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Synthesis of heterocyclic monoazo dyes derived from 1*H*-benzo[*g*]pyrazolo[3,4-*b*]quinoline-3-ylamine: their antimicrobial activity and their dyeing performance on various fibers

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Abstract Heterocyclic monoazobenzoquinoline-based azo dyes have been derived by diazotization of 1*H*-benzo[*g*]pyrazolo[3,4-*b*]quinoline-3-ylamine with a variety of phenylpyrazolone-based coupling compounds. The synthesized dyes were characterized by determination of their percentage yield, by elemental analysis, and by UV–visible, IR, and ^{1}H NMR spectroscopy. Dyeing performance on silk, wool, nylon, and polyester fibers was assessed. The fastness properties of the dyes on each fiber were moderate to excellent. The antimicrobial activity of the dyes at different concentrations were also examined, by use of the Kirby–Bauer disk diffusion method.

Keywords 1*H*-benzo[*g*]pyrazolo[3,4-*b*]quinoline-3-ylamine · Phenyl pyrazolone · Synthesis · Antimicrobial activity · Dyeing · Fastness properties

Introduction

The fastness of a variety of dyes based on heterocyclic ring systems is recognized as being extremely strong. Several azo dyes have been prepared from amino heterocycles by using selected quinoline, benzoquinoline, and quinazoline derivatives as coupling components [1–7]. Hence, in continuation of our research work on developing quinoline and benzoquinoline-containing heterocyclic azo compounds, because of their significant biological and dyeing applications, it seemed expedient to synthesize a series of heterocyclic monoazo compounds as possible antimicrobial and dyeing agents. Quinoline and benzoquinoline rings combined with five or six member rings in a linear arrangement are known to have good

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pharmacological activity and are also used as intermediates in the dyestuffs industry [8–22]. Therefore, it was thought of interest to synthesize a series of a heterocyclic monoazo dyes derived from 1*H*-benzo[*g*]pyrazolo[3,4-*b*]quinoline-3-ylamine which not only have good dyeing properties but also have pharmacological (antibacterial and antifungal) activity. This paper deals with the facile and convenient synthesis of novel benzoquinoline-based heterocyclic monoazo dyes. Study of their dyeing properties, fastness properties, and antimicrobial activity is also reported.

Experimental

Materials and methods

All chemicals were of analytical grade and used directly. All melting points were determined by use of a PMP-DM scientific melting-point apparatus and are uncorrected. The purity of all dyes was determined by thin-layer chromatography (TLC) on aluminium foil plates coated with silica gel G (0.5 mm layer thickness, Merck). Infrared spectra were recorded on a Shimadzu FT-IR 8400S model using KBr pellets. ^{1}H NMR spectra were acquired on a Varian 400 MHz model spectrophotometer using DMSO as a solvent and TMS as internal reference (chemical shifts in δ, ppm). Elemental analysis of C, H, and N was performed on a Carlo Erba 1108 instrument. Light fastness was assessed in accordance with BS: 1006-1978 (standard test method, 1978, 1994). The rubbing fastness test was carried out with a Crock meter (Atlas) in accordance with AATCC-1961 (AATCC test method, 1961) and the wash fastness test in accordance with IS: 765-1979 (Indian standard ISO, 1979).

Kirby–Bauer disk diffusion method

The synthesized 1*H*-benzo[*g*]pyrazolo[3,4-*b*]quinoline-3-ylamine derivatives **6a–j** were examined for antimicrobial activity against several bacteria (*Staphylococcus aureus* MTCC 96, *Bacillus subtilis* MTCC 619, *Escherichia coli* MTCC 739, *Pseudomonas aeruginosa* MTCC 741 and fungi *Candida albicans* MTCC 183, *Aspergillus niger* MTCC 282) by use of the Kirby–Bauer disk diffusion method.

Mueller–Hinton agar medium was sterilized (autoclaved at 120 °C for 30 min), poured at a uniform depth of 5 mm, and left to solidify. The microbial suspension (10^5 CFU/mL) (0.5 McFarland nephelometry standards) was streaked over the surface of the medium by use of a sterile cotton swab to ensure even growth of the organisms. The tested compounds were dissolved in dimethylformamide to give solutions of 20–500 μg/mL. Sterile filter paper disks measuring 6.25 mm in diameter (Whatman No. 1 filter paper), previously soaked in a known concentration of the respective test compounds in dimethylformamide, were placed on the solidified nutrient agar medium that had been inoculated with the respective microorganism and the plates were incubated for 24 h at 37 ± 1 °C. A control disk impregnated with an equivalent amount of dimethylformamide without any sample was also used and did not cause any inhibition. Ciprofloxacin and flucanazole

(100 μg/disk) were used as control drugs for antibacterial and antifungal activity, respectively. Each assay was performed in triplicate.

General procedure for synthesis of *N*-naphthalen-2-yl-acetamide (**1**)

A mixture of 1-naphthylamine (1.0 mmol) and a catalytic amount of triethylamine (1.2 mmol) in acetone was stirred at room temperature for an hour after which acetyl chloride (1.2 mmol) was added dropwise and the mixture was further stirred for another 1 h. The solution was then poured directly on to crushed ice. The resulting white precipitate was isolated by filtration, washed with water, and dried in air, and was pure enough for further use. A sample was recrystallized from ethanol to give compound **1** as white needles, mp 159–160 °C, IR (KBr disk) 3270 (NH), 1656 (CO), 1548, 1398 cm^{-1}, ^1H NMR (d_6-DMSO) 2.17 (3H, s, $COCH_3$), 7.46–8.42 (7H, m Ar–H).

General procedure for synthesis of 2-chlorobenzo[*h*]quinoline-3-carbaldehyde (**2**)

To a solution of *N*-naphthalen-2-yl-acetamide (5.4 mmol) in dry DMF (14 mmol) was added $POCl_3$ (102 mmol), and the mixture was stirred at 75 °C for 6 h. The mixture was poured on to crushed ice and the resulting solid was isolated by filtration, washed with water, and dried in an oven. A sample was recrystallized from ethyl acetate–petroleum ether 60–80 °C to give the compound **2** as yellow needles, mp 210–212 °C, IR (KBr disk) 1685 (CO), 1579, 1365 cm^{-1} (C–N, C=N), ^1H NMR ($CDCl_3$) 7.47–8.48 (7H, m, Ar–H), 10.58 (1H, s, CHO).

