Synthesis of dye-substituted polyanilines and study of their conducting and antimicrobial behavior

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Nirmala Kumari Jangid¹, Narendra Pal Singh Chauhan², Kiran Meghwal¹, Rakshit Ameta³ and Pinki Bala Punjabi¹*

Abstract: Conducting and antimicrobial properties of chemically synthesized polyanilines was found to be affective by varying the dye moieties. The temperature dependence of AC conductivity was studied by two-probe method to learn about the conduction behavior of the synthesized compounds. The conductivity of the dye-substituted polyanilines was found to be in the range of $10^{-3}$ S/cm. For the study of antimicrobial behavior of the synthesized dye-substituted polyanilines, different micro-organisms, namely, the bacteria Escherichia coli (MTCC 442), Pseudomonas aeruginosa (MTCC 441), Staphylococcus aureus (MTCC 96), and Staphylococcus pyogenus (MTCC 443) and fungal strains Candida albicans (MTCC 227), Aspergillus niger (MTCC 282), and Aspergillus clavatus (MTCC 1323), were chosen based on their clinical and pharmacological importance. Antimicrobial properties of dye-substituted polyanilines show very good results as compared to polyanilines and dyes individually.

Subjects: Chemistry; Medicinal & Pharmaceutical Chemistry; Organic Chemistry

Keywords: dye-substituted polyanilines; conducting behavior; antimicrobial properties

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PUBLIC INTEREST STATEMENT

In the last few decades, polyaniline, which is also known as PANI, has attracted the attention of researchers all over the world due to its high electrical conducting nature. It has been the most studied conducting polymer than others, as it has many attractive processing properties. PANI also shows antibacterial and antifungal activities. On the other hand, dye moieties also show such antimicrobial activities. It is worth mentioning here that the synthesized dye-substituted polyanilines in the present investigation showed good antimicrobial activity as compared to dye moieties and polyanilines, individually. This observation will explore the use of such scaffolds in newer antimicrobial drugs.
1. Introduction
The conducting polymers (CPs) such as polyanilines, polyacetylenes, polythiophenes, and polypyrroles, are promising materials for potential industrial applications such as electromechanics (ER), electronics, and optics due to their high electrical conductivity and good environmental stability (Gercek, Yavuz, Yilmaz, Sari, & Unal, 2007; Gumus, Unal, Erol, & Sari, 2011; Yilmaz et al., 2011). The conductivities of these conjugated polymers are achieved through chemical oxidation or reduction reactions using a series of simple anionic or cationic species called dopants (Chandrasekhar, 1999; Wallace, Spinks, & Kane-Maguire, 2003). The earliest reported application of conducting polymers (CPs) has been used in the free-standing polymers as sensor devices. Chemical sensors are analytical devices that convert the chemical potential energy of a targeted analyte into a proportionate measurable signal, usually electrical or optical. In these CPs, polyaniline is a typical phenylene-based polymer having a chemically flexible –NH– group in the polymer chain flanked on either side by a phenylene ring. The protonation, deprotonation, and various other physicochemical properties of polyaniline are due to the presence of the –NH– group.

There have been a number of reviews on CPs with regard to biomedical applications (Karunanithy et al., 2013; Marija, Gizdavic-Nikolaidis, Bennett, Allan, & Eastal, 2011 Nabi, Shahadat, Bushra, & Oves, 2011; Yehgambaram, Prasad, Jakka, Aparna, & Phani, 2013). The commercially available soluble CPs polyaniline (PANI) grafted to lignin, poly(aniline sulfonic acid), and polypyrrole (PPy) are effective scavengers of the stable 1,1-diphenyl-2-picrylhydrazyl (DPPH) free radical. This property may be particularly beneficial in tissues suffering from oxidative stress, where the ability to lower the excessive levels of reactive radical species is desirable. This free radical reducing ability of CPs is revealed by efficient scavenging of DPPH radicals, with two and four radicals scavenged per aniline or pyrrole monomer unit during the 30-min test period of the DPPH assay, indicating the potential for CPs to be effective antioxidants when present in biological medium (Vadukumpully, Paul, Mahanta, & Valiyaveettil, 2011). The various vitamins and polyphenol free radical scavenging antioxidants present in beverages, fruits, and vegetables are currently of great interest, as these antioxidants may offer protection against various diseases, such as cardiovascular diseases and cancer (Gizdavic-Nikolaidis, Travas-Sejdic, Bowmaker, Cooney, & Kilmartin, 2004).

