

Emerging poly(Ani-co-Py)/Bi₂O₃/AgI composites for antibacterial and antioxidant applications

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ABSTRACT

Poly(Ani-co-Py) was synthesized using aniline (Ani) and pyrrole (Py) and its composites poly(Ani-co-Py)/Bi₂O₃/AgI composites were fabricated with the extent of Bi₂O₃ and AgI maintaining 5 to 15 wt% ratio. FESEM analysis displayed that the freshly prepared copolymers and composites exhibited aggregated and spherical-shaped morphology with diameter 200–300 nm and 50–300 nm, respectively. The EDS data revealed the incorporation of both Bi₂O₃ and AgI in the composite samples. These poly(Ani-co-Py) and poly(Ani-co-Py)/Bi₂O₃/AgI composites were used to investigate their antibacterial properties using the resazurine-assisted microtiter plate-based antibacterial test. In the investigation, both the copolymers and composites exhibited antibacterial properties against *Escherichia coli* and *Bacillus subtilis* bacteria. Further, poly(Ani-co-Py) and Poly(Ani-co-Py)/Bi₂O₃/AgI composites with in vitro antioxidant activity was assessed by using free radical (α,α-diphenyl-β-picrylhydrazyl (DPPH) scavenging assay. The synthesized copolymers and composites exhibited IC₅₀ value around 38.74 and 41.70–42.60 μg/mL, respectively indicating their better antioxidant properties. This poly(Ani-co-Py)/Bi₂O₃/AgI composites could be an emerging materials in the area of antimicrobial and antioxidant activity.

1. Introduction

The presence of pathogenic microorganisms in different types of environments represents an important public health concern [1]. Microbial surface contamination leads to the transmission of infectious diseases [2] and underlines those interactive displays, common in both healthcare environments as well as public settings-may act as important fomites for pathogens [3]. The recent COVID-19 pandemic has heightened anxieties regarding the spread of pathogens through common tactile devices, and surfaces [4]. These surfaces are challenging or impossible to be disinfected by conventional disinfection techniques without affecting their performance [5,6]. For such purposes, there is a growing need for innovative surface coatings with built-in antibacterial properties to mitigate microbial contamination without impairing device functionality [7,8]. Thus, the antibacterial and antioxidant properties of materials can expose new scopes for the application area of the

fabricated product. In this context, metals, e.g. silver, bismuth and zinc; metal oxides for example zinc oxide, carbon-based materials say CNTs can be utilized as antibacterial nanomaterial coatings that project a broad-spectrum antimicrobial efficacy [9,10]. Among the metal oxides, Bi₂O₃ has potential prospects for its antibacterial properties reported in a recent study [11]. Other than the metal oxides, the antimicrobial activity of nanostructured semiconducting materials like AgI were observed for various bacterial [12].

Thus, a versatile platform for combining nanomaterials with antibacterial properties into polymer composites has been opened by metal oxides in polymer composites. Mechanical strength as well as water repellant properties were improved of such kind of composite materials [13]. The enhanced mechanical resilience and the hydrophobic characteristics of these materials have provided a very good solution to the antibacterial and antioxidant properties of conducting polymer-based composites. These materials not only attributes to prohibit microbial

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strains but also it makes them more useful especially in sensor technologies [14,15]. Furthermore, such conducting polymer composites is useful in medical purposes like; artificial muscles, drug delivery and nerve regeneration owing to its low cytotoxicity as well as excellent biocompatibility [16,17]. In addition, they are redox active and show electron transfer reactions that are important for biomedical setting functions such as antioxidants.

In this area, one of the major diseases in which oxidative stress plays a crucial role is cardiovascular diseases including cancer [18]. This means that while natural phenolic antioxidants work against free radicals, conducting polymers like polyaniline (PANI) and polypyrrole (PPy) have shown antioxidant properties and can be used in rubbers materials [19]. These devices or therapies hold promise for use in biological environments [20]. By motivating to these kinds of phenomena of PANI and PPy, we aimed to synthesize copolymers utilizing these two conducting polymers for antibacterial and antioxidant properties. Further, no report was found on the utilizing of copolymer, poly(Ani-co-Py) and its composites with Bi₂O₃ and AgI (poly(Ani-co-Py)/Bi₂O₃/AgI) for antimicrobial and antioxidant capacities.

Furthermore, the adoption of green synthesis methods is becoming increasingly important to ensure sustainability in material development. Green synthesis techniques utilize non-toxic, environmentally friendly reagents and processes to produce nanomaterials with enhanced biocompatibility and tailored morphological features [21–30]. Despite the growing information in literature emphasizing the advantages of green synthesis, there is still a lack of research on the use of these methods for developing multifunctional composites that incorporate Bi₂O₃ and AgI into conducting polymer matrices. To address these gaps, this work focuses on the synthesis of poly(Ani-co-Py)/Bi₂O₃/AgI composites using simple comparatively environment friendly techniques for antibacterial and antioxidant applications. By achieving a multifunctional material system with inherent antibacterial and antioxidant properties, this work may offer a pioneering approach to developing advanced materials for healthcare and surface protection applications.

