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Synthesis, Docking and Antimicrobial Activity of Some New Coumarin Incorporated Thiazole Derivatives

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Original Research Article

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ABSTRACT

Synthesis and screening of a series of new coumarin derivatives coupled with thiazole are performed for their antimicrobial properties. A series of new thiazolyl coumarin derivatives were synthesized upon refluxing 3-bromoaceytl coumarin, substituted benzaldehyde and thiosemicarbazide in the presence of glacial acetic acid. Substituted 3-acetyl coumarin undergoes bromination in the presence of bromine and chloroform to form 3-Bromoaceytl coumarin. The thiazolyl coumarin derivatives were characterized based on IR, ^{1}H NMR, and Mass spectral data. The docking studies have been carried out against the enzyme DNA gyrase (1KZN). Compound SCT 2 showed the highest docking score -5.662 compared to other compounds. The final synthesized compounds were screened for their antibacterial activity by tube dilution method. Compound SCT 1 and SCT 2 showed significant antibacterial activity with minimum inhibitory concentration of 12.5µg/ml and 6.25µg/ml, respectively, compared to standard Cephalosporin. The MIC results suggest that compounds SCT 1 and SCT 2 showed promising antibacterial activity. So these compounds are interesting lead molecules for further synthesis as antimicrobial agents.

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1. INTRODUCTION

Exposure of resistance by fungal and bacterial strains for already existing antimicrobial agents is one of the crucial problems and also a motive to synthesize a new class of antimicrobial agents having potential activity compared to the commonly used therapy. The structurally attractive compounds for synthesizing antimicrobial agents are coumarin derivatives. The issue is more critical than that can be imagined because of the frequent genetic development of pathogenic bacterial strains by accomplishing resistance to antibiotics/ drugs that were often not used for treatment. Sadly, newer resistant bacteria develop continually with new antibiotics or freshly launched drugs. Around 17 million people die from infectious diseases every year, and approximately 50,000 people are infected [1]. As a result, the evolution of new antibacterial drug candidates remains the future scope.

Numerous reports state that synthetic and natural Coumarin derivatives own antimicrobial activity [2-6]. Chlorobiocin and Novobiocin are acknowledged antimicrobials consisting of Coumarin (i.e.*2H*-1-benzopyran-2-ones) skeleton. Several Coumarin derivatives have been reported for antiviral, antiproliferative, anticancer, antiallergic, antioxidant, anti-HIV, anti-inflammatory, and anticoagulant activities. It was discovered that enhanced biological activity was produced when one biodynamic heterocyclic system was coupled with another heterocyclic system. The growing problem in treating infectious diseases caused by fungi and bacteria is drug resistance [7]. The discovery and evolution of beneficial antifungal and antibacterial [8]. drugs with novel action mechanisms have turned out to be serious duties for infectious disease research programs [9]. Coumarins present a variety of bioactivities, including estrogenic, dermal photosensitizing, antimicrobial, vasodilator, anticoagulant, molluscicidal, antihelmintic, sedative, and hypnotic, analgesic, and hypothermic actions. [10]. Additionally, coumarins' pharmacological properties and therapeutic applications rely on the substitution pattern. In recent times, they are stated to have several pharmacological activities, such as antimicrobial activity. Some of the coumarin drugs with antimicrobial activity are 2-quinoxalone-coumarin hydrazone, 3-acetylcoumarin-isonicotinic acid hydrazide hybrid, coumarin fused with tetrahydroisoquinoline, 4-methyl 7-hydroxy coumarin thiosemicarbazone, 4-methyl coumarin bearing thiazolidinone, 3-aminoalkyl-4-hydroxy coumarin, thiazolyl hydrazonyl substituted coumarin, 3,4,7-trisubstituted coumarin, 4-amino alkylated coumarin, etc.

