Preparation, characterization and use of new lignocellulose-based bio nanocomposite as a heterogeneous catalyst for sustainable synthesis of pyrimido benzazoles

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ABSTRACT
A sustainable combinatorial synthesis of densely substituted pyrimido [1,2-b] benzazole derivatives in water under microwave irradiation was performed using a new lignocellulose-based bio nanocomposite (BNC) as heterogeneous catalyst. The lignocellulosic waste peanut shells (LCWPS) were turned into a value-added product, a new BNC PS/ZnO, which was prepared via in situ hydrothermal synthesis. The as-prepared BNC was characterized by Fourier transform infrared spectroscopy, scanning electron microscopy, transmission electron microscopy, energy-dispersive X-ray spectroscopy and X-ray diffraction spectrum. PS/ZnO has been successfully used in a sustainable catalytic method for the synthesis of pyrimido [1, 2-b] benzazole derivatives in water under microwave irradiation. The time of this reaction was significantly reduced. This catalytic system has a very high turnover number (TON $\sim 10^3$) and turnover frequency (TOF $\sim 10^5$ h$^{-1}$). This paper presents the benefit of sustainable management of LCWPS, a bio-sourced polymeric carbohydrate for production of new nanocatalyst.

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Introduction
Peanut shells (PS), an agro-industrial waste constitute a considerable part of biodegradable lignocellulosic waste (LCW) (1). Every year around 13.7 million tons of PS are discarded in the environment or burned (2–4). In contrast limited value-added uses exist for their removal among which we can mention the preparation of solid acid catalyst for biodiesel production and etherification of glycerol (5–7), natural dye and metal absorbents (8–14), biofilter based on their mechanical and...
thermal properties (15–17), and they are also used in the production of cellulose (18). PS are mainly composed of three biopolymers: lignin, cellulose and hemicellulose. Among the three biopolymers present in PS, cellulose and lignin were the most abundant (19). The existing of many polar functional groups including hydroxyl group (primary, secondary and phenolic), methoxyl and carboxyl groups as well as aromatic ring in PS makes it a potential capping agent (20) for synthesis of nanoparticles (NPs) and might be placed in a class of abundant natural, renewable, nontoxic and very low or no cost environmentally friendly catalyst support. All these made it an attractive candidate for supported catalysis, and might offered important advantages in organic synthesis, such as operational simplicity, environmental compatibility, nontoxic, reusability, low-cost and ease of isolation. Newly, the effectiveness of NPs such as ZnO NPs was reported in several organic reactions (21–23). Raj et al. (20) have synthesized modified ZnO NPs through a sol–gel method, using different aromatic capping agent for the synthesis of pyrimidine derivatives.

This work discusses the in situ hydrothermal production of PS/ZnO, a nanocomposite materials based on LCWPS and examines their catalytic activity in multi-component reactions (MCRs), an appreciated sustainable approach in organic synthesis, which proceed with remarkably high atom economy and accelerate the formation of highly functionalized organic compounds, via a one-pot reaction between three or more reactants (24, 25). The PS could prevent the aggregation of ZnO NPs, which are shaped and distributed over a high surface area.

Polycyclic fused-ring heterocycles containing nitrogen and sulfur atom, are of great importance, especially in the pharmaceutical fields, because of their abundance in nature and their diverse biological properties (26–28). One of these important compounds, the pyrimido benzazole which is synthesized through Biginelli-like reaction (29, 30), was extensively studied for their medicinal applications such as antimicrobial, antifungal, antibacterial, antihypertensive, antiviral and anticancer activities (31–42). They are also potent HIV integrase inhibitors (25, 43), LTD4 receptor antagonists (34), and are also used for the treatment of bronchial asthma and neurodegenerative disease (37, 39, 44). Therefore, synthesis of this compound has attracted notable interest and a number of studies have been conducted on their synthesis methods, hence the great diversity of methods of preparation were described in the literature. Besides some advantages, Biginelli reactions need harsh conditions (40) and according to some reports (31, 45, 46), low yield, long reaction time and harmful organic solvents are some disadvantages of this reaction.