It appears that the presence of an acidic functional group (–COOH) in the polymer chain improves the antibacterial efficacy of the copolymer. Without being bound by theory, the acidic dopants on the molecular chains of copolymers may react with the bacteria (or other relevant microbial organism) which result in their death. Alternatively, due to electrostatic adherence between copolymer molecules and the bacteria, which carry charges of different polarity, the walls of the bacteria may break and the contents of the bacteria become exposed or leak out, which cause the bacteria to die (Allan, Marjia, & Srdjan, 2009).

Marija et al. (2011) has investigated the antimicrobial properties of conductive functionalized polyanilines by exploring their interaction with bacterial cells. It has been observed that lower concentrations of PANI strongly inhibited the growth of wild-type Escherichia coli, Pseudomonas aeruginosa, and Staphylococcus aureus as well as several other antibiotic resistant clinical pathogens.

Nanofibere of polyaniline combined with fluconazole have been prepared by simple and cost-effective sol–gel method using β-10-camphorsulfonic acid (β-CSA) as a dopant and as a surfactant, and ammonium persulfate as the oxidant. The synthesized nano-structured material was dissolved in dimethylsulfoxide at different concentrations and tested for its antifungal properties against Candida albicans (ATCC 140503), Candida tropicalis (ATCC 13803), and Candida krusei (ATCC 34135). The results showed that, compared to nanofiber-structured conducting PANI, polyaniline doped with fluconazole showed higher antifungal activity on all the species tested. It is very much evident that PANI-doped fluconazole has a considerably enhanced antifungal activity. C. tropicalis is more susceptible than C. albicans and C. krusei (Yehgambaram et al., 2013).
Polyaniline Zr(IV) sulfosalicylate has also been tested against various bacterial (E. coli, Bacillus thuringiensis, and P. aeruginosa) and fungal strains (A. nigrus, Fusarium oxysporum, and Penicillium chrysogenum). Relatively higher activities have been observed than the known antibiotics (Nabi et al., 2011).

Polyaniline-grafted chitosan (Chit-g-PANI) has been screened for its antimicrobial activity against Staphylococcus epidermidis, S. aureus, Staphylococcus pyogenes, E. coli, C. albicans, C. tropicalis, and C. krusei. The results of antimicrobial activity of PANI and Chit-g-PANI were assessed based on the average diameter of zones of inhibition. The results confirm that Chit-g-PANI has an enhanced antimicrobial activity compared to PANI (Karunanithy et al., 2013). Azo dyes are known for their medicinal importance and are well recognized for their use as antineoplastics (Child, Wilkinson, & Tomcu-Fucik, 1977), antidiabetics (Garg & Prakash, 1972), antiseptics (Browning, Cohen, Ellingworth, & Gulbransen, 1926), antibacterial (Khalid, Arshad, & Crowley, 2008), and antitumor (Thoraya & Abdallah, 2008) agents. They are known to be involved in a number of biological reactions such as inhibition of DNA, RNA, and protein synthesis, carcinogenesis, and nitrogen fixation (Park et al., 2007). Azo dyes are important structures in the medicinal and pharmaceutical fields (Chandrawadivelu & Senniappan, 2011) and it has been suggested that the azoimine linkage might be responsible for the biological activities displayed by some Schiff bases (Patel, 2012). In addition, evans blue and congo red azo dyes have been studied as HIV inhibitors of viral replications. This effect is believed to be caused by the binding of azo dyes to both protease and reverse transcriptase of this virus (Swati, Romila, Sharma, & Verma, 2011). The existence of an azo moiety in different types of compounds has caused them to show antibacterial and antifungal activities. In recent times, exploration of azo dyes as antimicrobial agents has received considerable attention (Avci, Ozkinali, Ozluk, Avci, & Kocaokutgen, 2012).

In the present study, dye-substituted polyanilines were synthesized by oxidative polymerization of aniline. Synthesis of different polyanilines was characterized by FTIR spectrum. It was observed that the dye-substituted polyanilines showed reasonably good antibacterial and antifungal activities as compared to different acid-doped polyanilines and dyes individually. Antimicrobial study of synthesized polyanilines was done by micro-broth dilution method.

