Efficient and Mild Synthesis of Pyranopyrimidines Catalyzed by Decorated Multi-walled Carbon Nanotubes Bearing Cobalt, Nickel, and Copper Metals in Water

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Abstract
The multicomponent reactions (MCRs) produce one compound from three or more reactants. Due to the innumerable combination possibilities of reagents, MCRs are popular because of their simplicity and versatility. In this research, an one-pot three-components reaction was carried out between 1,3-diethyl barbituric acid, malononitrile, and aldehydes in the presence of Cu/Co/Ni/MWCNTs as a recyclable catalyst. This catalyst indicated high catalytic activity with good proficiency and reusability under mild condition. This method proposed numerous materials such as being environmentally amicable in high product yields and short reaction times at ambient temperature. The catalysts were collected and specified by diverse spectroscopic techniques such as; FT-IR, X-ray diffraction, and scanning electron microscopy. After finalizing the reaction, the resulted compounds purified, and identified by the melting points, infrared spectroscopy (FT-IR), and the magnetic resonance of the hydrogen nucleus (1H NMR) techniques.

Keywords Multicomponent reaction · Heterogeneous catalyst · Nanocatalyst · Nanocomposite · Carbon nanotubes

Introduction
Medicinal and organic chemistry fields have given much attention to one-pot multicomponent reactions (MCRs) [1–3]. Researchers are continually investigating and developing new methods for the optimal synthesis of organic materials, so multicomponent reactions have been in the spotlight [4, 5]. These reactions have become increasingly popular due to their high flexibility compared with linear synthetic reactions [2, 6].

Pyran[2,3-d]pyrimidine can be prepared by the one-pot multicomponent reaction of 1,3-diethyl barbituric acid, various aldehydes, and malononitrile [7–10]. The different pyran[2,3-d]pyrimidine derivatives constituting so far indicate interesting anti-tumor, cardiotoxic, anti-bronchitis, and hepatoprotective. Moreover, polyfunctionalized pyran[2,3-d]pyrimidines formation is joint constructive subunit of actual intrinsic products [11–16].

Green chemistry has been a central topic in scientific and industrial research for centuries [17]. The development of clean and environmentally friendly methods is the main objective for synthesis of organic compounds. The organic solvents are often harmful because of this; their use should be minimized as far as possible. For example, water as a reaction solvent is highly regarded because it is a highly polar green solvent and therefore immiscible with organic compounds. The reaction in the water media is generally a friendly environment and is devoid of any cancer effects, which are very cheap and essential in the industry [18–20].

The CNTs are nanostructures with substantial electronic and mechanical properties. Since their detection in 1991 [21, 22], they have possessed theoretical interest due to their unique structure and attributes. The panorama of uses has led to the successful functionalization of single-walled carbon nanotubes (SWCNTs) and multi-walled carbon nanotubes (MWCNTs) [23–28]. The MWCNTs are considered excellent support for heterogeneous catalysts by providing a perfect frame for the support and adherence of metal particles.
The oxidation process is one of the first reactions performed on carbon nanotubes, mainly for the purification and removal of catalysts [23, 29]. One of the methods to remove graphite plate and metal catalysts in carbon nanotubes is acids [30–36].

**Experimental Section**

**Materials and Apparatus**

In high purity, all commercially available reagents were used and purchased from the Merck and Sigma-Aldrich Chemical Companies. All of the reagents were used without any additional purification. If needed, the products were purified via a column chromatography process to obtain the corresponding products in 69–98% yields. The $^1$H NMR spectra were recorded in DMSO-d$_6$ solvent on a Bruker DRX-400 spectrometer with TMS as an internal reference. IR spectra were recorded as KBr pellets on a Nicolet FT-IR spectrophotometer. XRD patterns were reported by an X’Pert Pro (Philips) apparatus with 1.54 Ångström wavelengths of the X-ray beam and Cu anode material. The field emission scanning electron microscope (FE-SEM) of nanoparticles was performed on the Zeiss that operated at a 15 kV accelerating voltage. Thermogravimetric analysis (TGA) was performed on a Mettler TA4000 system TG-50 at a heating rate of 10 K min$^{-1}$ under an N$_2$ atmosphere. Melting points were measured with Yanagimoto micro melting point equipment.

**General Procedure for Preparation of Cu/Co/Ni/MWCNTs Nanocatalyst**

Firstly, 2.5 g of MWCNTs were added to a 40 mL mixture of HNO$_3$ (65%) and H$_2$SO$_4$ (98%) (3:1 ratio). Then, 5 mL of ethanol were added to the mixture and stirred for 3 min. The reaction mixture refluxed for 120 min at 95 °C. Then the sediment was washed with water and ethanol, respectively, and dried for 5 h at 70 °C. Next, 0.15 g of the activated MWCNTs were added to the mixture of 30 mL of CuCl$_2$ (0.01 M), 30 mL of buffer (pH 9.5), and 10 mL of ethanol. Then 3 mL of formaldehyde was added slowly for 2 h to the mixture on the ultrasonic bath. Afterward, the reduced MWCNTs were filtered and washed with water and acetone, respectively, and dried for 3 h at 70 °C.