The present study reports the antibacterial and antioxidant capacities of poly(Ani-co-Py) and poly(Ani-co-Py)/Bi₂O₃/AgI composites employing the resazurine-assisted microtiter plate-based analysis and by free radical (DPPH) scavenging assay, respectively. This research investigates the two-fold functionality of conducting polymer-based composites as antibacterial capacity and antioxidants, therefore addressing their potential as emerging materials for biomedical devices performance. By testing them against microbial infections and antioxidant capacity, respectively, this work may provide a unique insight in conducting polymer-based copolymer composites for their application in healthcare technologies.

2. Experimental

2.1. Materials

The chemical reagents, including pyrrole, aniline, bismuth oxide (Bi₂O₃), silver iodide (AgI), ammonium persulphate (APS), hydrochloric acid (HCl, 1M), acetone, and ethanol, were procured from Merck (Germany) and utilized as received without further refinement. High-purity deionized water was used to prepare all the aqueous solutions.

2.2. Formation of poly(Ani-co-Py) and poly(Ani-co-Py)/Bi₂O₃/AgI composites

The poly(Ani-co-Py) copolymer was synthesized using a modified literature procedure [17,31]. The synthesis of such poly(Ani-co-Py) copolymer and poly(Ani-co-Py)/Bi₂O₃/AgI composites was recently reported by our group [31,32]. The synthesis of PANI and PPy was also carried out using similar procedures, with aniline and pyrrole monomers, respectively [33]. Four different synthesis batches of the composite samples were prepared by the loading of Bi₂O₃ and AgI ranging

Table 1

Synthesis identifier, loading of Bi₂O₃ and AgI for the copolymer and poly(Ani-co-Py)/Bi₂O₃/AgI composites preparation are listed.

Synthesis identifier	Loading of Bi ₂ O ₃ and AgI (wt%)
Poly(Ani-co-Py)	—
α	5
β	7
γ	10
δ	12

from 5–12 wt% (Table 1).

2.3. Characterizations

2.3.1. FTIR and UV–visible measurements

FTIR spectra of both copolymers and their composites were carried out by Shimadzu IR Prestige-21 (Japan) and the Shimadzu UV-1800 was utilized to attain the UV–visible spectra.

2.3.2. Morphological characterization

Using a JEOL JSM 7600F Field Emission FESEM fitted with an EDX, the morphological characteristics and elemental detection of the synthesized copolymer and composite samples were examined. Platinum was applied to the samples to facilitate FESEM and EDS studies.

2.4. Antibacterial property experiment

A resazurine-assisted microtiter plate-based antibacterial experiment was used to evaluate the antibacterial activity of the poly(Ani-co-Py) and poly(Ani-co-Py)/Bi₂O₃/AgI composites. The results were reported as MIC used a Gram-positive (*Bacillus subtilis* NCTC 8236) and a Gram-negative (*Escherichia coli* NCTC 12241) bacteria for antibacterial assessment [34]. In aseptic conditions, two distinct bacterial strains were added to two 100 mL bottles of Luria broth, so that each bottle contained just one type of bacteria. After that, these were kept at 35° C for 12 to 18 h in an incubator. All the bacterial cultures were centrifuged for five minutes after the incubation period. The pellets were then re-suspended in 20 mL of sterile normal saline and centrifuged for a further five minutes after the supernatant was discarded. Pellet was identified as “bacterial solution” when it was dissolved in 20 mL of sterile normal saline [35].

Aseptic conditions were maintained during the performance of the Resazurin-based Microtiter Dilution Assay in microtiter plates (Tarson). Test material dissolved in DMF was added to the first row of a microtiter plate. Nutrient broth filled each well on the micro titer plate. After the positive and negative control compounds were transferred, 100 µl from each well in the first row was transferred to the wells of the next row in a column, serially diluting the test material twice so that each well had 100 µl of the tested material at a decreasing concentration. Three controls were included in each microtiter plate: (a) Gentamicin was used as the Positive Control; (b) all solutions were added to the test extract, except for the Negative Control; and (c) the same solution was used in the other column, which substituted 10 µl of nutritional broth for the bacterial suspension. Following a 24-hour incubation period at 37°C in the air, the well was visually examined for color changes. The presence of nitrite is indicated by the appearance of a purple solution (negative); the change in color to pink or colorless is noted as positive. MIC values were defined as the lowest chemical compound concentration at which a color shift was noticeable. For every experiment, determinations were done in triplicate. Average values were estimated for the MIC of test substance [36,37].

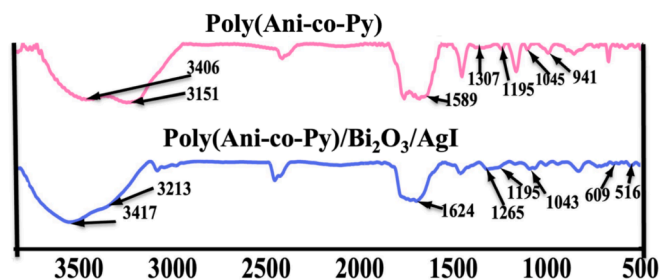


Fig. 1. FTIR spectrum of poly(Ani-co-Py), and poly(Ani-co-Py)/Bi₂O₃/AgI composite.

