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RESEARCH PAPER

Ultrasound-Assisted Preparation of Furo[3,2-c]Coumarin in the Presence of the N- GQDs-Sensitized NiO/Co_3O_4 Composite as a Robust Catalyst

Baram Ahmed Hamah Ameen

Department of Chemistry, College of Science, University of Sulaimani, Iraq

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ABSTRACT

Nitrogen-doped Graphene Quantum Dots (N-GQDs) are effective and the most recent expansion to carbon nanomatetials family and guarantee a wide range of novel applications that can be used especially in design of modern hybrid catalyst such as metal-organo catalyst. In this research paper, we report a concise and facile preparation of a series of the furo[3,2-c]coumarin compounds via multicomponent reaction of 2,4′-dibromoacetophenone, benzaldehyde, and 4-hydroxycoumarin under ultrasound irradiation conditions. Nanocomposite catalyst were characterized with powder X-ray diffraction (XRD), transmission electron microscope (TEM), Field emission scanning electronic microscopy (FE-SEM), Energy dispersive X-ray (EDX), and Fourier-transform infrared (FT-IR) spectroscopy. The concise and facile protocol suggests momentous advancement by simple generation of metal-organo catalyst in respect to resolve the issue of utilizing harsh catalysts. This protocol provides several advantages including facile workup, excellent yields, short reaction times, use of ultrasound source as a clean method, recoverability of the catalyst, and little catalyst loading.

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INTRODUCTION

Furo[3,2-*c*]coumarines are classified as an important natural and heterocyclic compounds [1] due to their biological activities, for instance, antibacterial [2], antifungal [3], vasorelaxant [4], nuclear factor kappa B (NF-κB) inhibitors [5, 6], HIV-1 integrate inhibitors [6]. Todays, the use of multicomponent reactions (MCRs) was developed by both medical and synthetic chemists. In fact, MCRs are known as a powerful protocol to preparation of bioactive heterocyclic compounds [7]. Thus, finding the concise and efficient methods for the preparation of the fure[3,2-*c*]coumarines via MCRs are a significant challenge.

* *Corresponding Author Email: baram.hamahameen@univsul.edu.iq*

Some methods have been reported for the preparation of the fure[3,2-*c*]coumarine compounds using various catalysts such as pyridine or a mixture of $AcONH_4$/AcOH [8], [BMIm]OH ionic liquids [9], Pd $(CF_3CO_2)_2$ [10], $CuBr_2$ [10], $Rh_2(OAc)_4$ [11], triethylamine and PBu_3 [12], and *N*-methyl imidazole [13]. However, a number of these reports have disadvantages: harsh reaction conditions, long reaction times, non-reusable catalysts, and use of toxic materials. Therefore, to overcome these limitations, the development of an efficient and facile available catalyst with high catalytic performance and short reaction time for the synthesis of furo[3,2-*c*]coumarines is still

favored.

Using ultrasound irradiation (US) technique as a green and safe source in multicomponent reactions could be improved their effectiveness from operating cost and ecological points of views [14, 15]. US technique is applied for a variety of heterocyclic compounds synthesis owing to excellent yields, short reaction times, and facile workup. Ultrasound energy is the result of the cavitation phenomenon. This energy not only extreme heating but also high pressure by imploding of bubbles which can accelerate an organic transformation at the synthesis pathway. Recently, nanocatalysts have emerged as an alternating method for the improvement of many important organic reactions. However, when the size of active site is reduced to nanoscale dimensions, the surface free energy is increased significantly [16]. Among them, graphene quantum dots (GQDs), which are unique fragment of carbon nanomaterials [17] have been revealed splendid properties such as excellent biocompatibility [18],emission and low cytotoxicity [19, 20],extremely soluble in various solvents [21],and photoluminescence (PL) [22]. Interestingly, GQDs due to their high specific surface area and functionalized with –OH, -CO_2H and etc. are capable to cover nanocomposites and carry different chiral small-molecules as a chemical catalysts [23-25].

Based on above results, we used nano-sized NiO/Co_3O_4@N-doped GQDs composite for the preparation of the furo[3,2-c]coumarine compounds. In this work, we report the successful preparation of NiO/Co_3O_4@N-doped GQDs nanocomposites as a robust and green catalyst. The NiO/Co_3O_4@N-GQDs nanostructure have been interested because of their unique properties and applications in diverse fields. Herein, we wish to report the use of NiO/Co_3O_4@N-GQDs nanocomposites as a robust catalyst for the synthesis of the furo[3,2-*c*]coumarine compounds via MCRs of 2,4'-dibromoacetophenon, various substituted benzaldehydes, and 4-hydroxycoumarine under US conditions (Fig. 1).

MATERIALS AND METHODS

Synthesis of NiO/Co_3O_4 nanocomposites (NiO/Co_3O_4 NCs)

The mixture of nickel(II) hexahydrate (1 g) and cobalt(II) acetate tetrahydrate (3 g) were dissolved completely in deionized water (40 mL). Next, the aqueous ammonia solution was droply added to set the pH to 9.0. After 5 min, the mixture was moved to autoclave at 160 °C for 6 h. After that, the obtained solid was filtered, washed with distilled