In the next step, 0.13 g of Cu/MWCNTs were added to the mixture of 15 mL CoCl$_2$ (0.01 M) and 15 mL NiCl$_2$ (0.01 M). Then 15 mL of ethanol and 65 mL of water were added to the mixture. Finally, 15 mL of NaOH (1 M) was added slowly for 2 h to the mixture on the ultrasonic bath. The sediment was washed with water/acetone and dried for 6 h at 80 °C.

**General Procedure for the Synthesis of Pyrano[2,3-d]pyrimidine**

The aromatic aldehyde (1 mmol), malononitrile (1.2 mmol), and 1,3-diethyl barbituric acid (1 mmol) were transferred to the 25 mL round-bottom flask and added Cu/Co/Ni/MWCNTs (0.005 g) as a catalyst. Then, 5 mL of the water was added to the mixture as a solvent. The mixture was stirred at room temperature, and the reaction progress was monitored by thin-layer chromatography (TLC) technique. After the completion of the reaction, the sediments were filtered and washed with ethanol. Then, with the help of ethyl acetate, the catalyst was separated from the reaction mixture. The recovered catalyst was washed with ethanol/water mixture and dried at 80 °C for reuse. The crude product was recrystallized in ethanol after evaporation of the ethyl acetate. As needed, the compounds were purified with the help of column chromatography.

**Analytical Data of Selected Compounds**

7 ‑Amino ‑1, 3‑dim ethyl‑5 ‑(4 ‑nit ro phe nyl )‑2 ,4‑dio xo‑1,3,4,5‑tet ra hy dro ‑2H ‑pyran o[2 ,3‑d]py rimi di ne‑6 ‑carbonitrile (4a)

White solid; m.p.: 227–228 °C (Lit. m.p 227–229 °C) [37]; IR (KBr) $\nu = 3389, 3306, 3075, 2958, 2204, 1685, 1631, 1487, 1515, 1382, 1230, 1186$ $^1$H NMR (400 MHz, DMSO-d$_6$) $\delta$ 3.10(3H, s, CH$_3$), 3.30(3H, s, CH$_3$), 4.50(1H, s, CH), 7.60(2H, d, $J = 8$ Hz, Ar–H), 8.15 (2H, d, $J = 8$ Hz, Ar–H), 7.49(2H, s, NH$_2$).

7‑Amino‑5‑(4‑chlorphenyl)‑1,3‑dimethyl‑2,4‑dio‑x o‑1,3,4,5‑tetrahydro‑2H‑pyrano[2,3‑d]‑pyrimidine‑6‑carbonitrile (4b)

White crystal; m.p.: 234–235 °C (Lit. m.p 234–237 °C) [37]; IR (KBr) $\nu = 3373, 3306, 3075, 2958, 2204, 1685, 1635, 1487, 1186$ $^1$H NMR (400 MHz, DMSO-d$_6$) $\delta$ 3.10(3H, s, CH$_3$), 3.30(3H, s, CH$_3$), 4.50(1H, s, CH), 7.25–7.28 (2H, d, $J = 8$ Hz, Ar–H), 7.31–7.36 (2H, d, $J = 8$ Hz, Ar–H), 7.36 (2H, s, NH$_2$).

7‑Amino‑5‑(4‑fluorophenyl)‑1,3‑dimethyl‑2,4‑dio‑x o‑1,3,4,5‑tetrahydro‑2H‑pyrano[2,3‑d]‑pyrimidine‑6‑carbonitrile (4c)

White solid; m.p.: 228–230 °C (Lit. m.p 227–229 °C) [37]; IR (KBr) $\nu = 3380, 3306, 3185, 2958, 2196, 1685, 1636, 1526, 1233, 1193, 857$. $^1$H NMR (400 MHz, DMSO-d$_6$) $\delta$ 3.07 (3H, s, CH$_3$), 3.34 (3H, s, CH$_3$), 4.34 (1H, s, CH), 7.25–7.28 (2H, d, $J = 8$ Hz, Ar–H), 7.31–7.36 (2H, d, $J = 8$ Hz, Ar–H), 7.36 (2H, s, NH$_2$).
**Fig. 1** Preparation of the Cu/Cu/Co/Ni/MWCNTs catalyst

7.25 (2H, d, J = 8 Hz, Ar–H), 7.31 (2H, d, J = 8 Hz, Ar–H), 7.36 (2H, s, NH₂).

**7-Amino-5-(4-methoxyphenyl)-1,3-dimethyl-2,4-dioxo-1,3,4,5-tetrahydro-2H-pyrano[2,3-d]-pyrimidine-6-carbonitrile(4d)**

White solid; m.p.: 280–284 °C (Lit. m.p 280 °C) [38]; IR (KBr) ν = 3417, 3302, 3189, 2946, 2192, 1700, 1638, 1509, 1227, 1186, 847. ¹H NMR (400 MHz, DMSO-d₆) δ 3.01 (3H, s, CH₃), 3.03 (3H, s, CH₃), 3.54 (3H, s, CH₃), 4.30 (1H, s, CH), 5.65 (2H, d, J = 8 Hz, Ar–H), 6.56 (2H, d, J = 8 Hz, Ar–H), 7.15 (2H, d, J = 8 Hz, Ar–H), 7.30 (2H, s, NH₂).