General procedure for synthesis of 2-chlorobenzo[*g*]quinoline-3-carbaldehyde oxime (**3**)

To a solution of 2-chlorobenzo[*g*]quinoline-3-carbaldehyde (1.0 mmol) in ethanol, hydroxylamine hydrochloride (1.2 mmol) and sodium acetate (1.2 mmol) were added at room temperature and the mixture was stirred for 1 h. During stirring a white precipitate formed. The reaction mixture was poured into ice-cold water and the solid was isolated by filtration, dried, and used for further reaction, mp 172–176 °C, IR (KBr disk) 1668 (CHO), 1548, 1398 (C–N, C=N), 758 cm^{-1} (C–Cl), ^1H NMR (d_6-DMSO) 2.55(1H, s, OH), 7.48–8.54 (7H, m Ar–H).

General procedure for synthesis of 2-chlorobenzo[*g*]quinoline-3-carbonitrile (**4**)

Thionyl chloride (3.0 mmol) was added dropwise over a 30 min period to a stirred solution of 2-chlorobenzo[*g*]quinoline-3-carbaldehyde oxime (1.0 mmol) in benzene which was then heated under reflux for 1 h. The solvent was removed by vacuum distillation. Brown–yellow needle crystals formed which were used for further reaction, mp 184–189 °C, IR (KBr disk) 2221 (CN), 1548, 1398 (C–N, C=N), 754 cm^{-1} (C–Cl), ^1H NMR (d_6-DMSO) 7.48–8.41 (7H, m Ar–H).

General procedure for synthesis of 1*H*-benzo[*g*]pyrazolo[3,4-*b*]quinoline-3-ylamine (**5**)

To a stirred suspension of 2-chlorobenzo[*g*]quinoline-3-carbonitrile (1.0 mmol) in ethanol was added hydrazine hydrate (1.2 mmol). The mixture was stirred under reflux for 24 h. The reaction mixture was poured into ice cold water, and the resulting yellow precipitate was isolated by filtration and dried, mp 286–290 °C, IR (KBr disk) 3200–3289 (–NH), 1548, 1398 (C–N, C=N), 758 cm^{-1} (C–Cl), ^{1}H NMR (d_6-DMSO) 7.48–8.79 (7H, m Ar–H), 12.56 (1H, s, NH).

Diazotization and coupling (**6**)

Concentrated HCl was added to a well stirred suspension of 1*H*-benzo[*g*]pyrazolo [3,4-*b*]quinoline-3-ylamine (0.0048 mol) in water and the mixture was heated to 70 °C and maintained at that temperature until a clear solution was obtained. After cooling of the solution to 0–5 °C in an ice-bath, an aqueous solution of sodium nitrite (0.66 g) was added dropwise over a period of 30 min with continuous stirring. The reaction was stirred at a temperature below 5 °C for approximately 1 h. Starch–iodide paper was used to test for the presence of excess nitrous acid, which was removed by adding the required amount of sulfamic acid solution (10%). The clear diazonium salt solution thus obtained was used immediately in the coupling reaction.

Coupling component (**6a–j**) was dissolved in sodium hydroxide solution. The solution was cooled to 0–5 °C in an ice-bath. To this well-stirred solution, the above diazonium solution was added dropwise keeping the temperature below 5 °C. The reaction mass was further stirred for 2 h at 0–5 °C maintaining the pH at 8.0 by adding the required amount of 10% sodium carbonate solution. The reaction mass was then heated to 60 °C and diluted with water. The dye was isolated by filtration, washed with hot water until the washings were neutral, dried, and powdered. The product was purified by dissolution in DMF and pouring into water. Similar coupling procedure and conditions were followed for all the dyes (Fig. 1 and Chart 1).

Dye **6a** (4-(1*H*-benzo[*g*]pyrazolo[3,4-*b*]quinoline-3-ylazo)-5-methyl-2-*p*-tolyl-2,4-dihydropyrazol-3-one): Yield: 78%; mp > 300 °C; IR (KBr) ν cm^{-1}: 3250 (NH), 1552 (N=N), 1330 and 1564 (C–N and C=N), 2900–3100 (–CH stretching), 1478 (CH bending); ^{1}H NMR (400 MHz, DMSO-*d*6) δ ppm: 2.10 (s, 3H, –CH_3 of pyrazolone ring, 2.42 (s, 3H, CH_3 of benzene ring), 7.68–9.07 (m, 11H, Ar–H), 12.08 (s, 1H, –NH, benzoquinoline ring); ^{13}C NMR (400 MHz, DMSO-*d*6) δ ppm: 13.42 (C-32, CH_3 group of pyrazolone ring), 21.15 (C-31,CH_3 group of benzene ring), 118–152.12 (21C, Ar–C), 152.61 (C-17, of pyrazole ring carbon atoms), 158, 160 (C-28, 30 of pyrazolone ring carbon atoms); $C_{25}H_{19}N_7O$ (433.67): Calc. C, 69.27; H, 4.42; N, 22.62, found: C, 69.24; H, 4.38; N, 22.57.

Dye **6b** (4-(1*H*-benzo[*g*]pyrazolo[3,4-*b*]quinoline-3-ylazo)-2-(2,5-dichlorophenyl)-5-methyl-2,4-dihydropyrazol-3-one): Yield: 78%; mp > 300 °C; IR (KBr) ν cm^{-1}: 3252 (NH), 1548 (N=N), 1333 and 1558 (C–N and C=N), 2982–3100 (CH stretching), 1475 (CH bending), 752–754 (Ar–Cl); ^{1}H NMR (400 MHz, DMSO-*d*6)