Small ring heterocycles, including sulfur and nitrogen, have been investigated for a long time because of their therapeutic relevance and synthetic diversity. Amongst the extensive range of heterocycles inspected by elite prospects in the discovery of drugs, it is identified that thiazoles play a vital role in medicinal chemistry. [11] Thiazole ring is a structural fragment of natural compounds such as carboxylase, epothilones, thiamine pyrophosphate (TPP, a coenzyme essential in respiration in the Krebs cycle), thiamine (vitamin B1), and the large family of macrocyclic thiopeptide antibiotics, micrococcin P1 and thiostrepton. [12] Thiazole derivatives are related with a broad spectrum of biological properties, including hypnotics, HIV infections, schizophrenia, inflammation, hypertension, anticancer, antimalarial, antiviral, antituberculous, antimicrobial, anticonvulsant, bacteriostatic activities, and very recently for the treatment of pain, as fibrinogen receptor antagonists with anti-thrombotic activity, as new inhibitors of bacterial DNA gyrase B. [13–15] They are also used in the drug development application for allergy treatment. [16] It is reported in the literature that when the thiazole ring is coupled with coumarins, the biological activity gets enhanced manifold. The challenges of antibacterial research are significant, and a good start towards developing a new class of hybrid antimicrobials and the aid of computer-aided drug design may deliver new antimicrobials to the clinic. Based on the above observation, it is worthwhile to prepare newer compounds for their antimicrobial activity.

2. MATERIALS AND METHODS

2.1 Materials

All chemicals used are of analytical grade: Salicylaldehyde, ethyl acetoacetate, piperidine, ammonium acetate, ethanol, substituted benzaldehyde, and sodium hydroxide. Determinations of melting points was done by the open capillary method and are uncorrected. The purity of the final compounds and intermediates

was checked by thin layer chromatography (TLC) using silica gel G plates. The spots were made visible under UV light. n-hexane: Ethylacetate (5:5) was used as a solvent for running the TLC of these compounds. All IR spectra were registered using the ATR method in Alpha Bruker. ^{1}H NMR spectra were recorded at 400 MHz Bruker Avance II NMR Spectrometer. The mass spectrum was recorded on GC-MS Perkin Elmer Clarus 680 Spectrometer obtained by electron impact ionization method.

2.2 General Procedure for the Synthesis of 3-Acetyl Coumarin

A mixture of salicylaldehyde (0.05 mol) and ethylacetoacetate was added to 250ml conical flask. It was then condensed by adding sufficient piperidine dropwise with stirring in ice-cold condition. The reaction mixture was then kept overnight in the refrigerator. The solid lumps were broken in cold ethanol. The resulting yellow-colored solid mass was filtered and washed with cold ethanol to remove the excess piperidine. It was then recrystallized from ethanol to give white needle-shaped crystals.

2.3 General Procedure for the Synthesis of 3-Bromo Acetyl Coumarin

3-acetyl-*2H*-chromene-2-one (0.01 mol) was dissolved in chloroform (0.1mol), and a solution of Bromine (0.01 mol) in chloroform was added drop-wise with continuous stirring, and mixture was kept in the water bath at 70^{o}C. The progression of the reaction was observed by thin layer chromatography. After the completion of the reaction, judged by TLC, the reaction mixture was washed with diethyl ether and recrystallized using ethanol to provide 3-(2-bromoacetyl)-2H-chromen-2-one.

2.4 General Procedure for the Synthesis of Thiazolyl Coumarin Derivatives (SCT1-SCT12)

An equimolar mixture of 3-Bromo Acetyl Coumarin (0.05 mol), thiosemicarbazide (0.05 mol), and various substituted benzaldehyde (0.05 mol) was refluxed in the presence of glacial acetic acid (2 ml) for 4-5 hours. The reaction mixture was transferred into crushed ice and stirred well until the product was formed. It was filtered, dried, and recrystallized using ethanol.

