Convenient synthesis of heterocyclic azo dyes in the class of pyranopyrazoles and chromenes

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A series of novel azo group fused 2*H*-chromenes and 4*H*-chromenes were synthesised as well as pyranopyrazole derivatives *via* the Knoevenagel condensation reaction of C–H acid compounds with 5-(arylazo)salicylaldehydes by a nucleophilic addition to the carbonyl group followed cyclisation.

Keywords: chromene, pyranopyrazole, azo dye, Knoevenagel condensation

Knoevenagel condensation, which was reported for the first time by Emil Knoevenagel,[1] is a nucleophilic addition of an active methylene component to carbonyl group of an aldehyde or ketone followed by elimination of water to generate an alkene.[2–6] This is an easy way to prepare α,β-unsaturated compounds. The existence of electron-withdrawing groups adjacent to the methylene group is essential. This reaction is usually catalysed by different weak and strong bases.[7–10]

Knoevenagel condensation is utilised in the synthesis of chromene and pyranopyrazole moieties, which are key core substances in a variety of natural products and biological structures.[11–15]

Figure 1 shows diverse compounds containing a pyranopyrazole or chromene nucleus with a variety of biological activities and pharmaceutical properties (**A**–**D**).[16–19]

Coupling of these scaffolds with the azo functional group generates unique structures with photochemical and photophysical properties as azo dye compounds. In this study, three novel azo dyes in the class of pyranopyrazoles and chromenes, namely, 6-amino-4-[2-hydroxy-5-(phenyldiazenyl)phenyl]-3-methyl-1,4-dihydropyrano[2,3-*c*]pyrazole-5-carbonitrile **2a**, 2-[2-amino-3-cyano-6-(phenyldiazenyl)-4*H*-chromen-4-yl]malononitrile **4a** and 2-imino-6-(phenyldiazenyl)-2*H*-chromene-3-carbonitrile **5a**, were synthesised and also some new derivatives of azo ketocoumarins **3** were prepared using an optimised method.

Results and discussion

The three-component reaction of 5-(phenyldiazenyl) salicylaldehyde (1 equiv.), malononitrile (1 equiv.) and 3-methyl-5-pyrazolone (1 equiv.) in ethanol was chosen for initial optimisation studies and pyranopyrazole **2a** was isolated for the first time. The reaction was carried out at ambient temperature in 30 min in the presence of an aliphatic amine, such as triethylamine, diethylamine and piperidine. Piperidine was the most efficient catalyst for the synthesis of **2a** (78% yield). The optimised conditions were then utilised for a range of azosalicylaldehyde substrates. Both electron-poor and electron-rich derivatives reacted well (Scheme 1).

The formation of azopyranopyrazole derivatives **2a**–**h** can be explained by a domino process. In the first step, an arylidene malononitrile intermediate is formed *via* Knoevenagel condensation between a 5-(phenyldiazenyl)salicylaldehyde derivative **1** and malononitrile. Then, Michael addition of pyrazolone to arylidenemalononitrile is accomplished followed by cyclisation and tautomerisation leading to product **2**.

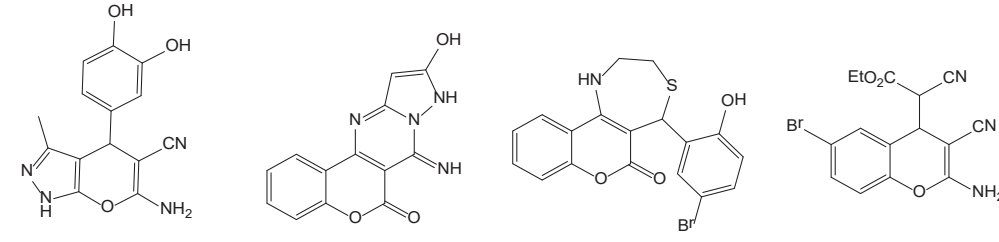
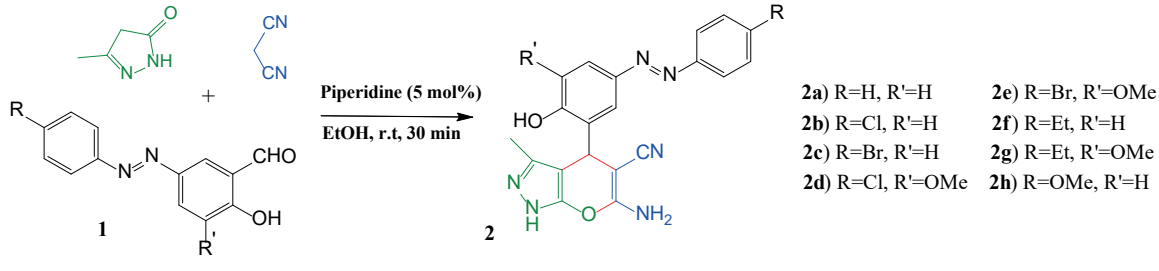


Fig. 1 Structures of some bioactive compounds bearing pyranopyrazole and chromene moieties.



Scheme 1 Synthesis of 6-amino-4-substituted-3-methyl-1,4-dihydropyrano[2,3-*c*]pyrazole-5-carbonitrile **2a**–**h**.

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Next, Knoevenagel condensation of a 5-(phenyldiazenyl) salicylaldehyde derivative **1** with ethylacetoacetate at 40 °C with 6–7 h stirring afforded the 6-(substituted phenyl) diazenylchromen-2-one derivatives **3a–f** (Scheme 2). We attempted to synthesise new derivatives of **3** compared with previous studies.[20,21]

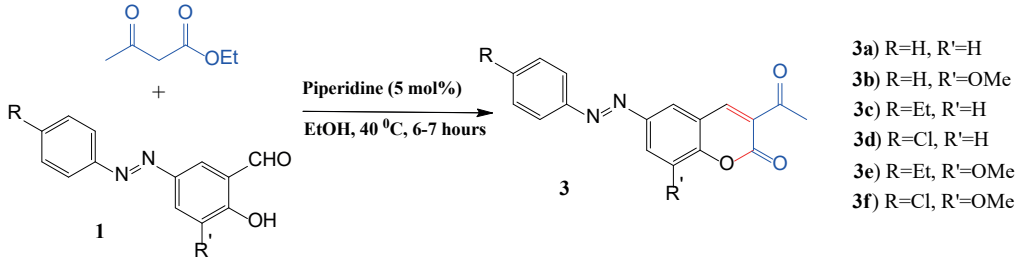
As shown in Scheme 3, the catalytic reaction of 5-(phenyldiazenyl)salicylaldehydes **1** and malononitrile was performed in ethanol at room temperature to gain substituted 4*H*-chromene **4** and 2*H*-chromene **5** derivatives. In initial studies, a mixture of products **4** and **5** were afforded for many conditions. The solvent quantity is very important for exclusive synthesis of **4** or **5**. With higher amounts of solvents, compound **4** was mostly obtained, but the reason is unclear. When the solvent quantity was reduced, a mixture of products or only compound **5** was obtained. However, in some cases, column chromatography was required to obtain the less polar product **5**.