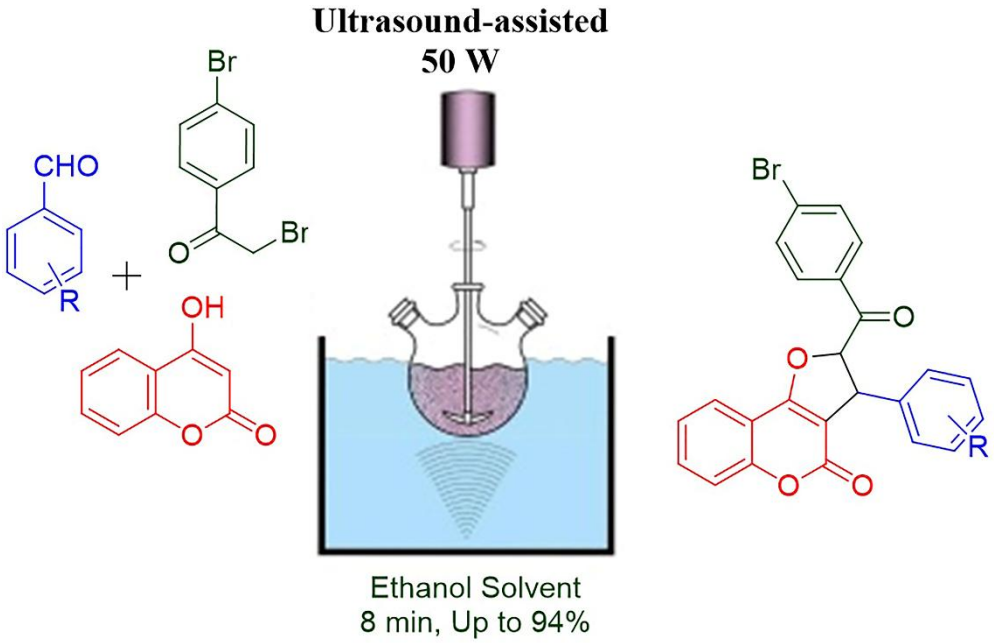


Fig. 1. Ultrasound assisted-synthesis of furo[3,2-*c*]coumarins using NiO/Co_3O_4@N-GQDs nanocomposites

water (2×20 mL), and dried at 50 °C for 5. To give NiO/Co_3O_4 *NCs,* the dried solid was calcined for 2 h at 550 °C [26].

Synthesis of NiO/Co_3O_4@N-GQDs NCs

0.3 mL of ethylenediamine was droply added to citric acid solution (0.25 *M*). The clear solution was stirred for 30 s. The prepared NiO/Co_3O_4 *NCs* (1 g) was then added to above solution and stirred for 5 min at room temperature. The mixture was moved to autoclave and heated for overnight at 180 °C. At completion, the as-prepared NiO/Co_3O_4/GQDs *NCs* was collected, washed with distilled water (2×15 mL), and dried in a vacuum oven until a constant weight was achieved [26].

General method for the synthesis of furo[3,2-c] coumarine

In 25 mL round bottom flask and in the presence of NiO/Co_3O_4@N-GQDs *NCs* as a catalyst, pyridine, 4-bromophenacyl bromide, various aromatic aldehydes, and 4-hydroxycoumarine were mixed in a 1:1:1:1 ratio in ethanol medium (10 mL). The mixture was refluxed for appropriate time. The completion of the reaction was controlled by TLC. At completion, the resulting solid was collected and recrystallized from ethanol to give pure product. The characteristics of products were determined by FT-IR and ^{1}H NMR spectroscopy.

Spectral Data

trans-2-4'-bromo-benzoyl-3-phenyl-2H-furo[3,2-c]chromen-4(3H)-one (4a): White powder, m.p 243-244 ºC, IR (KBr) cm^{-1}: 2931, 2853, 1718, 1644, 1452, 1404, 1025, 753, 576; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 4.82 (CH, 1H, d, *J*= 5.2 Hz), 6.11 (CH, 1H, d, *J*= 5.2 Hz), 6.88-7.03 (m, 7H), 7.34 (m, 1H), 7.55 (m, 2H), 7.84 (m, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 48.32, 92.19, 105.22, 112.22, 117.32, 121.25, 122.38, 123.98, 127.24, 128.62, 129.22, 130.50, 131.96, 133.20, 134.42, 138.88, 155.62, 159.41, 166.34, 192.03; Anal. Calcd for $C_{24}H_{15}BrO_4$:C, 64.45; H, 3.38; Found: C, 64.33; H, 3.27.

trans-2-4'-bromo-benzoyl-3-(3-methylphenyl)-2H-furo[3,2-c]chromen-4(3H)-one (4b): White powder, m.p 222-224ºC, IR (KBr) cm^{-1}: 2927, 2854, 1720, 1648, 1455, 1405, 1026, 753, 576; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 2.50 (CH_3, 3H), 4.80 (CH, 1H, d, *J*= 4.4 Hz), 6.09 (CH, 1H, d, *J*= 4.4 Hz), 7.04 (m, 6H), 7.34 (m, 1H), 7.60 (m, 2H), 7.99 (m, 3H);^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 21.2, 48.78, 92.11, 104.54, 112.02, 117.22, 120.93, 122.31, 124.25, 127.23, 127.99, 128.32, 128.45, 129.11, 130.51, 132.46, 133.25, 134.40, 139.12, 155.61, 159.42, 166.36, 192.02; Anal. calcd for$C_{25}H_{17}BrO_4$: C, 65.09; H, 3.71; Found: C, 65.16; H, 3.88;

trans-2-4'-bromo-benzoyl-3-(2-methylphenyl)-2H-furo[3,2-c]chromen-4(3H)-one (4c): White powder,m.p 171-173 ºC, IR (KBr) cm^{-1}:2923, 2851, 1721, 1645, 1453, 1407, 1029, 575; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 2.43 (CH_3, 3H), 5.20 (CH, 1H, d, *J* = 5.6 Hz), 6.02 (CH, 1H, d, *J* = 5.6 Hz), 6.89 (m, 1H), 7.27 (m, 7H), 7.60 (d, *J*= 8.8 Hz, 2H), 7.83 (d, *J* = 8.8 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 22.3, 48.79, 92.14, 104.63, 112.05,117.25, 120.95, 122.33, 124.26, 127.25, 128.08, 128.48, 129.14, 130.57, 130.59, 132.46, 133.27, 134.44, 139.15, 155.64, 159.44, 166.37, 192.10; Anal. calcd for$C_{25}H_{17}BrO_4$: C, 65.09; H, 3.71; Found: C,65.12; H, 3.82;