7-Amino-5-(4-methylphenyl)-1,3-dimethyl-2,4-dioxo-1,3,4,5-tetrahydro-2H-pyrano[2,3-d]-pyrimidine-6-carbonitrile(4e)

Yellow solid; m.p.: 226–227 °C (Lit. m.p 225 °C) [38]; IR (KBr) ν = 3380, 3310, 3200, 2923, 2199, 1687, 1640, 1490, 1228, 1185, 832. ¹H NMR (400 MHz, DMSO-d₆) δ 2.25 (3H, s, CH₃), 3.10 (3H, s, CH₃), 3.35 (3H, s, CH₃), 4.25 (1H, s, CH), 7.10 (2H, d, J = 8 Hz, Ar–H), 7.10 (2H, d, J = 8 Hz, Ar–H), 7.30 (2H, s, NH₂).
7-Amino-5-(3-fluorophenyl)-1,3-dimethyl-2,4-dioxo-1,3,4,5-tetrahydro-2H-pyrimidine-6-carbonitrile(4f)

White solid; m.p.: 227–229 °C (Lit. m.p 228–229 °C) [39];
IR (KBr) ν = 3390, 3314, 3197, 2965, 2201, 1688, 1642, 1489, 1229, 1186. ¹H NMR (400 MHz, DMSO-d₆) δ 3.08 (3H, s, CH₃), 3.50 (3H, s, CH₃), 4.50 (1H, s, CH), 7.30 (1H, d, Ar–H), 7.00 (2H, s, Ar–H), 7.00 (1H, t, J = 8 Hz, Ar–H), 7.00 (1H, d, J = 8 Hz, Ar–H), 7.40 (2H, s, NH₂).

7-Amino-5-(3-bromophenyl)-1,3-dimethyl-2,4-dioxo-1,3,4,5-tetrahydro-2H-pyrimidine-6-carbonitrile(4g)

White solid; m.p.: 216–218 °C (Lit. m.p 218–219 °C) [40];
IR (KBr) ν = 3377, 3313, 3197, 2960, 2202, 1684, 1638, 1490, 1228, 1186, 1071. ¹H NMR (400 MHz, DMSO-d₆) δ 3.02 (3H, s, CH₃), 3.34 (3H, s, CH₃), 4.34 (1H, s, CH), 7.25 (2H, m, Ar–H), 7.40 (1H, m, Ar–H), 7.42 (2H, s, NH₂).
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7-Amino-5-(3-methoxyphenyl)-1,3-dimethyl-2,4-dioxo-1,3,4,5-tetrahydro-2H-pyrano[2,3-d]-pyrimidine-6-carbonitrile (4h)

White solid; m.p.: 200–206 °C (Lit. m.p 200–206 °C) [8]; IR (KBr) v = 3407, 3318, 3199, 2951, 2193, 1688, 1649, 1494, 1229, 1187, 746. 1H NMR (400 MHz, DMSO-d_6) δ 3.08(3H, s, CH₃), 3.34(3H, s, CH₃), 3.72 (3H, s, CH₂), 4.30 (1H, s, CH), 6.72 (1H, s, Ar–H), 6.78 (2H, d, J = 8 Hz, Ar–H), 7.20(1H, t, J = 8 Hz, Ar–H), 7.32(2H, s, NH₂).

7-Amino-1,3-dimethyl-5-(3-nitrophenyl)-2,4-dioxo-1,3,4,5-tetrahydro-2H-pyrano[2,3-d]-pyrimidine-6-carbonitrile (4i)

White solid; m.p.: 255–226 °C (Lit. m.p 255–227 °C) [38]; IR (KBr) v = 3430, 3333, 3185, 2952, 2195, 1695, 1650, 1492, 1520, 1389, 1231, 1188, 776, 904. 1H NMR (400 MHz, DMSO-d_6) δ 3.06 (3H, s, CH₃), 3.36 (3H, s, CH₃), 4.56 (1H, s, CH), 7.32 (2H, s, NH₂), 7.60 (1H, t, J = 8 Hz, Ar–H), 7.78 (1H, d, J = 8 Hz, Ar–H), 8.10 (1H, d, J = 8 Hz, Ar–H), 8.10 (1H, s, Ar–H).

