and refluxed at 50-60 °C. In the second step, intermediate (2) (0.01 mol) was refluxed with 2-benzylidenemalononitrile (E) (0.01 mol) and catalytic amount of piperidine in presence of ethanol (99%, 30 mL) as a solvent gave compound (3). Intermediate (3) (0.01 mol) was further treated with various aromatic aldehydes (0.01 mol) and ethanol (99%, 30 mL) refluxed and the solid separated to obtain novel compounds of the series 4a-o. The structural assignments of the compounds 4a-o were based on the characterization of their 1H NMR, 13C NMR, and mass spectra. Satisfactory elemental analyses were obtained (Scheme 1).
A plausible mechanistic pathway for the formation of compounds 4a-o is suggested in Scheme 2. In first step, hydrazone (A) underwent Michael addition with Knoevenagel product (B) and produced the intermediate (C), which further undergoes intramolecular nucleophilic attack on cyanide carbon followed by annulation to yield intermediate (D). The intermediate (D) transformed to compound (E) by intramolecular electron transfer to nitrogen atom. In the last step, intermediate (E) was transformed to targeted compounds by intermolecular nucleophilic attack on carbonyl carbon of different aromatic aldehydes (Scheme 2).
Scheme 2. Plausible mechanistic pathway

2.2. Characterization of compounds 4a-o

The structure of compound 4a-o was confirmed on the basis of spectral data. The IR spectrum of compound 4a-o showed strong absorption band at 1700-1730 cm\(^{-1}\) due to >C=O stretching, coumarin ring. Absorption band appeared at 2203-2221 cm\(^{-1}\) due to stretching vibrations corresponding to cyano group and absorption band at 1591-1599, 1551-1562 cm\(^{-1}\) corresponding to C=C, C=N stretching, aromatic ring. Moreover absorption bands appeared in compounds 4a-o at 1251-1268 cm\(^{-1}\) indicated the C-O-C linkage present in coumarin ring. In \(^1\)H NMR spectra, the appearance of singlet peaks in compounds 4a-o at \(\delta = 8.65-9.30\) and \(9.05-9.25\) ppm was due to one proton of coumarin ring (C4-H) and Ar-CH=N- linkage. Three proton of Ar-C(CH\(_3\))=N- displayed singlet at \(\delta = 2.03-2.10\) ppm. Remaining all aromatic protons appeared multiplet in the region \(\delta = 6.90-8.53\) ppm. The \(^1\)C NMR spectrum of compound 4a-o showed characteristic signal at \(\delta = 159.2-159.9\) ppm due to carbonyl carbon at coumarine motif as well as the appearance of signal around \(\delta = 115.5\) (2) ppm was assignable to cyano group of the 2-pyridone ring. Carbon of -CH=N- linkage showed signal around \(\delta = 163.2\) ppm. The mass spectrum revealed a molecular ion peak in compound 4a-o at m/z = 509.15-599.18 in mass spectra, molecular ion peak was in agreement with proposed molecular weight and elemental analysis.

2.3. Antimicrobial Results

The activity of compounds was determined as per the National Committee for Clinical Laboratory Standards (NCCLS) protocol using Mueller-Hinton Broth (Becton–Dickinson, USA) [27,28,29,30]. All the newly synthesized compounds were evaluated against Gram-positive bacteria (Staphylococcus aureus, Staphylococcus pyogenes), Gram-negative bacteria (Escherichia coli, Pseudomonas aeruginosa) and fungi (Candida albicans, Aspergillus niger and Aspergillus clavatus) strains.
Table 1. Antibacterial and Antifungal activity of compounds 4a-o

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>-R</th>
<th>Minimum inhibitory concentrations for bacteria (MIC) in μg/ml</th>
<th>Minimum inhibitory concentration for fungi (MIC) in μg/ml</th>
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<tr>
<td></td>
<td></td>
<td>E. coli MTCC 443</td>
<td>S. aureus MTCC 96</td>
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<td>P. aeruginosa MTCC 1688</td>
<td>S. pyogenes MTCC 442</td>
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<td></td>
<td></td>
<td>C. albicans MTCC 227</td>
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<td></td>
<td></td>
<td>A. niger MTCC 282</td>
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<td></td>
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<td></td>
<td>A. clavatus MTCC 1323</td>
</tr>
<tr>
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<tr>
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<td>&gt;1000</td>
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<tr>
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<tr>
<td>Griseofulvin</td>
<td>-</td>
<td>-</td>
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</tr>
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</table>

2.3.1. Antibacterial activity

In preliminary screening, compounds 4a-o against the test microbes are listed in Table 1 along with MIC values of reference compounds ampicillin (for bacteria) and griseofulvin (for fungi). Although all coumarine base 2-pyridone derivatives 4a-o were found to show antimicrobial activity against different strains in these two assays, compounds 4g, 4j, 4k and 4o are clearly outstanding in their antibacterial properties. For several pathogens, these compounds were more active than the reference drugs.