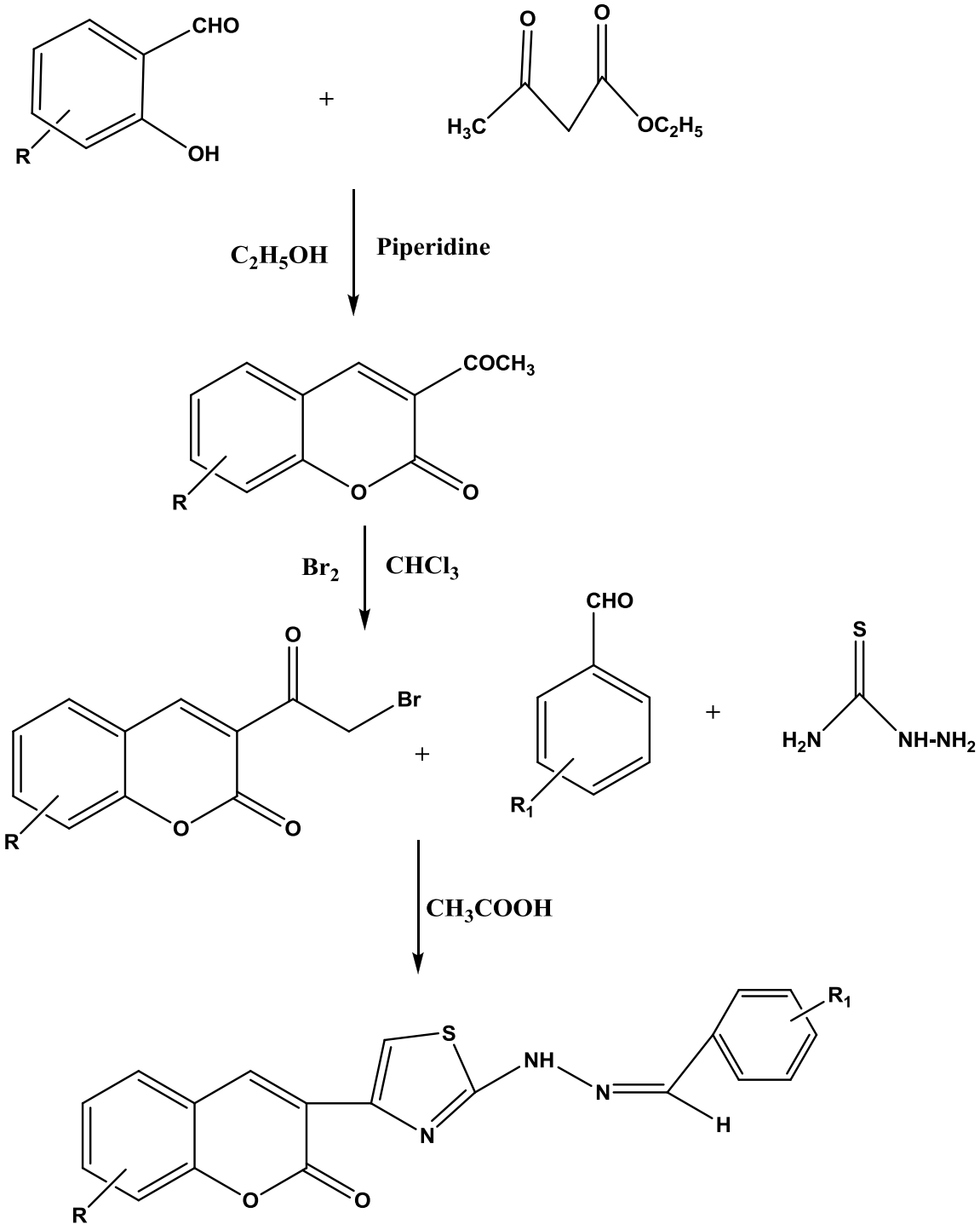
2.5 Minimum Inhibitory Concentration

The broth dilution test is one of the standard method for determining the level of resistance to an antibiotic. Serial dilutions of the antibiotic are made in a liquid medium inoculated with a standardized number of organisms and incubated for a prescribed time. The lowest concentration of antibiotic preventing the appearance of turbidity is considered to be the minimal inhibitory concentration (MIC). After preparing different concentrations of the test compound in nutrient broth (using the broth dilution method), we inoculate them with the test organism. The MIC is determined after incubation by choosing the lowest concentration in which no growth occurs. The MIC and the zone of inhibition are inversely correlated. In other words, the more susceptible the microorganism is to the antimicrobial agent, the lower the MIC and the larger the zone of inhibition. Conversely, the more resistant the microorganism, the higher the MIC and the smaller the zone of inhibition. The method gives information on the storage of standard antibiotic powder, preparation of the stock antibiotic solution, media, preparation of inocula, incubation condition, and reading and interpretation of results [17].

