

STEPWISE SYNTHESIS AND MULT SPECTROSCOPIC CHARACTERIZATION OF A 4-HYDROXYPHENYL-FUNCTIONALIZED BENZIMIDAZOLE BIS-IMINE AND ITS BIS(THIAZOLIDIN-4-ONE) DERIVATIVE

Kamal Yaseen Ali *

University of Kirkuk College of pharmacy.

* Corresponding Author

ORCID Details

Kamal Yaseen Ali: <https://orcid.org/0009-0005-3778-3736>

International Journal of Chemical and Pharmaceutical Research Updates, 2026, 07(01), 091–100

Publication history: Received on 17 August 2026; revised on 24 September 2026; accepted on 26 September 2026

Article DOI: <https://doi.org/10.53430/ijcpru.2026.7.1.0050>

Copyright © 2026 Author(s) retain the copyright of this article. This article is published under the terms of the Creative Commons Attribution License 4.0

ABSTRACT

A para-hydroxyphenyl-functionalized benzimidazole sequence was prepared through two consecutive carbonyl-amine condensations followed by thioglycolic-acid-mediated cyclization. 4-(1H-Benzimidazol-2-yl)aniline (K1) was condensed with 4-aminoacetophenone to give the amino-ketimine K2, and the remaining para-amino group was subsequently reacted with 4-hydroxybenzaldehyde to furnish the unsymmetrical bis-imine K3. Treatment of K3 the corresponding bis(thiazolidin-4-one) compound was obtained by cyclization with thioglycolic acid using anhydrous ZnCl_2 as a catalyst derivative K4. For K3, FTIR showed the phenolic/benzimidazole stretching region, conjugated imine bands and an aryl C–O absorption, while the ^1H and ^{13}C NMR spectra were consistent with the extended aromatic-imine framework. Cyclization to K4 was supported by the appearance of a strong thiazolidin-4-one C=O band at 1746 cm^{-1} , a carbonyl-carbon resonance at $\delta\ 170.19\text{ ppm}$ and new ^1H NMR resonances at $\delta\ 4.81$ and 3.75 ppm . High-resolution mass measurements closely matched the calculated $[\text{M}+\text{H}]^+$ values for K1–K4, and elemental analyses were consistent with the proposed molecular compositions. The combined analytical data establish a spectroscopically traceable para-hydroxy member of this benzimidazole bis-imine/thiazolidin-4-one series.

Keywords: Benzimidazole; Schiff base; Bis-imine; 4-hydroxybenzaldehyde; Thiazolidin-4-one; Thioglycolic acid; FTIR; ^1H NMR; ^{13}C NMR; HRMS

1 INTRODUCTION

Benzimidazole is a privileged fused N-heterocyclic scaffold that has been widely used in ligand design, medicinal chemistry, and functional molecular systems due to its rigid aromatic skeleton, donor/acceptor sites, and high substitution tolerance [2]. Recent benzimidazole–Schiff base studies illustrate how incorporation of imine linkages can extend conjugation and provide structurally tunable hybrid molecules that are readily characterized by vibrational, NMR and mass-spectrometric methods [3].

Schiff-base formation offers a direct route for elaborating benzimidazole-containing amines. Condensation of a primary amine with an aldehyde or ketone replaces the precursor carbonyl/amino combination with a C=N unit, and the resulting transformation can be followed by changes in the FTIR imine region together with characteristic ^1H and ^{13}C NMR resonances. For multi-step systems, the most reliable structural interpretation is obtained from the combined evolution of several independent spectral markers rather than from a single absorption or resonance [4].

In the present sequence, 4-hydroxybenzaldehyde was selected as the second carbonyl component. The para-hydroxyphenyl terminus introduces a phenolic O–H donor and an aryl C–O environment that provide additional spectroscopic handles[5], while the electron-donating hydroxyl substituent distinguishes this derivative from para-alkyl and para-halo analogues[6]. The resulting unsymmetrical bis-imine therefore permits the influence of a hydrogen-bonding terminal substituent to be followed across the imine-to-thiazolidinone transformation [7].

Thiazolidin-4-ones are widely studied five-membered N,S-heterocycles, and imine cyclocondensation with thioglycolic (mercaptoacetic) acid is a well-established route to this framework[8]. Ring closure converts the planar C=N functionality into a saturated N–C–S environment and introduces a lactam-type carbonyl; accordingly, the transformation is commonly supported by the emergence of a strong thiazolidinone C=O band and new aliphatic NMR environments, considered together with attenuation of the precursor imine features [9–12].

The immediate synthetic background is particularly relevant to the present design. Adnan et al. reported the preparation of 4-(1H-benzimidazol-2-yl)aniline, its condensation with 4-aminoacetophenone, subsequent reaction with substituted aromatic aldehydes, and conversion of the resulting imines to thiazolidin-4-one derivatives [13–14]. More recent studies have continued to develop benzimidazole/thiazolidin-4-one hybrids and have emphasized combined IR, NMR and mass-spectrometric characterization [5]. A closely related 2026 series employed the same benzimidazole–ketimine core with para-methyl- and para-bromobenzaldehydes before bis(thiazolidin-4-one) formation [15]. Against that background, the present work examines the para-hydroxybenzylidene member and focuses on the stepwise analytical signatures associated with the hydroxyl-substituted terminus.

The objectives were therefore to prepare the K1–K4 sequence, characterize formation of the amino-ketimine K2 and unsymmetrical hydroxy-substituted bis-imine K3, examine the subsequent bis-cyclization to K4, and integrate FTIR, ^1H NMR, ^{13}C NMR, HRMS and elemental-composition evidence into a consistent structural assignment. Because the final cyclization generates stereogenic centers and no chiral source was used, the structural discussion is restricted to constitutional assignment; absolute or relative stereochemistry is not assigned from the one-dimensional NMR data.