2.3.2. Antifungal activity

Compounds 4a-o were tested for antifungal activity in six sets against C. albicans, A. niger and A. clavatus at various concentrations of 1000, 500, 200 and 100 μg/ml as shown in Table 1. Synthesized compounds are diluted at 1000 μg ml⁻¹ concentration, as a stock solution. The data of antimicrobial evaluation of compounds 4a-o were collected in Table 1. Compound 4d selectively inhibits the growth of C. albicans and A. niger. Compound 4m, expressed excellent activity against A. niger and A. clavatus while compound 4n exhibited excellent activity against A. niger with a two to four fold higher (12.5-25 μg/ml) MIC value than the reference drug griseofulvin. Detailed activity results are summarized in Table 1.

3. Experimental

3.1. Materials and methods

All reactions except those in aqueous media were carried out by standard techniques for the exclusion of moisture. Melting points were determined on an electro thermal melting point apparatus and were reported uncorrected. TLC on silica gel plates (Merck, 60 F₂₅₄) was used for purity checking and reaction monitoring. Elemental analysis (% C, H, N) was carried out by a Perkin-Elmer 2400 CHN analyzer. IR spectra of all compounds were recorded on a Perkin-Elmer FT-IR spectrophotometer in KBr. ¹H NMR spectra were recorded on Varian Gemini 300 MHz and ¹³C NMR spectra are recorded with a Varian Mercury-400 (100 MHz) NMR spectrometer, using tetramethylsilane as the internal reference, with dimethyl sulfoxide (DMSO-d₆) as solvent. Mass spectra were scanned on a Shimadzu LCMS 2010 spectrometer.
Preparation of 2-cyano-N'-(2-(2-oxo-2H-chromen-3-yl)propylidene) acetohydrazide (2)
A mixture of 3-acetyl-2H-chromen-2-one (1) (0.01 mol) and 2-cyanoacetohydrazide (0.01 mol) in methanol (30 mL) was refluxed for 14 h and then cooled down to room temperature. The separated crystals were filtered, air dried and recrystallized from ethanol (95%). Yield: 72%; m.p.: 159 °C; Anal. calc. for C_{18}H_{13}N_{3}O_{3}: C-63.60, H-4.63, N-14.83; Found: C-63.63, H-4.56, N-14.76%.

Preparation of 6-amino-2-oxo-1-((1-(2-oxo-2H-chromen-3-yl)ethylidene)amino)-4-phenyl-1,2-dihydropyridine-3,5-dicarbonitrile (3)
A mixture containing 2-cyano-N'-(2-(2-oxo-2H-chromen-3-yl)propylidene) acetohydrazide (2) (0.01 mol), 2-benzylidenemalononitrile (0.01 mol) and 2 drops of piperidine in ethanol (95%) (30 mL) was refluxed for 22 h. The mixture was then cooled down to room temperature and diluted with few drops of water. The crystals formed were filtered, air dried and recrystallized from ethanol. Yield: 68%; m.p.: 190 °C; Anal. Calcd. for C_{24}H_{15}N_{5}O_{3}: C-68.40, H-3.59, N-16.62; Found: C-68.27, H-3.64, N-16.69%.

General preparation of 6-((benzylidene)amino)-2-oxo-1-((1-(2-oxo-2H-chromen-3-yl)ethylidene) amino)-4-phenyl-1,2-dihydropyridine-3,5-dicarbonitrile (4a-o)
Compound (3) (0.01 mol), benzaldehyde (0.01 mol) and ethanol (95%) (30 mL) were taken in a round bottom flask and refluxed for 12 h. Separated solid was filtered, dried and recrystallized from ethanol.