7-Amino-5-(2-bromophenyl)-1,3-dimethyl-2,4-dioxo-1,3,4,5-tetrahydro-2H-pyrano[2,3-d]-pyrimidine-6-carbonitrile (4j)

White solid; m.p.: 237 °C (Lit. m.p: 237–238 °C) [39]; IR (KBr) v = 3397, 3311, 3190, 2960, 2194, 1688, 1643, 1489, 1232, 1190, 1071. 1H NMR (400 MHz, DMSO-d_6) δ 3.04 (3H, s, CH₃), 3.34 (3H, s, CH₃), 4.86 (1H, s, CH), 7.12 (1H, m, J = 8 Hz, Ar–H), 7.25 (1H, d, J = 8 Hz, Ar–H), 7.26 (1H, t, J = 8 Hz, Ar–H), 7.52 (1H, d, J = 8 Hz, Ar–H), 7.42 (2H, s, NH₂).
**7-Amino-5-(2-fluorophenyl)-1,3-dimethyl-2,4-dioxo-1,3,4,5-tetrahydro-2H-pyrido[2,3-d]-pyrimidine-6-carbonitrile (4k)**

White solid; m.p.: 237–239 °C (Lit. m.p. 238–239 °C) [39]; IR (KBr) \(\nu = 3380, 3308, 3185, 2959, 2197, 1689, 1639, 1497, 1233, 1193, 748\). ¹H NMR (400 MHz, DMSO-d₆) \(\delta\) 3.05 (3H, s, CH₃), 3.35 (3H, s, CH₃), 4.70 (1H, s, CH), 7.10 (1H, t, \(J = 8\) Hz, Ar–H), 7.25 (1H, d, \(J = 8\) Hz, Ar–H), 7.25 (1H, t, \(J = 8\) Hz, Ar–H) 7.40 (2H, s, NH₂).

**7-Amino-5-(2-methylphenyl)-1,3-dimethyl-2,4-dioxo-1,3,4,5-tetrahydro-2H-pyrido[2,3-d]-pyrimidine-6-carbonitrile (4l)**

White solid; m.p.: 247 °C (Lit. m.p. 247–248 °C) [41]; IR (KBr) \(\nu = 3379, 3312, 3197, 2958, 2200, 1712, 1687, 1488, 1228, 1185, 751\). ¹H NMR (400 MHz, DMSO-d₆) \(\delta\) 2.26 (3H, s, CH₃), 3.06 (3H, s, CH₃), 3.34 (3H, s, CH₃), 4.26 (1H, s, CH), 7.00 (3H, m, Hz, Ar–H), 7.16 (1H, t, \(J = 8\) Hz, Ar–H), 7.30 (2H, s, NH₂).

**7-Amino-5-(2-chlorophenyl)-1,3-dimethyl-2,4-dioxo-1,3,4,5-tetrahydro-2H-pyrido[2,3-d]-pyrimidine-6-carbonitrile (4m)**

White solid; m.p.: 238–240 °C (Lit. m.p. 238–240 °C) [42]; IR (KBr) \(\nu = 3395, 3312, 3192, 2957, 2194, 1689, 1642, 1487, 1232, 1190, 751\). ¹H NMR (400 MHz, DMSO-d₆) \(\delta\) 3.05 (3H, s, CH₃), 3.35 (3H, s, CH₃), 4.85 (1H, s, CH), 7.20 (4H, t, \(J = 8\) Hz, Ar–H), 7.30 (2H, d, \(J = 8\) Hz, Ar–H), 7.29–7.38 (2H, d, \(J = 8\) Hz Ar–H), 7.35 (2H, s, NH₂).

**7-Amino-1,3-dimethyl-5-(2-nitrophenyl)-2,4-dioxo-1,3,4,5-tetrahydro-2H-pyrido[2,3-d]-pyrimidine-6-carbonitrile (4n)**

White solid; m.p.: 213–215 °C (Lit. m.p. 216 °C) [42]; IR (KBr) \(\nu = 3395, 3312, 3197, 2958, 2194, 1687, 1526, 1354, 1233, 1193, 747\). ¹H NMR (400 MHz, DMSO-d₆) \(\delta\) 3.00 (3H, s, CH₃), 3.31 (3H, s, CH₃), 3.34 (3H, s, CH₃), 4.26 (1H, s, CH), 7.42 (1H, t, \(J = 8\) Hz, Ar–H), 7.51 (1H, d, \(J = 8\) Hz Ar–H), 7.62 (1H, d, \(J = 8\) Hz, Ar–H), 7.82 (1H, d, \(J = 8\) Hz, Ar–H), 7.50 (2H, s, NH₂).

**7-Amino-5-(2,6-dichlorophenyl)-1,3-dimethyl-2,4-dioxo-1,3,4,5-tetrahydro-2H-pyrido[2,3-d]-pyrimidine-6-carbonitrile (4o)**

White solid; m.p.: 243–244 °C (Lit. m.p. 243–244 °C) [43]; IR (KBr) \(\nu = 3385, 3314, 3192, 3196, 2199, 1690, 1655, 1461, 1235, 1037, 755\). ¹H NMR (400 MHz, DMSO-d₆) \(\delta\) 3.04 (3H, s, CH₃), 3.34 (3H, s, CH₃), 5.38 (1H, s, CH), 7.26 (1H, t, \(J = 8\) Hz, Ar–H), 7.34 (1H, d, \(J = 8\) Hz Ar–H), 7.46 (1H, d, \(J = 8\) Hz, Ar–H), 7.46 (2H, s, NH₂).