2 EXPERIMENTAL

2.1 Chemicals and instrumentation

o-Phenylenediamine, 4-aminobenzoic acid, 4-aminoacetophenone, 4-hydroxybenzaldehyde, thioglycolic acid, anhydrous zinc chloride, hydrochloric acid, ethanol, 1,4-dioxane and sodium bicarbonate were of analytical grade and were used as received. Reaction progress and product homogeneity were followed by thin-layer chromatography on silica-gel plates. FTIR spectra were recorded over 4000–400 cm^{-1} using KBr pellets. ^1H NMR and ^{13}C NMR spectra were acquired in $\text{DMSO}-d_6$, and chemical shifts (δ) are reported in ppm relative to residual solvent signals. Melting points were determined by the capillary method. High-resolution mass spectrometry and elemental analysis were used to evaluate molecular composition; calculated and experimental values are summarized in Tables 1 and 2.

2.2 Preparation of 4-(1H-benzimidazol-2-yl)aniline (K1)

The benzimidazole precursor was prepared by acid-promoted cyclocondensation following the reported sequence [13,15]. Equimolar amounts of o-phenylenediamine and 4-aminobenzoic acid (0.01 mol each) were dissolved in 20 mL of 4 M hydrochloric acid and refluxed for 30 min. The reaction mixture was then allowed to cool, and the resulting precipitate was isolated by filtration, thoroughly rinsed with water, dried, and finally purified by recrystallization from absolute ethanol. K1 was obtained as a pale-yellow solid in 77% yield, mp 209–211 °C.

2.3 Preparation of the amino-ketimine intermediate K2

K1 A mixture containing 0.01 mol of each reactant and 4-aminoacetophenone was refluxed in ethanol (20 mL) for 2 h. according to the precursor sequence described for related derivatives [13,15]. The mixture was cooled and left undisturbed for approximately 24 h to complete crystallization. The product was filtered, dried and recrystallized from ethanol to give 4-[1-{{4-(1H-benzimidazol-2-yl)phenyl}imino}ethyl]aniline (K2) as a purple crystalline solid in 65% yield, mp 218–220 °C.

2.4 Preparation of the 4-hydroxyphenyl bis-imine K3

K2 (0.01 mol) and 4-hydroxybenzaldehyde (0.01 mol) were dissolved in ethanol (30 mL) and heated under reflux for approximately 20 min. After cooling, The reaction mixture was left undisturbed for 24 h, after which the precipitated product was collected by filtration, dried, and purified by recrystallization from ethanol to yield 4-[1-({4-(1H-benzimidazol-2-yl)phenyl}imino)ethyl]-N-(4-hydroxybenzylidene)aniline. (K3) as a golden-yellow to orange solid in 63% yield, m.p 165–170 °C (dec.).

2.5 Preparation of the bis(thiazolidin-4-one) product K4

A mixture of K3 (0.001 mol) and thioglycolic acid (0.002 mol) was prepared in 1,4-dioxane (20 mL), followed by addition of anhydrous ZnCl₂ (0.7 g), using the cyclization conditions applied to related imine substrates [13,15]. The reaction mixture was refluxed for 8 h and then allowed to cool. The formed precipitate was separated by filtration, washed first with aqueous sodium bicarbonate to remove residual acidic species, and subsequently rinsed with water. The solid was dried and recrystallized from absolute ethanol to afford K4 as a dark-brown solid in 71% yield, mp 205–210 °C (dec.).

2.6 Molecular and analytical data

The molecular formulas, calculated molar masses, monoisotopic exact masses and corresponding protonated [M+H]⁺ values are listed in Table 1. Physical properties, yields, HRMS results and elemental analyses are summarized in Table 2.

Table 1: Molecular identities and calculated mass data for K1–K4.

Compound	Systematic name	Formula	Molar mass (g mol ⁻¹)	Exact mass; [M+H] ⁺ (m/z)
K1	4-(1H-Benzimidazol-2-yl)aniline	C ₁₃ H ₁₁ N ₃	209.25	209.0953; 210.1026
K2	4-[1-({4-(1H-benzimidazol-2-yl)phenyl}imino)ethyl]aniline	C ₂₁ H ₁₈ N ₄	326.40	326.1531; 327.1604
K3	4-[1-({4-(1H-benzimidazol-2-yl)phenyl}imino)ethyl]-N-(4-hydroxybenzylidene)aniline	C ₂₈ H ₂₂ N ₄ O	430.51	430.1794; 431.1866
K4	3-[4-(1H-Benzimidazol-2-yl)phenyl]-2-{4-[2-(4-hydroxyphenyl)-4-oxo-1,3-thiazolidin-3-yl]phenyl}-2-methyl-1,3-thiazolidin-4-one	C ₃₂ H ₂₆ N ₄ O ₃ S ₂	578.71	578.1446; 579.1519