2.5. Antioxidant property measurement

2.5.1. DPPH free radical scavenging test

The free radical scavenging assay DPPH (2, 2-diphenyl-1-picrylhydrazyl) was employed to evaluate antioxidant capacity of sample [38]. First, an C₂H₅OH based 0.004% (w/v) DPPH solution was prepared. A variable concentration of 1 mL of crude extract in C₂H₅OH was combined with 3 mL of this solution. The assortment was then well agitated and placed in room temperature for approximately 30 min in a dark place for incubation. After this stage, absorbance was measured at 517 nm using UV-visible spectrophotometer. Equation following was used to calculate the percentage of scavenging activity:

$$\% \text{ of DPPH free radical scavenging performance} = [(A_0 - A_1)/A_0] \times 100$$

Here, A₀ is absorbance of control, and A₁ is absorbance of sample/positive control. After that, a graph demonstrating the half maximal inhibitory concentration (IC₅₀) was plotted by the percentage of scavenging activity versus log concentration [38].

2.5.2. DPPH free radical scavenging test

The free radical scavenging assay DPPH (2, 2-diphenyl-1-picrylhydrazyl) was employed to evaluate antioxidant capacity of sample [28]. First, an C₂H₅OH based 0.004% (w/v) DPPH solution was prepared. A variable concentration of 1 mL of crude extract in C₂H₅OH was combined with 3 mL of this solution. The assortment was then well agitated and placed in room temperature for approximately 30 min in a dark place. At 517 nm, absorbance was measured using UV-visible spectrophotometer. Equation following was used to calculate the percentage of scavenging activity:

$$\% \text{ of DPPH free radical scavenging performance} = [(A_0 - A_1)/A_0] \times 100$$

Here, A₀ is absorbance of control, and A₁ is absorbance of sample/positive control. After that, a graph demonstrating the half maximal inhibitory concentration (IC₅₀) was plotted by the percentage of scavenging activity versus log concentration [28].

3. Results and discussion

3.1. Incorporation of Bi₂O₃ and AgI into poly(Ani-co-Py)

Total five synthesis batches were performed to prepare the samples of poly(Ani-co-Py) and poly(Ani-co-Py)/Bi₂O₃/AgI composites, as presented in Table 1. The successful formation of both poly(Ani-co-Py) and poly(Ani-co-Py)/Bi₂O₃/AgI composites was explained by FTIR, UV-Visible and PL spectroscopy in a recent report by our group [32,33]. For instance, the FTIR spectra of synthesized copolymer and composite materials are presented in Fig. 1. For poly(Ani-co-Py), all typical signals of PANI and PPy are identified, such as the signal at 1589 cm⁻¹ signifies the stretching-ring-deformations of benzene, and peaks at 1307 cm⁻¹ and 1195 cm⁻¹ denoted to C=N and N=Q=N stretching [32,33]. Furthermore, the peaks identified at 1045 cm⁻¹ and 941 cm⁻¹ signified

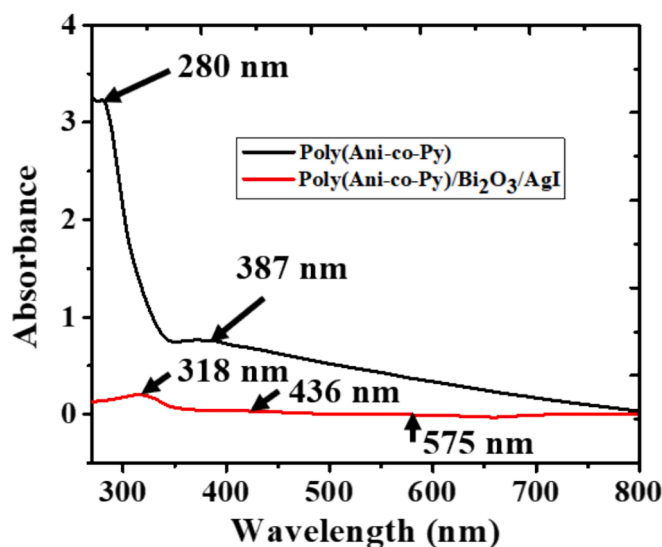


Fig. 2. UV-visible bands of poly(Ani-co-Py), and poly(Ani-co-Py)/Bi₂O₃/AgI composite.

=C—H deformation and vibration of PPy in poly(Ani-co-Py), correspondingly. The signals at 3406 and 3151 cm⁻¹ demonstrated the N—H stretching vibrations of PANI and PPy in the poly(Ani-co-Py) [32,33]. For poly(Ani-co-Py)/Bi₂O₃/AgI composite, the N—H stretching peaks of PANI and PPy are shifted, demonstrating the incorporation of Bi₂O₃ and AgI with the copolymer (Fig. 1). Moreover, the stretching modes of Bi—O and Ag—I bonds at around 516 cm⁻¹ and 609 cm⁻¹, respectively further confirm the integration of both Bi₂O₃ and AgI into the poly(Ani-co-Py) (Fig. 1).

The UV-visible absorption band of copolymer and poly(Ani-co-Py)/Bi₂O₃/AgI composite are presented in Fig. 2. For poly(Ani-co-Py), two absorption bands were identified at 280 nm and 387 nm. In the case of poly(Ani-co-Py)/Bi₂O₃/AgI, three absorption bands were visible at 318 nm, 436 nm, and 575 nm, respectively. Thus, it can be seen that the absorption band for the composites are shifted compared to poly(Ani-co-Py), which is owing to the integration of both Bi₂O₃ and AgI into the poly(Ani-co-Py).