***trans-2-4'-bromo-benzoyl-3-(4-chlorophenyl)-2H-furo[3,2-c]chromen-4(3H)-one (4d)*:** White powder, m.p 250-252 ºC, IR (KBr) cm^{-1}: 2924, 2824, 1722, 1646, 1412, 1024, 752, 534; ^{1}H NMR (400 MHz, DMSO-d_6): δ (ppm) 4.77 (CH, 1H, *J*= 5.0 Hz), 6.63 (CH, 1H, *J*= 5.0 Hz), 7.22-7.26 (m, 2H), 7.29-7.32 (m, 2H), 7.32 (m, 3H), 7.50-8.03 (m, 5H); ^{13}C NMR (100 MHz, DMSO-d_6): δ (ppm) 49.66, 93.51, 105.22, 112.20, 117.35, 121.28, 122.45, 124.32, 127.25, 128.63, 129.19, 130.59, 133.04, 133.21, 135.14, 139.15, 155.60, 159.42, 166.42, 192.24; Anal. calcd for $C_{24}H_{14}BrClO_4$: C, 59.84; H, 2.93; Found: C, 59.75; H, 2.82;

trans-2-4'-bromo-benzoyl-3-(2-chlorophenyl)-2H-furo[3,2-c]chromen-4(3H)-one (4e): White powder, m.p 219-221º C, IR (KBr) cm^{-1}:2922, 2853, 1718, 1644, 1453, 1402, 1024, 755, 574; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 5.58 (CH, 1H, *J*= 5.2 Hz), 6.08 (CH, 1H, *J*= 5.2 Hz), 7.17-7.31 (m, 6H), 7.37 (m, 3H), 7.43 (d, *J*= 8 Hz, 1H), 7.96 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 48.82, 92.19, 105.12, 112.14, 117.28, 121.08, 122.36, 124.28, 127.28, 128.17, 128.57, 129.24, 130.58, 130.69, 132.54, 133.27, 134.41, 139.14, 155.62, 159.42, 166.38, 192.18; Anal. calcd for$C_{24}H_{14}BrClO_4$:C, 59.84; H, 2.93; Found: C, 59.72; H, 2.79;

trans-2-4'-bromo-benzoyl-3-(4-nitrophenyl)-2H-furo[3,2-c]chromen-4(3H)-one (4f): White

powder, m.p 250-252 ºC, IR (KBr) cm^{-1}: 2932, 2834, 1734, 1636, 1432, 1025, 762, 535; ^{1}H NMR (400 MHz, DMSO-d_6): δ (ppm) 5.15 (CH, 1H, *J*= 4.8 Hz), 6.04 (CH, 1H, *J*= 4.8 Hz), 7.28 (m, 2H), 7.32 (t, *J* = 7.2 Hz, 1 H), 7.40 (m, 1H), 7.45 (d, *J* = 7.6 Hz, 2H), 7.49 (d, *J* = 7.6 Hz, 2H) 7.92- 8.12 (m, 4H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 48.05, 91.97, 104.35, 111.73, 117.28, 123.17, 124.48, 124.60, 128.75, 130.33, 130.65, 132.01, 132.57, 133.54, 146.47, 147.76, 155.48, 159.01, 166.38, 190.61; Anal. calcd for$C_{24}H_{14}BrNO_6$: C, 58.56; H, 2.87; N, 2.85;Found: C, 58.47; H, 2.79; N, 2.80;

trans-2-4'-bromo-benzoyl-3-(4-methylthiophenyl)-2H-furo[3,2-c]chromen-4(3H)-one (4g)*:* White powder, m.p 206-208 ºC, IR (KBr) cm^{-1}: 2925, 2829, 1724, 1647, 1406, 1027, 754, 538;^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 2.66 (s, CH_3, 3H), 4.77 (CH, 1H, d, *J*= 4.8 Hz), 6.07 (CH, 1H, d, *J*= 4.8 Hz), 7.16 (m, 4H), 7.30 (m, 1H), 7.41-7.87 (m, 7H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 15.68, 48.80, 92.04, 104.52, 112.03, 117.21, 120.94, 122.31, 124.24, 127.22, 127.99, 128.32, 130.53, 132.46, 133.25, 134.40, 139.17, 155.61, 159.42, 166.38, 192.03. Anal.calcd for $C_{25}H_{17}BrO_4S$: C, 60.86; H, 3.47; Found: C, 60.74; H, 3.54.

trans-2-4'-bromo-benzoyl-3-(4-bromophenyl)-2H-furo[3,2-c]chromen-4(3H)-one (**4h**): White powder, m.p 256-258 ºC, IR (KBr) cm^{-1}:2919, 2821, 1718, 1644, 1402, 1024, 751, 535; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 4.86 (CH, 1H, *J* =5.2 Hz), 6.05 (CH, 1H, *J* = 5.2 Hz), 7.18 (m, 2H), 7.23 (m, 2H), 7.34 (m, 1H), 7.50-7.93 (m, 7H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 48.51, 92.28, 105.24, 112.24, 117.31, 121.25, 122.38, 124.21, 127.22, 128.51, 129.17, 130.57, 132.53, 133.21, 134.42, 139.14, 155.62, 159.43, 166.44, 192.16; Anal. calcd for $C_{24}H_{14}Br_2O_4$: C, 54.78; H, 2.68; Found: C, 54.61; H, 2.55.

trans-2-4'-bromo-benzoyl-3-(3-nitrophenyl)-2H-furo[3,2-c]chromen-4(3H)-one (4i): White powder, m.p 250-252 ºC, IR (KBr) cm^{-1}: 2934, 2853, 1727, 1647, 1522, 1410, 747, 575;^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 5.17 (CH, 1H, *J*= 4.8 Hz), 6.07 (CH, 1H, *J*= 4.8 Hz), 7.34-7.39 (m, 2H), 7.42-7.47 (m, 4H), 7.92- 8.12 (m, 5H); 8.17 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 49.04, 93.50, 105.24, 112.28, 117.38, 121.29, 122.43, 124.33, 124.54, 127.37, 128.33, 128.39, 129.44, 131.73, 132.54, 133.35, 134.65, 139.16, 155.71, 159.48, 166.52, 193.10; Anal. calcd for$C_{24}H_{14}BrNO_6$: C, 58.56; H, 2.87; N, 2.85;Found: C, 58.47; H, 2.79; N, 2.80;

trans-2-4'-bromo-benzoyl-3-(4-methylphenyl)-2H-furo[3,2-c]chromen-4(3H)-one (4j)**:** White powder, m.p 204-206ºC, IR (KBr) cm^{-1}: 2932, 2862, 1721, 1646, 1458, 1403, 1025, 756, ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 2.45 (CH_3, 3H), 5.58 (CH, 1H, d, *J*= 5.4 Hz), 6.08 (CH, 1H, d, *J*= 5.4 Hz), 7.02-7.12 (m, 4H), 7.16-7.20 (m, 2H), 7.36-7.55 (m, 3H), 7.77-7.95 (m, 3H);^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 21.5, 48.65, 92.05, 104.52, 111.95, 117.18, 120.82, 124.22, 127.83, 128. 45,128.65, 129.14, 130.32, 132.42, 133.18, 134.32, 139.02, 155.55, 159.44, 166.30, 192.14; Anal.calcd for $C_{25}H_{17}BrO_4$: C, 65.09; H, 3.71; Found: C, 65.21; H, 3.85.