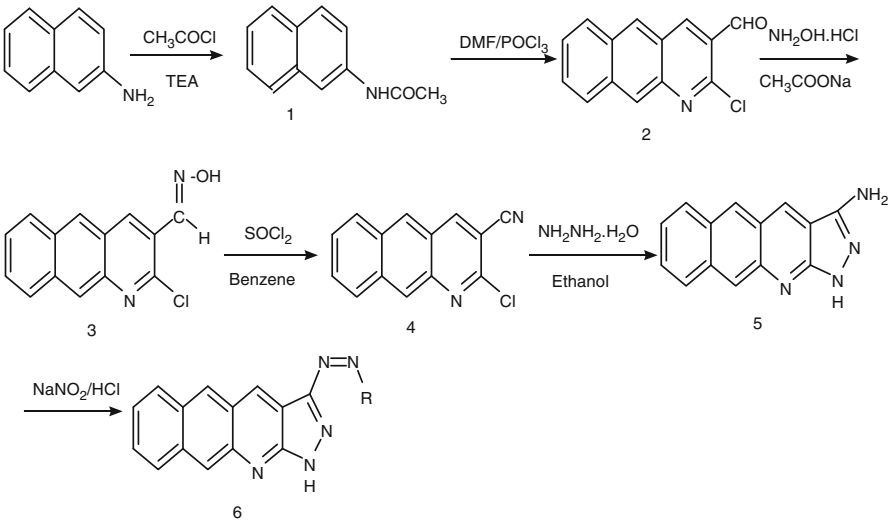

Fig. 1 Schematic diagram of the synthesis of the heterocyclic monoazo compounds

R= various phenyl pyrazolone derivatives as coupling components

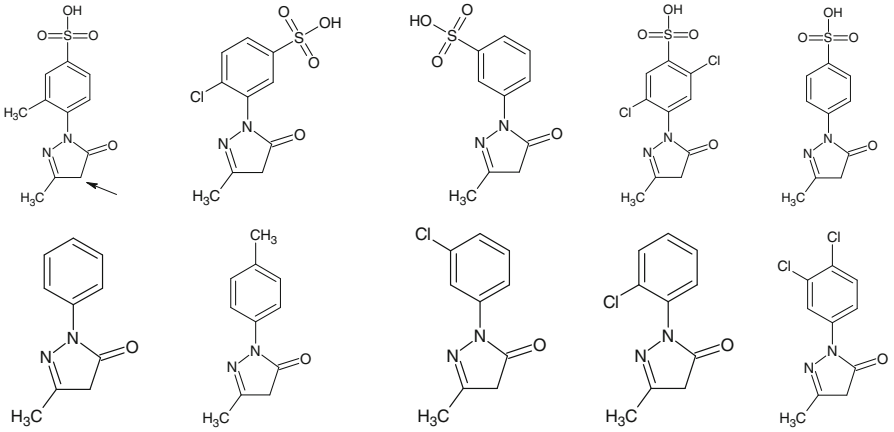

Chart 1 Phenylpyrazolones used as coupling reagents (R)

δ ppm: 2.04 (s, 3H, CH_3 of pyrazolone ring, 7.44–8.97 (m, 10H, Ar–H), 12.10 (s, 1H, –NH, benzoquinoline ring); ^{13}C NMR (400 MHz, DMSO-*d*6) δ ppm: 13.46 (C-31, CH_3 group of pyrazolone ring), 111.24–150.12 (19C, Ar–C), 152.58 (C-17, of pyrazole ring carbon atoms), 158.14, 160.12, (C-30, C-28, of pyrazolone ring carbon atoms; $C_{24}H_{15}Cl_2N_7O$ (487.07): Calc. C, 59.03; H, 3.10; N, 20.08; found: C, 59.00; H, 3.12; N, 20.12.

Dye **6c** (4-(1*H*-benzo[*g*]pyrazolo[3,4-*b*]quinoline-3-ylazo)-2-(3-chlorophenyl)-5-methyl-2,4-dihydropyrazol-3-one): Yield: 82%; mp > 300 °C; IR (KBr) ν cm^{-1}:

3242 (NH), 1556 (N=N), 1328 and 1545 (C–N and C=N), 2900–3100 (CH stretching), 1478 (CH_3 bending), 758 (Ar–Cl); ^{1}H NMR (400 MHz, DMSO-*d*6) δ ppm: 2.00 (s, 3H, CH_3 of pyrazolone ring, 12.10 (s, 1H, NH, benzoquinoline ring), 7.29–8.95 (m, 11H, Ar–H); ^{13}C NMR (400 MHz, DMSO-*d*6) δ ppm: 13.40 (C-31, –CH_3 group of pyrazolone ring), 112.24–150.12 (22C, Ar–C), 152.58 (C-17, of pyrazole ring carbon atoms), 157.14, 162.14, (C-30, C-28 of pyrazolone ring carbon atoms); $C_{24}H_{16}ClN_7O$ (453.11): Calc. C, 63.51; H, 3.55; N, 21.60; found: C, 63.55; H, 3.52; N, 21.64.

Dye **6d** (4-(1*H*-benzo[*g*]pyrazolo[3,4-*b*]quinoline-3-ylazo)-2-(2-chlorophenyl)-5-methyl-2,4-dihydropyrazol-3-one): Yield: 76%; mp > 300 °C; IR (KBr) ν cm^{-1}: 3252 (NH), 1560 (N=N), 1330 and 1548 (C–N and C=N), 2900–3100 (CH stretching), 1490 (CH bending), 760 (Ar–Cl); ^{1}H NMR (400 MHz, DMSO-*d*6) δ ppm: 2.06 (s, 3H, CH_3 of pyrazolone ring, 7.40–8.95 (m, 11H, Ar–H), 12.02 (s, 1H, NH, benzoquinoline ring); ^{13}C NMR (400 MHz, DMSO-*d*6) δ ppm: 13.38 (C-31, –CH_3 group of pyrazolone ring), 111.24–152.12 (22C, Ar–C), 152.60 (C-17, of pyrazole ring carbon atoms), 156.11, 160.16 (C-30, C-28 of pyrazolone ring carbon atoms); $C_{24}H_{16}ClN_7O$ (453.11): Calc. C, 63.51; H, 3.55; N, 21.60; found: C, 63.52; H, 3.52; N, 21.65.

Dye **6e** (4-(1*H*-benzo[*g*]pyrazolo[3,4-*b*]quinoline-3-ylazo)-2-(3,4-dichlorophenyl)-5-methyl-2,4-dihydropyrazol-3-one): Yield: 84%; mp > 300 °C. IR (KBr) ν cm^{-1}: 3242 (NH), 1556 (N=N), 1329 and 1552 (C–N and C=N), 2900–3100 (CH stretching), 1474 (CH bending), 760–774 (Ar–Cl); ^{1}H NMR (400 MHz, DMSO-*d*6) δ ppm: 2.04 (s, 3H, CH_3 of pyrazolone ring, 7.32–8.97 (m, 10H, Ar–H), 12.04 (s, 1H, NH, benzoquinoline ring); ^{13}C NMR (400 MHz, DMSO-*d*6) δ ppm: 13.32 (C-31, CH_3 group of pyrazolone ring), 110.16–150.10 (20C, Ar–C), 152.42 (C-17, of pyrazole ring carbon atoms), 158.11, 164.76, (C-30, C-28 of pyrazolone ring carbon atoms); $C_{24}H_{15}Cl_2N_7O$ (487.07): Calc. C, 59.03; H, 3.10; N, 20.08; found: C, 59.12; H, 3.16; N, 20.12.