To deepen the study of interaction of Bi₂O₃ and AgI into the poly(Ani-co-Py), EDS measurements were carried out. Fig. 3 displays, for instance, the EDS spectra of poly(Ani-co-Py)/Bi₂O₃/AgI composites attained with the loading of 10 wt% Bi₂O₃ and AgI. The resultant elemental compositions are given in inset of Fig. 3. The presence of Bi, Ag, and I along with the C, N, and O in the composite samples were perceived and the resultant atomic % of Bi, Ag, and I are 1.39, 0.87, and 0.36, respectively (inset of Fig. 3). Thus, this result indicates the incorporation of both Bi₂O₃ and AgI in the copolymers. Similar incorporation of metal oxides and semiconducting materials into the conducting polymers and copolymers and their presence with the products were reported in reference [17,33].

3.2. Morphology

Fig. 4 (panel a and b) displays the typical FESEM micrographs of poly(Ani-co-Py), and poly(Ani-co-Py)/Bi₂O₃/AgI composites. The poly(Ani-co-Py)/Bi₂O₃/AgI composites obtained at 10 wt% loading of Bi₂O₃ and AgI are presented here as an example (Fig. 4 b). For copolymers, the diameter remains in the range of 200–300 nm with aggregated and spherical-shaped morphology (Fig. 4a), whereas more agglomerated morphology of the composites is appreciated with diameter 50–300 nm (Fig. 4b). Similar morphology for both copolymers and composite materials are explained in our recent studies demonstrating that their unique structures are integral to maximizing their functional

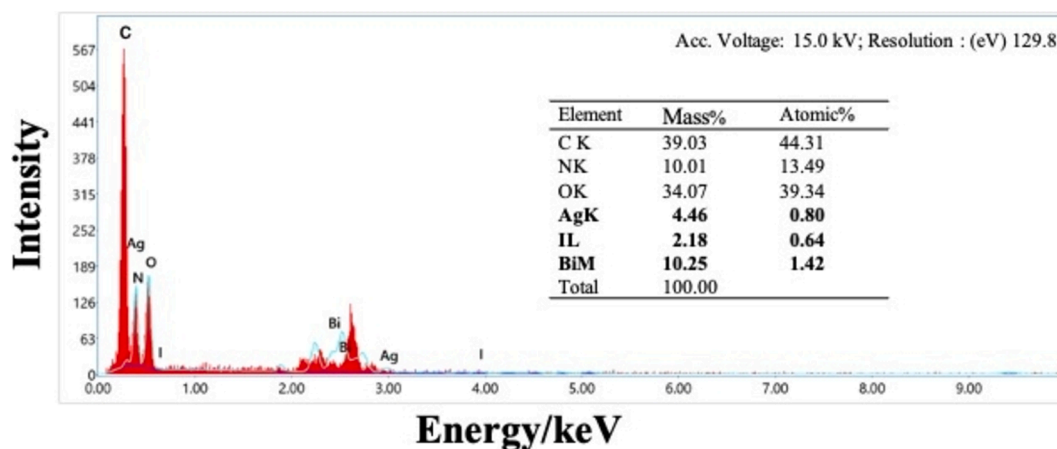


Fig. 3. EDS spectrum of poly(Ani-co-Py)/Bi₂O₃/AgI composites (sample γ).

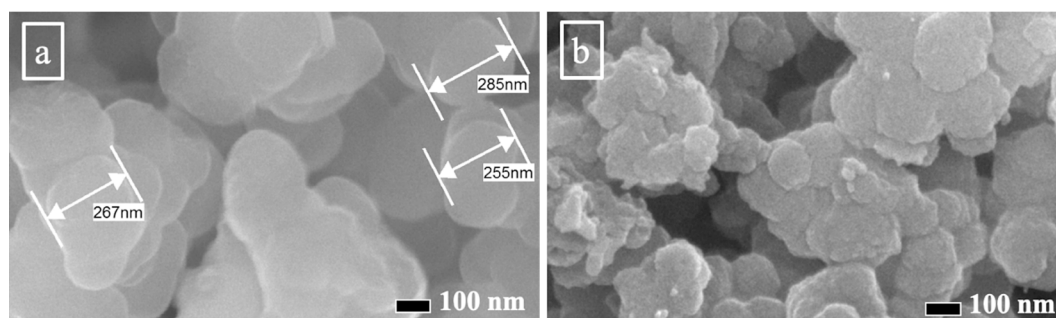


Fig. 4. SEM micrograph of (a) poly(Ani-co-Py), and (b) poly(Ani-co-Py)/Bi₂O₃/AgI composites (Sample β).

