Research on Chemical Intermediates
https://doi.org/10.1007/s11164-018-3560-4

Novel nano-titania embedded on graphite (nano-TiO_2@C_g) as an efficient, eco-friendly, and recyclable catalyst for one-pot, solvent-free synthesis of 4-aryl-3,4-dihydroquinolin-2(1*H*)-ones, 3-methyl-4-aryl/alkyl-2,4,5,7-tetrahydropyrazolo[3,4-*b*]pyridin-6-ones, and coumarin-3-carboxylic esters

Kobra Nikoofar[1] · **Fatemeh Molaei Yielzoleh**[1]

Received: 24 June 2018 / Accepted: 10 August 2018

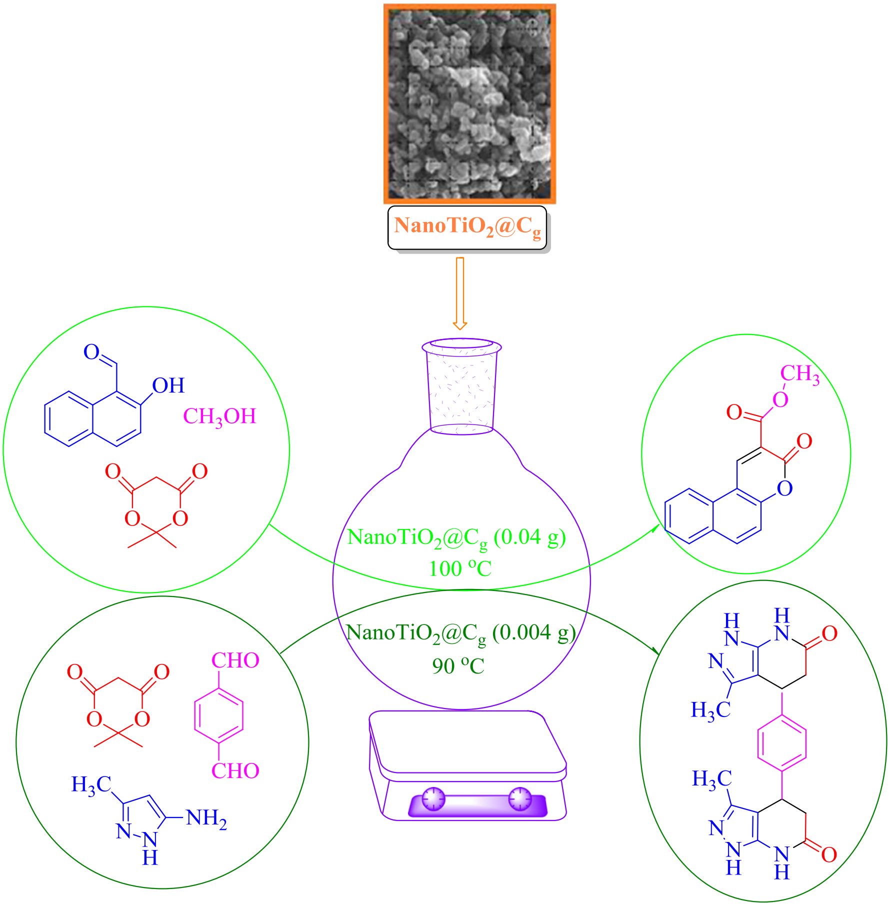
Abstract

A novel acid catalyst has been synthesized by commercial anatase phase nano-TiO_2 and graphite (nano-TiO_2@C_g) via a simple procedure and characterized by Fourier transform infrared spectroscopy, energy-dispersive X-ray spectroscopy, thermogravimetric analysis, field emission scanning electron microscopy, and potentiometric titration techniques. It has been utilized as a convenient nano-catalyst to accelerate the one-pot, solvent-free, three-component reaction of Meldrum's acid, aromatic amines (5-methylpyrazol-3-amine), and various aromatic aldehydes to form 4-aryl-3,4-dihydroquinolin-2-(1*H*)-ones and 3-methyl-4-aryl/alkyl-2,4,5,7-tetrahydropyrazolo[3,4-*b*]pyridin-6-ones, respectively. The catalytic activity has also examined for the preparation of coumarin-3-carboxylic esters from Meldrum's acid, salicylaldehydes, and alcohols successfully. Low catalyst loading, clean process without utilizing any hazardous solvent, easy workup procedure, reusability and recyclability of the nano-catalyst within four runs without activity loss, high yields of the products, in addition with utilizing a vast range of substrates are some highlighted points of the reported protocols.