2. Experimental

2.1. Materials

Aniline (Merck) and ammonium persulfate (Thomas Baker, India) were used as received. Tetrahydrofuran (THF) and n-BuLi (Sigma–Aldrich, India), Azure B (Hi–Media, India), Malachite green (Hi–Media, India), Methyl Violet (Hi–Media, India), Rhodamine 6G (Hi–Media, India), Methylene Blue (Hi–Media, India), and Methyl Orange (Hi–Media, India) were also used as supplied.

2.2. Synthesis of polyaniline

All chemicals used in this study were of analytical reagent grade and used as received. The PANI was synthesized by chemical oxidative polymerization of 0.1 M aniline (9.3 mL) in an aqueous acidic medium containing 1.0 M of tosic acid (TA) in double-distilled water. Polymerization was initiated by the dropwise addition of 1.0 M of ammonium persulfate as an oxidizing agent to the acidified solution containing the aniline monomer at room temperature under constant stirring for 2 h. After completion of the polymerization reaction (2 h), the blue-colored polyaniline was isolated by filtration and washed with double-distilled water and acetone until the filtrate was colorless to ensure the complete removal of unreacted reagents. Pure PANI synthesized by this method was found to be dark green in color after washing. The precipitate was allowed to equilibrate with an appropriate amount (30 mL) of ammonium hydroxide overnight. This process converted the PANI to its EB form. A free-flowing powder of the polyaniline was obtained by drying it in an oven at 50–90°C for 24 h. The overall reaction for the formation of emeraldine base form is depicted in Scheme 1. This same procedure also repeated with 1.0 M hippuric acid in other reaction mixture is shown in Scheme 2.
2.2.1. Synthesis of dye-substituted polyanilines

Synthesis of polyanilines was reported earlier in our previous papers (Jangid et al., 2014; Jangid, Chauhan, & Punjabi, 2014). The EB form of tosic acid-doped polyaniline (1.0 g) was dissolved in 30-mL THF. The solution was cooled to 0°C and a minimum amount of BuLi (2 mL) was added under stirring. The color of the solution changed from dark green to green black due to the formation of lithium salt of polyaniline (Scheme 3). In a dried conical flask, azure B dye (0.025 g) was dissolved in 10-mL THF. The solution of azure B dye was added to the reaction mixture obtained from the previous step. It is stirred at room temperature for 24 h. This procedure was also repeated with all dye (malachite green and methyl violet) solutions. The color of the solution turned black due to the formation of a black precipitate. The precipitate was filtered and washed with acetone and alcohol to remove residual amounts of unreacted azure B dye. The black powder was then subjected to characterization (Schemes 4–6). The above-mentioned procedure was also repeated with hippuric acid-doped polyaniline, in which rhodamine 6G, methylene blue, and methyl orange dye moieties were substituted on the backbone of hippuric acid-doped polyaniline (Schemes 7–9).
2.3. Characterization

A Perkin-Elmer Spectrum-2000 Fourier transform IR spectrophotometer was used to obtain the IR spectra between 400 and 4,000 cm\(^{-1}\). The samples were prepared in pellet form using spectroscopic grade KBr. Temperature-dependent conductivity measurements were carried out in the range from 35 to 105°C. The conductivities of different polyanilines were measured by two-probe measurements using a Keithley electrometer 6517-A (India). Electrical contacts were made using a silver paste. It has two spring load contact probes. These probes moved in a pipe and are insulated by Teflon washers. This probe arrangement is mounted in a suitable stand, which also holds the sample plate and resistance temperature detectors (RTD) sensor. The stand also serves as the lid for proportional–integral–derivative–(PID) controlled oven. Teflon-coated leads are provided for connecting with High voltage Power Supply EHT-11 and Digital Pico ammeter DPM-111. In the setup, the maximum voltage was equal to 1,000 V; current 100 × 10\(^{-12}\) A (max); and the thickness of the sample was 1.5 mm. For antimicrobial studies, the following micro-organisms were chosen based on their clinical and pharmacological importance: bacteria *E. coli* (MTCC 442), *P. aeruginosa* (MTCC 441), *S. aureus* (MTCC 96), and *Staphylococcus pyogenes* (MTCC 443) and fungal strains *C. albicans* (MTCC 227), *Aspergillus niger* (MTCC 282), and *Aspergillus clavatus* (MTCC 1323). The bacterial and fungal stock cultures were incubated for 24 h at 37°C on nutrient agar and potato dextrose agar (PDA) media.
Scheme 7. Synthesis of rhodamine 6G-substituted polyaniline (PANI-RG).