6-((benzylidene)amino)-2-oxo-1-((1-(2-oxo-2H-chromen-3-yl)ethylidene)amino)-4-phenyl-1,2-dihydropyridine-3,5-dicarbonitrile (4a)
Yield: 69 %, m.p. 223-227 °C. IR (KBr, cm\(^{-1}\)): 3133, 3029 (C-H stretching, aromatic ring), 2917 (C-H, CH\(_3\)), 2205 (C=N stretching, nitrile group), 1727 (>C=O stretching, coumarin ring), 1559, 1595 (>C=N\(_-=\)C< stretching, aromatic ring), 1586, 1402 (C-H bending, -CH=N linkage), 1251 (C-O-C coumarin ring). \(^1\)H NMR (300 MHz, DMSO-\(d_6\), \(\delta\) ppm): 9.49 (s, 1H, Ar-CH=N), 8.99 (s, 1H, C4 proton of coumarin), 7.13-7.83 (m, 14H, Ar-H of coumarin ring and phenyl ring), 2.03 (s, 3H, -C(CH\(_3\))=N-). \(^13\)C NMR (100 MHz, DMSO-\(d_6\), \(\delta\) ppm): 169.1, 163.5, 160.2, 159.9, 155.3, 153.6, 153.2, 133.1, 133.1, 129.4, 129.4, 128.7, 128.7, 128.5, 128.5, 128.1, 128.1, 128.0, 127.6, 127.6, 125.7, 123.5, 118.3, 116.2, 115.6, 115.2, 114.9, 4.6. MS: m/z 509.15 (M\(^+\)). Anal. Calcd. For C\(_{31}\)H\(_{19}\)N\(_{5}\)O\(_3\), C, 73.08; H, 3.76; N, 13.75 %. Found: C, 73.02; H, 3.79; N, 13.71 %.

6-(2-hydroxybenzylidene)amino)-2-oxo-1-((1-(2-oxo-2H-chromen-3-yl)ethylidene)amino)-4-phenyl-1,2-dihydropyridine-3,5-dicarbonitrile (4b)
Yield: 77 %, m.p. 174-177 °C. IR (KBr, cm\(^{-1}\)): 3415 (O-H, Ar-OH), 3133, 3034 (C-H stretching, aromatic ring), 2914 (C-H, CH\(_3\)), 2209 (C=N stretching, nitrile group), 1708 (>C=O stretching, coumarin ring), 1551, 1599 (>C=N\(_-=\)C< stretching, aromatic ring), 1404 (C-H bending, -CH=N linkage), 1252 (C-O-C coumarin ring). \(^1\)H NMR (300 MHz, DMSO-\(d_6\), \(\delta\) ppm): 11.02 (s, 1H, Ar-OH), 9.18 (s, 1H, Ar-CH=N), 9.25 (s, 1H, C4 proton of coumarin), 6.90-7.81 (m, 13H, Ar-H of coumarin ring and phenyl ring), 2.05 (s, 3H, Ar-C(CH\(_3\))=N). \(^13\)C NMR (100 MHz, DMSO-\(d_6\), \(\delta\) ppm): 169.6, 163.3, 161.5, 160.4, 159.7, 155.5, 153.3, 153.1, 133.7, 132.6, 132.4, 123.6, 128.7, 128.7, 128.4, 128.4, 128.1, 127.7, 127.7, 125.6, 123.6, 121.6, 118.6, 118.2, 117.5, 116.3, 115.6, 115.6, 115.5, 114.5, 4.6. MS: m/z 525.14 (M\(^+\)). Anal. Calcd. For C\(_{31}\)H\(_{19}\)N\(_{5}\)O\(_4\), C, 70.85; H, 3.64; N, 13.33 %. Found: C, 70.82; H, 3.69; N, 13.36 %.

6-((3-hydroxybenzylidene)amino)-2-oxo-1-((1-(2-oxo-2H-chromen-3-yl)ethylidene)amino)-4-phenyl-1,2-dihydropyridine-3,5-dicarbonitrile (4c)
Yield: 71 %, m.p. 198-202 °C. IR (KBr, cm\(^{-1}\)): 3405 (O-H, Ar-OH), 3131, 3035 (C-H stretching, aromatic ring), 2914 (C-H, CH\(_3\)), 2212 (C=N stretching, nitrile group), 1713 (>C=O stretching, coumarin ring), 1562, 1599 (>C=N\(_-=\)C< stretching, aromatic ring), 1406 (C-H bending, -CH=N linkage), 1266 (C-O-C coumarin ring). \(^1\)H NMR (300 MHz, DMSO-\(d_6\), \(\delta\) ppm): 9.49 (s, 1H, Ar-
OH), 9.22 (s, 1H, Ar–CH=N–), 8.90 (s, 1H, C4 proton of coumarin), 6.94-7.84 (m, 13H, Ar–H of coumarin ring and phenyl ring), 2.05 (s, 3H, Ar-C(CH3)=N–). 13C NMR (100 MHz, DMSO-d6, δ ppm): 169.2, 163.9, 160.5, 159.7, 158.7, 155.7, 153.7, 153.3, 135.3, 133.6, 132.2, 130.6, 128.5, 128.2, 128.2, 128.0, 127.8, 127.8, 125.1, 122.6, 121.3, 118.4, 118.2, 116.3, 115.7, 115.7, 115.3, 114.6, 114.5, 4.6. MS: m/z 525.14 (M+) Analy. calcd. For C31H19N3O4, C, 70.85; H, 3.64; N, 13.33 %. Found: C, 70.87; H, 3.61; N, 13.35 %.