Hence, we applied a combinatorial methodology to synthesis densely substituted pyrimido benzazoles derivatives using PS/ZnO bio nanocatalyst. This new nanocomposite based on PS was prepared via in situ hydrothermal synthesis and its catalytic activity was examined for the synthesis of pyrimido benzenzoles by a one-pot three-components condensation of 2-amino-benzimidazole (3a), 2-aminobenzothiazole (3b) or guanidinium chloride (3c), aldehydes (1a–j) and C–H acidic compounds such as 2-hydroxy-1,4-naphtoquinone (2a), dimedone (2b), malononitrile (2c) and ethyl acetoacetate(2d) under microwave irradiation in water (Scheme 1).

Results and discussion

The catalytic activity of PS/ZnO was investigated in a domino reaction for the synthesis of pyrimidobenzazole derivatives. The reaction of 4-chlorobenzaldehyde (1a), lawson (2a) (2-hydroxy-1,4-naphtoquinone) and 2-aminobenzimidazole (3a) was considered as a model reaction (Scheme 2).

To specify the most efficient catalyst, the model reaction was carried out using different catalysts such as PS, ZnO, PS/ZnO, Fe3O4/PS/ZnO, Chitin/ZnO, Fe3O4/PS/CuO, and also in the absence of catalyst under reflux condition. The results are shown in Table 1. As can be seen, in the absence of the catalyst the yield of the reaction is very low whatever the reaction conditions (entry 1–4). When 20 mg of PS was used as a catalyst in reflux condition, the yield increased moderately (entry 5). The use of ZnO as a catalyst resulted in a modest increase in yield under the same reflux conditions (entry 9). Thus, we decided to study the synergetic effect of PS and ZnO, by preparing PS/ZnO nanocomposite. As could be guessed, the use of this hybrid system shows a higher activity. Consequently, higher yield in a shorter time was obtained even by decreasing the loading of the catalyst, which shows their additive or synergistic effects (entry 13). Next, an attempt was made to prepare a magnetically separable Fe3O4/PS/ZnO nanocomposite. But, surprisingly, the reaction efficiency decreased when this nanocomposite was used as the catalyst (entry 14).

Chitin/ZnO and Fe3O4/PS/CuO were also used (entry 15 and 16) but the results were not satisfactory. So, PS/ZnO was selected as the best catalyst for the model reaction. The catalyst loading and heating conditions were also optimized (entry 13, 17, 18). As a result, the optimum conditions obtained were the use of 20 mg of PS/ZnO under microwave irradiation and a reaction
time of 2 min. To determine the best solvent for this reaction, the effect of various solvents was examined and based on the obtained results, water was selected as the best solvent (see supporting information for details, Figure S1). Microwave, ultrasound, and grinding conditions were also applied for other catalysts (entry 22–28), but none of these catalysts have shown the effectiveness of PS/ZnO.

The proposed mechanism for the model reaction is presented in Scheme 3. In this mechanism, it was suggested that PS/ZnO acts as a bifunctional Lewis acid/base catalyst and facilitates the Knoevenagel condensation between activated 4-chlorobenzaldehyde (1a) and Lawsone anion (2a) followed by Michael addition of 2-aminobenzimidazole (3a) to 3-arylidenedenaphtho-1,2,4-(3H)-trione 1 leading to the desired pyrimidobenzazoles. The addition of 2-aminobenzimidazole (3) to aryldenedenaphtho-1 may proceed by two conceivable mechanistic paths (A or B) contingent on whether the early attack of the 2-aminobenzimidazole is done through the nitrogen of side chain amine or by the ring nitrogen to give the isomeric pyrimido[1,2-a]benzimidazoles 4 or 4'.