Scheme 8. Synthesis of methylene blue-substituted polyaniline (PANI-MB).

Scheme 9. Synthesis of methyl orange-substituted polyaniline (PANI-MO).
(Microcare Lab., Surat, India) following refrigeration storage at 4°C. The bacterial strains were grown in Mueller-Hinton agar (MHA) plates at 37°C (the bacteria were grown in the nutrient both at 37°C and maintained on nutrient agar slants at 4°C), whereas the fungi were grown in sabouraud dextrose agar and PDA media, respectively, at 28°C. The stock cultures were maintained at 4°C.

3. Result and discussion

3.1. FTIR

In the IR vibration spectra of the dye-substituted polyanilines, five essential absorption bands centered around 1,585, 1,490, 1,290, 1,165, and 840 cm\(^{-1}\) are observed. Comparing to polyaniline, some shifted bands in the spectra of dye-substituted polyanilines were observed, as shown in Table 1. The results suggest that the shifting of the IR absorption peaks is referred to be a signature of the conversion of the quinoid rings to the benzenoid rings due to the proton-induced spin-unpairing mechanism, which was considered to be an indication of increasing degree of charge delocalization on the polyaniline’s backbone due to substitution. IR shift also indicates that the degree of charge delocalization of polymerization increases by introducing dye moieties into the polyaniline backbone.

3.2. Conductivity measurement

The modified polyaniline has enough stability for charge storage applications. Therefore, the fact that reductive degradation removes the attached groups strongly supports the hypothesis that N–N linkages are produced by the coupling of polyaniline with different dyes in basic media, as described in Schemes (4–6) and (7–9). All dye moieties do not have continuous conjugation, but due to the substitution on the polyaniline backbone, conjugation of dye-substituted polyanilines extends in a continuous manner. Therefore, due to the conjugation and presence of positive charge in the form of quaternary ammonium cation, conductivity of dye-substituted polyanilines increases when compared to acid-doped polyanilines. Plotted graphs between \(\log_{10}\rho\) and \(1,000/T\) are shown in Figures 1 and 2. Slope (m) and conductivity of different dye-substituted polyanilines are shown in Table 2.

| Table 1. IR vibrational frequencies of polyanilines |
| S. No. | Vibrational mode | Observed frequency of different polyanilines (cm\(^{-1}\)) | Reported (cm\(^{-1}\)) |
|--------|-----------------|-------------------------------------------------|-----------------|
| 1. | Para substituted | PANI-TA 828 | 830 | 845 | 825 | 832 | 826 | 820 | 855 | 850 |
| 2. | Benzenoid rings | PANI-MG 1,168 and 693 | 1,180 and 695 | 1,165 and 680 | 1,150 and 670 | 1,163 and 690 | 1,165 and 685 | 1,190 and 690 | 1,170 and 690 | 1,165 and 695 |
| 3. | C–H stretching (aromatic ring) | PANI-MV 2,953 | 2,858 | 2,923 | 2,920 | 2,920 | 2,938 | 2,950 | 2,830 | 2,900 |
| 4. | N–H stretching | PANI-HA 3,450 | 3,480 | – | – | 3,365 | 3,312 | 3,200 | 3,300 | 3,400 |
| 5. | Quinoid rings | PANI-RG 1,595 | 1,540 | 1,540 | 1,565 | 1,578 | 1,550 | 1,565 | 1,530 | 1,585 |
| 6. | C–N stretching | PANI-MB 1,270 | 1,309 | 1,315 | 1,310 | 1,315 | 1,310 | 1,315 | 1,320 | 1,305 | 1,300 |
| 7. | C=C stretching (aromatic ring) | PANI-MO 1,665–1,496 | 1,620–1,465 | 1,635–1,495 | 1,635–1,465 | 1,685–1,470 | 1,650–1,480 | 1,665–1,445 | 1,665–1,430 | 1,695–1,455 |
| 8. | C–H stretching | COOH stretching – | – | – | – | 2,500–2,800 | – | – | – | 2,500–3,000 |
| 9. | C–C stretching | C–O stretching – | – | – | – | 1,047 | – | – | – | 1,020 |
| 10. | COOH stretching | – | – | – | – | 1,750 | – | – | – | 1,740–1,760 |
Figure 1. Plot between $\log_{10} \rho$ and $1,000/T$ of dye-substituted polyaniline on tosic acid-doped polyaniline backbone.