6-((4-hydroxybenzylidene)amino)-2-oxo-1-(((1-oxo-2H-chromen-3-yl)ethyldene)amino)-4-phenyl-1,2-dihydropyrididine-3,5-dicarbonitrile (4d)

Yield: 63 %, m.p. 162-166 °C. IR (KBr, cm−1): 3419 (O-H, Ar–OH), 3127, 3039 (C-H stretching, aromatic ring), 2918 (C-H, CH3), 2206 (>C=N stretching, nitrile group), 1704 (>C=O stretching, coumarin ring), 1551, 1596 (>C=N–, >C=C< stretching, aromatic ring), 1409 (C-H bending, -CH=N linkage), 1261 (O-C coumarin ring). 1H NMR (300 MHz, DMSO-d6, δ ppm): 9.74 (s, 1H, Ar-OH), 9.20 (s, 1H, Ar–CH=N–), 8.65 (s, 1H, C4 proton of coumarin), 6.91-7.89 (m, 13H, Ar-H of coumarin ring and phenyl ring), 2.03 (s, 3H, Ar-C(CH3)=N–). 13C NMR (100 MHz, DMSO-d6, δ ppm): 169.5, 163.5, 160.9, 160.7, 159.7, 155.3, 153.5, 153.0, 133.7, 132.8, 130.4, 130.4, 128.8, 128.8, 128.5, 128.5, 128.1, 127.7, 127.7, 126.5, 125.4, 123.6, 118.4, 116.2, 116.0, 116.0, 115.6, 115.1, 114.3, 4.4. MS: m/z 525.14 (M+). Analy. calcd. For C31H19N3O4, C, 70.85; H, 3.64; N, 13.33 %. Found: C, 70.78; H, 3.59; N, 13.26%.

6-((2-nitrobenzylidene)amino)-2-oxo-1-(((1-oxo-2H-chromen-3-yl)ethyldene)amino)-4-phenyl-1,2-dihydropyrididine-3,5-dicarbonitrile (4e)

Yield: 68 %, m.p. 236-239 °C. IR (KBr, cm−1): 3136, 3031 (C-H stretching, aromatic ring), 2920 (C-H, CH3), 2205 (>C=N stretching, nitrile group), 1711 (>C=O stretching, coumarin ring), 1553, 1593 (>C=N–, >C=C< stretching, aromatic ring), 1484, 1356 (-NO2), 1401 (C-H bending, -CH=N linkage), 1262 (O-C coumarin ring). 1H NMR (300 MHz, DMSO-d6, δ ppm): 9.07 (s, 1H, Ar-CH=N–), 9.30 (s, 1H, C4 proton of coumarin), 7.15-8.09 (m, 13H, Ar-H of coumarin ring and phenyl ring), 2.05 (s, 3H, C(CH3)=N–). 13C NMR (100 MHz, DMSO-d6, δ ppm): 169.5, 163.9, 160.3, 159.5, 155.4, 153.5, 153.1, 147.4, 134.7, 133.6, 132.3, 131.4, 130.3, 128.6, 128.6, 128.3, 128.3, 128.2, 128.0, 127.5, 127.5, 125.3, 124.1, 123.4, 118.5, 116.3, 115.5, 115.5, 114.6, 4.7. MS: m/z 554.13 (M+). Analy. calcd. For C31H18N6O5, C, 67.15; H, 3.27; N, 15.16 %. Found: C, 67.21; H, 3.18; N, 15.23 %.

6-((3-nitrobenzylidene)amino)-2-oxo-1-(((1-oxo-2H-chromen-3-yl)ethyldene)amino)-4-phenyl-1,2-dihydropyrididine-3,5-dicarbonitrile (4f)