trans-2-4'-bromo-benzoyl-3-(2-fluorophenyl)-2H-furo[3,2-c]chromen-4(3H)-one (4k): White powder, m.p 186-188º C, IR (KBr) cm^{-1}: 2922, 2853, 1718, 1644, 1453, 1402, 1024, 755, 574; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 5.50 (CH, 1H, *J* = 5.2 Hz), 6.18 (CH, 1H, *J* = 5.2 Hz), 7.27-7.51 (m, 6H), 7.47 (m, 3H), 7.53 (d, *J*= 7.6 Hz, 1H), 7.96 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 48.93, 92.31, 105.22, 113.02, 117.22, 121.18, 122.45, 124.20, 127.28, 128.17, 128.61, 129.31, 130.65, 131.72, 133.54, 133.71, 135.52, 139.21, 155.81, 159.52, 166.56, 192.30; Anal. calcd for $C_{24}H_{14}BrFO_4$: C, 61.96; H, 3.03; Found: C, 61.82; H, 2.92;

2-Benzoyl-3-p-chlorophenyl-2,3-dihydrofuro[3,2-c]chromen-4-one (**4l**): White powder, m.p 170-172º C, IR (KBr) cm^{-1}: 2924, 2855, 1717, 1643, 1454, 1406, 1024, 756, 572; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 4.85 (d, *J* = 5.2 Hz, 1H, CH), 6.06 (d, *J* = 5.2 Hz, 1H, CH), 7.20-7.89 (m, 13 H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 48.72, 92.44, 104.92, 112.12, 117.14, 123.22, 124.23, 129.04, 129.10, 129.52, 133.12, 133.22, 134.15, 134.17, 134.60, 138.12, 155.43, 159.27, 166.58, 191.84; Anal. calcd for $C_{24}H_{15}ClO_4$: C, 71.56; H, 3.75; Found: C, 71.45; H, 3.69;

2-Benzoyl-3-3-fluorophenyl-2,3-dihydrofuro[3,2-c]chromen-4-one **(4m):** White powder, m.p 210-212º C, IR (KBr) cm^{-1}: 3052, 1704, 1648, 1605, 1500, 1449, 1410, 1326, 887, 756; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 4.90 (d, *J* = 5.2 Hz, 1H, CH), 6.07 (d, *J* = 5.2 Hz, 1H, CH), 7.12-7.87 (m, 13 H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 48.30, 92.21, 104.32, 111.83, 117.22, 122.52, 123.34,

124.44, 129.28, 129.32, 130.34, 133.21, 133.39, 133.45, 134.24, 134.75, 141.64, 148.96, 155.54, 159.18, 166.76, 191.48; Anal. calcd for $C_{24}H_{15}FO_4$: C, 74.61; H, 3.91; Found: : C, 74.55; H, 3.87;

trans-2-4'-bromo-benzoyl-3-phenyl-8-methoxy-2H-furo[3,2-c]chromen-4(3H)-one **(4o):** White powder, m.p 218-220º C, IR (KBr) cm^{-1}: 3045, 1701, 1645, 1603, 1503, 1448, 1412, 1325, 882, 754; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 3.61 (s, 3H, OCH_3), 5.20 (d, *J* = 5.6 Hz, 1H, CH), 6.03 (d, *J* = 5.6 Hz, 1H, CH), 6.88-7.83 (m, 12 H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 48.62, 55.25, 92.36, 105.27, 112.29, 115.09, 121.29, 122.48, 123.99, 127.35, 128.76, 129.37, 131.15, 131.97, 133.34, 134.55, 138.78, 155.59, 159.48, 166.51, 192.08; Anal.

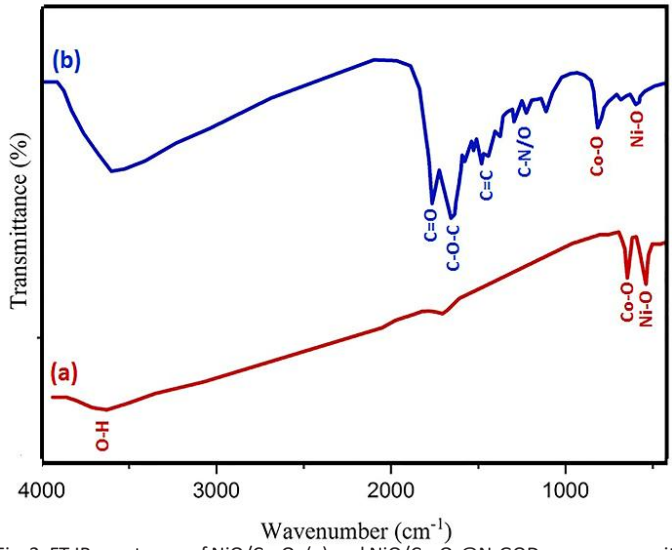


Fig. 2. FT-IR spectrums of NiO/Co_3O_4 (a) and NiO/Co_3O_4@N-GQDs nanocomposites (b).