Dye **6f** (4-[4-(1*H*-benzo[*g*]pyrazolo[3,4-*b*]quinoline-3-ylazo-3-methyl-5-oxo-4,5-dihydropyrazol-1-yl]-3-methylbenzenesulfonic acid): Yield: 80%. mp > 300 °C (DMF). IR (KBr) cm^{-1}: 3252 (NH), 1560 (N=N), 1328 and 1558 (C–N and C=N), 2900–3100 (CH stretching), 1476 (CH bending). ^{1}H NMR (400 MHz, DMSO-d_6): δ = 1.92 (s, 3H, CH_3 of pyrazolone ring, 2.20 (s, 3H, CH_3 of benzene ring), 7.64–8.65 (m, 10H, Ar–H), 13.28 (s, 1H, NH, benzoquinoline ring),^{13}C NMR (100 MHz, DMSO-d_6): δ = 13.42 (C-32, –CH_3 group of pyrazolone ring), 18.11 (C-31, CH_3 group of benzene ring), 111.20–150.25 (20C, Ar–C), 152.42 (C-17, of pyrazole heteroatom ring carbon atoms), 159.25, 160.73, (C-30, C-28 of pyrazolone heteroatom ring carbon atoms), Anal. Calcd. for $C_{25}H_{18}N_7NaO_4S$: C, 56.07; H,3.39; N, 18.31. Found: C, 56.12; H, 3.34; N, 18.36.

Dye **6g** (4-[4-(1*H*-benzo[*g*]pyrazolo[3,4-*b*]quinoline-3-ylazo-3-methyl-5-oxo-4,5-dihydropyrazol-1-yl]benzenesulfonic acid): Yield: 76%. mp > 300 °C (DMF). IR (KBr) cm^{-1}: 3258 (NH), 1554 (N=N), 1332 and 1560 (C–N and C=N), 2900–3100 (CH stretching), 1498 (CH bending). ^{1}H NMR (400 MHz, DMSO-d_6): δ = 1.98 (s, 3H, CH_3 of pyrazolone ring; 7.69–8.65 (m, 11H, Ar–H), 13.20 (s, 1H, –NH, benzoquinoline ring), ^{13}C NMR (100 MHz, DMSO-d_6): δ = 13.40 (C-32, CH_3 group of pyrazolone ring), 110.20–150.25 (23C, Ar–C), 152.65 (C-17, of

pyrazole heteroatom ring carbon atoms), 157.25, 160.12 (C-28, C-30 of pyrazolone heteroatom ring carbon atoms), Anal. Calcd. for $C_{24}H_{16}N_7NaO_4S$: C, 55.28; H,3.09; N, 18.80. Found: C, 55.36; H, 3.10; N, 18.82.

Dye **6h** (4-[4-(1*H*-benzo[*g*]pyrazolo[3,4-*b*]quinoline-3-ylazo-3-methyl-5-oxo-4,5-dihydropyrazol-1-yl]-2,5-dichlorobenzenesulfonic acid): Yield: 82%. mp > 300 °C (DMF). IR (KBr) cm^{-1}: 3256 (NH), 1562 (N=N), 1330 and 1552 (C–N and C=N), 2900–3100 (CH stretching), 1478 (CH bending), 752–754 (Ar–Cl). ^{1}H NMR (400 MHz, DMSO-d_6): $\delta = 1.94$ (s, 3H, -CH_3 of pyrazolone ring, 7.69–8.65 (m, 9H, Ar–H), 13.22 (s, 1H, NH, benzoquinoline ring), ^{13}C NMR (100 MHz, DMSO-d_6): $\delta = 13.42$ (C-31, –CH_3 group of pyrazolone ring), 110.20–152.25 (23C, Ar–C), 152.65 (C-17, of pyrazole heteroatom ring carbon atoms), 158.25, 162.12, (C-30, C-28 of pyrazolone heteroatom ring carbon atoms), Anal. Calcd. for $C_{24}H_{14}Cl_2N_7NaO_4S$: C, 48.83; H,2.39; N, 16.61. Found: C, 48.88; H, 2.42; N, 16.64.

Dye **6i** (3-[4-(1*H*-benzo[*g*]pyrazolo[3,4-*b*]quinoline-3-ylazo-3-methyl-5-oxo-4,5-dihydropyrazol-1-yl]benzenesulfonic acid): Yield: 74%. mp > 300 °C (DMF). IR (KBr) cm^{-1}: 3248 (NH), 1560 (N=N), 1328 and 1554 (C–N and C=N), 2900–3100 (CH stretching), 1474 (CH bending). ^{1}H NMR (400 MHz, DMSO-d_6): $\delta = 1.92$ (s, 3H, CH_3 of pyrazolone ring, 7.69–8.65 (m, 9H, Ar–H), 13.22 (s, 1H, NH, benzoquinoline ring), ^{13}C NMR (100 MHz, DMSO-d_6): $\delta = 13.42$ (C-31, CH_3 group of pyrazolone ring), 111.20–154.25 (23C, Ar–C), 152.65 (C-17, of pyrazole heteroatom ring carbon atoms), 157.30, 162.16 (C-30, C-28 of pyrazolone heteroatom ring carbon atoms), Anal. Calcd. for $C_{24}H_{16}N_7NaO_4S$: C, 55.28; H, 3.09; N, 18.80. Found: C, 55.34; H, 3.14; N, 18.86.