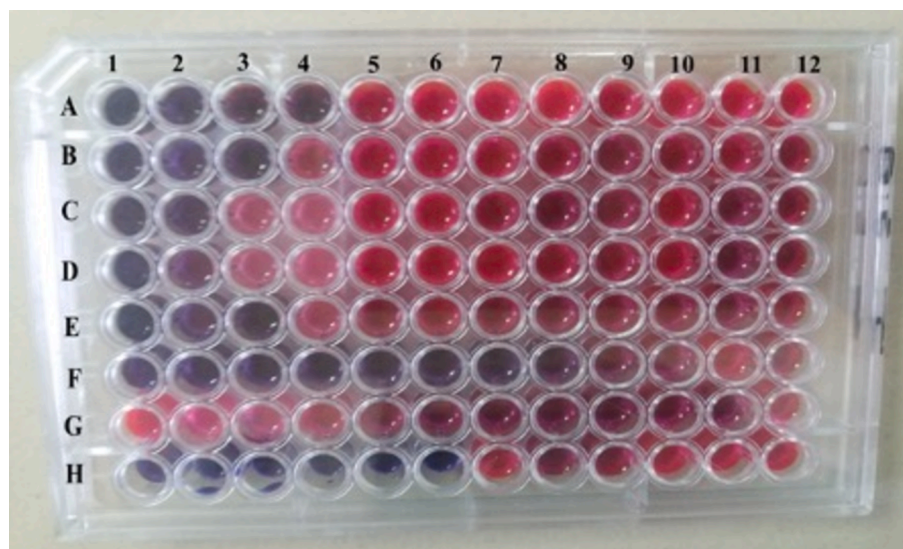


Fig. 5. [A = Nutrient broth + poly(Ani-co-Py) + *E. coli*; B = Nutrient broth + α + *E. coli*; C = Nutrient broth + β + *E. coli*; D = Nutrient broth + γ + *E. coli*; E = Nutrient broth + δ + *E. coli*; F = Nutrient broth + Gentamicin + *E. coli*; G = Nutrient broth + *E. coli*; H (1–6) = Nutrient broth; H(7–12) = Solvent + *E. coli*]. (Here, α, β, γ, δ are the poly(Ani-co-Py)/Bi₂O₃/AgI composites synthesized at different loadings of Bi₂O₃ and AgI as presented in Table 1).

effectiveness [31,32].

3.3. Antibacterial property analysis

The antibacterial activity of the synthesized poly(Ani-co-Py) and poly(Ani-co-Py)/Bi₂O₃/AgI composites were examined using a resazurin-assisted microtiter plate-based antibacterial measurement,

and outcomes were conveyed as MIC (Sarker, Nahar et al. 2007). Here, a gram-positive (*B. subtilis* NCTC 8236) and a gram-negative (*E. coli* NCTC 12241) bacteria were expended for the antibacterial screening [34,35].

3.3.1. Treatments against *Escherichia coli*

In the antibacterial test, *E. coli* bacteria was used and the color change in the microtiter plates were perceived visually. Any color

Table 2Absorbance of treatments against *E. coli*.

Identifier Treatment	Concentration ($\mu\text{g/mL}$)											
	2000	1000	500	250	125	62.5	31.25	15.63	7.81	3.91	1.95	0.97
B1	0.96	1.07	1.15	1.21	1.71	1.92	2.15	2.34	2.48	2.63	2.74	2.82
B2	1.01	1.09	1.18	1.49	1.65	1.86	1.98	2.26	2.41	2.55	2.73	2.89
B3	1.15	1.33	1.58	1.76	1.85	2.06	2.24	2.37	2.52	2.71	2.83	2.95
B4	1.02	1.17	1.39	1.58	1.73	1.88	2.13	2.31	2.56	2.63	2.75	2.81
B5	1.04	1.16	1.19	1.32	1.47	1.62	1.87	2.25	2.43	2.61	2.76	2.85
Control	200	100	50	25	12.5	6.25	3.13	1.56	0.78	0.39	0.2	0.1
C1	0.87	0.91	0.96	0.99	1.08	1.11	1.17	1.27	1.38	1.61	1.88	2.07