2.6 Procedure

Double concentration of the nutrient broth was prepared. Distribute each 2.5 ml into 8 test tubes and label them A1 to A8. Distribute 2.5 ml in two test tubes and label them as positive control and negative control. Prepare a drug stock solution of 2000 µg/ml by dissolving the drug in water. From this stock solution, the following dilutions were prepared; 2.5 ml of the stock solution diluted to 25 ml with water to give 200 µg/ml. Serial dilution of the same was performed to give 100 µg/ml, 50 µg/ml, 25 µg/ml, 12.5 µg/ml and 6.25 µg/ml respectively. Add 2.5 ml of each double concentration nutrient broth to 2.5 ml of the above dilutions so that the concentration further gets halved. i.e., 100 µg/ml, 50 µg/ml, 25 µg/ml, 12.5 µg/ml, 6.25 µg/ml and 3.12 µg/ml respectively. 2.5 ml of water was added to positive control and negative control tube and well mixed. Mix all the tubes well close with nonabsorbent cotton plugs and sterilize by autoclaving 15 lbs./sq. in (121°C) for 15 min.

Cooled the tubes to room temperature and inoculated all the tubes with one loopful of the test organism *Escherichia coli* , except in the negative control tube. Incubated all the tube at 37°C for 48 hrs and observed the turbidity.



Thiazolyl Coumarin Derivatives (SCT1-SCT12)

Scheme 1. Synthesis of Thiazolyl Coumarin Derivatives

Negative control: In this, no growth is expected. It confirms that the medium is sterile.

Positive control: In this the growth of the inoculated organism is expected. This indicates that (a) The nutrient of the medium supports the growth of organism that has been inoculated. (b) Inoculation of live organisms.

2.7 Molecular Docking Study

Molecular docking study was done to understand the interconnections between receptor and ligand (synthesized compounds). In silico analysis was performed on Schrodinger 2018-3 suite device Maestro 11.7.012, (Ligprep, Glide XP docking, QikProp), this software package programmed on DELL Inc.27" workstation machine running on Intel Core i7-7700 CPU @ 3.60 GHz x8, the processor with 8 GB RAM and 1 TB hard disk with Linux –X6_64 as the operating system. QikProp was used to predict the ADME properties of synthesized compounds. For docking calculation, the protein (PDB code: 1KZN) was downloaded from the protein data bank and refined using the protein preparation wizard. Assessment of binding affinity was done in terms of binding free energies (S-score, kcal/mol). The synthesized compounds were all docked in the groove of the binding site present in DNA Gyrase 1KZN.

3. RESULTS

3.1 Spectral Data

3-(2-(2-(4-hydroxybenzylidene) hydrazinyl) thiazol-4-yl)-2*H*-chromen-2-one (SCT1)

IR (cm^{-1}): 1571 (Ar C=C str), 1709 (C=O str of δ lactone), 1600 (C=N str), 3314 (NH str), 3650 (OH-phenolic str).

^{1}H NMR (400 MHz, DMSO-d_6): δ 11.493 (s, NH, 1H), 10.012 (s, 1H, OH), 7.120-8.627 (m, 10H, Ar-H)

Mass (m/z): 363 (M^+)

3-(2-(2-(4-chlorobenzylidene) hydrazinyl) thiazol-4-yl)-2*H*-chromen-2-one (SCT2)

IR (cm^{-1}): 1483 (C=C str), 1725 (C=O str of δ lactone), 1601 (C=N str), 3486 (NH str), 749 (C-Cl str).

^{1}H NMR (400 MHz, DMSO-d_6): δ 11.482 (s, NH, 1H), 7.160-8.727 (m, Ar-H, 10H), 7.405-8.727 (m, 1H, thiazole).