Michael addition of malononitrile to the 2*H*-chromene **5** was also investigated. As a result, transformation to **4** was not observed.

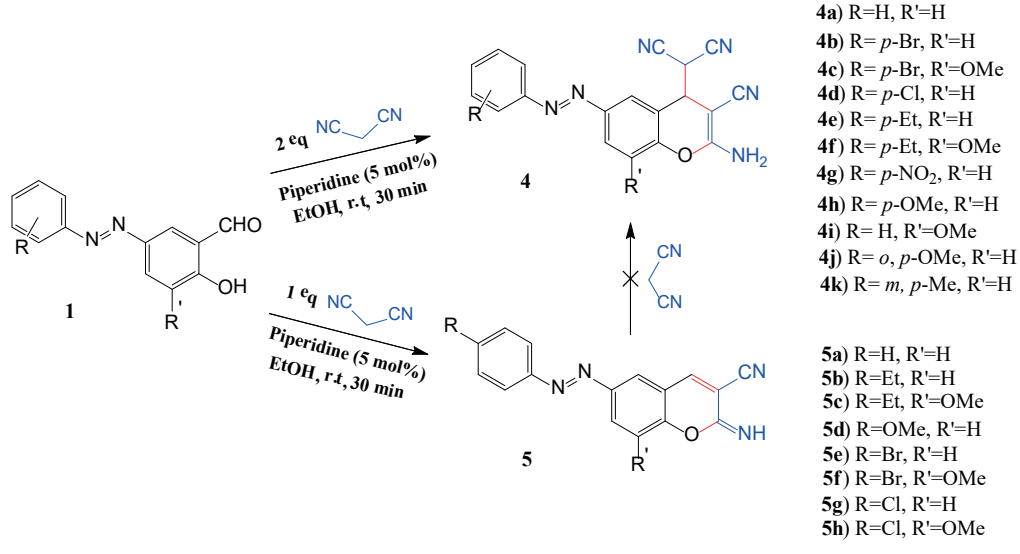
A plausible mechanism for the reaction is shown in Scheme 4. By the reaction of compound **1** with malononitrile, the arylidenemalononitrile intermediate **A** is formed, which can then be converted in two ways. The first is intramolecular cyclisation followed by tautomerisation to form product **5**. The second is Michael addition of a second equivalent of malononitrile leading to intermediate **B** followed by cyclisation and tautomerisation to obtain product **4**.

Conclusion

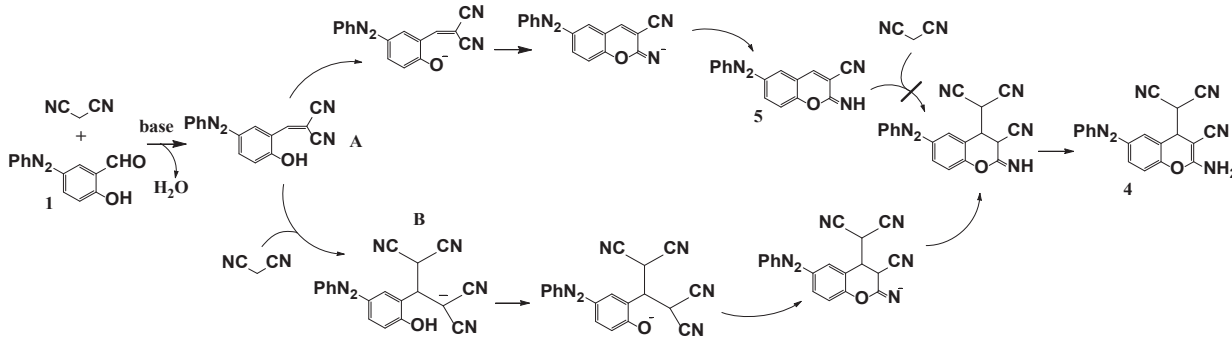
An approach for the synthesis of a new series of azochromene and azopyranopyrazole dyes was described. To the best of our knowledge, this is the first report on the synthesis of these novel pyrano[2,3-*c*]pyrazoles *via* a multicomponent pathway. The



Scheme 2 Synthesis of 3-acetyl-6-(phenyldiazenyl)chromen-2-one derivatives **3a–f**.



Scheme 3 Reaction of 5-(phenyldiazenyl)salicylaldehyde derivatives **1** with malononitrile to afford products **4** and **5**.



Scheme 4 Plausible route for the formation of azochromene dyes **4** and **5**.

reactions conditions are very mild with high yields and easy purification. Moreover, our method provides an opportunity to consider and study the biological activities of these heterocyclic azo compounds. Its further applications in the field of azo products synthesis are under investigation in our team and will be reported in due course.

Experimental

5-(Phenyldiazenyl)salicylaldehyde derivatives **1** were prepared according to a previous reported method.[22] All of the reagents and solvents were purchased from Merck, Sigma-Aldrich and Fluka. They were used without any purification. TLC was carried out on coated plastic sheets (25DCUV-254). Melting points were measured on an electrothermal Gallenkamp melting point apparatus. Elemental analysis for C, H and N were analysed using a Thermo Finnigan Flash EA1112 instrument. IR spectra were obtained on a Shimadzu FT-IR-4300 spectrophotometer using KBr discs. ^{1}H NMR and ^{13}C NMR spectra were obtained on Bruker 250 and 300 MHz spectrometers in $CDCl_3$ and DMSO-d_6 solutions and chemical shifts are noted in δ (ppm) relative to TMS as standard.

Synthesis of azopyranopyrazole derivatives (**2a**–**h**); *general procedure*

Piperidine (5 mol%) was added to a solution of 5-(phenyldiazenyl) salicylaldehyde derivative 1 (5 mmol), 3-methyl-5-pyrazolone (0.49 g, 5 mmol) and malononitrile (0.33 g, 5 mmol) in ethanol (25 mL) under rapid stirring at ambient temperature. After 30 min, the precipitate was collected and washed with cold ethanol to gain pure **2a–h** in good yield.