Yield: 61 %, m.p. 244-247 °C. IR (KBr, cm−1): 3130, 3034 (C-H stretching, aromatic ring), 2924 (C-H, CH3), 2221 (>C=N stretching, nitrile group), 1700 (>C=O stretching, coumarin ring), 1553, 1598 (>C=N–, >C=C< stretching, aromatic ring), 1480, 1352 (-NO2), 1403 (C-H bending, -CH=N linkage), 1266 (O-C coumarin ring). 1H NMR (300 MHz, DMSO-d6, δ ppm): 9.15 (s, 1H, Ar-CH=N–), 8.87 (s, 1H, C4 proton of coumarin), 7.19-8.53 (m, 13H, Ar-H of coumarin ring and phenyl ring), 2.08 (s, 3H, C(CH3)=N–). 13C NMR (100 MHz, DMSO-d6, δ ppm): 169.7, 163.3, 160.1, 159.2, 155.9, 153.4, 148.1, 135.4, 134.9, 133.7, 132.7, 129.4, 128.9, 128.9, 128.7, 128.7, 128.5, 128.0, 127.7, 127.7, 126.3, 125.4, 123.6, 121.5, 118.4, 116.3, 115.7, 115.7, 115.1, 114.9, 4.7. MS: m/z 554.13 (M+). Analy. calcd. For C31H18N6O5, C, 67.15; H, 3.27; N, 15.16 %. Found: C, 67.12; H, 3.21; N, 15.21 %.

6-((4-nitrobenzylidene)amino)-2-oxo-1-(((1-oxo-2H-chromen-3-yl)ethyldene)amino)-4-phenyl-1,2-dihydropyrididine-3,5-dicarbonitrile (4g)

Yield: 72 %, m.p. 221-225 °C. IR (KBr, cm−1): 3137, 3031 (C-H stretching, aromatic ring), 2926 (C-H, CH3), 2215 (>C=N stretching, nitrile group), 1730 (>C=O stretching, coumarin ring), 1557, 1594 (>C=N–, >C=C< stretching, aromatic ring), 1487, 1359 (-NO2), 1268 (C-O-C coumarin ring), 1405 (C-H bending, -CH=N linkage). 1H NMR (300 MHz, DMSO-d6, δ ppm): 9.12 (s, 1H, Ar-CH=N–), 8.70 (s, 1H, C4 proton of coumarin), 7.22-8.37 (m, 13H, Ar-H of coumarin ring and
6-((2-chlorobenzylidene)amino)-2-oxo-1-((1-(2-oxo-2H-chromen-3-yl)ethylidene)amino)-4-phenyl-1,2-dihydropyridine-3,5-dicarbonitrile (4h)

Yield: 73 %, m.p. 217-221 °C. IR (KBr, cm⁻¹): 3139, 3029 (C-H stretching, aromatic ring), 2928 (C-H, CH₃), 2208 (C≡N stretching, nitrile group), 1706 (C=O stretching, coumarin ring), 1560, 1594 (>C=N, >C=C< stretching, aromatic ring), 1408 (C-H bending, -CH=N linkage), 754 (C-Cl). ¹H NMR (300 MHz, DMSO-d₆, δ ppm): 9.18 (s, 1H, Ar-CH=N-), 8.94 (s, 1H, C4 proton of coumarin), 7.14-7.90 (m, 13H, Ar-H of coumarin ring and phenyl ring), 2.06 (s, 3H, -C(CH₃)=N-). ¹³C NMR (100 MHz, DMSO-d₆, δ ppm): 169.9, 163.5, 160.3, 159.6, 155.3, 153.4, 153.2, 135.3, 134.5, 133.7, 133.2, 131.4, 130.6, 128.8, 128.8, 128.6, 128.6, 128.1, 127.7, 127.7, 127.5, 127.4, 125.8, 123.6, 118.3, 116.7, 115.9, 115.9, 115.5, 114.5, 4.6. MS: m/z 543.11 (M⁺). Anal. calcd. For C₃₁H₁₈ClN₅O₅, C, 68.45; H, 3.34; N, 12.87 %. Found: C, 68.51; H, 3.29; N, 12.96 %.

6-((3-chlorobenzylidene)amino)-2-oxo-1-((1-(2-oxo-2H-chromen-3-yl)ethylidene)amino)-4-phenyl-1,2-dihydropyridine-3,5-dicarbonitrile (4i)

Yield: 65 %, m.p. 226-230 °C. IR (KBr, cm⁻¹): 3143, 3025 (C-H stretching, aromatic ring), 2923 (C-H, CH₃), 2203 (C≡N stretching, nitrile group), 1716 (C=O stretching, coumarin ring), 1557, 1597 (>C=N, >C=C< stretching, aromatic ring), 1410 (C-H bending, -CH=N linkage), 1258 (C-O-C coumarin ring), 757 (C-Cl). ¹H NMR (300 MHz, DMSO-d₆, δ ppm): 9.10 (s, 1H, Ar-CH=N-), 9.11 (s, 1H, C4 proton of coumarin), 7.16-7.89 (m, 13H, Ar-H of coumarin ring and phenyl ring), 2.09 (s, 3H, -C(CH₃)=N-). ¹³C NMR (100 MHz, DMSO-d₆, δ ppm): 169.4, 163.9, 160.5, 159.7, 155.3, 153.4, 153.2, 133.6, 133.5, 133.5, 133.1, 132.7, 132.6, 130.3, 128.7, 128.7, 128.5, 128.5, 128.2, 127.8, 127.8, 127.3, 126.7, 125.6, 123.4, 118.2, 116.3, 115.7, 115.7, 115.3, 114.6, 4.7. MS: m/z 543.11 (M⁺). Anal. calcd. For C₃₁H₁₈ClN₅O₅, C, 68.45; H, 3.34; N, 12.87 %. Found: C, 68.36; H, 3.26; N, 12.81 %.