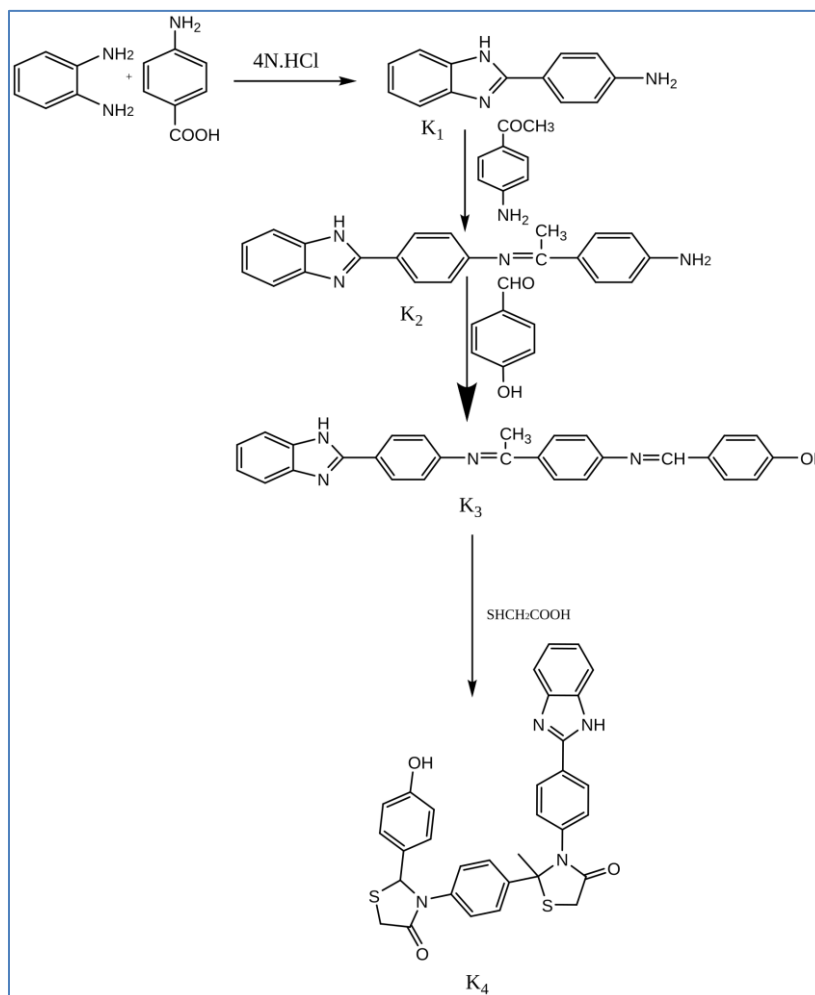
Table 2: Physical and analytical data for compounds K1–K4.

ID	Appearance	Yield (%)	mp (°C)	TLC behavior	HRMS [M+H] ⁺ , calcd/found (m/z)	Elemental analysis, calcd/found (%)
K1	Pale yellow	77	209–211	Single spot	210.1026 / 210.1024	C 74.62/74.52; H 5.30/5.31; N 20.08/19.98
K2	Purple	65	218–220	Single spot	327.1604 / 327.1601	C 77.28/77.18; H 5.56/5.62; N 17.17/17.04
K3	Golden yellow–orange	63	165–170 (dec.)	Single spot	431.1866 / 431.1864	C 78.12/78.04; H 5.15/5.18; N 13.01/12.93
K4	Dark brown	71	205–210 (dec.)	Single spot	579.1519 / 579.1516	C 66.42/66.31; H 4.53/4.56; N 9.68/9.60

3 RESULTS AND DISCUSSION

3.1 Synthetic strategy and structural rationale

The K1-K4 sequence was designed such that each step would yield a analytically distinguishable change (Scheme 1). The benzimidazole containing aniline K1 was obtained by acid catalyzed cyclocondensation. Condensation with 4-aminoacetophenone gave K2, thus introducing the first ketimine and still maintaining a para-amino group for a second condensation. Treatment with 4-hydroxybenzaldehyde gave then the unsymmetrical bis-imine K3 and the phenolic terminus was introduced. Finally, treatment with two equivalents of thioglycolic acid converted the two imine sites into a bis(thiazolidin-4-one) framework. This sequence follows the established reactivity of the precursor core [13,15], while the para-hydroxyphenyl group provides an O-H/C-O spectral signature absent from the previously reported para-methyl and para-bromo analogues [15].



Scheme 1: Stepwise synthesis of K1–K4. Reaction conditions: (i) 4 M HCl, reflux; (ii) 4-aminoacetophenone, EtOH, reflux; (iii) 4-hydroxybenzaldehyde, EtOH, reflux; (iv) thioglycolic acid, anhydrous ZnCl₂, 1,4-dioxane, reflux.

3.2 Spectroscopic characterization of K1 and K2

The FTIR spectrum of K1 displayed N–H/NH₂ stretching absorptions at 3328 and 3256 cm^{−1} together with aromatic C–H bands in the 3114–3045 cm^{−1} region. Absorptions at 1607 and 1582 cm^{−1} fall within the benzimidazole C=N/aromatic skeletal region, while bands at 1516, 1480 and 1427 cm^{−1} arise from aromatic-ring vibrations. The 1344–1015 cm^{−1} region contains C–N and in-plane aromatic modes. In combination with the molecular-composition data in Tables 1 and 2, this pattern is consistent with the benzimidazole-bearing aromatic amine K1.

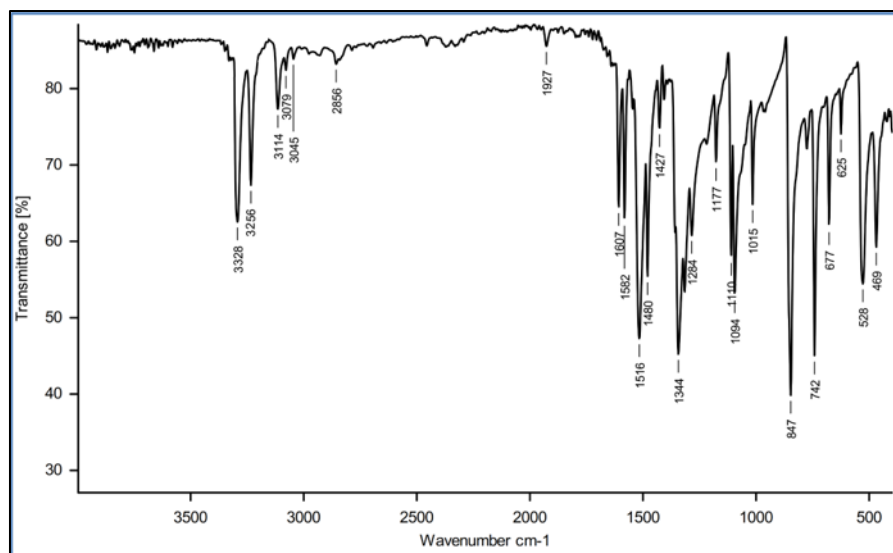


Figure 1: FTIR spectrum of compound K1.