6-Amino-4-[2-hydroxy-5-(phenyldiazenyl)phenyl]-3-methyl-1,4-dihydropyrano[2,3-c]pyrazole-5-carbonitrile (**2a**): Yellow-orange solid; yield 1.34 g (72%); m.p. 225–227 °C; IR (KBr) (υ cm^{-1}): 3416, 3330 (NH_2), 3268 (OH), 2185 (CN), 1644 (C=N), 1577, 1538, 1510 (C–N), 1478 (N=N), 1256 (C–N); ^{1}H NMR (300 MHz, DMSO-d_6): δ 1.96 (s, 3H, CH_3), 4.69 (s, 1H, CH), 6.77 (s, 2H, NH_2), 7.07 (d, *J* = 8.75 Hz, 1H, ArH), 7.45–7.77 (m, 7H, ArH), 9.0–10.5 (br s, 1H, OH), 10.5–12.0 (br s, 1H, N–H). Anal. calcd for $C_{20}H_{16}N_6O_2$: C, 64.51; H, 4.33; N, 22.57; found: C, 64.42; H, 4.39; N, 22.62%.

6-Amino-4-{5-[(4-chlorophenyl)diazenyl]-2-hydroxyphenyl}-3-methyl-1,4-dihydropyrano[2,3-c]pyrazole-5-carbonitrile (**2b**): Yellow solid; yield 1.40 g (69%); m.p. 245–247 °C; IR (KBr) (υ cm^{-1}): 3416, 3331 (NH_2), 3268 (OH), 2186 (CN), 1644 (C=N), 1577, 1538, 1510 (C–N), 1479 (N=N), 1251 (C–N); ^{1}H NMR (300 MHz, DMSO-d_6): δ 2.04 (s, 3H, CH_3), 4.75 (s, 1H, CH), 6.85 (s, 2H, NH_2), 7.14 (d, *J* = 8.75 Hz, 1H, ArH), 7.54 (d, *J* = 2.1 Hz, 1H, ArH), 7.58 (d, *J* = 9 Hz, 2H, ArH), 7.71 (dd, *J* = 8.75 Hz, *J* = 2.1 Hz, 1H, ArH), 7.83 (d, *J* = 9 Hz, 2H, ArH), 9.0–10.5 (br s, 1H, OH), 10.5–12.0 (br s, 1H, N–H). Anal. calcd for $C_{20}H_{15}ClN_6O_2$: C, 59.05; H, 3.72; N, 20.66; found: C, 59.01; H, 3.80; N, 20.61%.

6-Amino-4-{5-[(4-bromophenyl)diazenyl]-2-hydroxyphenyl}-3-methyl-1,4-dihydropyrano[2,3-c]pyrazole-5-carbonitrile (**2c**): Yellow-orange solid; yield 1.53 g (68%); m.p. 236–238 °C; IR (KBr) (υ cm^{-1}): 3423, 3332 (NH_2), 3272 (OH), 2186 (CN), 1642 (C=N), 1576, 1538, 1510 (C–N), 1477 (N=N), 1251 (C–N); ^{1}H NMR (300 MHz, DMSO-d_6): δ 2.04 (s, 3H, CH_3), 4.75 (s, 1H, CH), 6.85 (s, 2H, NH_2), 7.16 (d, *J* = 8.72 Hz, 1H, ArH), 7.55–7.75 (m, 6H, ArH), 9.0–10.5 (br s, 1H, OH), 10.5–12.0 (br s, 1H, N–H). Anal. calcd for $C_{20}H_{15}BrN_6O_2$: C, 53.23; H, 3.35; N, 18.62; found: C, 53.16; H, 3.41; N, 18.69%.

6-Amino-4-{5-[(4-chlorophenyl)diazenyl]-2-hydroxy-3-methoxyphenyl}-3-methyl-1,4-dihydropyrano[2,3-c]pyrazole-5-carbonitrile (**2d**): Orange solid; yield 1.57 g (72%); m.p. 262–264 °C; IR (KBr) (υ cm^{-1}): 3385 (OH), 2187 (CN), 1658 (C=N), 1579, 1521 (C–N), 1473 (N=N), 1256 (C–N); ^{1}H NMR (300 MHz, DMSO-d_6): δ 2.04 (s, 3H, CH_3), 3.90 (s, 3H, CH_3), 4.73 (s, 1H, CH), 6.86 (s, 2H, NH_2), 7.20 (d, *J* = 1.73 Hz, 1H, ArH), 7.34 (d, *J* = 1.73 Hz, 1H, ArH), 7.59 (d, *J* = 8.6 Hz, 2H, ArH), 7.84 (d, *J* = 8.6 Hz, 2H, ArH), 9.0–10.5 (br s, 1H, OH), 10.5–12.0 (br s, 1H, N–H). Anal. calcd. for $C_{21}H_{17}ClN_6O_3$: C, 57.74; H, 3.92; N, 19.24; found: C, 57.80; H, 3.96; N, 19.19%.

6-Amino-4-{5-[(4-bromophenyl)diazenyl]-2-hydroxy-3-methoxyphenyl}-3-methyl-1,4-dihydropyrano[2,3-c]pyrazole-5-carbonitrile (**2e**): Yellow-orange solid; yield 1.58 g (66%); m.p. 248–250 °C; IR (KBr) (υ cm^{-1}): 3389 (OH), 2187 (CN), 1660 (C=N), 1579, 1519 (C–N), 1473 (N=N), 1256 (C–N); ^{1}H NMR (300 MHz, DMSO-d_6): δ 2.04 (s, 3H, CH_3), 3.90 (s, 3H, CH_3), 4.73 (s, 1H, CH), 6.86 (s, 2H, NH_2), 7.21 (d, *J* = 1.8 Hz, 1H, ArH), 7.35 (d, *J* = 1.8 Hz, 1H, ArH), 7.72–7.80 (m, 4H, ArH), 9.0–10.5 (br s, 1H, OH), 10.5–12.0 (br s, 1H, N–H). Anal. calcd for $C_{21}H_{17}BrN_6O_3$: C, 52.40; H, 3.56; N, 17.46; found: C, 52.47; H, 3.61; N, 17.40%.