**7-Amino-5-(2,4-dichlorophenyl)-1,3-dimethyl-2,4-dioxo-1,3,4,5-tetrahydro-2H-pyrido[2,3-d]-pyrimidine-6-carbonitrile (4p)**

White solid; m.p.: 243–245 °C (Lit. m.p. 243–246 °C) [43]; IR (KBr) \(\nu = 3391, 3310, 3192, 2960, 2195, 1690, 1540, 1461, 1228, 1186\). ¹H NMR (400 MHz, DMSO-d₆) \(\delta\) 3.02 (3H, s, CH₃), 3.34 (3H, s, CH₃), 4.84 (1H, s, CH), 7.32–7.38 (2H, m, Ar–H), 7.41 (1H, s, Ar–H), 7.41 (2H, s, NH₂).

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Fig. 6  The EDX spectrum of the Cu/Co/Ni/MWCNTs catalyst
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7-Amino-5-(3,4,5-trimethoxyphenyl)-1,3-dimethyl-2,4-dioxo-1,3,4,5-tetrahydro-2H-pyran[2,3-d]-pyrimidine-6-carbonitrile (4q)

Yellow solid; m.p.: 262–264 °C (Lit. m.p 263–265 °C) [8]; IR (KBr) ν = 3342, 3191, 2945, 2197, 1694, 1648, 1496, 1184, 1119. 1H NMR (400 MHz, DMSO-d₆) δ 3.10 (3H, s, CH₃), 3.35 (3H, s, CH₃), 3.60 (3H, s, CH₃), 3.70 (6H, s, CH₃), 4.30 (1H, s, CH), 6.50 (2H, s, Ar–H), 7.30 (2H, s, NH₂).

7-Amino-1,3-dimethyl-2,4-dioxo-5-phenyl-1,3,4,5-tetrahydro-2H-pyran[2,3-d]-pyrimidine-6-carbonitrile (4r)

White solid; m.p.: 259–260 °C (Lit. m.p 260–262 °C) [43]; IR (KBr) ν = 3374, 3308, 3194, 2961, 2194, 1688, 1636,1493, 1229, 1188. 1H NMR (400 MHz, DMSO-d₆) δ 3.07 (3H, s, CH₃), 4.31 (1H, s, CH), 7.20 (5H, m, Hz Ar–H), 7.32 (2H, s, NH₂).

Results and Discussion

Preparation and Characterization of Catalyst

The functionalization of multi-walled carbon nanotubes was performed using sulfuric acid and nitric acid under reflux conditions to form the hydroxyl groups and carboxylic groups. Then, the obtained structure was activated by doping the Ni²⁺, Co²⁺, and Cu²⁺ metal ions (Fig. 1).

The Cu/Co/Ni/MWCNTs catalyst is prepared in three steps described in Fig. 2. At first, the MWCNTs are activated...
by H$_2$SO$_4$ and HNO$_3$. As a result, the hydroxyl and carboxylic groups are formed on the surface of the MWCNTs and activating them. In the second step, the Cu is stabilized on the activated MWCNTs with the help of these organic groups created in the previous step through creating bonds. Then Cu$^{2+}$ is reduced to Cu$^0$ by using the formaldehyde. Finally, the Co and Ni metals are fixed on the Cu/MWCNTs.

The FT-IR spectra are indicated in Fig. 3 that including the primary carbon nanotube (Fig. 3a) and the oxidized carbon nanotube (Fig. 3b). As shown in this Figure, the weak absorption bands are seen in the spectrum due to the high symmetry of the initial nanotube. But in the oxidized form, the absorption bands of 3600 cm$^{-1}$ related to the O–H bond are shown. The absorption band appeared is about 1700 cm$^{-1}$ belonging to the C = O bond of the carboxylic acid group. Another absorption band at 1200 cm$^{-1}$ can correspond to the C-O bond.

The activated multi-walled carbon nanotubes (Fig. 4a), Cu/MWCNTs (Fig. 4b), and Cu/Co/Ni/MWCNTs (Fig. 4c) were studied by the XRD method. The diffraction pattern of the activated multi-walled carbon nanotubes shows a sharp peak at 26.75°, which is characteristic of carbon (JCPDS No. 00–008-0415). The XRD pattern of the Cu/ MWCNTs shows the Cu(OH)$_2$ and CuCO$_3$ in the structure of the multi-walled carbon nanotubes, which is incredibly near to the values in the literature (JCPDS No. 00-001-0959). Finally, the X-ray diffraction pattern of the Cu/Co/Ni/MWCNTs proves the presence of Cu(OH)$_2$, CuCO$_3$, NiCo$_2$O$_4$ (JCPDS No. 00-024-0523), and NiO (JCPDS No.78-0643) compounds stabilized on the multi-walled carbon nanotubes and agreement with the pattern of all reference literature.

The field emission scanning electron microscopy (FE-SEM) images of the Cu/Co/Ni/MWCNTs nanocatalyst showed the level morphologies of the catalysts. Metal nanoparticles with particle sizes of 22 to 42 nm are well dispersed on the surface of multi-walled carbon nanotubes (Fig. 5).

The EDX pattern of the Cu/Co/Ni/MWCNTs catalyst is shown in Fig. 6. According to the analysis, nickel, copper, cobalt, and oxygen atoms on the catalyst surface have been demonstrated. The presence of carbon as a catalyst substrate has also been shown.