Dye **6j** (4-[4-(1*H*-benzo[*g*]pyrazolo[3,4-*b*]quinoline-3-ylazo-3-methyl-5-oxo-4,5-dihydropyrazol-1-yl]-3-chlorobenzenesulfonic acid): Yield: 86%. mp > 300 °C (DMF). IR (KBr) cm^{-1}: 3254 (NH), 1568 (N=N), 1332 and 1552 (C–N and C=N), 2900–3100 (CH stretching), 1480 (CH bending), 752–754 (Ar–Cl). ^{1}H NMR (400 MHz, DMSO-d_6): $\delta = 1.94$ (s, 3H, CH_3 of pyrazolone ring, 7.69–8.65 (m, 10H, Ar–H), 13.26 (s, 1H, NH, benzoquinoline ring), ^{13}C NMR (100 MHz, DMSO-d_6): $\delta = 13.44$ (C-31, CH3 group of pyrazolone ring), 111.38–150.25 (22C, Ar–C), 152.48 (C-17, of pyrazole heteroatom ring carbon atoms), 156.34, 164.16 (C-30, C-28 of pyrazolone heteroatom ring carbon atoms), Anal. Calcd. for $C_{24}H_{16}N_7NaO_4S$: C, 55.28; H, 3.09; N, 18.80. Found: C, 55.32; H, 3.14; N, 18.78.

Results and discussion

Chemistry

A variety of routes have been developed for functionalized quinolines and benzoquinolines; the Vilsmeier [23] approach is among the most efficient for achieving useful transformations and heteroannulations. Thus, in this communication we report the synthesis of 2-chlorobenzo[*h*]quinoline-3-carbaldehyde **2** by reaction of *N*-naphthalen-2-yl-acetamide with Vilsmeier reagent and transformation of the 2-chloro and 3-carbaldehyde groups into different functionality. The required

N-naphthalen-2-yl-acetamide **1** intermediate was obtained in very good yield by reaction of 1-naphthylamine with acetyl chloride in the presence of a catalytic amount of TEA at room temperature, as was confirmed by the disappearance of $-NH_2$ group and the appearance of –NH and –C=O groups in the IR spectrum, which contained bands at 3,345 and 1,710 cm^{-1}. Vilsmeier cyclization of acetanilide **1** was achieved by adding $POCl_3$ to the substrate in DMF at 0–5 °C followed by heating to 90 °C to afford 2-chlorobenzo[*h*]quinoline-3-carbaldehyde **2** in good to moderate yield. The IR spectrum of compound **2** contained a sharp and strong stretching absorption band in the region 1,680–1,700 cm^{-1} for the aldehyde group and absorption at approximately 2,720 and 2,830 cm^{-1} for the aldehyde proton. Reaction was also confirmed by the presence of –C–N and –C=N of the benzoquinoline ring, as stretching bands at 1,342 and 1,562 cm^{-1}, respectively. The carbaldehyde group in quinolines **2** was also transformed into other functionality to afford new quinolines which are equally important reagents for synthesis of fused quinoline systems. Compound **2** condensed with hydroxylamine hydrochloride in the presence of sodium acetate at room temperature to give 2-chlorobenzo[*g*]quinoline-3-carbaldehyde oxime **3**, as confirmed by the appearance of a broad –OH stretching band at 3,400–3,500 cm^{-1} in the IR spectrum. Compound **3** heated under reflux with $SOCl_2$ gave 2-chlorobenzo[*g*]quinoline-3-carbonitrile **4** in good yield, confirmed by the presence of the –CN group which had a characteristic stretching band at 2,221 cm^{-1}. Compound **4** on further cyclization with hydrazine hydrate gave 1*H*-benzo[*g*]pyrazolo[3,4-*b*]quinoline-3-ylamine **5**; two characteristic bands in the region 3,200–3,400 cm^{-1} confirmed the presence of the $-NH_2$ group. Compound **5** on diazotization then coupling with different phenylpyrazolones yielded benzoquinoline-based azo compounds **6a–j** in high yield. The ^{1}H NMR spectra of **6a–j** contained signals at 1.94 ppm, because of the $-CH_3$ group of the pyrazolone ring, and a singlet at 2.32 because of the $-CH_3$ of the benzene ring. The spectra of compounds **6a–j** contained a singlet at 13.23 ppm, because of the presence of –NH in the benzoquinoline ring, and the remaining aromatic protons resonated at 7.28–8.67 ppm as a multiplet. The ^{13}C NMR spectra contained signals in the range between 13.22 and 13.70, because of the $-CH_3$ group of the pyrazolone ring, in the range 18.00–21.15, because of the presence of the $-CH_3$ group of benzene ring, at 160 and 158 ppm, attributed to the carbon atoms of the pyrazolone heteroatom ring, and at 152.61, attributed to the carbon atoms of the pyrazole heteroatom ring; all remaining aromatic carbons resonated in the range 118–152.12. The principle benefit of using the benzoquinoline-based moiety is high percentage yield and a simple workup procedure which facilitates easy preparation of the starting material.

Spectral properties of the dyes

The visible absorption spectroscopic properties of the dyes were recorded in water and DMF and are listed in Table 1. From these results it is clear that the value of λ_{max} depends on the nature and position of the coupling component used. The color change observed for each dye is because of alternation of electrons and the presence of additional substituents.

Table 1 Characterization of heterocyclic monoazo dyes **6a–6j**

Dye no.	Shade of dyed fiber	λ_{max} (nm)	Coupling component
6a	Yellow	422	*p*-Toluenephenylmethylpyrazolone
6b	Dark yellow	440	2,5-Dichlorophenylmethylpyrazolone
6c	Yellow	420	*m*-Chlorophenylmethylpyrazolone
6d	Yellow	428	*o*-Chlorophenylmethylpyrazolone
6e	Dark yellow	430	3,4-Dichlorophenylmethylpyrazolone
6f	Yellow	432	*o*-Toluenesulfophenylmethylpyrazolone
6g	Yellow	420	*o*-Chlorosulfophenylmethylpyrazolone
6h	Yellow	430	2,5-Dichlorosulfophenylmethylpyrazolone
6i	Yellow	432	1,3-Sulfophenylmethylpyrazolone
6j	Yellow	440	1,4-Sulfophenylmethylpyrazolone

Dyeing of fibers

All the dyes **6a–j** were applied to silk, wool, nylon, and polyester fibers in 2% (owf) shade in accordance with the procedures described below. The variation in the hues of the dyed fibers resulted from changing the coupling components used. A remarkable degree of levelness after washing indicated good penetration and excellent affinity of these dyes for the silk, wool, nylon, and polyester fibers.