6-Amino-4-{5-[(4-ethylphenyl)diazenyl]-2-hydroxyphenyl}-3-methyl-1,4-dihydropyrano[2,3-c]pyrazole-5-carbonitrile (**2f**): Yellow-orange solid; yield 1.54 g (77%); m.p. 220–222 °C; IR (KBr) (υ cm^{-1}): 3415, 3330 (NH_2), 3263 (OH), 2186 (CN), 1643 (C=N), 1576, 1539, 1509 (C–N), 1480 (N=N), 1256 (C–N); ^{1}H NMR (300 MHz, DMSO-d_6): δ 1.20 (t, *J* = 7.5 Hz, 3H, CH_3), 2.03 (s, 3H, CH_3), 2.67 (q, *J* = 7.5 Hz, 2H, CH_2), 4.75 (s, 1H, CH), 6.83 (s, 2H, NH_2), 7.14 (d, *J* = 9 Hz, 1H, ArH), 7.37 (d, *J* = 8.1 Hz, 2H, ArH), 7.52 (d, *J* = 1.18 Hz, 1H, ArH), 7.69–7.77 (m, 3H, ArH), 9.0–10.5 (br s, 1H, OH), 10.5–12.0 (br s, 1H, N–H). Anal. calcd for $C_{22}H_{20}N_6O_2$: C, 65.99; H, 5.03; N, 20.99; found: C, 65.90; H, 5.09; N, 21.05%.

6-Amino-4-{3-[(4-ethylphenyl)diazenyl]-6-hydroxy-2-methoxyphenyl}-3-methyl-1,4-dihydropyrano[2,3-c]pyrazole-5-carbonitrile (**2g**): Orange solid; yield 1.68 g (78%); m.p. 232–234 °C; IR (KBr) (υ cm^{-1}): 3492 (NH_2), 3390 (OH), 2187 (CN), 1656 (C=N), 1576, 1515 (C–N), 1471 (N=N), 1256 (C–N); ^{1}H NMR (300 MHz, DMSO-d_6): δ 1.19 (t, *J* = 7.5 Hz, 3H, CH_2), 2.03 (s, 3H, CH_3), 2.66 (q, *J* = 7.5 Hz, 2H, CH_2), 3.90 (s, 3H, CH_3), 4.73 (s, 1H, CH), 6.84 (s, 2H, NH_2), 7.17 (s, 1H, ArH), 7.33 (s, 1H, ArH), 7.37 (d, *J* = 7.5 Hz, 2H, ArH), 7.77 (d, *J* = 7.5 Hz, 2H, ArH), 9.0–10.5 (br s, 1H, OH) 10.5–12.0 (br s, 1H, N–H); ^{13}C NMR (75 MHz, DMSO-d_6): δ 9.9, 15.2, 28.07, 28.09, 55.07, 55.81, 101.2, 104.75, 117, 120.5, 122.5, 124.6, 128.7, 137.2, 140.2, 141.2, 147.6, 147.8, 150, 159. Anal. calcd for $C_{23}H_{22}N_6O_3$: C, 64.17; H, 5.15; N, 19.52; found: C, 64.11; H, 5.09; N, 19.60%.

6-Amino-4-{2-hydroxy-5-[(4-methoxyphenyl)diazenyl]phenyl}-3-methyl-1,4-dihydropyrano[2,3-c]pyrazole-5-carbonitrile (**2h**): Brown solid; yield 1.25 g (62%); m.p. 246–248 °C; IR (KBr) (υ cm^{-1}): 3417, 3331 (NH_2), 3271 (OH), 2186 (CN), 1644 (C=N), 1578, 1538, 1502 (C–N), 1250 (C–N); ^{1}H NMR (300 MHz, DMSO-d_6): δ 2.03 (s, 3H, CH_3), 3.83 (s, 3H, CH_3), 4.75 (s, 1H, CH), 6.82 (s, 2H, NH_2), 7.06 (d, *J* = 8.5 Hz, 2H, ArH), 7.12 (d, *J* = 8.8 Hz, 1H, ArH), 7.49 (d, *J* = 1.96 Hz, 1H, ArH), 7.67 (dd, *J* = 8.8, 1.96 Hz, 1H, ArH), 7.80–7.88 (m, 2H, ArH), 9.0–10.5 (br s, 1H, OH), 10.5–12.0 (br s, 1H, N–H). Anal. calcd for $C_{21}H_{18}N_6O_3$: C, 62.68; H, 4.51; N, 20.88; found: C, 62.61; H, 4.45; N, 20.95%.

Synthesis of 6-(substituted phenyl)diazenylchromen-2-one derivatives (**3a**–**f**); *general procedure*

Piperidine (5 mol%) was added to a solution of 5-(phenyldiazenyl) salicylaldehyde derivative 1 (5 mmol) and ethyl acetoacetate (0.65 g, 5 mmol) in ethanol (20 mL) under stirring and heating at 40 °C for 6–7 h. After cooling, the precipitate was filtered and washed with cold ethanol to afford pure product 3a–f in good yield.

3-Acetyl-6-(phenyldiazenyl)-2H-chromen-2-one (**3a**): Orange solid; yield 1.05 g (72%); m.p. 201–203 °C; IR (KBr) (υ cm^{-1}): 3049 (sp^2 C–H), 2948 (sp^3 C–H), 1735 (C=O), 1676 (C=O), 1477 (N=N); ^{1}H NMR (300 MHz, DMSO-d_6): δ 2.62 (s, 3H, CH_3), 7.55–7.69 (m, 4H, ArH), 7.92–7.95 (t, 2H, ArH), 8.24 (dd, *J* = 7.5 Hz, 1H, ArH), 8.55 (s, 1H, ArH), 8.84 (s, 1H, =C–H); ^{13}C NMR (75 MHz, DMSO-d_6): δ 26.9, 121.5, 122.6, 126.6, 129.5, 138.2, 146.5, 151.3, 155.5, 171.5, 194.2. Anal. calcd for $C_{17}H_{12}N_2O_3$: C, 69.86; H, 4.14; N, 9.58; found: C, 69.81; H, 4.08; N, 9.61%.