Figure 2. Plot between $\log_{10} \rho$ and $1,000/T$ of dye-substituted polyaniline on hippuric acid-doped polyaniline backbone.

Table 2. Slope and conductivity of different polyanilines

| S. No | Polyaniline name                  | Slope (m) | Conductivity (S/cm) |
|-------|----------------------------------|-----------|---------------------|
| 1.    | Azure B-substituted polyaniline  | 1.40667   | $6.20 \times 10^{-3}$ |
| 2.    | Malachite green-substituted polyaniline | 1.15251 | $4.28 \times 10^{-3}$ |
| 3.    | Methyl violet-substituted polyaniline | 0.85607 | $4.23 \times 10^{-3}$ |
| 4.    | Rhodamine 6G-substituted polyaniline | 1.25783 | $6.20 \times 10^{-3}$ |
| 5.    | Methylene blue-substituted polyaniline | 0.71910 | $5.28 \times 10^{-3}$ |
| 6.    | Methyl orange-substituted polyaniline | 1.40777 | $4.60 \times 10^{-3}$ |
3.3. Antimicrobial properties

The antimicrobial activity of different polyanilines was studied in different concentrations (200, 100, 50, 25, 12.5, and 6.250 μg/mL) against four pathogenic bacterial strains, two Gram positive (S. aureus MTCC 96 and S. pyogenus MTCC 443), two Gram negative (E. coli MTCC 442, P. aeruginosa MTCC 441), and three fungal strains (C. albicans MTCC 227, A. niger MTCC 282, and A. clavatus MTCC 1323). Antibacterial and antifungal activities of various polyanilines, different dyes, and dye-substituted polyanilines were assessed in terms of minimum inhibitory concentration (MIC). MIC is the lowest level of antibiotic in a culture media that will prevent growth, while zone of inhibition is the area around an antibiotic disk that has no bacterial growth. To find MIC, grow bacteria in decreasing amounts of antibiotic and find a concentration of antibiotic that the bacteria grows in; the dilution right before that is the MIC. Previously, antimicrobial and antifungal activities of polyaniline–emeraldine base have been studied by zone of inhibition method. The results of antibacterial activity (shown

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### Table 3. MIC values for tosic acid-doped polyaniline, dyes, and dye-substituted derivatives of polyanilines

| Polyaniline | Minimum inhibitory concentration (μg/mL) |
|-------------|------------------------------------------|
|             | E. coli (MTCC 442) | P. aeruginosa (MTCC 441) | S. aureus (MTCC 96) | S. pyogenus (MTCC 443) |
| PANI-TA     | 250 | 200 | 100 | 100 |
| Azure B     | 200 | 250 | 100 | 100 |
| Malachite green | 100 | 100 | 62.5 | 62.5 |
| Methyl violet | 100 | 200 | 100 | 100 |
| PANI-AB     | 100 | 62.5 | 12.5 | 50 |
| PANI-MG     | 100 | 62.5 | 25 | 25 |
| PANI-MV     | 62.5 | 100 | 50 | 50 |
| Gentamycin  | 0.05 | 1 | 0.25 | 0.5 |
| Ampicillin  | 100 | 100 | 250 | 100 |
| Chloramphenicol | 50 | 50 | 50 | 50 |
| Ciprofloxacin | 25 | 25 | 50 | 50 |
| Norfloxacin | 10 | 10 | 10 | 10 |

### Table 4. MIC values for hippuric acid-doped polyaniline, dyes, and dye-substituted derivatives of polyanilines

| Polyaniline | Minimum inhibitory concentration (μg/mL) |
|-------------|------------------------------------------|
|             | E. coli (MTCC 442) | P. aeruginosa (MTCC 441) | S. aureus (MTCC 96) | S. pyogenus (MTCC 443) |
| PANI-HA     | 62.5 | 250 | 200 | 200 |
| Rhodamine 6G | 62.5 | 200 | 100 | 100 |
| Methylene blue | 100 | 200 | 50 | 50 |
| Methyl orange | 100 | 250 | 200 | 200 |
| PANI-RG     | 100 | 100 | 50 | 50 |
| PANI-MB     | 50 | 62.5 | 12.5 | 12.5 |
| PANI-MO     | 250 | 200 | 100 | 100 |
| Gentamycin  | 0.05 | 1 | 0.25 | 0.5 |
| Ampicillin  | 100 | 100 | 250 | 100 |
| Chloramphenicol | 50 | 50 | 50 | 50 |
| Ciprofloxacin | 25 | 25 | 50 | 50 |
| Norfloxacin | 10 | 10 | 10 | 10 |
in Tables 3 and 4 and Figures 3 and 4) and antifungal activity (shown in Tables 5 and 6 and Figures 5 and 6) of different acid doped polyanilines, dyes, and dye-substituted polyanilines are shown in the respective tables and figures. By comparing the result of antimicrobial activity of polyaniline which is studied by both methods (Zone of inhibition and MIC), we observed that the best result was by MIC. So, in the present study, MIC method is used for antimicrobial activity.