It can be seen from the TGA diagram that the first mass reduction at 200–300 °C is due to the removal of water and solvents from the pores of the nanostructure. Decarboxylation of the carboxylic acid group also occurs in this fracture. Also, the weight loss observed at 750 °C, is related to the destruction of carbon nanotubes, and finally, remains 40% of the material (Fig. 7).

### Investigation of Catalytic Activity

The catalytic performance of the prepared Cu/Co/Ni/MWCNTs nanocatalysts was investigated for the synthesis of pyrano[2,3-d]pyrimidine derivatives. The reaction between 1,3-diethyl barbituric acid, malononitrile, and 4-nitro benzaldehyde was selected as a model reaction. Finally, the conditions such as solvent, temperature, and catalyst loading were investigated to optimize the factors. Low yields of the products were seen using toluene and DMF (Table 1, entries 1-3).
Table 3  Synthesis of pyrano[2,3-d]pyrimidine derivatives

![Chemical structure](image)

| Entry | Product | Time (min) | Yield (%) |
|-------|---------|------------|-----------|
| 1     | ![Image](image) | 10         | 98        |
| 2     | ![Image](image) | 20         | 85        |
| 3     | ![Image](image) | 12         | 89        |
| 4     | ![Image](image) | 25         | 60        |
| Entry | Product | Time (min) | Yield (%) |
|-------|---------|------------|-----------|
| 5     | ![Structure (4e)](image) | 16         | 79        |
| 6     | ![Structure (4f)](image) | 20         | 89        |
| 7     | ![Structure (4g)](image) | 15         | 80        |
| 8     | ![Structure (4h)](image) | 30         | 52        |
| 9     | ![Structure (4i)](image) | 14         | 89        |
| 10    | ![Structure (4j)](image) | 15         | 68        |
| Entry | product | Time (min) | Yield (%) |
|-------|---------|------------|-----------|
| 11    | ![4k](image) | 15         | 70        |
| 12    | ![4l](image) | 20         | 63        |
| 13    | ![4m](image) | 12         | 68        |
| 14    | ![4n](image) | 12         | 80        |
| 15    | ![4o](image) | 20         | 75        |
| 16    | ![4p](image) | 15         | 79        |
Table 3 (continued)

| Entry | product | Time (min) | Yield (%) |
|-------|---------|------------|-----------|
| 17    | ![image](image1.png) | 38         | 73        |
| 18    | ![image](image2.png) | 12         | 79        |

Reaction conditions: Aromatic aldehyde (1 mmol), malononitrile (1.2 mmol), 1,3-dimethyl barbituric acid (1 mmol), catalyst (0.005 mg), and H₂O (5 ml) solvent at 25°C

Table 4 Comparison the catalytic activity of the Cu/Co/Ni/MWCNTs with other reported catalysts for the synthesis of 4a

| Entry | Catalyst (conditions) | Time (min) | Yielda (%) | Ref |
|-------|------------------------|------------|------------|-----|
| 1     | Zn[2-bromophenylsalicyldiminemethylpyranopyrazole] Cl₂ (8 mol%, ethanol; water monomer, 40 °C) | 12         | 96         | [40]  |
| 2     | Nano-titania sulfuric acid (20 mg, ethanol; water monomer (19:1), Reflux) | 21         | 88         | [44]  |
| 3     | 1,8-diazabicyclo [5.4.0] undec-7-ene (10 mol%, H₂O, Reflux) | 50         | 82         | [45]  |
| 4     | Magnetized deionized water (5 ml, H₂O, 70 °C) | 49         | 97         | [46]  |
| 5     | Cu/Co/Ni/MWCNTs (0.005 mg, H₂O, 25 °C) | 10         | 98         | This work |

aIsolated yield

Fig. 9 The pyrano[2,3-d]pyrimidine formation of 1,3-diethyl barbituric acid, aromatic aldehyde, and malononitrile in the presence of reused Cu/Co/Ni/MWCNTs
5 and 4), while the H2O was selected as the prime solvent for the model reaction at 25 °C (Table 1, entry 10) to produce pyrano[2,3-d]pyrimidine in excellent yield.

To further optimize the catalyst synergy conditions, the synthesis of pyrano[2,3-d]pyrimidines for several types of catalysts was investigated (Fig. 8). For this reaction, it was used other catalysts such as Co/MWCNTs, Ni/MWCNTs, Co/Ni/MWCNTs, Ni/Cu/MWCNTs, and Co/Cu/MWCNTs, which resulted in lower yields. The resulting increase in the catalytic activity of Cu/Co/Ni/MWCNTs could be attributed to the synergistic catalytic effect between the metallic species.

Table 2 shows the results of the synthesis of several pyrano[2,3-d]pyrimidine derivatives by using the catalysts Ni/Cu/MWCNTs, Co/Ni/MWCNTs, Cu/MWCNTs, Co/MWCNTs, and Ni/MWCNTs. This Table illustrates well how different metals work synergistically, increasing efficiency and reducing reaction time.