Dyeing of silk

The dye (0.2 g) was made into a paste with a drop of cold water and then approximately 80 mL cold water was added and the mixture was stirred well to give a clear solution. Dye solution (20 mL), acetic acid (2 mL of 10% *v*/*v*), and water 18 mL were then diluted to 100 mL. The dye bath temperature was maintained at 30 °C, the silk fabric (2 g) was immersed, and the temperature was increased to 40 °C over 20 min. At this temperature formic acid (1.5 mL of 40% *v*/*v*) was added to the dye bath to achieve good exhaustion. The dyeing was continued for 40 min more and then the dyed material was washed with cold water and soap solution, and dried.

Dyeing of wool

Dye (0.2 g) was made into a paste with a few drops of cold water and then approximately 80 mL cold water was added and the mixture was stirred. Dye solution (20 mL), acetic acid (1.5 mL of 10% *v*/*v*), Glauber's salt solution (4 mL of 10% *w*/*v*), and water (14.4 mL) were then diluted to 100 mL. Wool fabric (2 g) was immersed in the dye bath at 30 °C and the temperature was increased to 40 °C over 20 min. Sulfuric acid (0.4 mL of 10% *v*/*v*) was then added and the dyeing was continued for 40 min more at the same temperature. The material was then removed, rinsed with cold water and soap solution, and dried.

Dyeing of nylon

Dye (0.2 g) was made into a paste with a few drops of cold water and then approximately 80 mL cold water was added and the mixture was stirred. Dye solution (20 mL), Glauber's salt solution (4 mL of 10% *w*/*v*), and water (14.4 mL) were then diluted to 100 mL. Nylon fabric (2 g) was immersed in the dye bath at 30 °C and the temperature was increased to 40 °C over 20 min. Soda ash (Na_2CO_3) solution (0.4 mL of 10% *v*/*v*) was then added to achieve fixation and the dyeing was continued for 40 min more at the same temperature. The material was then removed, rinsed with cold water and soap solution, and dried.

Dyeing of polyester

Dye (0.2 g) was made into a paste with few drops of cold water and then approximately 40 mL cold water was added and the mixture was stirred, The dye solution and dispersing agent were then diluted to 100 mL. Polyester fabric (2 g) was then immersed in the dye bath at 30 °C and the temperature increased to 130 °C over 20 min. Soda ash (Na_2CO_3) solution (0.4 mL of 10% *v*/*v*) was then added to achieve fixation and the dyeing was continued for 40 min more at the same temperature. The material was then removed, rinsed with cold water and soap solution, and dried.

Wash-off process

The dyed fabrics (silk, wool, nylon, and polyester) were rinsed in warm water, scoured with 2 g/L Lissapol detergent at 90 °C for 5 min, and rinsed again in warm water. The dyed fabrics afforded color in the first warm water rinse, less color in the scouring bath, and almost no color in the second water rinse. This indicated that the unfixed dyes were easily removed from the fiber surface. Hydrolyzed dye of low substantivity was released easily from the substrate after two or three washes.

Exhaustion and fixation study

The percentage dye bath exhaustion and percentage dye bath fixation of the dyed fabric were determined in accordance with a reported method [24]; the results are summarized in Table 2. It is observed that the percentage exhaustion of 2% dye ranges from 71 to 75% for silk, from 70 to 75% for wool, from 62 to 69% for nylon, and from 62 to 69% for polyester. The percentage fixation of 2% dye varied from 85 to 90% for wool, from 83 to 87% for silk, from 85 to 87% for nylon, and from 85 to 87% for polyester.

The data summarized in Table 2 show that the exhaustion and fixation values are very good. This is because diffusion of the dye molecule within the fabric is rapid, so the rate of diffusion is high. The lower exhaustion is because of the lower substantivity, as a result of lower hydrophobicity.

Table 2 Percentage exhaustion, percentage fixation, and fastness data of dyes **6a–6j**

Dye no.	Percentage exhaustion				Percentage fixation				Light fastness				Wash fastness				Rubbing fastness							
																	Dry				Wet			
	S	W	N	P	S	W	N	P	S	W	N	P	S	W	N	P	S	W	N	P	S	W	N	P
6a	75.18	70.15	67.00	–	83.80	89.09	85.82	–	3–4	4	4	–	3–4	3	3	–	3	5	4	–	3–4	4	5	–
6b	74.25	74.00	68.80	–	85.52	87.83	85.75	–	3	4	4	–	3–4	3–4	4	–	3	4	5	–	3	3	4	–
6c	76.80	70.10	63.93	–	86.58	86.30	86.04	–	5–6	3	3–4	–	3	2	4–5	–	3–4	3–4	4–5	–	3–4	3	4	–
6d	77.83	74.28	66.12	–	84.81	85.49	85.44	–	3–4	3–4	4	–	3	3–4	5	–	3–4	3	4	–	4	3–4	3	–
6e	71.85	70.55	62.00	–	86.29	88.58	85.48	–	5	3	3–4	–	4–5	4	3–4	–	3–4	4	3	–	3	3	3–4	–
6f	–	–	–	67.15	–	–	–	85.94	–	–	–	4	–	–	–	3	–	–	–	4	–	–	–	5
6g	–	–	–	68.60	–	–	–	85.78	–	–	–	4	–	–	–	4	–	–	–	5	–	–	–	4
6h	–	–	–	63.90	–	–	–	86.14	–	–	–	3–4	–	–	–	4–5	–	–	–	4–5	–	–	–	4
6i	–	–	–	66.22	–	–	–	85.34	–	–	–	4	–	–	–	5	–	–	–	4	–	–	–	3
6j	–	–	–	62.00	–	–	–	85.68	–	–	–	3–4	–	–	–	3–4	–	–	–	3	–	–	–	3–4

6a–6e, acid dye; **6f–6j**, dispersed dye; *S* silk, *W* wool, *N* nylon, *P* polyester

Light fastness: 1, poor; 2, slight; 3, moderate; 4, fair; 5, good; 6, very good; 7, excellent

Wash and rubbing fastness: 1, poor; 2, fair; 3, good; 4, very good; 5, excellent

Fastness properties

The light, wash, and rubbing fastness properties were assessed in accordance with the standard method [25]. As shown in Table 2, the light fastness rating of all the dyes was 3–5 for all the fabrics, which shows light fastness is moderate to good. The wash fastness rating of all the dyes was 3–5 for all the fabrics, which shows wash fastness is good to excellent. The rubbing (dry and wet) fastness rating of all the dyes was 3–5 for all the fabrics, which shows rubbing fastness is good to excellent.