To reveal which of the two potential products 4 or 4' are obtained, 1H nuclear Overhauser effect (NOE) experiments were performed. The irradiation of H_a led to an enhancement in the signal of H_b. These results are in accordance with the structure 4 (for details see the

Scheme 1. Synthesis of benzimidazo [2,1-b]quinazolin-1(1 H)-ones and pyrimidobenzazole derivatives.

Scheme 2. Model reaction between 4-chlorobenzaldehyde, 2-aminobenzimidazole and 2-hydroxy-1,4-naphtoquinone.
supporting information Figure S3), which means that anion attack would preferably take place on the N atom of the heterocyclic ring of 2-aminobenzimidazole. These results are in accordance with our previous work (47) which corroborant that the N atom in the heterocyclic ring is more active than other N atom in 2-aminobenzimidazole.

To further extended the scope of this new protocol and to explore the effectiveness of the catalyst PS/ZnO, the reaction between various aromatic aldehydes, C–H acidic compounds and 2-aminobenzazole derivatives, or guanidinium chloride in optimized conditions was realized and led to a series of pyrimidobenzazole with high in a short reaction time yields (Table 2).

To demonstrate the effectiveness of PS/ZnO nano-composite as a catalyst, it has been compared with previously reported and published procedures which shows that PS/ZnO is a good catalyst for synthesis of pyrimido benzazole (Table 3). The results undoubtedly illustrate that this procedure using PS/ZnO bio nanocatalyst is indeed higher than other in terms of product yield, reaction time and workup. As can be seen from the data in Table 3, the time of the reaction was considerably reduced nevertheless, the yield is higher. The TON and TOF for this catalytic system are very high ($\sim 10^3$ and $\sim 10^5$ h$^{-1}$). The SEM image of PS/ZnO (Figure 3(b)) showed that the rod-like ZnO NPs are embedded in the peanut shells network. The PS could prevent the aggregation of ZnO NPs, which are shaped and distributed over a high surface area and provide a good template for the nucleation and growth of NPs. These results revealed that PS could serve as a good capping agent due to its mechanical and thermal properties and the residual PS not only has no unfavorable effect but on the contrary, shows a favorable effect in catalytic applications.

**Experimental**

**Materials**

All reagents and materials were purchased from commercial sources and used without purification. All of them

**Table 1. The effect of nature of catalyst, catalyst loading and reaction conditions on model reaction in water.**

| Entry | Catalyst | Loading (mg) | Condition | Time (min) | Yield (%) |
|-------|----------|--------------|-----------|------------|-----------|
| 1     | –        | –            | Reflux    | 120        | Very low  |
| 2     | –        | –            | Microwave | 120        | –         |
| 3     | –        | –            | Ultrasonic| 120        | –         |
| 4     | –        | –            | Ball mill | 120        | –         |
| 5     | PS†      | 20           | Reflux    | 120        | 32        |
| 6     | PS†      | 20           | Ball mill | 120        | –         |
| 7     | PS†      | 20           | Ultrasonic| 120        | –         |
| 8     | PS†      | 20           | Microwave | 120        | Very low  |
| 9     | ZnO      | 20           | Reflux    | 120        | 47        |
| 10    | ZnO      | 20           | Microwave | 120        | 40        |
| 11    | ZnO      | 20           | Ultrasonic| 120        | 33        |
| 12    | ZnO      | 20           | Ball mill | 120        | Very low  |
| 13    | PS/ZnO   | 20           | Reflux    | 120        | 63        |
| 14    | Fe$_3$O$_4$/PS/ZnO | 20        | Reflux    | 120        | 43        |
| 15    | Chitin/ZnO | 20         | Reflux    | 120        | 51        |
| 16    | Fe$_3$O$_4$/PS/CuO | 20       | Reflux    | 120        | 39        |
| 17    | PS/ZnO   | 15           | Reflux    | 120        | 52        |
| 18    | PS/ZnO   | 25           | Reflux    | 120        | 65        |
| 19    | PS/ZnO   | 20           | Ball mill | 120        | 15        |
| 20    | **PS/ZnO** | **20**     | Microwave | **2**      | **72****$^*$** |
| 21    | PS/ZnO   | 20           | Ultrasonic| 120        | 65        |
| 22    | Fe$_3$O$_4$/PS/ZnO | 20       | Ultrasonic| 120        | 34        |
| 23    | Fe$_3$O$_4$/PS/CuO | 20      | Microwave | 120        | –         |
| 24    | Chitin/ZnO | 20          | Ultrasonic| 120        | Very low  |
| 25    | Chitin/ZnO | 20          | Microwave | 20         | 30        |
| 26    | Chitin/ZnO | 20          | Ball mill | 120        | –         |
| 27    | Fe$_3$O$_4$/PS/CuO | 20      | Ultrasonic| 120        | Very low  |
| 28    | Fe$_3$O$_4$/PS/CuO | 20      | Microwave | 120        | –         |