3-Acetyl-8-methoxy-6-(phenyldiazenyl)-2H-chromen-2-one (**3b**): Orange solid; yield 1.24 g (77%); m.p. 198–200 °C; IR (KBr) (υ cm^{-1}): 3053 (sp^2 C–H), 2941 (sp^3 C–H), 1736 (C=O), 1678 (C=O), 1462 (N=N); ^{1}H NMR (300 MHz, DMSO-d_6): δ 2.54 (s, 3H, CH_3), 4.02 (s, 3H, CH_3), 7.58–7.63 (m, 3H, ArH), 7.77 (d, *J* = 1.5 Hz, 1H, ArH), 7.90 (m, 2H, ArH), 8.13 (d, *J* = 2.5 Hz, 1H, ArH), 8.78 (s, 1H, =C–H). Anal. calcd for $C_{18}H_{14}N_2O_4$: C, 67.07; H, 4.38; N, 8.69; found: C, 67.01; H, 4.42; N, 8.61%.

*3-Acetyl-6-[(4-ethylphenyl)diazenyl]-2*H*-chromen-2-one* (**3c**): Orange solid; yield 1.10 g (69%); m.p. 148–150 °C; IR (KBr) (υ cm^{-1}): 3048 (sp^2 C–H), 2962 (sp^3 C–H), 1742 (C=O), 1677 (C=O), 1483 (N=N); ^{1}H NMR (300 MHz, DMSO-d_6): δ 1.22 (t, *J* = 7.5 Hz, 3H, CH_3), 2.58 (s, 3H, CH_3), 2.70 (q, *J* = 7.5 Hz, 2H, CH_2), 7.42 (d, *J* = 8.1 Hz, 2H, ArH), 7.60 (d, *J* = 8.7 Hz, 1H, ArH), 7.81 (d, *J* = 8.1 Hz, 2H, ArH), 8.15 (m, 1H, ArH), 8.45 (d, *J* = 1.2 Hz, 1H, ArH), 8.78 (s, 1H, =C–H). Anal. calcd for $C_{19}H_{16}N_2O_3$: C, 71.24; H, 5.03; N, 8.74; found: C, 71.19; H, 4.99; N, 8.80%.

*3-Acetyl-6-[(4-chlorophenyl)diazenyl]-2*H*-chromen-2-one* (**3d**): Yellow solid; yield 1.06 g (65%); m.p. 181–183 °C; IR (KBr) (υ cm^{-1}): 3052 (sp^2 C–H), 1739 (C=O), 1671 (C=O), 1479 (N=N); ^{1}H NMR (300 MHz, DMSO-d_6): δ 2.59 (s, 3H, CH_3), 7.82–7.90 (m, 4H, ArH), 8.10–8.19 (m, 2H, ArH), 8.49 (s, 1H, ArH), 8.79 (s, 1H, =C–H). Anal. calcd for $C_{17}H_{11}ClN_2O_3$: C, 62.49; H, 3.39; N, 8.57; found: C, 62.54; H, 3.43; N, 8.50%.

*3-Acetyl-6-[(4-ethylphenyl)diazenyl]-8-methoxy-2*H*-chromen-2-one* (**3e**): Orange solid; yield 1.08 g (62%); m.p. 192–194 °C; IR (KBr) (υ cm^{-1}): 2933 (sp^3 C–H), 1744 (C=O), 1678 (C=O), 1461 (N=N); ^{1}H NMR (300 MHz, DMSO-d_6): δ 1.22 (t, *J* = 7.5 Hz, 3H, CH_3), 2.65 (q, 2H, CH_2), 2.85 (s, 3H, CH_3), 4.02 (s, 3H, CH_3), 7.71–7.85 (m, 5H, ArH), 8.09 (d, *J* = 1.8 Hz, 1H, ArH), 8.77 (s, 1H, =C–H). Anal. calcd for $C_{20}H_{18}N_2O_4$: C, 68.56; H, 5.18; N, 8.00; found: C, 68.49; H, 5.22; N, 8.09%.

*3-Acetyl-6-[(4-chlorophenyl)diazenyl]-8-methoxy-2*H*-chromen-2-one* (**3f**): Orange solid; yield 1.08 g (61%); m.p. 175–177 °C; IR (KBr) (υ cm^{-1}): 2934 (sp^3 C–H), 1738 (C=O), 1650 (C=O), 1474 (N=N); ^{1}H NMR (300 MHz, DMSO-d_6): δ 2.57 (s, 3H, CH_3), 3.76 (s, 3H, CH_3), 7.57–7.93 (m, 6H, ArH), 8.18 (d, *J* = 1.8 Hz, 1H, ArH), 8.79 (s, 1H, =C–H); Anal. calcd for $C_{18}H_{13}ClN_2O_4$: C, 60.60; H, 3.67; N, 7.85; found: C, 60.66; H, 3.62; N, 7.79%.

*Synthesis of 4*H*-chromene derivatives* (**4a–k**); *general procedure*

5-(Phenyldiazenyl)salicylaldehyde derivative **1** (1 mmol) was dissolved in ethanol (20 mL). Then malononitrile (0.13 g, 2 mmol) and a catalytic amount of piperidine (5 mol%) were added and the resulting solution was stirred at room temperature for 30 min. The precipitate was filtered and washed with cold ethanol to afford product **4a–k**.

*2-(2-Amino-3-cyano-6-(phenyldiazenyl)-4*H*-chromen-4-yl) malononitrile* (**4a**): Yellow-orange solid; yield 0.21 g (63%); m.p. >250 °C; IR (KBr) (υ cm^{-1}): 3442 (N–H), 3326 (N–H), 2193 (CN), 2147 (CN), 1640 (C=C), 1419 (N=N); ^{1}H NMR (250 MHz, DMSO-d_6): δ 4.80 (d, *J* = 3.75 Hz, 1H, C–H), 5.24 (d, *J* = 3.75 Hz, 1H, C–H), 7.36 (d, *J* = 8.75 Hz, 1H, ArH), 7.60–7.67 (m, 3H, ArH), 7.70 (s, 2H, N–H), 7.88–7.91 (m, 2H, ArH), 7.98 (dd, *J* = 9.0, 2.0 Hz, 1H, ArH), 8.11 (d, *J* = 1.75 Hz, 1H, ArH); ^{13}C NMR (75 MHz, DMSO-d_6): δ 32.9, 37.7, 49.3, 113.2, 113.4, 118.1, 119.5, 119.6, 123, 124.4, 124.5, 129.9, 132, 149.2, 152.1, 152.3, 163.6. Anal. calcd for $C_{19}H_{12}N_6O$: C, 67.05; H, 3.55; N, 24.69; found: C, 67.11; H, 3.61; N, 24.60%.