The FTIR spectrum of K2 showed N-H/NH₂ stretching bands at 3393 and 3362 cm⁻¹, demonstrating retention of the free para-amino group required for the next condensation. Aromatic C-H stretching occurred near 3062 cm⁻¹ and an aliphatic C-H band associated with the methyl-containing fragment appeared near 2926 cm⁻¹. The conjugated imine/aromatic region was represented by absorptions at 1618, 1586 and 1546 cm⁻¹, with C-N and aromatic skeletal bands between 1404 and 1015 cm⁻¹. Relative to K1 and the ketone precursor, the combined retention of NH₂ functionality and development of the conjugated C=N region supports selective formation of the amino-ketimine intermediate K2.

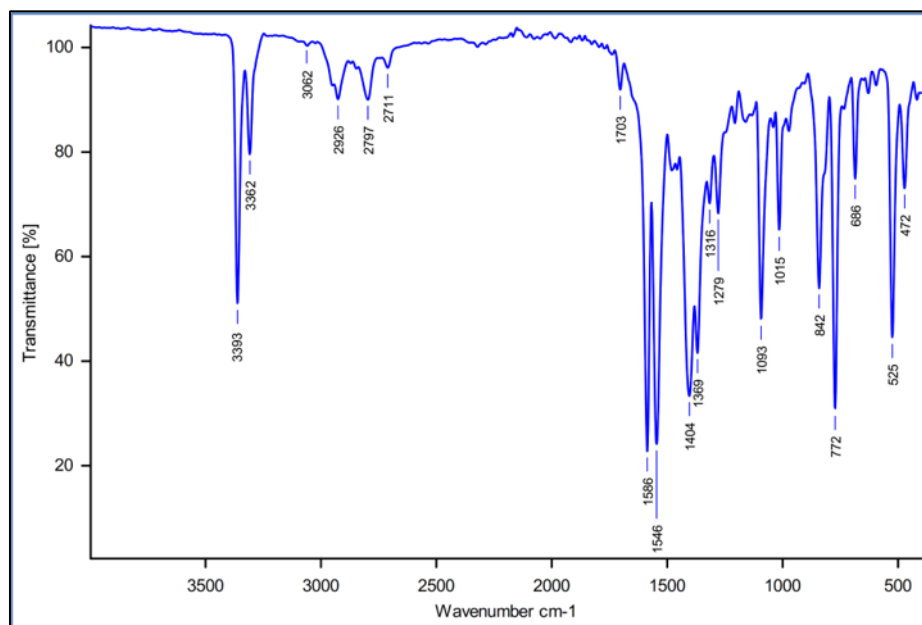


Figure 2: FTIR spectrum of compound K2.

3.3 Formation and characterization of the para-hydroxy bis-imine K3

The second condensation converted the remaining para-amino group of K2 into the 4-hydroxybenzylidene imine K3. Its FTIR spectrum displayed a broad band centered near 3286 cm⁻¹, attributable to overlapping phenolic O-H and benzimidazole N-H stretching. Bands at 1641, 1610, 1547 and 1495 cm⁻¹ define the conjugated azomethine/aromatic region, while the intense absorption at 1218 cm⁻¹ is consistent with the phenolic aryl C-O vibration. The disappearance of the characteristic NH₂ stretching pattern of K2, together with the O-H/C-O features and extended imine region, supports completion of the second condensation.

This assignment is strengthened by the orthogonal analytical data: K3 gave [M+H]⁺ at m/z 431.1864 (calcd 431.1866), and the found C, H and N percentages closely matched the calculated composition for C₂₈H₂₂N₄O. Thus, the FTIR and

composition data jointly support formation of the unsymmetrical para-hydroxyphenyl bis-imine rather than relying on a single vibrational band.

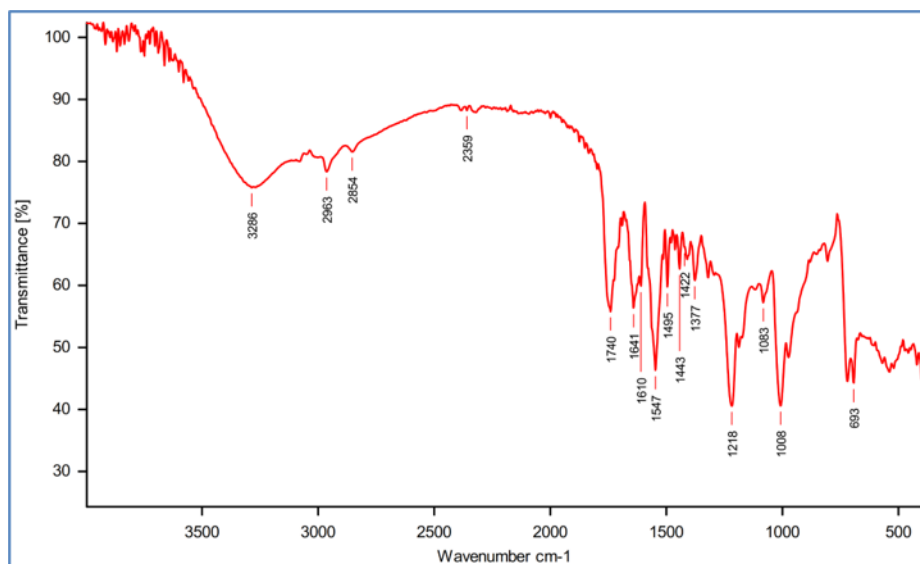


Figure 3: FTIR spectrum of compound K3.