*$^*$TON $\sim 10^4$ and TOF $\sim 10^5$ h$^{-1}$.

†Treated PS.

**Scheme 3. Suggested mechanism for model reaction.**
were analytical grade. Peanut shells were purchased from a local farmer market in the north of Iran. All microwave reactions were carried out in a Milestone MicroSYNTH Labstation (power 600 watts). 1H, 13C NMR spectra were recorded on a Bruker Avance DPX500. The chemical shifts (δ) are given in parts per million and referenced to TMS internal standard. IR spectra were recorded in KBr on the Shimadzu FT-IR spectrometer and are reported in wave numbers (cm⁻¹). All melting points were measured on a capillary melting point apparatus. Scanning electron microscopy (SEM) was recorded on a VEG//TESCAN 100EM10C-KV with Gold Coating, transmission electron microscopy (TEM) analyze was performed by Zeiss-EM10C-100 KV device, and energy-dispersive X-ray spectroscopy (EDX) was recorded on a VEG//TESCAN-XMU. Powder X-ray diffraction measurements were performed using Philips analyzer (PANalytical X’Pert Pro X-ray diffractometer with the Cu Kα radiation (λ = 0.15406 nm). Mass spectra were produced by an Agilent Technology (HP) Model: 5973 Network Mass Selective Detector.

### Preparation of PS/ZnO

The PS were washed with distilled water several times to remove impurities, dried in an oven at 70°C and ballmilled for 1 h. The ball-milled PS (0.14 g) and 20 mL deionized water were poured into an Erlenmeyer flask and stirred at room temperature. Then, 20 mL of Zn (CH₃COO)₂·2H₂O solution (0.625 M) was added dropwise to the mixture under vigorous stirring. The mixture was ultrasonically irradiated for 10 min to obtain a stable dispersion. The pH was adjusted to 12 using an aqueous solution of sodium hydroxide (1 M) and subjected to further ultrasonic irradiation for 10 min. The solution was then transferred to a 50 mL Teflon-lined stainless steel autoclave, sealed and heated at 70°C in an oven for 3 h. PS/ZnO NPs were centrifuged, filtered and washed with water and dried in vacuum (see supporting information, Figure S1).

### Characterization of PS and PS/ZnO nanocomposite

The structures of PS and the as-prepared nanocomposite PS/ZnO were elucidated by FT-IR analysis, EDX and X-ray diffraction spectrum (XRD) (Figure 1) and SEM (Figure 2). FT-IR spectroscopic interpretations allow us to characterize the interaction of PS in the composite structure from different absorption bands (Figure 1(a)). The broad band in the 3600–3100 cm⁻¹ region corresponds to the hydroxyl stretching vibration, while the band at 2920 cm⁻¹ corresponds to a weak C–H stretching vibration in glucose unit. The β-glycosidic linkage between glucose units was characterized by the absorption band at 895 cm⁻¹. The presence of cellulose in nanocomposite samples can be confirmed by the presence of the C–H stretching vibration band at lower wave number, 2904 cm⁻¹, with a strong decrease in the intensity of this