*2-(2-Amino-6-[(4-bromophenyl)diazenyl]-3-cyano-4*H*-chromen-4-yl)malononitrile* (**4b**): Brown solid; yield 0.28 g (66%); m.p. >250 °C; IR (KBr) (υ cm^{-1}): 3429 (N–H), 3336 (N–H), 2192 (CN), 1643 (C=C), 1416 (N=N); ^{1}H NMR (300 MHz, DMSO-d_6): δ 4.78 (d, *J* = 3.3 Hz, 1H, C–H), 5.21 (d, *J* = 3.9 Hz, 1H, C–H), 7.35 (d, *J* = 8.7 Hz, 1H, ArH), 7.68 (s, 2H, N–H), 7.79–7.81 (m, 4H, ArH), 7.96 (dd, *J* = 8.7, 2.1 Hz, 1H, ArH), 8.10 (d, *J* = 1.8 Hz, 1H, ArH). Anal. calcd for $C_{19}H_{11}BrN_6O$: C, 54.43; H, 2.64; N, 20.05; found: C, 54.38; H, 2.60; N, 20.09%.

*2-(2-Amino-6-[(4-bromophenyl)diazenyl]-3-cyano-8-methoxy-4*H*-chromen-4-yl)malononitrile* (**4c**): Orange solid; yield 0.30 g (67%); m.p. >250 °C; IR (KBr) (υ cm^{-1}): 3429 (N–H), 3337 (N–H), 2191 (CN), 1648 (C=C), 1422 (N=N); ^{1}H NMR (300 MHz, DMSO-d_6): δ 3.95 (s, 3H, CH_3), 4.76 (d, *J* = 2.7 Hz, 1H, C–H), 5.20 (d, *J* = 3.6 Hz, 1H, C–H), 7.59 (s, 1H, ArH), 7.70–7.72 (m, 3H, N–H, ArH), 7.80–7.81 (m, 4H, ArH); Anal. calcd for $C_{20}H_{13}BrN_6O_2$: C, 53.47; H, 2.92; N, 18.71; found: C, 53.40; H, 2.99; N, 18.76%.

*2-{2-Amino-6-[(4-chlorophenyl)diazenyl]-3-cyano-4*H*-chromen-4-yl}malononitrile* (**4d**): Yellow-orange solid; yield 0.26 g (71%); m.p. >250 °C; IR (KBr) (υ cm^{-1}): 3427 (N–H), 3334 (N–H), 2191 (CN), 1644 (C=C), 1417 (N=N); ^{1}H NMR (300 MHz, DMSO-d_6): δ 4.77 (s, 1H, C–H), 5.22 (d, *J* = 1.2 Hz, 1H, C–H), 7.35 (d, *J* = 9.0 Hz, 1H, ArH), 7.66–7.68 (m, 4H, N–H, ArH), 7.88–7.90 (m, 2H, ArH), 7.96 (dd, *J* = 8.7, 1.8 Hz, 1H, ArH), 8.09 (s, 1H, ArH). Anal. calcd for $C_{19}H_{11}ClN_6O$: C, 60.89; H, 2.96; N, 22.42; found: C, 60.93; H, 2.91; N, 22.47%.

*2-{2-Amino-3-cyano-6-[(4-ethylphenyl)diazenyl]-4*H*-chromen-4-yl}malononitrile* (**4e**): Orange solid; yield 0.24 g (65%); m.p. >250 °C; IR (KBr) (υ cm^{-1}): 3426 (N–H), 3334 (N–H), 2190 (CN), 1645 (C=C), 1417 (N=N); ^{1}H NMR (300 MHz, DMSO-d_6): δ 1.22 (t, *J* = 6.7 Hz, 3H, CH_3), 2.70 (q, *J* = 7.5 Hz, 2H, CH_2), 4.77 (d, *J* = 3.3 Hz, 1H, C–H), 5.21 (d, *J* = 3.9 Hz, 1H, C–H), 7.33 (d, *J* = 8.7 Hz, 1H, ArH), 7.43 (d, *J* = 8.1 Hz, 2H, ArH), 7.66 (s, 2H, N–H), 7.81 (d, *J* = 8.1 Hz, 2H, ArH), 7.91–7.95 (m, 1H, ArH), 8.06 (s, 1H, ArH). Anal. calcd for $C_{21}H_{16}N_6O$: C, 68.47; H, 4.38; N, 22.81; found: C, 68.50; H, 4.33; N, 22.74%.

*2-{2-Amino-3-cyano-6-[(4-ethylphenyl)diazenyl]-8-methoxy-4*H*-chromen-4-yl}malononitrile* (**4f**): Orange solid; yield 0.27 g (69%); m.p. >250 °C; IR (KBr) (υ cm^{-1}): 3422 (N–H), 3334 (N–H), 2191 (CN), 1648 (C=C), 1420 (N=N); ^{1}H NMR (300 MHz, DMSO-d_6): δ 1.22 (t, *J* = 7.5 Hz, 3H, CH_3), 2.70 (q, *J* = 7.5 Hz, 2H, CH_2), 3.94 (s, 3H, CH_3), 4.75 (d, *J* = 3.0 Hz, 1H, C–H), 5.20 (d, *J* = 3.0 Hz, 1H, C–H), 7.43 (d, *J* = 7.8 Hz, 2H, ArH), 7.56 (s, 1H, ArH), 7.68 (s, 3H, ArH, N–H), 7.82 (d, *J* = 7.2 Hz, 2H, ArH). Anal. calcd for $C_{22}H_{18}N_6O_2$: C, 66.32; H, 4.55; N, 21.09; found: C, 66.36; H, 4.60; N, 21.01%.

*2-{2-Amino-3-cyano-6-[(4-nitrophenyl)diazenyl]-4*H*-chromen-4-yl}malononitrile* (**4g**): Red solid; yield: 0.23 g (60%); m.p. >250 °C; IR (KBr) (υ cm^{-1}): 3463 (N–H), 3350 (N–H), 2263 (CN), 2186 (CN), 1636 (C=C), 1416 (N=N); ^{1}H NMR (300 MHz, DMSO-d_6): δ 4.75 (d, *J* = 3 Hz, 1H, C–H), 5.22 (d, *J* = 3.6 Hz, 1H, C–H), 7.37 (d, *J* = 8.7 Hz, 1H, ArH), 7.70 (s, 2H, N–H), 8.00–8.05 (m, 3H, ArH), 8.16 (s, 1H, ArH), 8.39 (d, *J* = 5.7 Hz, 2H, ArH). Anal. calcd for $C_{19}H_{11}N_7O_3$: C, 59.22; H, 2.88; N, 25.44; found: C, 59.28; H, 2.91; N, 25.50%.