Color measurement

The color of the dyes was measured for silk, wool, and nylon fibers and expressed as CIELAB values. The CIELAB coordinates measured were lightness (L*), chroma (C*), and hue angle from 0 to 360° (H); the a* value represents the degree of redness (positive) and greenness (negative) and the b* value represents the degree of yellowness (positive) and blueness (negative). A reflectance spectrophotometer was used for the colorimetric measurements on the dyed samples. *K/S* values given by the reflectance spectrophotometer are calculated at λ_{max} and are directly correlated with the dye concentration on the substrate, in accordance with the Kubelka–Munk equation [26]:

$$K/S = (1 - R)^2/2R,$$

where K is the absorbance coefficient, S the scattering coefficient, and R the reflectance ratio.

The results obtained are listed in Table 3.

The color coordinates Table 3 indicate that the dyes have high affinity for silk, wool, and nylon fibres. The results summarized in Table 3 show that for silk fabric the dyeing achieved by use of dye **6c** was greener (as evidenced by the lower a* value), duller (as shown by the lower C* value), and lighter (as shown by the higher L* value) than that achieved with dye **6b**. Results are similar when dye **6c** is compared with dye **6b**. The dyeing achieved by use of dye **6g** was greener, duller, and darker than that achieved by use of dye **6d**. The color strength (*K/S*) values of dyes **6a–e** for silk fabric followed the order:

$$\mathbf{6a} > \mathbf{6b} > \mathbf{6c} > \mathbf{6d} \gg \mathbf{6e}$$

Dye **6a** had the maximum value of color strength (*K/S*) whereas dye **6e** had the minimum value of color strength. The results summarized in Table 3 show that for wool fabric the dyeing achieved by use of dye **6c** was greener, duller, and darker than that achieved by use of dye **6b**, whereas dye **6d** was redder, duller, and darker than dye **6b**. The *K/S* value of dyes **6a–e** for wool fabric followed the order:

$$\mathbf{6a} > \mathbf{6b} > \mathbf{6d} > \mathbf{6c} > \mathbf{6e}$$

Antimicrobial activity

The antimicrobial bioassay results presented in Table 4 indicate that all the compounds tested tended to be more active against Gram-positive bacteria than

Table 3 Colorimetric data for the synthesized dyes

Dye no.	L*			a*			b*			c*			H*			*K/S*		
	S	W	N	S	W	N	S	W	N	S	W	N	S	W	N	S	W	N
6a	45.40	32.34	42.10	54.10	49.42	54.14	06.34	17.32	11.50	54.58	52.00	55.24	06.72	19.56	12.08	10.80	26.22	13.42
6b	60.80	53.21	64.26	39.12	38.12	36.58	49.16	51.82	50.48	62.82	64.28	62.42	51.56	53.80	54.10	07.70	14.40	06.24
6c	68.38	51.30	64.28	29.44	35.70	34.02	33.96	45.68	38.12	45.08	57.96	51.12	49.12	52.10	48.20	02.56	13.30	03.80
6d	71.18	43.22	51.42	22.48	39.92	38.90	14.64	32.36	31.14	26.84	51.45	49.80	32.96	39.14	38.70	00.96	14.16	07.08
6e	78.45	55.32	67.20	13.70	34.96	26.12	14.92	45.48	25.30	20.24	57.34	36.34	47.70	52.48	44.12	00.48	08.80	01.64

against Gram-negative bacteria. Benzoquinoline derivative **6b** had excellent activity (MIC 20 μg/mL, 22 mm zone of inhibition) against the Gram-positive organism *S. aureus*. Compounds **6c**, **6d**, and **6a** were half as active (MIC 50 μg/mL) against *S. aureus* as compound **6b**. Benzoquinolines **6b** and **6e** had strong inhibitory action (MIC 20 μg/mL); the zone of inhibition against Gram-positive *B. subtilis* was 24 mm. The MIC of compound **6e** against *S. aureus* (20 μg/mL) was similar to those of **6b** and **6c** but the zone of inhibition was 4 mm less (20 mm). Compound **6d** was half as active (MIC 50 μg/mL) against *B. subtilis* as the most active analogues **6b** and **6e**. Compound **6e** was found to have promising activity (MIC 50 μg/mL, 20 mm zone of inhibition) against the Gram-negative organism *E. coli*. Compound **6b** had a similar MIC of 50 μg/mL against *E. coli* with a zone of inhibition (19 mm) 1 mm less than that of **6e**. Compound **6h** was half as active (MIC 100 μg/mL) against *E. coli* as the most active analogue **6e**. Compound **6e** had remarkable activity against Gram-negative *P. aeruginosa* (MIC 50 μg/mL) whereas compounds **6h** and **6j** had half this activity (MIC 100 μg/mL) against the same bacteria. All the remaining benzoquinoline derivatives had good to moderate activity, with MIC values ranging from 20 to 100 μg/mL; some derivatives were found to have weak activity at higher concentrations (200–500 μg/mL). Figure 2 shows the zones of inhibition of compounds **6a**–**j**. These results show that compounds **6b** and **6e** were the best compounds of the series, with good antibacterial activity against both Gram-positive and Gram-negative bacteria.

The antifungal bioassay results summarized in Table 4 reveal that benzoquinoline derivatives **6b** and **6e** had antigrowth activity (MIC, 50 μg/mL) against *A. niger*. Compounds **6a**, **6h**, and **6g** had activity against the same fungi with similar growth inhibition diameter (14–19 mm) and half the MIC (100 μg/mL). Compound