The ^1H NMR spectrum of K3 exhibited downfield exchangeable resonances at δ 10.78 and 9.52 ppm, assigned to the benzimidazole N–H and phenolic O–H protons, respectively. The benzylidene/aromatic region extended from δ 8.17 to 6.27 ppm and contained the azomethine proton together with the proton environments of the four aromatic rings. The intense signals near δ 3.31 and 2.50 ppm correspond to residual water/DMSO- d_6 and were excluded from structural assignment; the minor low-field aliphatic signal near δ 1.15 ppm was likewise treated as non-diagnostic. The diagnostically useful downfield and aromatic pattern is consistent with the hydroxy-substituted bis-imine framework when considered together with FTIR, HRMS and elemental analysis.

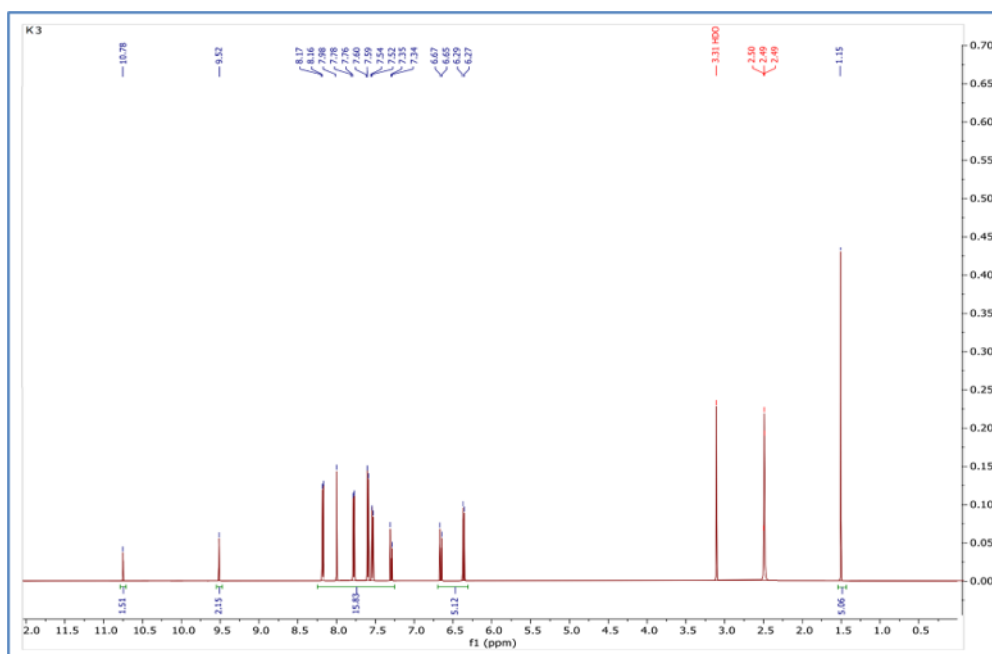


Figure 4: ^1H NMR spectrum of compound K3 in DMSO- d_6 .

The ^{13}C NMR spectrum of K3 displayed resonances at δ 159.16 and 153.73 ppm in the downfield imine/phenolic ipso-carbon region, together with signals at δ 148.91, 146.40, 141.97, 139.93, 138.75, 135.10, 134.91, 130.96, 128.85, 128.59, 126.50, 123.83, 123.72 and 121.15 ppm from the aromatic and heteroaromatic framework. The solvent cluster around δ 39.5–40.5 ppm was excluded from assignment, and a minor resonance at δ 29.89 ppm was not used as a primary structural marker. The distribution of the downfield sp^2 signals, in conjunction with the complementary analytical evidence, supports the extended conjugated structure assigned to K3.

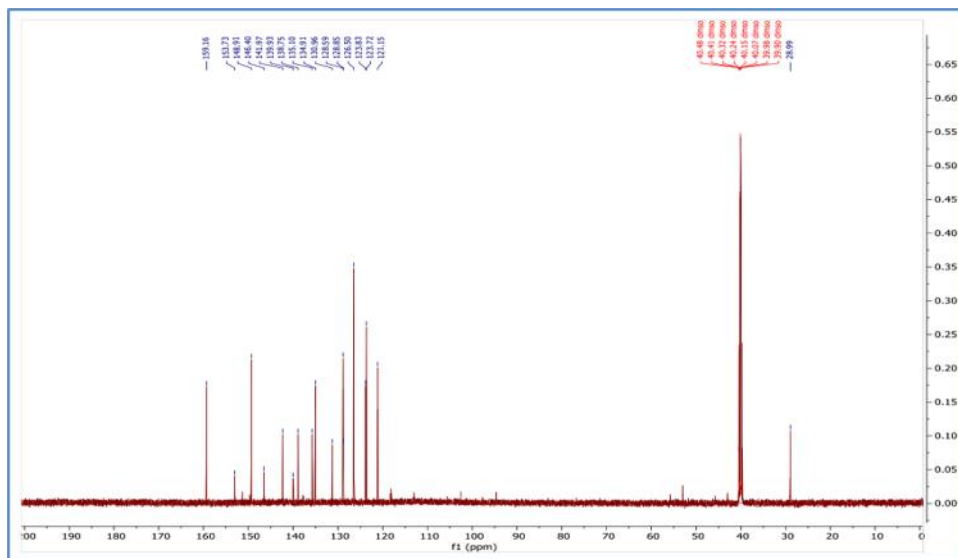


Figure 5: ^{13}C NMR spectrum of compound K3 in DMSO-d_6 .

3.4 Bis-cyclization to the thiazolidin-4-one framework K4

Cyclization of K3 with thioglycolic acid produced a distinct FTIR pattern for K4. A strong band at 1746 cm^{-1} was assigned to the thiazolidin-4-one carbonyl groups, while broad absorptions at 3348 and 3228 cm^{-1} were associated with the retained phenolic O–H and benzimidazole N–H functions. Bands at 1659 , 1605 , 1561 , 1495 and 1421 cm^{-1} arise from the benzimidazole and aromatic framework. The appearance of the strong lactam-type carbonyl band, accompanied by reorganization of the former imine region, provides the principal FTIR evidence for conversion of the bis-imine precursor into the cyclized product.