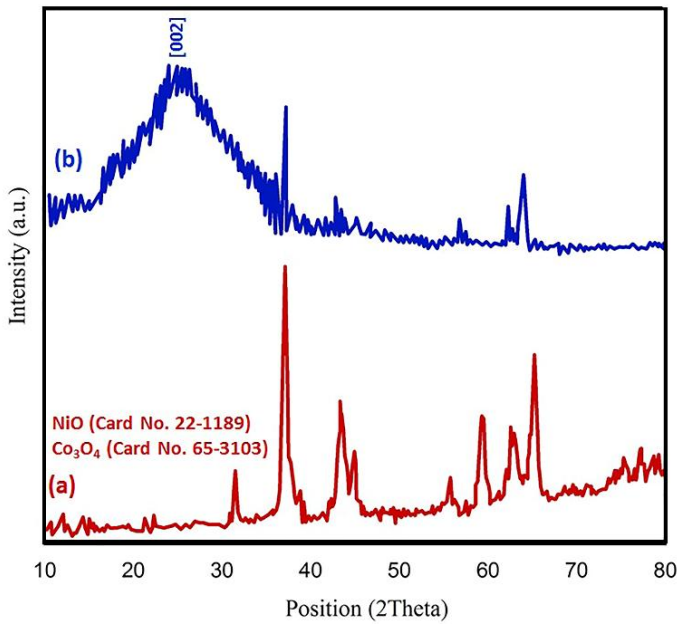


Fig. 3. XRD patterns of NiO/Co_3O_4 (a) and NiO/Co_3O_4@N-GQDs nanocomposites (b).

Calcd for $C_{25}H_{17}BrO_5$: C, 62.91; H, 3.59; Found: C, 62.89; H, 3.61.

RESULTS AND DISCUSSION

Initially, we fabricated NiO/Co_3O_4 and NiO/Co_3O_4@N-GQDs *NCs* via hydrothermal method [25]. The FT-IR graphs of NiO/Co_3O_4 and NiO/Co_3O_4@N-GQDs *NCs* are revealed in Fig. 1. The peaks at 3330 and 1635 cm^{-1} correspond to the stretching and bending absorptions of hydroxyl group, respectively. The absorption peaks at 460, 570, and 655 cm^{-1} are related to Ni-O, $Co^{(II)}$-O, and $Co^{(III)}$-O, respectively (Fig. 2a). In addition, the characteristics bands at 1703, 1125, and 1475-1590 cm^{-1} are belong to C=O, C-O-C, and C=C functional groups in N-GQDs structure (Fig. 2b).

The XRD patterns of each step displayed if Fig. 2. The first pattern confirms the presence of NiO (Code. No. 22-1189) and Co_3O_4 (Code. No. 65-3103) (Fig. 3a). Besides, the new peak located at 2ϑ= 24.3° is assigned reflection of [002] plane of N-GQDs (Fig. 3b).

Besides of FT-IR and XRD results, the Energy-dispersive X-ray graph (EDS) confirms the presence of Ni, Co, O, C, and N elements in the structure of NiO/Co_3O_4@N-GQDs nanocomposites (Fig. 4). Also, to study of the morphology and particle size of as-prepared nanocomposites, the FE-SEM technique and Digimizer software were applied, respectively. The FE-SEM images of NiO/Co_3O_4 and NiO/Co_3O_4@N-GQDs *NCs* are shown in Fig. 5a-c. Moreover, the average particles size of final structure was measured about nm (Fig. 4d).

We investigated the systematic evaluation of various catalysts for the reaction of benzaldehyde, 4-hydroxycoumarine, 2,4'-dibromoacetophenone, and pyridine as a model reaction. The slected reaction was done in the presence of various

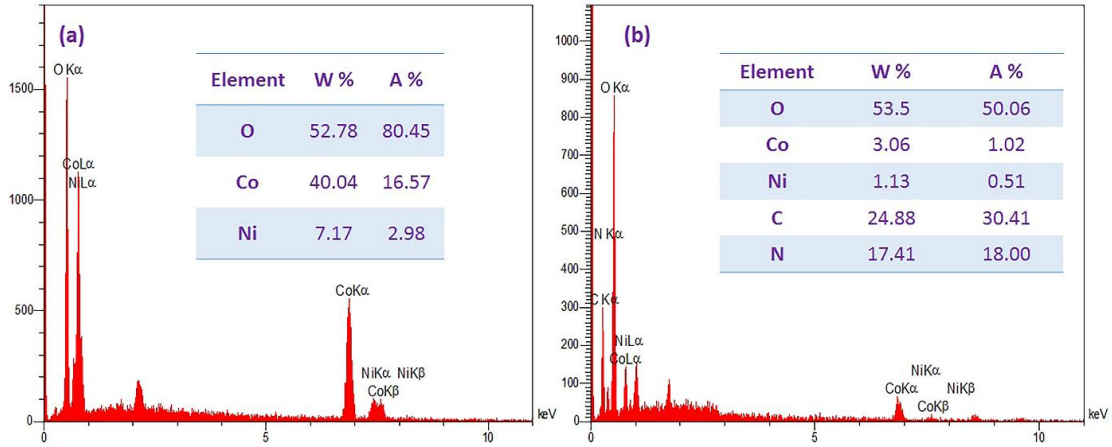


Fig. 4. EDS patterns of NiO/Co_3O_4 (a) and NiO/Co_3O_4@N-GQDs nanocomosites (b).

Table 1. Optimization of the model reaction using various catalysts

No.	Solvent	Conditions	Catalyst (amount)	Time (min)	Yield (%)[a]
1	Acetonitrile	Reflux	Morpholine (6 mol%)	180	35
2	Water	Reflux	NiO/Co_3O_4 *NCs* (10 mol%)	150	62
3	Dimethylformamide	Reflux	NiO/Co_3O_4 *NCs* (10 mol%)	150	48
4	Ethanol	Reflux	NiO/Co_3O_4 *NCs* (10 mol%)	150	70
5	Ethanol	US (40 W)	NiO/Co_3O_4 *NCs* (10 mol%)	8	78
6	Ethanol	US (40 W)	NiO/Co_3O_4@N-GQDs *NCs* (10 mol%)	8	89
7	Ethanol	US (50 W)	NiO/Co_3O_4@N-GQDs *NCs* (10 mol%)	8	94
8	Ethanol	US (60 W)	NiO/Co_3O_4@N-GQDs *NCs* (10 mol%)	8	94
9	Ethanol	US (50 W)	NiO/Co_3O_4@N-GQDs *NCs* (8 mol%)	8	91
10	Ethanol	US (50 W)	NiO/Co_3O_4@N-GQDs *NCs* (12 mol%)	8	94

Benzaldehyde, 4-hydroxycoumarine, and 2,4'-dibromoacetophenone.
US: Ultrasound irradiations.
[a] Isolated Yield.