Mass (m/z): 382 (M^+)

3-(2-(2-(4-bromobenzylidene) hydrazinyl) thiazol-4-yl)-6-nitro-2*H*-chromen-2-one (SCT3)

IR (cm^{-1}): 1592 (Ar C=C str), 1704 (C=O str of δ lactone), 1517 (C=N str), 3467 (NH str), 1362 (NO_2 str), 627 (C-Br str).

^{1}H NMR (400 MHz, DMSO-d_6): δ 11.487 (s, NH, 1H), 7.609-8.713 (m, 1H, thiazole), 7.591-8.713 (m, Ar-H, 9H).

Mass (m/z): 472 (M+1)

6-bromo-3-(2-(2-(4-hydroxybenzylidene) hydrazinyl) thiazol-4-yl)-2*H*-chromen-2-one (SCT6)

IR in cm^{-1}: 1464 (Ar C=C str), 1678 (C=O str of δ lactone), 1507 (C=N str), 3125 (NH str), 644 (C-Br str), 3511 (OH-phenolic str).

^{1}H NMR (400 MHz, DMSO-d_6): δ 7.002-8.611 (m, Ar-H, 9H), 11.420 (s, NH, 1H), 9.875 (s, OH, 1H), 7.419-8.611 (m, 1H, thiazole).

Mass (m/z): 443 (M+1)

6-chloro-3-(2-(2-(3,4-dimethoxybenzylidene) hydrazinyl) thiazol-4-yl)-2*H*-chromen-2-one (SCT9)

IR in cm^{-1}: 1510 (C=C str), 1685 (C=O str of δ lactone), 1540 (C=N str), 3328 (NH str), 806 (C-Cl str), 1229 (C-O str).

^{1}H NMR (400 MHz, DMSO-d_6): δ 7.009-8.643 (m, Ar-H, 8H), 11.318 (s, NH, 1H), 3.511 (s, 6H, OCH_3), 7.398-8.643 (m, 1H, thiazole).

Mass (m/z): 443 (M+1)

3-(2-(2-(4-bromobenzylidene) hydrazinyl) thiazol-4-yl)-6-chloro-2*H*-chromen-2-one (SCT12)

IR in cm^{-1}: 1463 (C=C str), 1714 (C=O str of δ lactone), 1602 (C=N str), 2921 (NH str), 731 (C-Cl str), 612 (C-Br str).

^{1}H NMR (400 MHz, DMSO-d_6): δ 11.326 (s, NH, 1H), 7.112-8.608 (m, 9H, Ar-H)

Mass (m/z): 462 (M+1)

Table 1. Physical Data of Thiazolyl Coumarin Derivatives

Comp code	R	R^1	Mol. Formula	Mol. Wt	m.p (°C)	% Yield
SCT 1	H	4-OH	$C_{19}H_{13}N_3O_3S$	363	182-184	89%
SCT 2	H	4-Cl	$C_{19}H_{12}ClN_3O_2S$	382	180-182	81%
SCT 3	6-NO_2	4-Br	$C_{19}H_{11}BrN_4O_4S$	471	161-163	78%
SCT 4	6-NO_2	3,4-OCH_3	$C_{21}H_{16}N_4O_6S$	452	169-171	69%
SCT 5	6-NO_2	4-OH	$C_{19}H_{12}N_4O_5S$	408	153-155	87%
SCT 6	6-Br	4-OH	$C_{19}H_{12}BrN_3O_3S$	442	177-179	74%
SCT 7	6-Br	3,4-OCH_3	$C_{21}H_{16}BrN_3O_4S$	486	134-136	83%
SCT 8	6-Br	4-$N(C_2H_5)_2$	$C_{23}H_{21}BrN_4O_2S$	490	182-184	77%
SCT 9	6-Cl	3,4-OCH_3	$C_{21}H_{16}ClN_3O_4S$	442	178-180	80.6%
SCT 10	6-Cl	4-$N(C_2H_5)_2$	$C_{23}H_{21}ClN_4O_2S$	453	166-168	78%
SCT 11	6-Cl	4-OH	$C_{19}H_{12}ClN_3O_3S$	398	164-166	89%
SCT 12	6-Cl	4-Br	$C_{19}H_{11}BrClN_3O_2S$	461	121-123	84%