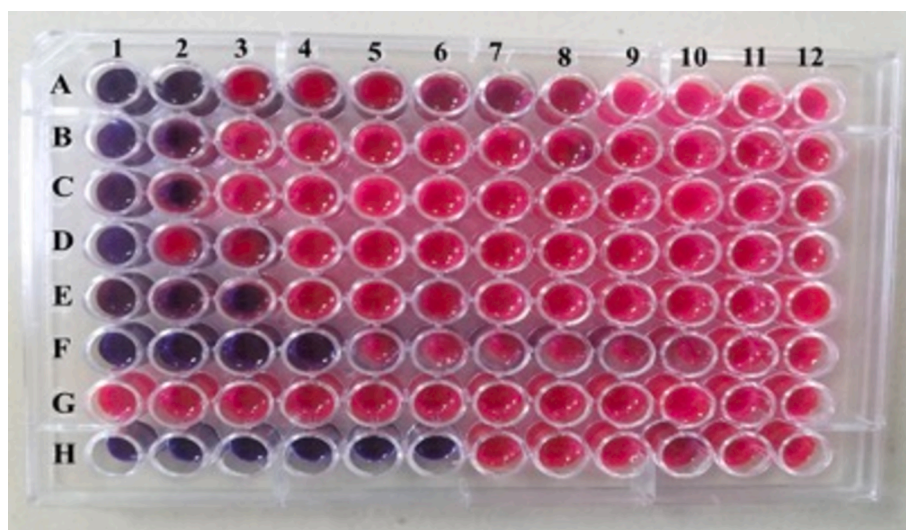


Fig. 6. [A = Nutrient broth + B1 + *B. subtilis*; B = Nutrient broth + B2 + *B. subtilis*; C = Nutrient broth + B3 + *B. subtilis*; D = Nutrient broth + B4 + *B. subtilis*; E = Nutrient broth + B5 + *B. subtilis*; F = Nutrient broth + Gentamicin + *B. subtilis*; G = Nutrient broth + *B. subtilis*; H (1–6) = Nutrient broth; H (7–12) = Solvent + *B. subtilis*]. (Here, α , β , γ , δ are the poly(Ani-co-Py)/ Bi_2O_3 /AgI composites synthesized at different loadings of Bi_2O_3 and AgI as presented in Table 1).

Table 3Absorbance of treatments against *B. subtilis*.

Treatment	Concentration ($\mu\text{g/mL}$)											
	2000	1000	500	250	125	62.5	31.25	15.63	7.81	3.91	1.95	0.97
B1	1.06	1.21	1.35	1.57	1.71	1.92	2.15	2.34	2.48	2.63	2.74	2.82
B2	1.01	1.19	1.38	1.49	1.65	1.86	1.98	2.26	2.41	2.55	2.73	2.89
B3	1.15	1.33	1.58	1.76	1.85	2.06	2.24	2.37	2.52	2.71	2.83	2.95
B4	1.02	1.17	1.39	1.58	1.73	1.88	2.13	2.31	2.56	2.63	2.75	2.81
B5	1.04	1.16	1.19	1.32	1.47	1.62	1.87	2.25	2.43	2.61	2.76	2.85
Control	25	12.5	6.25	3.13	1.56	0.78	0.39	0.2	0.1	0.05	0.02	0.01
C1	0.87	0.98	1.08	1.13	1.27	1.38	1.61	1.88	2.07	2.28	2.41	2.54

change observed from pink to purple was taken as positive (Fig. 5). The results are clearly appreciated from the Fig. 5, as the color change from pink to purple was occurred for the corresponding *E. coli* bacteria using the poly(Ani-co-Py) and poly(Ani-co-Py)/ Bi_2O_3 /AgI samples. Similar outcomes for the *E. coli* bacteria using conducting polymers and other phytochemicals were reported in reference [34,39]. The lowest concentration of chemical compound at which color change occurred was recorded as the MIC value which was identified by yellow highlighter in Table 2. All the experiments were performed in triplicates [34,35].

3.3.2. Treatments against *Bacillus subtilis*

Similarly, the antibacterial test was performed exploiting the copolymer and composite samples for the *B. subtilis* bacteria. In the antibacterial measurement, the *B. subtilis* bacteria was used and the color change in the microtiter plates were perceived visually (Fig. 6). Any color change identified from pink to purple was considered as positive and the corresponding outcome for this bacterium is presented

in Fig. 6. The antibacterial property against *B. subtilis* is clearly appreciated from Fig. 6. The outcomes exhibit that both the copolymers and composites work well for their antibacterial activity against this bacterium. A similar antibacterial property of conducting polymers like polyaniline and polypyrrole and other polymeric materials was reported by the researchers [39,40,41]. The lowest concentration of chemical compound at which color change occurred was recorded as the MIC value which was identified by yellow highlighter in Table 3.

3.4. Antioxidant property analysis

Fig. 7 illustrate the antioxidant activity of ascorbic acid, copolymers, and synthesized composites (α , β and γ) analyzed through the DPPH free radical scavenging assay. The DPPH assay is a common method to evaluate antioxidant capacity by measuring the % inhibition of DPPH free radicals at various concentrations of antioxidant compounds. Ascorbic acid, a well-known antioxidant, demonstrates high %