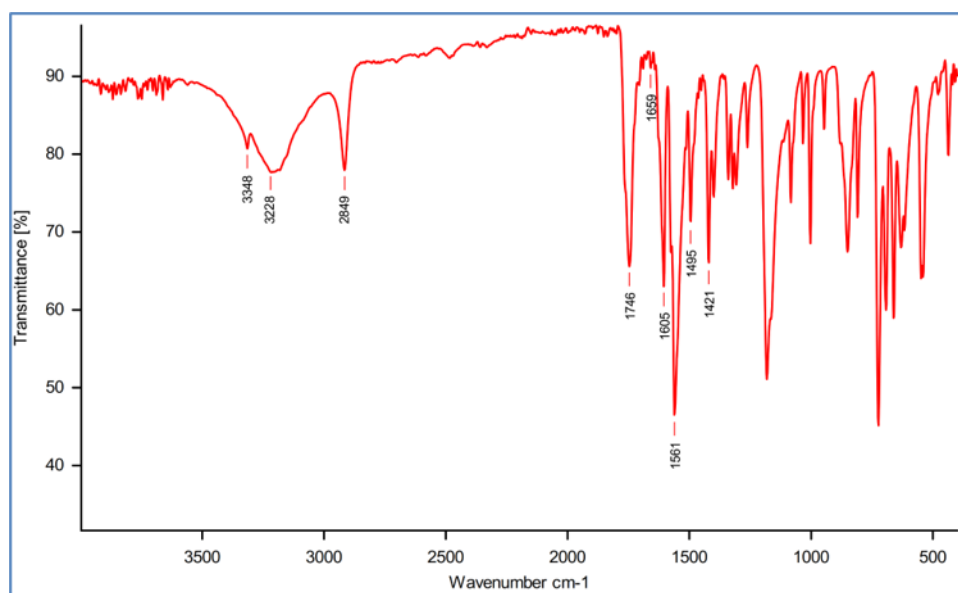


Figure 6: FTIR spectrum of compound K4.

The ^1H NMR spectrum of K4 retained downfield exchangeable signals at δ 10.97 and 9.52 ppm for the benzimidazole N–H and phenolic O–H protons. Aromatic and heteroaromatic resonances were concentrated in the δ 7.79–6.41 ppm region. New signals at δ 4.81 and 3.75 ppm were assigned to the aldimine-derived thiazolidinone methine and overlapping sulfur-adjacent methylene environments, respectively, while the methyl substituent appeared at δ 1.73 ppm. Because the two newly formed thiazolidinone rings are chemically nonequivalent and the sulfur-adjacent methylene protons may be magnetically nonequivalent, partial overlap in the aliphatic region is expected. The appearance of these resonances after cyclization, together with the FTIR carbonyl marker, supports formation of the saturated heterocyclic framework.

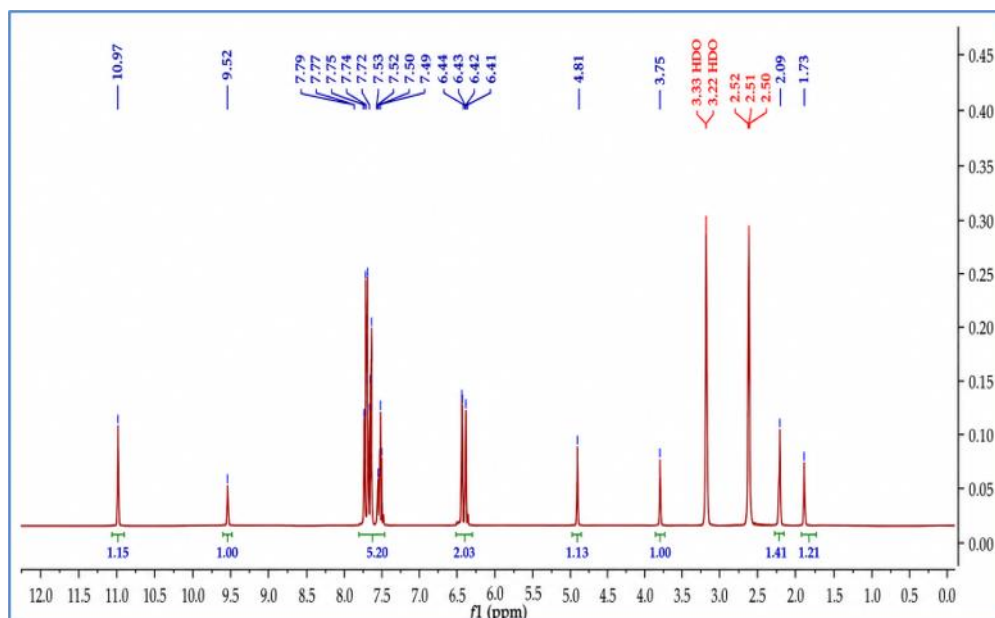


Figure 7: ^1H NMR spectrum of compound K4 in DMSO-d_6 .

The ^{13}C NMR spectrum of K4 showed a characteristic thiazolidin-4-one carbonyl resonance at δ 170.19 ppm. Signals at δ 156.37, 154.19, 151.34, 149.30, 145.24, 144.32, 141.31, 140.27, 137.13, 133.59, 130.18, 127.37, 125.24, 123.31, 122.36, 120.47 and 118.73 ppm were assigned to the phenolic, benzimidazole and aromatic/heteroaromatic sp^2 framework. The solvent cluster around δ 39.5–40.5 ppm was excluded from assignment, and the methyl carbon was observed at δ 22.23 ppm. The carbonyl marker and overall sp^2 pattern are consistent with K4 and complement the more diagnostic FTIR and ^1H NMR changes associated with ring formation.