Table 4 Antimicrobial activity of heterocyclic azo compounds

Compd	*R*	Gram negative		Gram positive		Fungal species	
		E. Coli	*P. aeruginosa*	*S. aureus*	*B. subtilis*	*A. niger*	*C. albicans*
6a	PTPMP	12 (100)	14 (100)	14 (50)	16 (50)	12 (100)	11 (100)
6b	2:5 DCPMP	19 (50)	18 (50)	22 (20)	24 (20)	14 (50)	24 (50)
6c	MCPMP	16 (50)	16 (50)	16 (50)	16 (50)	12 (50)	14 (50)
6d	OCPMP	17 (50)	15 (50)	16 (50)	18 (50)	16 (50)	19 (50)
6e	3:4 DCMPMP	20 (50)	21 (50)	20 (20)	24 (20)	22 (50)	23 (50)
6f	OTSPMP	12 (100)	11 (100)	12 (100)	11 (100)	16 (100)	14 (100)
6g	1:4 SPMP	<10 (100)	<10 (100)	14 (100)	12 (100)	12 (100)	12 (100)
6h	2:5 DCSPMP	16 (100)	15 (100)	18 (50)	20 (50)	12 (50)	18 (100)
6i	1:3 SPMP	<10 (100)	<10 (100)	11 (100)	12 (100)	11 (100)	14 (100)
6j	OCSPMP	18 (100)	14 (100)	18 (50)	14 (50)	18 (100)	19 (100)
Ciprofloxacin (100 μg/disk)		30 (≤1)	31 (≤1)	32 (≤1)	33 (≤1)	–	–
Flucanazole (100 μg/disk)		–	–	–	–	30 (≤3)	33 (≤1)
DMF		–	–	–	–	–	–

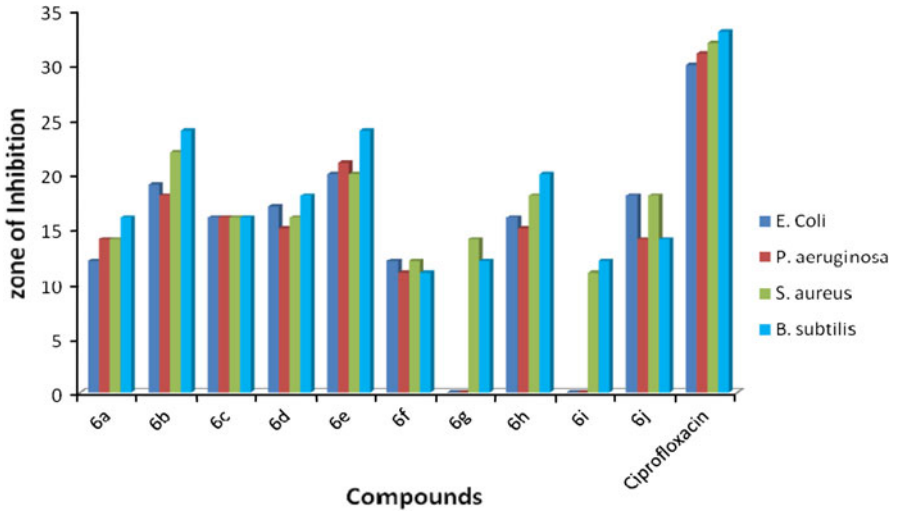

Fig. 2 Zones of inhibition of 1*H*-benzo[*g*]pyrazolo[3,4-*b*]quinoline-3-ylamine derivatives **6a–j** against Gram-positive and Gram-negative bacteria

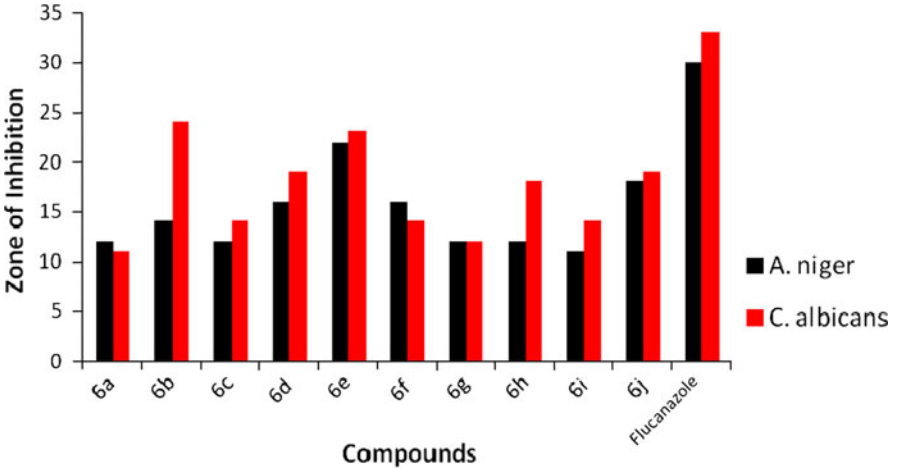

Fig. 3 Zones of inhibition of 1*H*-benzo[*g*]pyrazolo[3,4-*b*]quinoline-3-ylamine derivatives **6a–j** against fungi

6b seemed to inhibit *C. albicans* at 50 μg/mL. Against *C. albicans*, compounds **6a**, **6g**, **6h**, and **6j** had half the activity (100 μg/mL) of the most active analogues tested. Figure 3 shows the zones of inhibition of compounds **6a–j** as antifungal agents. All the other benzoquinoline derivatives had good to moderate activity with minimum inhibitory concentrations ranging from 20 to 100 μg/mL. Some of the derivatives had weak activity at higher concentrations (200–500 μg/mL).

Conclusion

A series of heterocyclic azo dyes containing the benzoquinoline moiety have been synthesized by a conventional method and their different properties examined in solution and applied to silk, wool, nylon and polyester fabrics. The dyes gave yellow and light yellow shades with very good fastness properties. This type of dye synthesis is generally convenient and economical. Variations in the hues of the dyed fabrics result from the both the nature and position of the substituent present on the coupler ring. The exhaustion and fixation of these dyes are very good; this indicates the dyes have good affinity for and solubility in the fabric. The remarkable uniformity of color before and after washing indicates the good penetration of these dyes and their affinity for the fabric. We have developed efficient and potent benzoquinoline-based heterocyclic azo compounds which among the active constituents present in many standard drugs, and are known to increase the pharmacological activity of molecules. The azo linkage in the compounds increases the activity of the compounds. The results of screening clearly indicated the compounds have good antibacterial and antifungal activity similar to that of standard drugs. Moreover, phenylpyrazolone as coupling component in all compounds increased antimicrobial activity. Our results indicated that chlorine-containing benzoquinoline compounds are more efficacious antimicrobial agents than compounds with sulfonic acid groups in the phenylpyrazolone ring. Hence, there is enough scope for further study in developing such compounds with good lead activity. Most of the compounds had moderate to promising activity compared with standard drugs against all the representative bacterial and fungal strains. In conclusion, compounds with pyrazolones as coupling components could be useful for derivatization to develop more effective microbial agents.

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