The reaction of pyrano[2,3-d]pyrimidines was carried out after optimizing the conditions in the presence of Ni/Cu catalyst and achieved a 90% yield after 10 min (Table 3). In addition, the synthetic reaction of various pyrano[2,3-d]pyrimidines were carried out under optimized conditions. The products are obtained with excellent yields and short reaction times. The aromatic aldehydes that have an electron-withdrawing substituents, such as the nitro group have high efficiency and the reaction is completed in less time. On the other hand, the presence of electron donating groups has a strong inactivation effect on the positive carbon of aldehydes.

Table 4 compares the performance of the Cu/Co/Ni/MWCNTs with the previously reported catalysts for synthesis of 4a. In this Table, it is shown that the Cu/Co/Ni/MWCNTs have superior performance to the catalysts that have been reported so far. The synergistic effect between nickel, cobalt, and copper enhanced the activity of the catalyst and increased the yield, as well as reduced the reaction time (Table 4, entry 5 vs. entries 1–4).

The most fundamental properties of catalysts are their reusability which must be examined. The reusing of the Cu/Co/Ni/MWCNTs catalysts in the synthesis of pyrano[2,3-d]pyrimidines was studied. The catalyst is easily separated by filtration by dissolving the reaction product in ethyl acetate. The recovered catalyst was washed...
three times with acetone and three times with water. After six recovery stages, the catalyst had not lost its function and could be reused (Fig. 9).

In conforming to the FE-SEM picture of the used catalyst after six recycles, no considerable change in the morphology of the Cu/Co/Ni/MWCNTs catalyst from that of the new catalyst was identified (Fig. 10).

According to the XRD image of the catalyst, after six steps of recovery, there are no remarkable changes to the primary catalyst (Fig. 11).

**Proposed Reaction Mechanism**

Firstly, between the aromatic aldehyde (1a–l) and the malononitrile (b), the Knoevenagel condensation reaction occurs and gives an electrophilic olefin (c) in the next step 1,3-diethyl barbituric acid (i) attack on electrophilic olefin to give (d) which then tautomerize to give (e). The average (e) by intramolecular nucleophilic addition gives (f), which is then converted to the terminal production (4a–l) by intramolecular Thorpe-Zeigler reaction (Scheme 1).

**Conclusions**

In summary, it was prepared Cu/Co/Ni/MWCNTs from multi-walled carbon nanotubes and nickel, cobalt, and copper as catalysts and characterized using several techniques such as; FT-IR spectroscopy, FE-SEM, EDX, and TGA. At first, it was performed the reaction of pyrano [2,3-d] pyrimidines by using Cu/Co/Ni/MWCNTs catalyst. The advantages of this reaction are high efficiency, short reaction times, environmental solvent, easily product separation, cost-effective catalyst, and easy catalyst recovery.