*2-{2-Amino-3-cyano-6-[(4-methoxyphenyl)diazenyl]-4*H*-chromen-4-yl}malononitrile* (**4h**): Orange solid; yield 0.26 g (71%); m.p. >250 °C; IR (KBr) (υ cm^{-1}): 3412 (N–H), 3329 (N–H), 2191 (CN), 1648 (C=C), 1413 (N=N); ^{1}H NMR (300 MHz, DMSO-d_6): δ 3.85 (s, 3H, CH_3), 4.76 (d, *J* = 3.3 Hz, 1H, C–H), 5.20 (d, *J* = 3.6 Hz, 1H, C–H), 7.13 (d, *J* = 8.4 Hz, 2H, ArH), 7.31 (d, *J* = 8.7 Hz, 1H, ArH), 7.65 (s, 2H, N–H), 7.86–7.91 (m, 3H, ArH), 8.02 (s, 1H, ArH). Anal. calcd for $C_{20}H_{14}N_6O_2$: C, 64.86; H, 3.81; N, 22.69; found: C, 64.80; H, 3.77; N, 22.75%.

*2-[2-Amino-3-cyano-8-methoxy-6-(phenyldiazenyl)-4*H*-chromen-4-yl]malononitrile* (**4i**): Orange solid; yield: 0.22 g (60%); m.p. >250 °C; IR (KBr) (υ cm^{-1}): 3429 (N–H), 3336 (N–H), 2190 (CN), 1647 (C=C), 1420 (N=N); ^{1}H NMR (300 MHz, DMSO-d_6): δ 3.96 (s, 3H, CH_3), 4.76 (d, *J* = 3.3 Hz, 1H, C–H), 5.20 (d, *J* = 3.9 Hz, 1H, C–H), 7.58–7.61 (m, 4H, ArH), 7.69–7.71 (s, 3H, N–H, ArH), 7.88 (d, *J* = 6.6 Hz, 2H, ArH). Anal. calcd for $C_{20}H_{14}N_6O_2$: C, 64.86; H, 3.81; N, 22.69; found: C, 64.82; H, 3.85; N, 22.74%.

*2-{2-Amino-3-cyano-6-[(2,4-dimethoxyphenyl)diazenyl]-4*H*-chromen-4-yl}malononitrile* (**4j**): Brown solid; yield: 0.24 g (59%); m.p. >250 °C; IR (KBr) (υ cm^{-1}): 3470 (N–H), 3351 (N–H), 2184 (CN), 1633 (C=C), 1417 (N=N); ^{1}H NMR (300 MHz, DMSO-d_6): δ 3.86 (s, 3H, CH_3), 3.96 (s, 3H, CH_3), 4.80 (d, *J* = 3.3 Hz, 1H, C–H), 5.19 (d, *J* = 3.6 Hz, 1H, C–H), 6.62 (dd, *J* = 9.3, 1.2 Hz, 1H, ArH), 6.77 (d, *J* = 1.2 Hz, 1H, ArH), 7.29 (d, *J* = 8.7 Hz, 1H, ArH), 7.59 (s, 1H, ArH), 7.62 (s, 2H, N–H), 7.82 (d, *J* = 8.7 Hz, 1H, ArH), 7.96 (s, 1H, ArH). Anal. calcd for $C_{21}H_{16}N_6O_3$: C, 62.99; H, 4.03; N, 20.99; found: C, 63.03; H, 4.00; N, 20.91%.

*2-{2-Amino-3-cyano-6-[(3,4-dimethylphenyl)diazenyl]-4*H*-chromen-4-yl}malononitrile* (**4k**): Orange solid; yield 0.24 g (66%); m.p. >250 °C; IR (KBr) (υ cm^{-1}): 3417 (N–H), 3330 (N–H), 2192 (CN), 1647 (C=C), 1415 (N=N); ^{1}H NMR (300 MHz, DMSO-d_6): δ 2.30 (s, 3H, CH_3), 2.32 (s, 3H, CH_3), 4.76 (d, *J* = 3.3 Hz, 1H, C–H), 5.21 (d, *J* = 3.9 Hz, 1H, C–H), 7.31–7.36 (m, 2H, ArH), 7.61–7.66 (m, 4H, N–H, ArH), 7.92 (dd, *J* = 9.0, 1.2 Hz, 1H, ArH), 8.04 (s, 1H, ArH). Anal. calcd for $C_{21}H_{16}N_6O$: C, 68.47; H, 4.38; N, 22.81; found: C, 68.39; H, 4.44; N, 22.75%.

Synthesis of 2H-*chromene derivatives* (**5a**–**h**); *general procedure*

A solution of malononitrile (0.13 g, 2 mmol / 2 mL ethanol) was added dropwise to a stirring solution of 5-(phenyldiazenyl)salicylaldehyde derivative **1** (2 mmol) in ethanol (15 mL) in the presence of piperidine (5 mol%) at ambient temperature. The resulting mixture was stirred for 30 min. Then the precipitate was filtered, washed with cold ethanol and purified with column chromatography (ethyl acetate: *n*-hexane; 70:30 v/v) to obtain the less polar product **5a**–**h**.

*2-Imino-6-(phenyldiazenyl)-2*H-*chromene-3-carbonitrile* (**5a**): Yellow-orange solid; yield 0.32 g (59%); m.p. 176–178 °C; IR (KBr) (υ cm^{-1}): 3307 (N–H), 2230 (CN), 1661 (C=N), 1422 (N=N); ^{1}H NMR (250 MHz, DMSO-d_6): δ 7.30 (d, *J* = 8.0 Hz, 1H, ArH), 7.53–7.57 (m, 3H, ArH), 7.90–7.94 (m, 2H, ArH), 8.02 (d, *J* = 2.25 Hz, 1H, ArH), 8.10 (d, *J* = 8.75 Hz, 1H, ArH), 8.45 (s, 1H, =C–H), 8.86 (s, 1H, N–H); ^{13}C NMR (75 MHz, DMSO-d_6): δ 105.2, 114.9, 115.1, 119.1, 120.9, 123.2, 124.6, 124.7, 129.8, 132.5, 149.2, 150.1, 152.6, 154.6. Anal. calcd for $C_{16}H_{10}N_4O$: C, 70.06; H, 3.67; N, 20.43; found: C, 70.11; H, 3.61; N, 20.51%.