6-((4-chlorobenzylidene)amino)-2-oxo-1-((1-(2-oxo-2H-chromen-3-yl)ethylidene)amino)-4-phenyl-1,2-dihydropyridine-3,5-dicarbonitrile (4j)

Yield: 62 %, m.p. 239-244 °C. IR (KBr, cm⁻¹): 3137, 3021 (C-H stretching, aromatic ring), 2930 (C-H, CH₃), 2217 (C≡N stretching, nitrile group), 1722 (C=O stretching, coumarin ring), 1559, 1591 (>C=N, >C=C< stretching, aromatic ring), 1416 (C-H bending, -CH=N linkage), 1255 (C-O-C coumarin ring), 751 (C-Cl). ¹H NMR (300 MHz, DMSO-d₆, δ ppm): 9.20 (s, 1H, Ar-CH=N-), 9.15 (s, 1H, C4 proton of coumarin), 7.14-7.87 (m, 13H, Ar-H of coumarin ring and phenyl ring), 2.06 (s, 3H, -C(CH₃)=N-). ¹³C NMR (100 MHz, DMSO-d₆, δ ppm): 169.7, 163.6, 160.2, 159.6, 155.5, 153.5, 153.4, 136.6, 133.3, 132.3, 131.7, 130.6, 130.6, 128.7, 128.7, 128.7, 128.7, 128.4, 128.2, 127.7, 127.7, 125.7, 123.5, 118.3, 116.5, 115.9, 115.9, 115.6, 114.4, 4.5. MS: m/z 543.11 (M⁺). Anal. calcd. For C₃₁H₁₈ClN₅O₅, C, 68.45; H, 3.34; N, 12.87 %. Found: C, 68.59; H, 3.42; N, 12.98 %.

6-((4-fluorobenzylidene)amino)-2-oxo-1-((1-(2-oxo-2H-chromen-3-yl)ethylidene)amino)-4-phenyl-1,2-dihydropyridine-3,5-dicarbonitrile (4k)

Yield: 69 %, m.p. 243-246 °C. IR (KBr, cm⁻¹): 3134, 3029 (C-H stretching, aromatic ring), 2934 (C-H, CH₃), 1135 (C-F), 2219 (C≡N stretching, nitrile group), 1719 (C=O stretching, coumarin ring), 1561, 1599 (>C=N, >C=C< stretching, aromatic ring), 1419 (C-H bending, -CH=N linkage), 1260 (C-O-C coumarin ring). ¹H NMR (300 MHz, DMSO-d₆, δ ppm): 9.25 (s, 1H, Ar-CH=N-), 9.07 (s, 1H, C4 proton of coumarin), 7.11-7.92 (m, 13H, Ar-H of coumarin ring and phenyl ring), 2.10 (s, 3H, -C(CH₃)=N-). ¹³C NMR (100 MHz, DMSO-d₆, δ ppm): 169.9, 165.6, 163.2, 160.6,
159.8, 155.9, 153.7, 153.4, 133.9, 132.1, 130.9, 130.9, 129.6, 128.7, 128.7, 128.5, 128.5, 128.1, 127.4, 127.4, 125.4, 123.2, 118.5, 116.4, 115.5, 115.5, 115.3, 115.3, 114.9, 4.7. MS: m/z 527.14 (M+). Anal. calcd. for C31H18FN2O3, C, 70.58; H, 3.44; N, 13.28 %. Found: C, 70.66; H, 3.52; N, 13.34 %.