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**Table 2. One-pot synthesis of pyrimido benzazole derivatives in water under microwave irradiation.**

| Entry | Aldehyde C–H acidic compounds | Amine Products | Time (min) | Yield (%) | TON | TOF (h⁻¹) | m.p. (°C) | Lit. m.p. (°C) |
|-------|-------------------------------|---------------|------------|-----------|-----|-----------|-----------|-------------|
| 1     | 4-ClC₆H₄ (1a)                 | 2a            | 3a         | 4a        | 2   | 72        | 4800      | >300        | >300 (46) |
| 2     | 2,4-Cl₂C₆H₃ (1b)              | 2a            | 3a         | 4b        | 1   | 92        | 6100      | >300        | >300 (46) |
| 3     | 3-HO₂C₆H₄ (1c)                | 2a            | 3a         | 4c        | 4   | 59        | 3900      | >300        | >300 (46) |
| 4     | 4-BrC₆H₄ (1d)                 | 2a            | 3a         | 4d        | 1   | 70        | 4700      | >300        | >300 (46) |
| 5     | 4-BrC₆H₄ (1e)                 | 2a            | 3b         | 5b        | 2   | 93        | 6200      | >300        | >300 –     |
| 6     | Thiophene-2-carbaldehyde (1e) | 2a            | 3a         | 4e        | 2   | 96        | 6400      | 1.9 × 10⁵   | >300 –     |
| 7     | Thiophene-2-carbaldehyde (1e) | 2a            | 3c         | 5c        | 2   | 87        | 5800      | 1.7 × 10⁵   | >300 –     |
| 8     | 2,4-Cl₂C₆H₃ (1b)              | 2b            | 3b         | 6b        | 5   | 86        | 5700      | 0.7 × 10⁵   | >300 >300 |
| 9     | 3-HO₂C₆H₄ (1c)                | 2b            | 3a         | 6c        | 3   | 89        | 5900      | 1.2 × 10⁵   | >300 >300 |
| 10    | 4-BrC₆H₄ (1d)                 | 2b            | 3b         | 6d        | 3   | 74        | 4900      | 0.9 × 10⁴   | 173        | 176–180 (45) |
| 11    | 4-BrC₆H₄ (1e)                 | 2c            | 3a         | 7b        | 2   | 99        | 6600      | 1.9 × 10⁴   | 219        | 212–214 (48) |
| 12    | 4-HO₂C₆H₄ (1f)                | 2c            | 3a         | 7f        | 2   | 71        | 4700      | 1.4 × 10⁵   | 234–235    | 234–235 (49) |
| 13    | 4-NC₆H₄ (1g)                 | 2c            | 3a         | 7g        | 1   | 93        | 6200      | 3.7 × 10⁵   | 210–215    | 215 (50)   |
| 14    | 4-CH₂C₆H₄ (1h)               | 2c            | 3a         | 7h        | 3   | 89        | 5900      | 1.2 × 10⁵   | 244        | 238–239 (51) |
| 15    | 4-(CH₃O)C₆H₄ (1i)             | 2c            | 3a         | 7i        | 4   | 85        | 5700      | 0.8 × 10⁵   | 230–234    | 230–233 (51) |
| 16    | 2,4-Cl₂C₆H₃ (1b)              | 2d            | 3b         | 8b        | 2   | 75        | 5000      | 1.5 × 10⁵   | 128        | 133–135 (33) |
| 17    | 4-HO₂C₆H₄ (1f)                | 2d            | 3b         | 8f        | 8   | 91        | 6066      | 0.4 × 10⁵   | 215        | 213–214 (52) |
| 18    | 4-(CH₃O)C₆H₄ (1i)             | 2d            | 3b         | 8i        | 6   | 85        | 5700      | 0.6 × 10⁵   | 140        | 141–144 (32) |

*New derivatives.