Table 2. Docking score of thiazolyl coumarin derivatives with 1KZN

Comp code	Docking score
SCT1	-5.482
SCT2	-5.662
SCT3	-4.913
SCT4	-4.968
SCT5	-4.511
SCT6	-4.442
SCT7	-4.883
SCT8	-3.806
SCT9	-4.662
SCT10	-4.416
SCT11	-4.633
SCT12	-4.668
Ciprofloxacin	-5.746

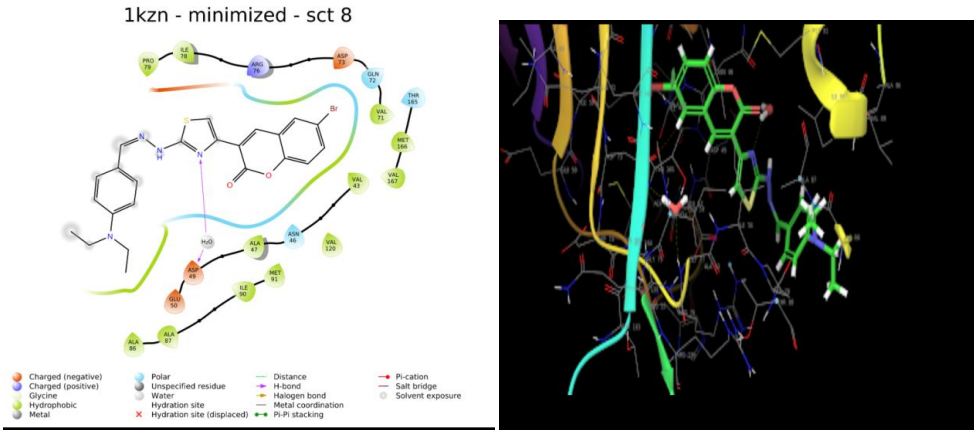


Fig. 1. 2D and 3D ligand interaction of compound SCT 8 with 1KZN

Table 3. Antibacterial activity of thiazolyl coumarin derivatives (SCT 1-SCT 12)

Comp code	100 µg/ml	50 µg/ml	25 µg/ml	12.5 µg/ml	6.25 µg/ml	3.12 µg/ml	1.2 µg/ml
SCT 1	-	-	-	-	+	+	+
SCT 2	-	-	-	-	-	+	+
SCT 3	-	-	-	+	+	+	+
SCT 4	-	-	+	+	+	+	+
SCT 5	-	-	+	+	+	+	+
SCT 6	-	-	+	+	+	+	+
SCT 7	-	-	-	+	+	+	+
SCT 8	-	-	-	+	+	+	+
SCT 9	-	-	+	+	+	+	+
SCT 10	-	-	+	+	+	+	+
SCT 11	-	-	-	+	+	+	+
SCT 12	-	-	-	+	+	+	+

+: Growth, -: No growth

Table 4. Antimicrobial activity of thiazolyl coumarin derivatives (SCT 1-SCT 12) by tube dilution method

Comp code	MIC (µg/ml)
SCT 1	12.5
SCT 2	6.25
SCT 3	25
SCT 4	50
SCT 5	50
SCT 6	50
SCT 7	25
SCT 8	25
SCT 9	50
SCT 10	50
SCT 11	25
SCT 12	25
Positive control	+
Negative control	-

4. DISCUSSION

4.1 Chemistry

The conventional method has been used to synthesize new series of thiazolyl coumarin derivatives using substituted benzaldehyde and thiosemicarbazide, as given in Scheme 1. The structure of all the synthesized compounds was confirmed on the basis of. IR, ^{1}H NMR, and Mass Spectroscopy. Molecular docking was performed for target protein 1KZN.