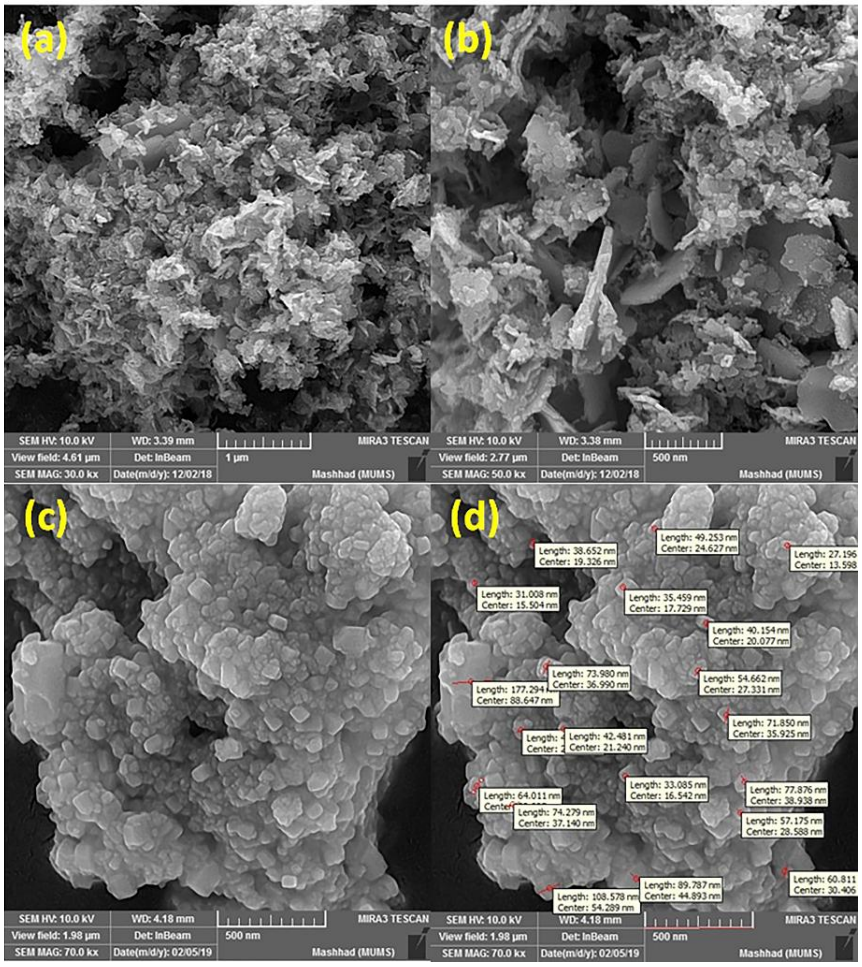
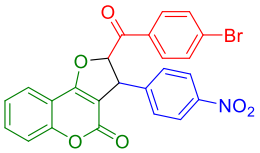
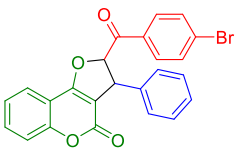
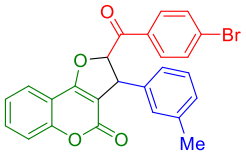
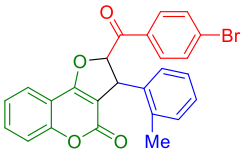
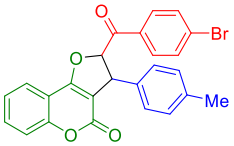
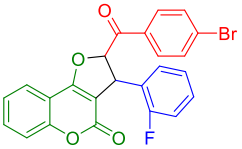
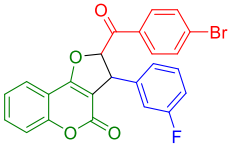
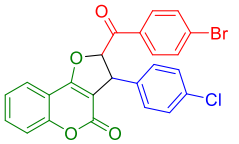
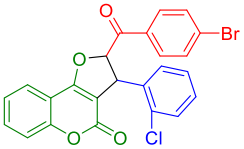
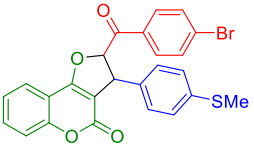
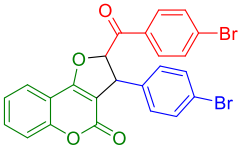
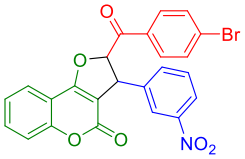


Fig. 5. FE-SEM images of NiO/Co_3O_4 (a-b), NiO/Co_3O_4@N-GQDs (c), and calculated average particle size (d).

Table 2. Preparation of furo[3,2-c]coumarins using NiO/Co_3O_4@N-GQDs (10 mol%) under US conditions (50 W)

 4a, 8 min, 94%	 4b, 9 min, 91%	 4c, 10 min, 88%	 4d, 10 min, 87%
 4e, 9 min, 89%	 4f, 8 min, 93%	 4g, 8 min, 94%	 4h, 8 min, 93%
 4i, 9 min, 92%	 4j, 10 min, 90%	 4k, 8 min, 93%	 4l, 9 min, 92%

catalysts, which are tabulated in Table 1. When the reaction was done using NiO/Co_3O_4@N-GQDs nanoomposites, the product could be obtained in a good to excellent yield. The NiO/Co_3O_4 nanostructure covered by N-GQDs shows good catalytic activity due to their large number of active sites which are mainly responsible for their catalytic activity. The most ideal results were seen under ultrasound irradiations (50 W) in ethanol medium and the reaction gave satisfy results in the presence of the NiO/Co_3O_4@N-GQDs as a new catalyst. When the amount of catalyst was raised, the yield of the reaction was increased. Consequently, 10 mol% of NiO/Co_3O_4@N-GQDs were an expedient and an excessive amount of NiO/Co_3O_4@N-GQDs did not change the yield, remarkably (Table 1). When the reaction was done under ultrasound irradiations (US) conditions, the