6-((3-methoxybenzylidene)amino)-2-oxo-1-((1-(2-oxo-2H-chromen-3-yl)ethylidene)amino)-4-phenyl-1,2-dihydropyridine-3,5-dicarbonitrile (4l)

Yield: 74 %, m.p. 206-209 °C. IR (KBr, cm⁻¹): 3133, 3036 (C-H stretching, aromatic ring), 2939 (C-H, CH₃), 2214 (-C=O stretching, nitrile group), 1709 (>C=O stretching, coumarin ring), 1558, 1595 (>C=N-, >C=C< stretching, aromatic ring), 1426 (C-H bending, -CH=N linkage), 1263 (C-O-C coumarin ring), 1214, 1152 (C-O-C). ¹H NMR (300 MHz, DMSO-d₆, δ ppm): 9.05 (s, 1H, Ar-CH=N-), 8.77 (s, 1H, C=O proton of coumarin), 7.03-7.82 (m, 13H, Ar-H of coumarin ring and phenyl ring), 3.73 (s, 3H, -OCH₃), 2.05 (s, 3H, -C(CH₃)=N-). ¹³C NMR (100 MHz, DMSO-d₆, δ ppm): 169.1, 163.9, 162.6, 160.4, 159.8, 155.9, 153.1, 153.0, 133.9, 132.6, 130.5, 130.5, 128.8, 128.8, 128.5, 128.5, 128.1, 127.6, 126.6, 125.6, 123.9, 118.2, 116.3, 115.5, 115.1, 114.8, 114.5, 114.5, 55.4, 4.6. MS: m/z 539.16 (M+). Anal. calcd. For C₃₃H₂₁N₅O₄, C, 71.24; H, 3.92; N, 12.98 %. Found: C, 71.29; H, 3.83; N, 12.91 %.

6-((4-methoxybenzylidene)amino)-2-oxo-1-((1-(2-oxo-2H-chromen-3-yl)ethylidene)amino)-4-phenyl-1,2-dihydropyridine-3,5-dicarbonitrile (4m)

Yield: 70 %, m.p. 214-218 °C. IR (KBr, cm⁻¹): 3126, 3041 (C-H stretching, aromatic ring), 2943 (C-H, CH₃), 2218 (-C=O stretching, nitrile group), 1717 (>C=O stretching, coumarin ring), 1555, 1597 (>C=N-, >C=C< stretching, aromatic ring), 1429 (C-H bending, -CH=N linkage), 1254 (C-O-C coumarin ring), 1210, 1155 (C-O-C). ¹H NMR (300 MHz, DMSO-d₆, δ ppm): 9.20 (s, 1H, Ar-CH=N-), 9.10 (s, 1H, C=O proton of coumarin), 7.05-7.88 (m, 13H, Ar-H of coumarin ring and phenyl ring), 3.86 (s, 3H, -OCH₃), 2.03 (s, 3H, -C(CH₃)=N-). ¹³C NMR (100 MHz, DMSO-d₆, δ ppm): 169.1, 163.9, 162.6, 160.4, 159.8, 155.9, 153.1, 153.0, 133.9, 132.6, 130.5, 130.5, 128.8, 128.8, 128.5, 128.5, 127.6, 126.6, 125.6, 123.9, 118.2, 116.3, 115.5, 115.1, 114.8, 114.5, 114.5, 55.4, 4.6. MS: m/z 539.16 (M+). Anal. calcd. For C₃₃H₂₁N₅O₄, C, 71.24; H, 3.92; N, 12.98 %. Found: C, 71.18; H, 3.89; N, 12.95 %.

2-oxo-1-((1-(2-oxo-2H-chromen-3-yl)ethylidene)amino)-4-phenyl-6-(3,4,5-trimethoxybenzylidene)amino)-1,2-dihydropyridine-3,5-dicarbonitrile (4n)

Yield: 66 %, m.p. 229-233 °C. IR (KBr, cm⁻¹): 3129, 3044 (C-H stretching, aromatic ring), 2946 (C-H, CH₃), 2220 (-C=O stretching, nitrile group), 1702 (>C=O stretching, coumarin ring), 1561, 1596 (>C=N-, >C=C< stretching, aromatic ring), 1433 (C-H bending, -CH=N linkage), 1251 (C-O-C coumarin ring), 1218, 1159 (C-O-C). ¹H NMR (300 MHz, DMSO-d₆, δ ppm): 9.25(s, 1H, Ar-CH=N-), 8.92 (s, 1H, C=O proton of coumarin), 7.12-7.78 (m, 11H, Ar-H of coumarin ring and phenyl ring), 3.83 (s, 9H, -OCH₃), 2.08 (s, 3H, -C(CH₃)=N-). ¹³C NMR (100 MHz, DMSO-d₆, δ ppm): 169.7, 163.5, 160.2, 159.7, 155.3, 153.5, 153.5, 153.2, 141.6, 133.5, 132.5, 128.8, 128.8, 128.5, 128.5, 128.2, 128.0, 127.7, 127.7, 125.6, 123.5, 118.4, 116.6, 115.9, 115.9, 115.5, 114.6, 104.3, 104.3, 60.4, 56.5, 56.5, 4.6. MS: m/z 599.18 (M+). Anal. calcd. For C₃₄H₂₃N₃O₆, C, 68.11; H, 4.20; N, 11.68 %. Found: C, 68.02; H, 4.12; N, 11.72 %.