The synthesized thiazolyl coumarin derivatives yield was obtained in the range of 74-89%. IR spectra showed characteristic absorption bands 1678-1725 (C=O str of δ lactone) coumarin. The IR spectra of final compounds showed a characteristic absorption band at 1517 (C=N str), 3467 (NH str), which was absent in the intermediate 3-Bromoacetyl coumarin. Similarly, the ^{1}H NMR of the synthesized thiazolyl coumarin derivatives showed a characteristic signal at 11.420 (s, NH, 1H), 7.419-8.611 (m, 1H, thiazole), which was absent in the ^{1}H NMR spectra of 3-Bromoacetyl coumarin. Hence the formation of the thiazolyl coumarin derivatives was confirmed and further established by mass spectra which are in accordance with the molecular formula.

Final synthesized compounds SCT1-SCT12 interacted with receptor DNA Gyrase (PDB code: 1KZN), and their binding energy and interaction pattern was studied. Compounds SCT1-SCT12 showed the binding energy in the range of -3.806 to -5.662 kcal/mol. Compound SCT2 showed the best interaction with the receptor and binding energy of -5.662 kcal/mol. These compounds interacted with forces such as hydrogen bond,

hydrophobic interaction, charged negative, charged positively with the various amino acid of the receptor. Best docked compound SCT2 forms one hydrogen bond with amino acid VAL-43, hydrophobic interaction with amino acid ALA-47, ILE-78, PRO-79, charged negatives ARG-76, LYS-21, MET-166, and polar interaction ASP-73 and THR-165 of the receptor DNA Gyrase.

4.2 Antibacterial Activity

The different thiazolyl coumarin derivatives were evaluated for their antibacterial activity by Tube dilution method. Compound SCT1 and SCT2 showed significant antibacterial activity with MIC of 12.5µg/ml and 6.25µg/ml respectively compared to standard Cephalosporin as given in Table 3 and 4. The presence of electron donating groups like hydroxyl and electron withdrawing group like chloro resulted in increased antibacterial activity. Compound SCT1 and SCT2 resulted in increased antibacterial activity due to the unsubstituted coumarin moiety and the presence of electron donating hydroxyl group and electron withdrawing chloro group in the phenyl ring.

5. CONCLUSION

The study reports the successful synthesis of thiazolyl coumarin derivatives from cyclization of 3-Bromoacetyl coumarin with moderate yields. Thiazole incorporated coumarin ring was synthesized by the new synthetic route, and few compounds have shown significant antibacterial activity by tube dilution method. Compound SCT2 showed the highest docking score compared to other compounds, which also showed significant antibacterial activity with MIC of 6.25µg/ml. Compounds SCT1 and SCT2 might be useful as a lead molecule for pharmaceutical industries. So the current work requires further structural modification to get better antimicrobial actions.

CONSENT

It is not applicable.

ETHICAL APPROVAL

It is not applicable.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Holmes KK, Bertozzi S, Bloom BR, Jha P, Gelband H, DeMaria LM et al. Major Infectious Diseases: Key Messages from Disease Control Priorities. Arab J Chem. 2017;3(6):1-54.
   Available: https://doi.org/10.1596/978-1-4648-0524-0_ch1
2. Amarnath A, Lenin V, Archunan G. Evaluation of the hypolipidemic activity of 6,7-dimethoxycoumarin on placental tissue factor mRNA expression in experimental anti-phospholipid syndrome. Pharmacogn Mag. 2013;9(35):264-70.
   DOI: 10.4103/0973-1296.113287
3. Wangboonskul J, Tunsirikongkon A, Sasithornwetchakun W. Simultaneous determination of nine analytes in Clausena harmandiana Pierre. by new developed high-performance liquid chromatography method and the influence of locations in Thailand on level of nordentatin and dentatin. Pharmacogn Mag. 2015;11(41): 1-7.
   DOI: 10.4103/0973-1296.149666
4. Ranasinghe P, Perera S, Gunatilake M, Abeywardene E, Gunapala N, Premakumara S et al. Effects of Cinnamomum zeylanicum (Ceylon cinnamon) on blood glucose and lipids in a diabetic and healthy rat model. Phcog Res. 2012;4(2):73-79.
   Available: https://doi.org/10.4103/0974-8490.94719
5. Patel PB, Patel TK, Baxi SN, Acharya HR, Tripathi C. Antitubercular effect of 8-[(4-Chloro phenyl) sulfonyl]-7-Hydroxy-4-Methyl-2*H*-chromen-2-One in guinea pigs. J Pharmacol Pharmacother. 2011;2:253-60.
   DOI: 10.4103/0976-500X.85951
6. Khan MS, Agrawal R, Ubaidullah M, Hassan MI, Tarannum N. Design, synthesis and validation of anti-microbial coumarin derivatives: An efficient green approach. Heliyon. 2019;5(10):e02615.
   DOI.ORG/10.1016/J.HELIYON.2019.E02615
7. Raman N, Sakthivel A, Rajasekaran K. Synthesis and spectral characterization of antifungal sensitive Schiff base transition metal complexes. Mycobiology. 2007;35(3):150-53.
   Available:https://doi.org/10.4489/MYCO.2007.35.3.150