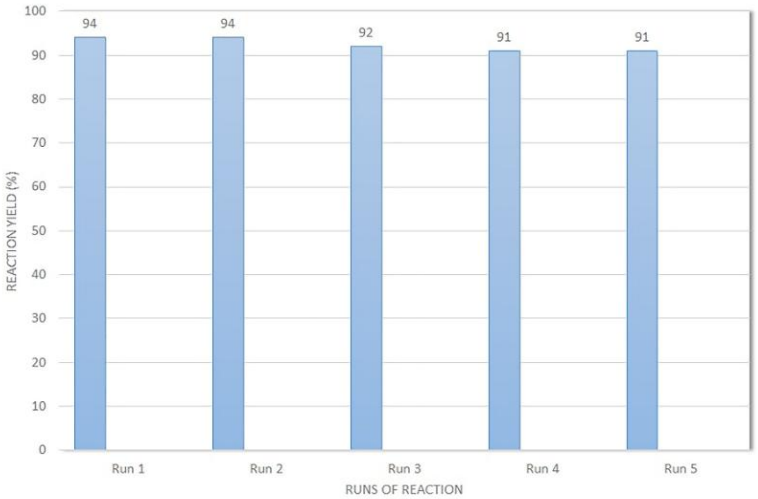


Fig. 6. Recycling of Catalyst

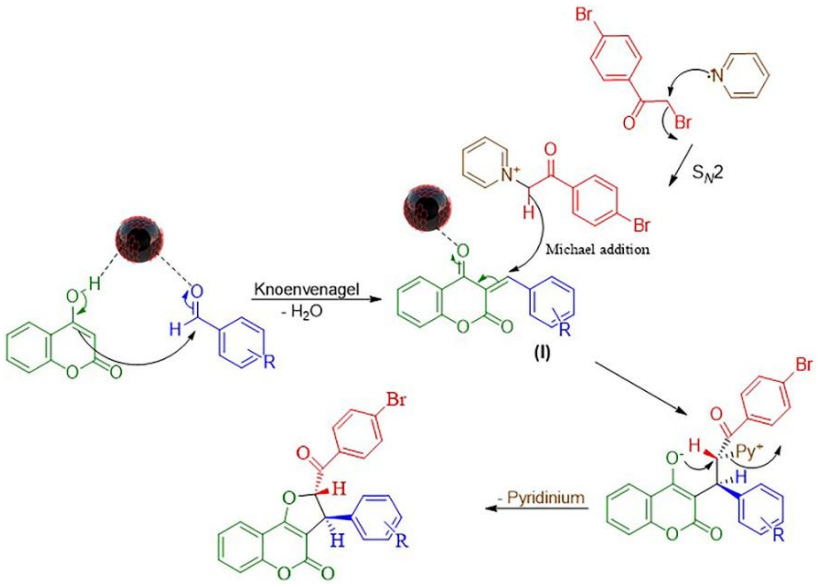


Fig. 7. Proposed mechanism

rate of the reaction increased considerably. In this research, US is applied as a green method for the synthesis of the furo[3,2-*c*]coumarines.

With these helpful data in hand, we turned to study the scope of the reaction by different aryl aldehydes, 4-hudroxycoumarine, and 2,4'-dibromoacetophenone as starting chemicals under optimized conditions (Table 2). It was observed that the electron-withdrawing groups reacted faster than electron-donation groups. In the interim, it is shown that the best yield are obtained with starting materials having electron-withdrawing groups. The all prepared product was summarized in Table 2. In the recovering method of NiO/Co_3O_4@N-GQDs nanocatalyst, chloroform was added to curd product after terminating the reaction. The nanocatalyst was not dissolve in chloroform and was separated by simple filtering. The reusing ability of the nanocatalyst was checked for 5 runs, proving almost similar yield of the desired product (Fig. 6).

A proposed mechanism was revealed in Fig. 7. We supposed that the reaction occurs via Knoevenagel condensation between 4-hydroxycoumarine and substituted aryl aldehydes to form intermediate (**I**). After that, the Michael addition of pyridinium yield with enones affords the zwitterions intermediate and followed by cyclization affords the product. The final step includes classical S_N2 reaction. Besides, pyridine plays an important role. It acts as a nucleophilic tertiary amine to form zwitterionic salt and acts as a leaving group to finish the intermolecular substitutions reaction. In this proposed mechanism, NiO/Co_3O_4@N-GQDs was introduced as an acid catalyst and active the carbonyl group.

CONCLUSION

As a result, we have developed the green, flexible, and highly efficient method for the synthesis of furo[3,2-*c*]coumarines catalyzed by NiO/Co_3O_4@N-GQDs nanocomposites. The present protocol tolerates most of the substrates and the designed catalyst can be recovered at least 5 runs without remarkable loss of activity. The advantage of this research are using ultrasound irradiations as a green and clean source, efficient and recoverable catalyst, little catalyst loading, and facile separation of product. This job reveals the advantage of ultrasound irradiations-assisted heterogeneous catalyst in the preparation of furo[3,2-*c*]coumarines.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