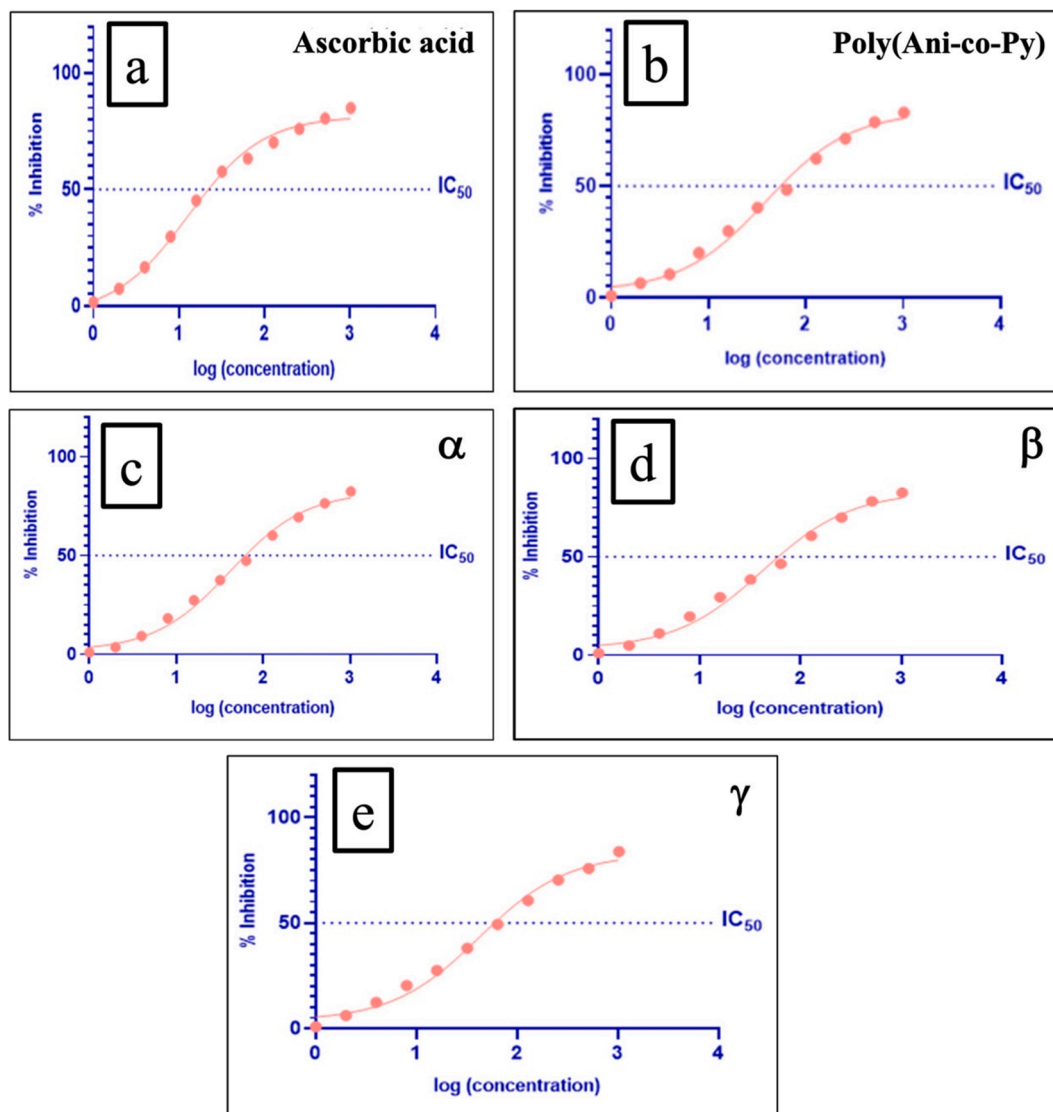


Fig. 7. % of Inhibition vs log concentration of Ascorbic acid, copolymers, and synthesized composites (α , β , and γ).

Table 4

The IC_{50} value for free radical scavenging activity.

Sample	IC_{50} ($\mu\text{g/mL}$)
Ascorbic Acid	12.89
Poly(Ani-co-Py)	38.74
α	41.70
β	42.24
γ	42.60

inhibition at lower concentrations than the other samples, indicating robust DPPH radical scavenging activity. It can be seen that ascorbic acid achieves around 85–90% inhibition, while poly(Ani-co-Py) and poly(Ani-co-Py)/ $\text{Bi}_2\text{O}_3/\text{AgI}$ composites reach approximately 82–83% and 82–85% inhibition, respectively (Fig. 7). These values suggest that ascorbic acid is the most effective antioxidant among the tested compounds, showing the lowest IC_{50} , followed by poly(Ani-co-Py), which has slightly lower antioxidant activity. Compounds α , β , and γ exhibit moderate activity, with γ having the lowest IC_{50} among them, indicating better potency in scavenging DPPH radicals. This analysis highlights the potential of these compounds as antioxidants, with lower IC_{50} values correlating to stronger antioxidant capacity. Such findings can be valuable for evaluating antioxidants in various applications.

3.4.1. DPPH free radical scavenging activity

The antioxidant activity of poly(Ani-co-Py) copolymer and its composites were determined by DPPH free radical scavenging method [40]. The IC_{50} value for free radical scavenging performance was measured and compared with standard ascorbic acid as shown in Fig. 7 for all samples. IC_{50} value for poly(Ani-co-Py) and poly(Ani-co-Py) $\text{Bi}_2\text{O}_3/\text{AgI}$ composites were found to be around 38.74 and 41.70–42.60 $\mu\text{g/mL}$, respectively whereas for standard ascorbic acid, the value was 12.89 $\mu\text{g/mL}$ [38]. The IC_{50} value of all the samples are listed in Table 4. It was identified that IC_{50} value was higher for both the copolymer and composites samples compared to ascorbic acid. A similar superior free radical scavenging performance for nanocomposites was reported in reference [42]. These outcomes indicate the better antioxidant properties of the prepared copolymers and composite samples.

We also measured the antioxidant activity of poly(Ani-co-Py) and poly(Ani-co-Py)/ $\text{Bi}_2\text{O}_3/\text{AgI}$ -composites which were determined by DPPH free radical scavenging method. For instance, the value of % of inhibition for absorbance were identified for both ascorbic acid and synthesized composites in various log concentration is presented in Fig. 8 and the values are listed in Table 5. The value was found for ascorbic acid 86.21, whereas the values are 83.25 and 82.54–83.22 for poly(Ani-co-Py) and poly(Ani-co-Py) / $\text{Bi}_2\text{O}_3/\text{AgI}$ composites, respectively. These outcomes are consistent with the previous reports [28].