*6-[(4-Ethylphenyl)diazenyl]-2-imino-2*H-*chromene-3-carbonitrile* (**5b**): Orange solid; yield 0.33 g (54%); m.p. 157–159 °C; IR (KBr) (υ cm^{-1}): 3303 (N–H), 2231 (CN), 1659 (C=N), 1422 (N=N); ^{1}H NMR (300 MHz, DMSO-d_6): δ 1.22 (t, *J* = 7.5 Hz, 3H, CH_3), 2.70 (q, *J* = 7.5 Hz, 2H, CH_2), 7.36 (d, *J* = 8.7 Hz, 1H, ArH), 7.43 (d, *J* = 8.1 Hz, 2H, ArH), 7.81 (d, *J* = 8.1 Hz, 2H, ArH), 8.06–8.09 (m, 2H, ArH), 8.50 (s, 1H, =C–H), 9.10 (s, 1H, N–H). Anal. calcd for $C_{18}H_{14}N_4O$: C, 71.51; H, 4.67; N, 18.53; found: C, 71.57; H, 4.61; N, 18.59%.

*6-[(4-Ethylphenyl)diazenyl]-2-imino-8-methoxy-2*H-*chromene-3-carbonitrile* (**5c**): Orange solid; yield 0.37 g (56%); m.p. 189–191 °C; IR (KBr) (υ cm^{-1}): 3288 (N–H), 2190 (CN), 1663 (C=N), 1424 (N=N); ^{1}H NMR (300 MHz, DMSO-d_6): δ 1.19 (t, *J* = 7.8 Hz, 3H, CH_3), 2.67 (q, *J* = 7.5 Hz, 2H, CH_2), 3.97 (s, 3H, CH_3), 7.42 (d, *J* = 7.8 Hz, 2H, ArH), 7.66–7.71 (m, 2H, ArH), 7.77–7.84 (m, 2H, ArH), 8.46 (s, 1H, =C–H), 9.18 (s, 1H, N–H). Anal. calcd for $C_{19}H_{16}N_4O_2$: C, 68.66; H, 4.85; N, 16.86; found: C, 68.57; H, 4.90; N, 16.81%.

*2-Imino-6-[(4-methoxyphenyl)diazenyl]-2*H-*chromene-3-carbonitrile* (**5d**): Orange solid; yield 0.37 g (61%); m.p. 172–174 °C; IR (KBr) (υ cm^{-1}): 3305 (N–H), 2191 (CN), 1649 (C=N), 1417 (N=N); ^{1}H NMR (300 MHz, DMSO-d_6): δ 3.86 (s, 3H, CH_3), 7.11 (d, *J* = 7.8 Hz, 2H, ArH), 7.30 (d, *J* = 8.1 Hz, 1H, ArH), 7.81 (d, *J* = 7.5 Hz, 2H, ArH), 8.07–8.13 (m, 2H, ArH), 8.54 (s, 1H, =C–H), 9.12 (s, 1H, N–H). Anal. calcd for $C_{17}H_{12}N_4O_2$: C, 67.10; H, 3.97; N, 18.41; found: C, 67.17; H, 4.01; N, 18.49%.

*6-[(4-Bromophenyl)diazenyl]-2-imino-2*H-*chromene-3-carbonitrile* (**5e**): Orange solid; yield 0.39 g (55%); m.p. 225–227 °C; IR (KBr) (υ cm^{-1}): 3297 (N–H), 2235 (CN), 1656 (C=N), 1413 (N=N); ^{1}H NMR (300 MHz, DMSO-d_6): δ 7.39 (d, *J* = 8.7 Hz, 1H, ArH), 7.63–7.82 (m, 4H, ArH), 8.06–8.14 (m, 2H, ArH), 8.52 (s, 1H, =C–H), 9.14 (s, 1H, N–H). Anal. calcd for $C_{16}H_9BrN_4O$: C, 54.41; H, 2.57; N, 15.86; found: C, 54.48; H, 2.49; N, 15.80%.

*6-[(4-Bromophenyl)diazenyl]-2-imino-8-methoxy-2*H-*chromene-3-carbonitrile* (**5f**): Orange solid; yield 0.44 g (58%); IR (KBr) (υ cm^{-1}): 3287 (N–H), 2232 (CN), 1659 (C=N), 1425 (N=N); ^{1}H NMR (300 MHz, DMSO-d_6): δ 3.95 (s, 3H, CH_3), 7.68–7.87 (m, 6H, ArH), 8.48 (s, 1H, =C–H), 9.22 (s, 1H, N–H). Anal. calcd for $C_{17}H_{11}BrN_4O_2$: C, 53.28; H, 2.89; N, 14.62; found: C, 53.33; H, 2.96; N, 14.57%.

*6-[(4-Chlorophenyl)diazenyl]-2-imino-2*H-*chromene-3-carbonitrile* (**5g**): Orange solid; yield 0.38 g (62%); m.p. 205–207 °C; IR (KBr) (υ cm^{-1}): 3297 (N–H), 2248 (CN), 1656 (C=N), 1417 (N=N); ^{1}H NMR (300 MHz, DMSO-d_6): δ 7.37 (d, *J* = 8.7 Hz, 1H, ArH), 7.62–7.69 (m, 2H, ArH), 7.86–7.92 (m, 2H, ArH), 8.09–8.14 (m, 2H, ArH), 8.52 (s, 1H, =C–H), 9.14 (s, 1H, N–H). Anal. calcd for $C_{16}H_9ClN_4O$: C, 62.25; H, 2.94; N, 18.15; found: C, 62.32; H, 3.01; N, 18.10%.

*6-[(4-Chlorophenyl)diazenyl]-2-imino-8-methoxy-2*H-*chromene-3-carbonitrile* (**5h**): Orange solid; yield 0.42 g (63%); m.p. 231–233 °C; IR (KBr) (υ cm^{-1}): 3284 (N–H), 2235 (CN), 1659 (C=N), 1425 (N=N); ^{1}H NMR (300 MHz, DMSO-d_6): δ 3.92 (s, 3H, CH_3), 7.37–7.91 (m, 6H, ArH), 8.48 (s, 1H, =C–H), 9.22 (s, 1H, N–H). Anal. calcd for $C_{17}H_{11}ClN_4O_2$: C, 60.28; H, 3.27; N, 16.54; found: C, 60.33; H, 3.22; N, 16.60%.

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