REFERENCE

1. Safaei-Ghomi J, Babaei P, Shahbazi-Alavi H, Pyne SG, Willis AC. A concise synthesis of furo[3,2-c]coumarins catalyzed by nanocrystalline $ZnZr_4(PO4)_6$ ceramics under microwave irradiation. Journal of the Iranian Chemical Society. 2016;13(8):1439-1448.
2. Al-Sehemi AG, El-Gogary SR. Synthesis and Photooxygenation of Furo[3,2-c]coumarin Derivatives as Antibacterial and DNA Intercalating Agent. Chin J Chem. 2012;30(2):316-320.
3. Sardari S, Mori Y, Horita K, Micetich RG, Nishibe S, Daneshtalab M. Synthesis and antifungal activity of coumarins and angular furanocoumarins. Bioorganic and Medicinal Chemistry. 1999;7(9):1933-1940.
4. Campos-Toimil M, Orallo F, Santana L, Uriarte E. Synthesis and Vasorelaxant Activity of New Coumarin and Furocoumarin Derivatives. Bioorganic and Medicinal Chemistry Letters. 2002;12(5):783-786.
5. Piccagli L, Borgatti M, Nicolis E, Bianchi N, Mancini I, Lampronti I, et al. Virtual screening against nuclear factor κB (NF-κB) of a focus library: Identification of bioactive furocoumarin derivatives inhibiting NF-κB dependent biological functions involved in cystic fibrosis. Bioorganic and; Medicinal Chemistry. 2010;18(23):8341-8349.
6. Borgatti M, Chilin A, Piccagli L, Lampronti I, Bianchi N, Mancini I, et al. Development of a novel furocoumarin derivative inhibiting NF-κB dependent biological functions: Design, synthesis and biological effects. Eur J Med Chem. 2011;46(10):4870-4877.
7. Babaei P, Safaei-Ghomi J. l-proline covered N doped graphene quantum dots modified CuO/ZnO hexagonal nanocomposite as a robust retrievable catalyst in synthesis of substituted chiral 2-amino-4H-chromenes. Materials Chemistry and Physics. 2021;267:124668.
8. Altieri E, Cordaro M, Grassi G, Risitano F, Scala A. Regio and diastereoselective synthesis of functionalized 2,3-dihydrofuro[3,2-c]coumarins via a one-pot three-component reaction. Tetrahedron. 2010;66(49):9493-9496.
9. Safaei-Ghomi J, Babaei P, Shahbazi-Alavi H, Zahedi S. Diastereoselective synthesis of trans -2,3-dihydrofuro[3,2-c] coumarins by MgO nanoparticles under ultrasonic irradiation. Journal of Saudi Chemical Society. 2017;21(8):929-937.
10. Tan X-c, Zhao H-y, Pan Y-m, Wu N, Wang H-s, Chen Z-f. Atom-economical chemoselective synthesis of furocoumarins via cascade palladium catalyzed oxidative alkoxylation of 4-oxohydrocoumarins and alkenes. RSC Advances. 2015;5(7):4972-4975.
11. Gu L-H, Zhang D-D, Qi Q-R, Yin P, He L. A mild and efficient amidation of cyclic ethers catalyzed by rhodium caprylate. Tetrahedron. 2014;70(43):8155-8160.
12. Lee CJ, Tsai CC, Hong SH, Chang GH, Yang MC, Möhlmann L, et al. Preparation of Furo[3,2-c]coumarins from 3-Cinnamoyl-4-hydroxy-2H-chromen-2-ones and Acyl Chlorides: A Bu_3P-Mediated C-Acylation/Cyclization Sequence. Angew Chem Int Ed. 2015;54(29):8502-8505.

13. Kumar A, Srivastava S, Gupta G. Cascade [4 + 1] annulation via more environmentally friendly nitrogen ylides in water: synthesis of bicyclic and tricyclic fused dihydrofurans. Green Chem. 2012;14(12):3269.
14. Dongamanti A, Bommidi VL, Arram G, Sidda R. Microwave-assisted synthesis of (E)-7-[(1-benzyl-1H-1,2,3-triazol-4-yl) methoxy]-8-(3-arylacryloyl)-4-methyl-2H-chromen-2-ones and their antimicrobial activity. Heterocycl Commun. 2014;20(5):293-298.
15. Wang S-L, Wu F-Y, Cheng C, Zhang G, Liu Y-P, Jiang B, et al. Multicomponent Synthesis of Poly-Substituted Benzo[a] pyrano[2,3-c]phenazine Derivatives under Microwave Heating. ACS Combinatorial Science. 2011;13(2):135-139.
16. Babaei P, Safaei-Ghomi J, Rashki S, Mahmoudi Kharazm A. Morphology modified by polyvinylpyrrolidone for enhanced antibacterial and catalytic execution of bioactive Ag/ZnO composites based on hydroxyapatite in the synthesis of O-Aminocarbonitriles. Ceram Int. 2023;49(14):22826-22836.
17. Yang J-S, Pai DZ, Chiang W-H. Microplasma-enhanced synthesis of colloidal graphene quantum dots at ambient conditions. Carbon. 2019;153:315-319.
18. Xi F, Zhao J, Shen C, He J, Chen J, Yan Y, et al. Amphiphilic graphene quantum dots as a new class of surfactants. Carbon. 2019;153:127-135.
19. Tang L, Ji R, Cao X, Lin J, Jiang H, Li X, et al. Deep Ultraviolet Photoluminescence of Water-Soluble Self-Passivated Graphene Quantum Dots. ACS Nano. 2012;6(6):5102-5110.
20. Razmi H, Mohammad-Rezaei R. Graphene quantum dots as a new substrate for immobilization and direct electrochemistry of glucose oxidase: Application to sensitive glucose determination. Biosensors and Bioelectronics. 2013;41:498-504.
21. Zhang Y, He YH, Cui PP, Feng XT, Chen L, Yang YZ, et al. Water-soluble, nitrogen-doped fluorescent carbon dots for highly sensitive and selective detection of Hg^{2+} in aqueous solution. RSC Advances. 2015;5(50):40393-40401.
22. Mandani S, Sharma B, Dey D, Sarma TK. Carbon nanodots as ligand exchange probes in Au@C-dot nanobeacons for fluorescent turn-on detection of biothiols. Nanoscale. 2015;7(5):1802-1808.
23. Yan Y, Chen J, Li N, Tian J, Li K, Jiang J, et al. Systematic Bandgap Engineering of Graphene Quantum Dots and Applications for Photocatalytic Water Splitting and CO_2 Reduction. ACS Nano. 2018;12(4):3523-3532.
24. Murugesan B, Pandiyan N, Arumugam M, Veerasingam M, Sonamuthu J, Jeyaraman AR, et al. Two dimensional graphene oxides converted to three dimensional P, N, F and B, N, F tri-doped graphene by ionic liquid for efficient catalytic performance. Carbon. 2019;151:53-67.
25. Babaei P, Safaei-Ghomi J. Engineered N-doped graphene quantum dots/$CoFe_2O_4$ spherical composites as a robust and retrievable catalyst: fabrication, characterization, and catalytic performance investigation in microwave-assisted synthesis of quinoline-3-carbonitrile derivatives. RSC advances. 2021;11(55):34724-34734.
26. Safaei-Ghomi J, Bateni FS, Babaei P. CeO_2/CuO@N-GQDs@NH_2 nanocomposite as a high-performance catalyst for the synthesis of benzo[g]chromenes. Appl Organomet Chem. 2020;34(7).