**Table 3. The comparison of PS/ZnO nanocomposite as catalyst for the synthesis of pyrimidine derivatives with other catalysis.**

| Entry | Cat. & loading | Solvent | Condition | Time (min) | Yield (%) | TON | TOF (h⁻¹) | m.p. (°C) | Lit. m.p. (°C) |
|-------|----------------|---------|-----------|------------|-----------|-----|-----------|-----------|-------------|
| 1     | [bmim][BF₄] (2.7 mol %) | –       | 100°C     | 11–14      | 82–86     | ~30 | ~3        |          |            |
| 2     | Amberlyst-15 (10% mol) | Neat    | 100°C     | 1.5–3      | 79–93     | ~10 | ~6        |          |            |
| 3     | ZnO NPs (0.4 mol %)    | –       | Ballmilling, rt. | 40 min   | 73–87     | ~10² | ~3 × 10⁷ |          |            |
| 4     | PS/ZnO (0.015 mol %)   | H₂O     | MW        | 2 min      | 72–99     | ~10³ | ~10³      |          |            | This work |

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Figure 1. (a) IR adsorption of ZnO; PS/ZnO and peanut shell; (b) EDX analysis of PS/ZnO and (c) elements distribution map (EDM); (d) X-Ray diffraction spectrum (XRD).
band in PS/ZnO. The adsorption bands from the 1635–1024 cm\(^{-1}\) region are strongly reduced in intensity, or even absent as in the case of adsorption band in 1635 cm\(^{-1}\) which is accredited to polymer-bound water in PS. As can be seen in Figure 1(a), the absorption peaks observed in the range of 440–550 cm\(^{-1}\) belongs to the stretching vibration band Zn–O and confirmed the presence of Zinc in the PS/ZnO composite.

The EDX analysis revealed that Zn, O, C and N are the main elements present in the bio nanocomposite with Zn being the most abundant with a ratio of Zn/C equal to 59.44/19.48 (Figure 1(b)). The map shows the distribution of these elements and homogenous structure of the catalyst.

Figure 1(d) shows the XRD patterns of PS/ZnO. The peaks at \(2\theta = 31.79^\circ, 34.44^\circ, 36.28^\circ, 47.56^\circ, 56.62^\circ,\)
62.86°, 66.39°, 67.97°, 72.55° and 76.96° were attributed to (100), (002), (101), (102), (110), (103), (200), (112), (201), (004) and (202) of ZnO NPs, indicating that the samples were polycrystalline wurtzite structure (JCPDS card No 36-1451). No characteristic peaks of any impurities were detected, suggesting that high-quality ZnO NPs were synthesized. The average crystallite size (22.40 nm) of ZnO NPs was estimated by Scherrer’s formula. \( D_p = \frac{K \lambda}{\beta \cos 2\theta} \).

PS as the carbon source has an important role in XRD peaks broadening and because of amorphous structures (lignin and hemicellulose) and lower contribution in composite, there were no salient peaks in the 20–30° 2\( \theta \) range but as can be seen, 2\( \theta = 21 \) peak corresponds to the crystallographic plane of cellulose.

SEM was used to investigate the morphology of PS/ZnO prepared by different methods (Figure 2(b,c)). The SEM images revealed that the nanocomposites prepared by the hydrothermal method (Figure 2(b)) have a uniform morphology and size distribution compared to the ultrasonic method (Figure 2(c)). It can also be seen that the rod-like ZnO NPs are embedded in the peanut shells network. The SEM image of rod-like ZnO NPs prepared by the hydrothermal method was shown in Figure 2(d). Magnetic ferroferric oxide nanocomposites based on PS (Fe3O4/PS/CuO and Fe3O4/PS/ZnO) were also synthesized and their SEM images are depicted in Figure 2(e–f) (for experimental details see the supporting information).