Dye-substituted polyanilines show very good antimicrobial activity results when compared to polyanilines and dyes individually. Abstraction of a hydrogen atom from a nitrogen atom of the imine group on the polymeric chain backbones by butyl lithium and further attachment of dye moieties enhance the antimicrobial activities, which may be attributed to greater extent of charge delocalization and alteration in chemical structure and also the conductivity. The presence of quaternary ammonium cations further affects the antimicrobial activities. It is clear from the above-mentioned
Table 5. MIC values for tosic acid-doped polyaniline, dyes, and dye-substituted derivatives of polyanilines

| Polyanilines  | Minimum inhibitory concentration (µg/mL) |
|---------------|----------------------------------------|
|               | C. albicans (MTCC 227) | A. niger (MTCC 282) | A. clavatus (MTCC 1323) |
| PANI-TA       | 500                      | 250                   | 250                      |
| Azure B       | 200                      | 250                   | 250                      |
| Malachite green | 200                     | 250                   | 250                      |
| Methyl violet | 250                      | 200                   | 200                      |
| PANI-AB       | 250                      | 200                   | 200                      |
| PANI-MG       | 100                      | 50                    | 100                      |
| PANI-MV       | 100                      | 62.5                  | 100                      |
| Nystatin      | 100                      | 100                   | 100                      |
| Greseofulvin  | 500                      | 100                   | 100                      |

Table 6. MIC values for hippuric acid-doped polyaniline, dyes, and dye-substituted derivatives of polyanilines

| Polyanilines | Minimum inhibitory concentration (µg/mL) |
|--------------|----------------------------------------|
|              | C. albicans (MTCC 227) | A. niger (MTCC 282) | A. clavatus (MTCC 1323) |
| PANI-HA      | 500                        | 200                   | 250                      |
| Rhodamine 6G | 250                        | 200                   | 250                      |
| Methylene blue | 200                      | 200                   | 100                      |
| Methyl orange | 250                      | 200                   | 100                      |
| PANI-RG      | 200                        | 62.5                  | 200                      |
| PANI-MB      | 100                        | 100                   | 50                       |
| PANI-MO      | 200                        | 62.5                  | 100                      |
| Nystatin     | 100                        | 100                   | 100                      |
| Greseofulvin | 500                        | 100                   | 100                      |

Figure 5. Antifungal activity of tosic acid-doped polyaniline, dyes, and dye-substituted polyanilines against (1) C. albicans, (2) A. niger, and (3) A. clavatus.
results that the possible causes for better antimicrobial activities of dye-substituted polyanilines when compared to acid-doped polyanilines are the delocalization of electron density in side chain groups and presence of quaternary ammonium ions.

4. Conclusions
The dye-substituted polyanilines have been prepared by substitution of dye moieties on polyaniline backbone. An enhancement of conductivity is demonstrated by substitution on polyaniline backbone. The conductivity is observed in the range of $10^{-3}$ S/cm for dye-substituted polyanilines. Antimicrobial resistance is a global problem. Emergence of multidrug resistance has limited the therapeutic options. Hence, monitoring is of paramount importance. Hence, this study was aimed to focus the antimicrobial properties of polyanilines, different dyes, and dye-substituted polyanilines against Gram-positive and Gram-negative bacteria and fungal organisms. In current investigations, dye-substituted polyanilines were found to be active against bacteria and fungi when compared to standard drugs. This study has justified that substitution of dye moieties on polyaniline backbone increases the antimicrobial properties when compared to polyanilines and dyes individually.

Figure 6. Antifungal activity of hippuric acid-doped polyaniline, dyes, and dye-substituted polyanilines against (1) C. albicans, (2) A. niger, and (3) A. clavatus.

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