8. Ironmonger A, Whittaker B, Baron AJ, Clique B, Adams CJ, Ashcroft AE et al. Scanning conformational space with a library of stereo- and regiochemically diverse aminoglycoside derivatives: The discovery of new ligands for RNA hairpin sequences. Org Biomol Chem. 2007;5: 1081-86.
Available:https://doi.org/10.1039/b618683a
9. Kumar G, Kumar D, Devi S, Verma R, Johari R. Synthesis, spectral characterization of biologically active compounds derived from oxalyldihydrazide and 5-tertbutyl-2-hydroxy-3-(3- phenylpent-3-yl)benzaldehyde and their Cu(II), Ni(II) and Co(II) Complexes. Int J Eng Sci Technol. 2011;1(3):1630-35.
10. Parmer S, Kumar R. Substituted quinazolone hydrazides as possible antituberculous agents. J Med Chem. 1968;11:635-36.
Available:https://doi.org/10.1021/jm00309a064
11. Parekh NM, Juddhawala KV, Rawal BM. Antimicrobial activity of thiazolyl benzenesulfonamide-condensed 2, 4-thiazolidinediones derivatives. Med Chem Res. 2013;6(22):2737-45.
Available:http://dx.doi.org/10.1007%2Fs00044-012-0273-x
12. Yadlapalli RK, Chourasia OP, Jogi MP, Podile AR, Perali RS. Design, synthesis and in vitro antimicrobial activity of novel phenylbenzamido-aminothiazole-based azasterol mimics. Med Chem Res. 2013; 6(22):2975-83.
13. Banothu J, Vaarla K, Bavantula R, Crooks PA. Sodium fluoride as an efficient catalyst for the synthesis of 2,4-disubstituted-1,3-thiazoles and selenazoles at ambient temperature. Chin Chem Lett. 2014;1(25): 172-75.
Available:https://doi.org/10.1016/j.cclet.2013.10.001
14. Gouda MA, Berghot MA, Abd El-Ghani GE, Khalil AM. Synthesis and antimicrobial activities of some new thiazole and pyrazole derivatives based on 4,5,6,7-tetrahydrobenzothiophene moiety. Eur J Med Chem. 2010;4(45):1338-45.
Available:https://doi.org/10.1016/j.ejmech.2009.12.020
15. Lv PC, Wang KR, Yang Y, Mao WJ, Chen J, Xiong J et al. Design, synthesis and biological evaluation of novel thiazole derivatives as potent FabH inhibitors. Bioorg Med Chem Lett. 2009;23(19): 6750-54.
DOI: 10.1016/j.bmcl.2009.09.111
16. Zablotskaya A, Segal I, Geronikaki A, Eremkina T, Belyakov S, Petrova M et al. Synthesis, physicochemical characterization, cytotoxicity, antimicrobial, anti-inflammatory and psychotropic activity of new N-[1,3-(benzo)thiazol-2-yl]-ω-[3,4-dihydroisoquinolin-2(1*H*)-yl]al-Kanamides. Eur J Med Chem. 2013;23(70):846-56.
DOI: 10.1016/j.ejmech.2013.10.008
17. Andrews JM. Determination of minimum inhibitory concentrations. J Antimicrob Chemother. 2001;48(S1):5-16.
DOI: 10.1093/jac/48.suppl_1.5

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