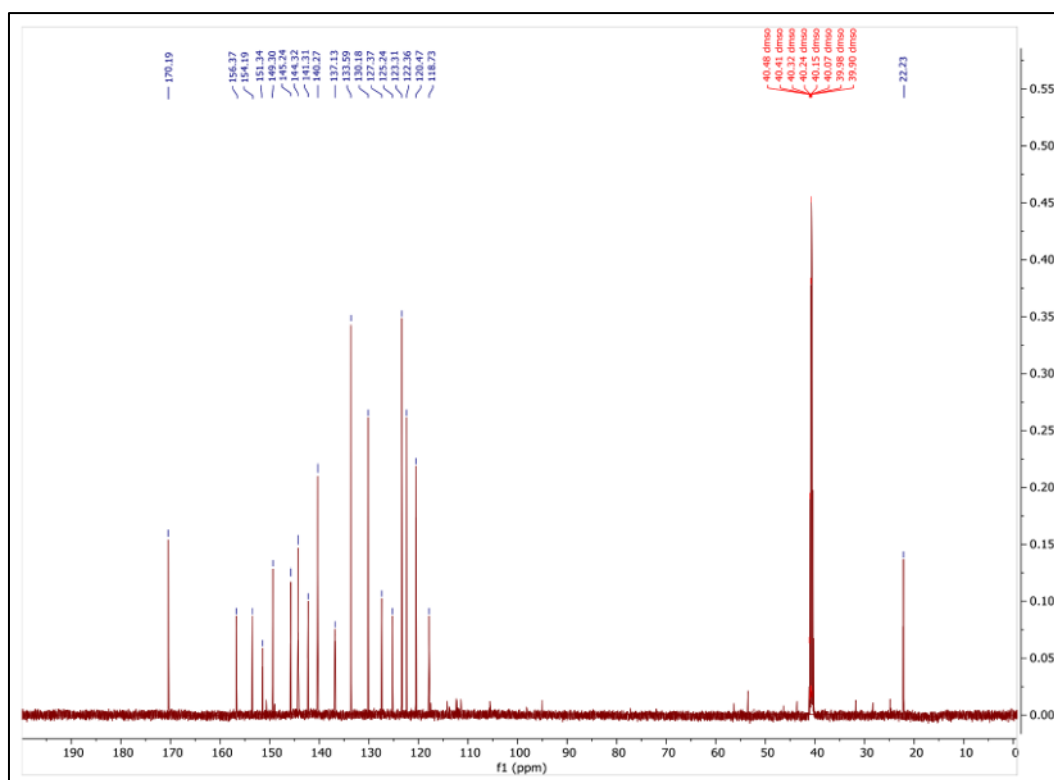


Figure 8: ^{13}C NMR spectrum of compound K4 in DMSO-d_6 .

3.5 Integrated transformation markers

Comparison across the K1–K4 sequence reveals a coherent progression of independent analytical markers. The first condensation retains the para-amino functionality while introducing a ketimine environment; the second removes the NH_2 pattern and introduces phenolic O–H/C–O and benzylidene features; and the final step introduces a thiazolidin-4-

one carbonyl together with new saturated-ring ^1H NMR resonances. The HRMS data provide an additional composition check: the found $[\text{M}+\text{H}]^+$ values for K1–K4 differ from the calculated values by less than approximately 1 ppm, while the elemental analyses show close agreement between calculated and found C, H and N percentages. These complementary observations are summarized in Table 3 and provide a stronger basis for structural assignment than any individual spectral feature alone.

Table 3: Diagnostic evidence across the K1→K4 sequence.

Transformation	Structural change	Diagnostic evidence	Interpretation
K1 → K2	Formation of the first ketimine while retaining para- NH_2	NH_2/NH stretching retained; developed conjugated $\text{C}=\text{N}$ region; methyl-containing $\text{C}-\text{H}$ environment; HRMS/CHN agreement	Supports selective first condensation while preserving the second amino reaction site.
K2 → K3	Conversion of the remaining NH_2 group into a 4-hydroxybenzylidene imine	Loss of NH_2 pattern; phenolic $\text{O}-\text{H}$ and aryl $\text{C}-\text{O}$ bands; benzylidene/aromatic NMR pattern; $[\text{M}+\text{H}]^+$ 431.1864	Supports formation of the unsymmetrical para-hydroxyphenyl bis-imine.
K3 → K4	Cyclization of both imine sites to thiazolidin-4-one rings	$\nu(\text{C}=\text{O})$ 1746 cm^{-1} ; ^{13}C δ 170.19 ppm; new ^1H δ 4.81 and 3.75 ppm; $[\text{M}+\text{H}]^+$ 579.1516	Combined FTIR, ^1H NMR and composition data support the bis(thiazolidin-4-one) framework.

3.6 Stereochemical considerations

Cyclization of the two $\text{C}=\text{N}$ units creates two tetrahedral C-2 centers in K4, one originating from the ketimine and the other from the benzylidene imine. Since the reaction was performed in the absence of a chiral source, no single absolute configuration preference is assumed and multiple stereoisomeric forms may contribute to the observed ^1H NMR pattern. Accordingly, K4 is represented without R/S descriptors. The spectroscopic discussion is limited to constitutional connectivity and functional-group assignment; relative and absolute stereochemistry would require stereochemically informative data beyond the present one-dimensional spectra.