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References

1. A. Dönmling and I. Ugi (2000). Angew. Chemie Int. Ed. 39, 3168.
2. G. Shanthi and P. T. Perumal (2009). Tetrahedron Lett. 50, 3959.
3. M. Khorasani, and H. Naeimi (2022). Synth. Commun., 1.
4. C. Hulme and V. Gore (2003). Curr. Med. Chem. 10, 51.
5. L. Weber, K. Ilgen, and M. Almstetter (1999). Synlett. 3, 366.
6. G. A. Chass, C. J. O’Brien, N. Hadei, E. A. B. Kantchev, W. Mu, D. Fang, A. C. Hopkinson, I. G. Csizmadia, and M. G. Organ (2009). Chem. Eur. J. 15, 4281.
7. Y. Rajinder, M. Gupta, and J. Kour (2019). J. Iran. Chem. Soc. 16, 1977.
8. M. Abasszadeh, S. J. Roudbaraki, and M. Ghashang (2019). Org. Prep. Proced. Int. 51, 255.
9. M. C. Bagley, D. D. Hughes, M. C. Lubinu, E. A. Merritt, P. H. Taylor, and N. C. O. Tomkinson (2004). QSAR Comb. Sci. 23, 859.
10. M. N. Elinson, A. I. Ilovaisky, V. M. Merkulova, T. A. Zaimovskaya, and G. I. Nikishin (2011). Mendeleev Commun. 21, 122.
11. S. Beheshti, V. Safarifard, and A. Morsali (2018). Inorg. Chem. Commun. 94, 80.
12. J. A. Valderrama, P. Colonelli, D. Vásquez, M. F. González, J. A. Rodriguez, and C. Theodulou (2008). Bioorg. Med. Chem. 16, 10172.
13. M. A. Gonzalez and R. L. Smith (2003). Environ. Prog. 22, 269.
14. S. Iijima (1991). Nature. 354, 56.
15. H. Naeimi, A. Mohajeri, L. Moradi, and A. M. Rashidi (2009). Appl. Surf. Sci. 256, 631.
16. H. Naeimi and M. Dadaei (2015). RSC Adv. 5, 76221.
17. P. Mandal and S. C. Mondal (2019). Mater. Manuf. Process. 34, 1326.
18. A. Dömling and I. Ugi (2000). Angew. Chemie Int. Ed. 39, 3168.
19. G. Shanthi and P. T. Perumal (2009). Tetrahedron Lett. 50, 3959.
20. M. Khorasani, and H. Naeimi (2022). Synth. Commun., 1.
21. C. Hulme and V. Gore (2003). Curr. Med. Chem. 10, 51.
22. L. Weber, K. Ilgen, and M. Almstetter (1999). Synlett. 3, 366.
23. G. A. Chass, C. J. O’Brien, N. Hadei, E. A. B. Kantchev, W. Mu, D. Fang, A. C. Hopkinson, I. G. Csizmadia, and M. G. Organ (2009). Chem. Eur. J. 15, 4281.
24. Y. Rajinder, M. Gupta, and J. Kour (2019). J. Iran. Chem. Soc. 16, 1977.
25. M. Abasszadeh, S. J. Roudbaraki, and M. Ghashang (2019). Org. Prep. Proced. Int. 51, 255.
26. M. C. Bagley, D. D. Hughes, M. C. Lubinu, E. A. Merritt, P. H. Taylor, and N. C. O. Tomkinson (2004). QSAR Comb. Sci. 23, 859.
27. M. N. Elinson, A. I. Ilovaisky, V. M. Merkulova, T. A. Zaimovskaya, and G. I. Nikishin (2011). Mendeleev Commun. 21, 122.
28. S. Beheshti, V. Safarifard, and A. Morsali (2018). Inorg. Chem. Commun. 94, 80.
29. J. A. Valderrama, P. Colonelli, D. Vásquez, M. F. González, J. A. Rodriguez, and C. Theodulou (2008). Bioorg. Med. Chem. 16, 10172.
30. M. A. Gonzalez and R. L. Smith (2003). Environ. Prog. 22, 269.
31. S. Iijima (1991). Nature. 354, 56.
32. H. Naeimi, A. Mohajeri, L. Moradi, and A. M. Rashidi (2009). Appl. Surf. Sci. 256, 631.
33. H. Naeimi and M. Dadaei (2015). RSC Adv. 5, 76221.
34. P. Mandal and S. C. Mondal (2019). Mater. Manuf. Process. 34, 1326.
35. Y. Peng and H. Liu (2006). Ind. Eng. Chem. Res. 45, 6483.
36. T. Belin and F. Epron (2005). Mater. Sci. Eng. B. 119, 105.
37. N. V. Qui, P. Scholz, T. Krech, T. F. Keller, K. Pollitk, and B. Ondruschka (2011). Catal. Commun. 12, 464.
38. A. Dömling and I. Ugi (2000). Angew. Chemie Int. Ed. 39, 3168.
39. G. Shanthi and P. T. Perumal (2009). Tetrahedron Lett. 50, 3959.
40. M. Khorasani, and H. Naeimi (2022). Synth. Commun., 1.
41. C. Hulme and V. Gore (2003). Curr. Med. Chem. 10, 51.
42. L. Weber, K. Ilgen, and M. Almstetter (1999). Synlett. 3, 366.
43. G. A. Chass, C. J. O’Brien, N. Hadei, E. A. B. Kantchev, W. Mu, D. Fang, A. C. Hopkinson, I. G. Csizmadia, and M. G. Organ (2009). Chem. Eur. J. 15, 4281.
44. Y. Rajinder, M. Gupta, and J. Kour (2019). J. Iran. Chem. Soc. 16, 1977.
45. M. Abasszadeh, S. J. Roudbaraki, and M. Ghashang (2019). Org. Prep. Proced. Int. 51, 255.
46. M. C. Bagley, D. D. Hughes, M. C. Lubinu, E. A. Merritt, P. H. Taylor, and N. C. O. Tomkinson (2004). QSAR Comb. Sci. 23, 859.
47. M. N. Elinson, A. I. Ilovaisky, V. M. Merkulova, T. A. Zaimovskaya, and G. I. Nikishin (2011). Mendeleev Commun. 21, 122.
48. S. Beheshti, V. Safarifard, and A. Morsali (2018). Inorg. Chem. Commun. 94, 80.
49. J. A. Valderrama, P. Colonelli, D. Vásquez, M. F. González, J. A. Rodriguez, and C. Theodulou (2008). Bioorg. Med. Chem. 16, 10172.
50. M. A. Gonzalez and R. L. Smith (2003). Environ. Prog. 22, 269.
51. S. Iijima (1991). Nature. 354, 56.
52. H. Naeimi, A. Mohajeri, L. Moradi, and A. M. Rashidi (2009). Appl. Surf. Sci. 256, 631.
53. H. Naeimi and M. Dadaei (2015). RSC Adv. 5, 76221.
54. P. Mandal and S. C. Mondal (2019). Mater. Manuf. Process. 34, 1326.
55. Y. Peng and H. Liu (2006). Ind. Eng. Chem. Res. 45, 6483.
56. T. Belin and F. Epron (2005). Mater. Sci. Eng. B. 119, 105.
57. N. V. Qui, P. Scholz, T. Krech, T. F. Keller, K. Pollitk, and B. Ondruschka (2011). Catal. Commun. 12, 464.

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