6-((4-bromobenzylidene)amino)-2-oxo-1-((1-(2-oxo-2H-chromen-3-yl)ethylidene)amino)-4-phenyl-1,2-dihydropyridine-3,5-dicarbonitrile (4o)

Yield: 64 %, m.p. 208-212 °C. IR (KBr, cm⁻¹): 3140, 3035 (C-H stretching, aromatic ring), 2936 (C-H, CH₃), 2207 (-C=O stretching, nitrile group), 1719 (>C=O stretching, coumarin ring), 1552, 1593 (>C=N-, >C=C< stretching, aromatic ring), 1424 (C-H bending, -CH=N linkage), 1267 (C-O-C coumarin ring), 1084, 1012 (C-Br). ¹H NMR (300 MHz, DMSO-d₆, δ ppm): 9.11 (s, 1H, Ar-CH=N-), 9.27 (s, 1H, C=O proton of coumarin), 7.14-7.85 (m, 13H, Ar-H of coumarin ring and phenyl ring), 2.08 (s, 3H, -C(CH₃)=N-). ¹³C NMR (100 MHz, DMSO-d₆, δ ppm): 169.2, 163.9, 160.3, 159.7, 155.8, 153.4, 153.2, 133.7, 132.3, 132.2, 131.6, 131.6, 128.9, 128.9, 128.7, 128.7,
SAR studies

The structure-activity relationships (SAR) of compounds 4a-o were determined on the basis of results presented in Table 1. The substitution pattern on the coumarin based 2-pyridone ring system derivatives was carefully selected to confer different electronic environment of the molecules. From the activity data, compounds containing electron withdrawing group at \( \text{para} \) position lead to enhance bacterial activity. Compounds 4g (4-NO\(_2\)-C\(_6\)H\(_4\)), 4j (4-Cl-C\(_6\)H\(_4\)) and 4k (4-F-C\(_6\)H\(_4\)) containing 4-NO\(_2\), 4-Cl and 4-F group showed highest inhibition at MIC = 12.5-25 \( \mu \)g ml\(^{-1}\) against bacterial strain \( E. \) coli and \( P. \) aeruginosa. Same results observed in compounds 4j (4-Cl-C\(_6\)H\(_4\)) and 4k (4-F-C\(_6\)H\(_4\)) showed highest inhibition at MIC = 12.5-25 \( \mu \)g ml\(^{-1}\) against \( S. \) pyogenes and compound 4o -4-Br group showed highest inhibition at MIC =12.5 \( \mu \)g ml\(^{-1}\) against \( P. \) aeruginosa and \( S. \) aureus. On the basis of screening results, it has been observed that the compound containing electron releasing groups such as -OH, -OCH\(_3\) lead to enhance fungal activity. Compounds 4d (4-OH-C\(_6\)H\(_4\)), 4m (4-OCH\(_3\)-C\(_6\)H\(_4\)) and 4n (-3,4,5-(OCH\(_3\))\(_3\)-C\(_6\)H\(_2\)) exhibited excellent inhibitory action against \( A. \) niger. While compounds 4d (4-OH-C\(_6\)H\(_4\)) and 4m (4-OCH\(_3\)-C\(_6\)H\(_4\)) also showed reasonably excellent inhibition against \( C. \) albicans and \( A. \) clavatus respectively. SAR studies revealed that the presence of electron withdrawing and electron releasing group in title compound increase the antibacterial and antifungal activity respectively.

Conclusion

New coumarin based 2-pyridone derivatives 4a-o were synthesized and screened for their antimicrobial activity. Compounds 4g (4-NO\(_2\)-C\(_6\)H\(_4\)), 4j (4-Cl-C\(_6\)H\(_4\)), 4k (4-F-C\(_6\)H\(_4\)) and 4o (4-Br-C\(_6\)H\(_4\)) exhibit outstanding antibacterial and compounds 4d (4-OH-C\(_6\)H\(_4\)), 4m (4-OCH\(_3\)-C\(_6\)H\(_4\)) and 4n (-3,4,5-(OCH\(_3\))\(_3\)-C\(_6\)H\(_2\)) exhibit antifungal properties. On the basis biological activity results can be concluded that above scaffolds would play an important role in the development of antimicrobial agents in future.

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References