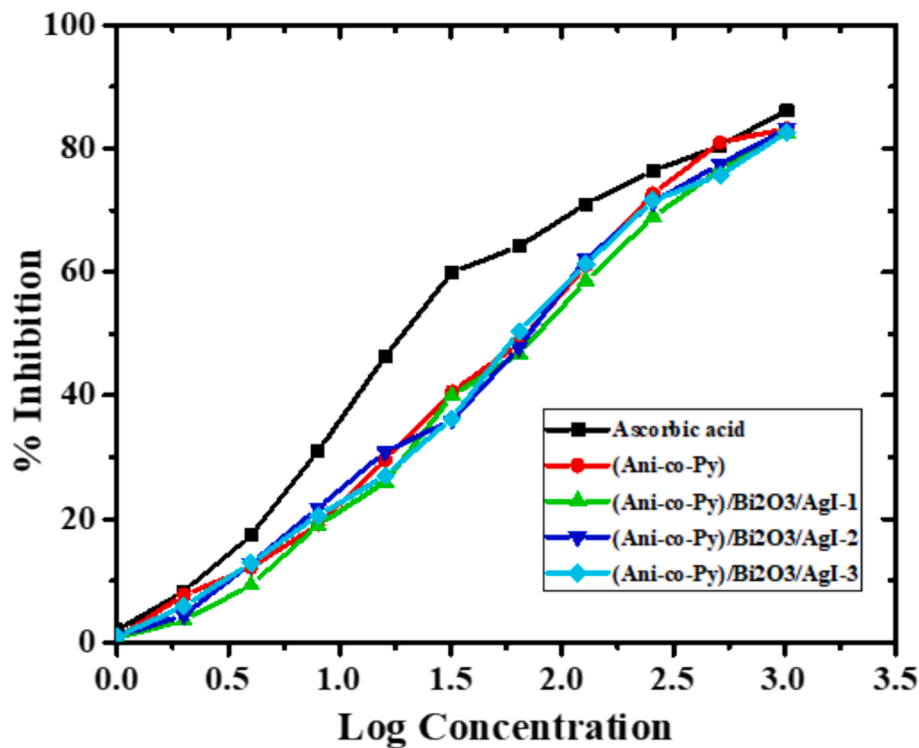


Fig. 8. The % of inhibition for absorbance vs log concentration of Ascorbic acid and synthesized composites.

Table 5
The value of % of Inhibition for Absorbance vs log concentration of Ascorbic acid and synthesized composites.

Log Conc.	% of Inhibition for absorbance				
Sample	Ascorbic acid	Poly(Ani-co-Py)	α	β	γ
Blank	—	—	—	—	—
0.000	2.03	0.79	0.73	1.04	1.03
0.301	8.26	7.70	3.60	4.41	5.86
0.602	17.37	12.11	9.30	12.82	12.90
0.903	31.03	19.08	18.99	21.83	20.54
1.204	46.38	29.58	26.00	30.92	27.04
1.505	59.97	40.63	39.94	36.02	36.31
1.806	64.17	48.48	46.82	47.83	50.42
2.107	71.03	61.11	58.56	62.15	61.30
2.408	76.41	72.70	68.95	71.32	71.59
2.709	80.48	81.01	76.58	77.55	75.71
3.010	86.21	83.25	82.55	83.22	82.66

However, no significant variations were observed among the composite's samples. Such outcome further indicates the better antioxidant properties of the copolymers and composite samples.

4. Conclusions

Poly(Ani-co-Py) and poly(Ani-co-Py)/Bi₂O₃/AgI composites was synthesized by chemical oxidative polymerization for antibacterial and antioxidant applications. Both the copolymers and composites exhibited aggregated and spherical-shaped morphology with diameter 200–300 nm and 50–300 nm, respectively identified by FESEM measurements. In the antibacterial test, Poly(Ani-co-Py) and poly(Ani-co-Py)/Bi₂O₃/AgI composites exhibited inhibition against *E. coli* and *B. subtilis* bacteria. However, composites showed better antibacterial activity relative to copolymers. Further, the free radical (DPPH) scavenging assay demonstrated in vitro antioxidant activity of both poly(Ani-co-Py) and poly(Ani-co-Py)/Bi₂O₃/AgI with IC₅₀ value around 38.74 and 41.70–42.60 µg/mL, respectively. These results indicate the better antioxidant

properties of composites than copolymer alone.

CRediT authorship contribution statement

Mohammad Mizanur Rahman Khan: Writing – original draft, Supervision, Methodology, Investigation, Conceptualization. **Mohammad Riaz Hosen Shohag:** . **Mohammad Shahadat Hossain Chowdhury:** Data curation, Investigation, Validation, Writing – review & editing. **Md Sultan Mahmud Rony:** Writing – review & editing, Validation, Investigation, Data curation. **Shaikh Jamal Uddin:** Writing – review & editing, Validation, Investigation, Data curation. **Mobinul Islam:** Writing – review & editing, Validation, Investigation, Data curation. **Jae-Ho Jeong:** Data curation, Investigation, Validation, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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