4 CONCLUSION

The K1–K4 sequence provides a stepwise route from a benzimidazole-containing aromatic amine to an unsymmetrical para-hydroxyphenyl bis-imine and subsequently to a bis(thiazolidin-4-one) derivative. Formation of K3 is supported by disappearance of the precursor NH_2 pattern, appearance of phenolic $\text{O}-\text{H}/\text{C}-\text{O}$ and extended imine features, and close agreement of HRMS and elemental-composition data with the proposed formula. Conversion to K4 is marked by the 1746 cm^{-1} thiazolidin-4-one carbonyl band, the δ 170.19 ppm carbonyl-carbon resonance and new ^1H NMR signals at δ 4.81 and 3.75 ppm, together with $[\text{M}+\text{H}]^+$ at m/z 579.1516 (calcd 579.1519). In comparison with the aforementioned para-methyl and the para-bromo congeners of the same pre-organisation type, the para-hydroxy derivative adds an easily detectable phenolic $\text{O}-\text{H}/\text{C}-\text{O}$ motif and broadens the range of substituents utilizable in the series. The FTR, NMR, HRMS and elemental analyses data are consistent with a single structural assignment and will serve as a reference for future substituent-dependent structural or application investigations.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

Disclosure of conflict of interest

The authors declare no conflict of interest.

REFERENCES

- [1] Abd El-Lateef HM, Elbastawesy MAI, Abdelghani Ibrahim TM, Khalaf MM, Gouda M, Wahba MGF, et al. Design, synthesis, docking study, and antiproliferative evaluation of novel Schiff base–benzimidazole hybrids with VEGFR-2 inhibitory activity. *Molecules*. 2023;28(2):481. doi:10.3390/molecules28020481.

- [2] Hussain R, Khan S, Ullah H, Ali F, Khan Y, Sardar A, et al. Benzimidazole-based Schiff base hybrid scaffolds: a promising approach to develop multi-target drugs for Alzheimer's disease. *Pharmaceuticals (Basel)*. 2023;16(9):1278. doi:10.3390/ph16091278.
- [3] Prakasha G, Revanasiddappa HD, Jayalakshmi B, Prabhakar BT, Shivamallu C, Viswanath PM, et al. Novel benzimidazole-derived imine ligand and its Co(III) and Cu(II) complexes as anticancer agents: chemical synthesis, DFT studies, in vitro and in vivo biological investigations. *Pharmaceuticals (Basel)*. 2023;16(1):125. doi:10.3390/ph16010125.
- [4] Al-Hakimi AN, Alresheedi TM, Albarrak RA, Albadri AEAE, Abd El-Hady MM, Saeed SES. Synthesis and characterization of a fluorinated Schiff base from benzimidazole and its metal complexes for antimicrobial and UV-protective cotton fabrics. *Coatings*. 2025;15(4):380. doi:10.3390/coatings15040380.
- [5] Khraisat LMAF, Sabuncuoglu S, Girgin G, Unsal Tan O. Synthesis and tyrosinase inhibitory activity of novel benzimidazole/thiazolidin-4-one hybrid derivatives. *Chem Biodivers*. 2024;21(2):e202301489. doi:10.1002/cbdv.202301489.
- [6] Haque A, Khan MWA, Alenezi KM, Soury R, Khan MS, Ahamad S, et al. Synthesis, characterization, antiglycation evaluation, molecular docking, and ADMET studies of 4-thiazolidinone derivatives. *ACS Omega*. 2024;9(1):1810–1820. doi:10.1021/acsomega.3c08463.
- [7] Kumar D, Aggarwal N, Kumar H, Kapoor G, Deep A, Bibi S, et al. 2-Substituted-3-(5-substituted-1,3,4-oxadiazol/thiadiazol-2-yl) thiazolidin-4-one derivatives: synthesis, anticancer, antimicrobial, and antioxidant potential. *Pharmaceuticals (Basel)*. 2023;16(6):805. doi:10.3390/ph16060805.
- [8] Ture A, Ergul M, Ergul M, Altun A, Kucukguzel I. Design, synthesis, and anticancer activity of novel 4-thiazolidinone-phenylaminopyrimidine hybrids. *Mol Divers*. 2021;25(2):1025–1050. doi:10.1007/s11030-020-10087-1.
- [9] Tahmasvand R, Bayat P, Vahdaniparast SM, Dehghani S, Kooshafar Z, Khaleghi S, et al. Design and synthesis of novel 4-thiazolidinone derivatives with promising anti-breast cancer activity: synthesis, characterization, in vitro and in vivo results. *Bioorg Chem*. 2020;104:104276. doi:10.1016/j.bioorg.2020.104276.
- [10] Petrou A, Eleftheriou P, Geronikaki A, Akrivou MG, Vizirianakis I. Novel thiazolidin-4-ones as potential non-nucleoside inhibitors of HIV-1 reverse transcriptase. *Molecules*. 2019;24(21):3821. doi:10.3390/molecules24213821.
- [11] Sharma A, Sharma D, Saini N, Sharma SV, Thakur VK, Goyal RK, Sharma PC. Recent advances in synthetic strategies and SAR of thiazolidin-4-one containing molecules in cancer therapeutics. *Cancer Metastasis Rev*. 2023;42(3):847–889. doi:10.1007/s10555-023-10106-1.
- [12] Seboletswe P, Cele N, Singh P. Thiazolidinone-heterocycle frameworks: a concise review of their pharmacological significance. *ChemMedChem*. 2023;18(7):e202200618. doi:10.1002/cmdc.202200618.
- [13] Adnan S, Hassan K, Thamer H. Synthesis and identification some of heterocyclic compounds from imidazole derivatives. *Iraqi National Journal of Chemistry*. 2013;(51):327–337.
- [14] Belwal CK, Joshi KA. Synthesis and antifungal activity of some novel thiazolidinone derivatives of 4-(4-oxo-2-phenylthiazolidin-3-yl)benzoic acid. *Int J ChemTech Res*. 2012;4(4):1758–1764.
- [15] Eraibi FA. Synthesis, characterization, and antibacterial activity of benzimidazole Schiff bases and bis(thiazolidin-4-one) derivatives. *World Journal of Chemical and Pharmaceutical Sciences*. 2026;9(1):26–40. doi:10.53346/wjcps.2026.9.1.0023.