To determine the nanostructure of the prepared nanocomposite, TEM analyze was performed by Zeiss-EM10C-100 KV device. As seen in Figure 2(g), the PS/ZnO composite was composed of PS-coated ZnO. From the results of SEM and TEM, it can be spontaneously seen that the QAL/ZnO composites are successfully prepared.

**Figure 3.** Recyclability of PS/ZnO for five successive run and FT-IR analyze of fresh and recycled catalyst.
**General procedure for the synthesis of products 4, 5, 6 and 7**

A mixture of aromatic aldehyde (1a–i, 1 mmol), C–H acidic compounds (dimeadone, malononitrile, 2-hydroxy-1,4-naphthoquinone or ethyl acetoacetate, 2a–d, 1 mmol), benzimidazol derivatives (2-aminobenzimidazole or 2-aminobenzothiazole) or guanidinium chloride (3a–c, 1 mmol) and 0.02 g PS/ZnO in 3 ml of deionized water was placed into a round-bottom flask equipped with a reflux condenser and exposed to microwave irradiation. The accomplishment of the reaction was scrutinized by TLC. After completion of the reaction, the mixture was cooled at room temperature. The catalyst was separated by filtration after dissolving the crude product in hot ethanol. Pure product was obtained by recrystallization in hot ethanol.

One of the advantages of heterogeneous catalysts is their reusability. The reusability of PS/ZnO was investigated in the synthesis of 7b and illustrated in Figure 3. To this end, the catalyst was collected from the reaction mixture and washed with ethyl acetate, normal hexane and ethanol, then it was dried at 50°C in a vacuum oven. The recycled catalyst was reused five times in similar reaction conditions. The results show that recyclability has not significantly decreased the catalytic performance.

**Selected spectral data for new compounds**

**4e**: (2-thiophenyl)benzo[g]benzimidazo[1,2-b]quinazoline-7,12(6H, 13H)-dione

mp > 300°C; IR (KBr, v, cm⁻¹): 3427, 3010, 1589; 1HNMR (500 MHz, DMSO-d6) (δ, ppm): 5.92 (1H, S, CH), 7.90 (1H, s, CH), 7.23 (1H, s, CH), 7.45 (1H, s, CH), 7.57–7.60 (1H, t, t = 7.3 Hz), 7.66–7.69 (1H, t, t = 7.3 Hz), 7.73–7.78 (2H, dd, d, J = 7.8 Hz), 7.80–7.81 (1H, d, d = 7.5 Hz), 7.86–7.88 (1H, d, J = 8 Hz), 7.97–7.99 (1H, d, d = 7.5 Hz). CHN analysis calcd for C₂₂H₁₃N₃O₂S; C, 68.91; H, 3.42; N, 10.96; found C, 68.54; H, 3.46; N, 10.85.

**5d**: 2-amino-4-(4-bromophenyl)benzo[g]quinazoline-5,10(1H,4H)-dione

mp > 300°C; IR (KBr, v, cm⁻¹): 3438, 3419, 3388, 3068, 1587; 1HNMR (500 MHz, DMSO-d6) (δ, ppm): 6.68 (1H, s, CH), 6.79–6.81 (1H, t, J = 4.6 Hz), 6.83 (1H, s, NH), 6.91 (2H, s, NH₂), 7.17–7.16 (1H, d, J = 4.6 Hz), 7.71–7.68 (1H, t, J = 7.5 Hz), 7.8–7.77 (1H, t, J = 7.5 Hz), 7.99–7.98 (1H, d, d = 7.5 Hz), 7.91–7.9 (1H, d, J = 7.5 Hz). CHN analysis calcd for C₁₈H₁₂BrN₃O₂S; C, 56.56; H, 3.16; N, 10.99; found C, 56.49; H, 3.21; N, 11.05.

**Disclosure statement**

No potential conflict of interest was reported by the authors.

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