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s11164-018-3560-4) contains supplementary material, which is available to authorized users.

Extended author information available on the last page of the article

Graphical abstract



Keywords Meldrum's acid · 4-Aryl-3,4-dihydroquinolin-2-(1*H*)-one · 3-Methyl-4-aryl/alkyl-2,4,5,7-tetrahydropyrazolo[3,4-*b*]pyridin-6-one · Nano-TiO_2@C_g · Coumarin-3-carboxylic esters · Solvent-free conditions · Multi-component reaction

Introduction

Titanium dioxide or titania (TiO_2) as a white eco-friendly (LD_{50} oral rat $> 10{,}000$ mg kg^{-1}) pigment has widely been applied in the manufacture of paint, surface coatings on paper, and as a filler in rubber and plastics [1]. This nano-metal oxide, has been confirmed to be a widely used dual-functionality reagent/

catalyst due to its high activity, non-toxicity, easy availability, reusability, strong oxidizing power, and long-term stability. Examples of its industrial application include its antibacterial effect on Escherichia coli strain [2], catalyst support for proton-exchange membrane fuel cells [3], catalyst for rhodamine B degradation [4], and photosensitization effect of nano-TiO_2 thin film on dye-sensitized solar cells (DSSCs) [5]. The titanium nano-sized oxide showed catalytic activity in some organic transformations such as Hantzsch ester and polyhydroquinoline derivative synthesis [6], preparation of quinoxalines [7], Knoevenagel–Michael cyclocondensation reaction [8], and bis(indolyl)methane synthesis [9].

Graphite is a natural source of carbon with uniform hybridization and long-range order [10] that has been built from hexagonal planes of carbon atoms.

Geim et al. mechanically demonstrated that the energy level between single sheets from the π-stacked layers of graphite are about 5.9 kJ mol^{-1} which is related to the cohesive Van der Waals forces [11]. It is a highly ordered and crystalline material composed of aromatic sheets with a constant interlayer spacing of 0.335 nm [12].

Over the past few years, graphite has been considered to be an effective, alternative, and promising Lewis acid catalyst and has received much attention because of its low price, sustainability, ready availability, lack of toxicity, easy handling, and environmentally friendly properties [13].

It has been used as catalyst and mixed catalyst-support for different kinds of transformations such as preparation of 1,5-benzodiazepines [14], synthesis of amidoalkyl naphthols [15], solvent-free oxidation of dec-1-ene [16], four-component preparation of highly functionalized pyrroles [17], Meerwein arylation of pyrroles, multi-component click preparation of 1,2,3-triazoles [12], and Michael addition of indoles to nitroolefins [18].

Hetero compounds containing 4-aryl-3,4-dihydroquinolin-2-one motifs possess promising biological activities and pharmaceutical properties, and function as cancer chemoprotectives [19], atypical antipsychotics [20], and antidepressants [21]. Some these classes of adducts are key building blocks for the synthesis of marine alkaloid acridine units [22]. 4-Aryl-3,4-dihydroquinolin-2(1*H*)-one scaffolds have been prepared through various strategies such as an internal Friedel–Crafts alkylation of *N*-cinnamoylanilines in the presence of trifluoroacetic acid (TFA) [23], an aldol reaction [24], Ru-catalyzed 6-endo-trig cyclization of *N*-[2-(1-phenylvinyl)phenyl]formamide [25], Schmidt rearrangement [26], and other routes [27].

Pyrazolopyridone derivatives are another form of Meldrum's acid-based heterocycles which demonstrate many biological and medicinal activities, such as a noncovalent DprE1 inhibitor with potent anti-mycobacterial activity [28], anti-cancer properties [29], and anti-bacterial activities against ATPase subunit of DNA gyrase B [30]. Commonly, they have been prepared via three-component reaction of an aldehyde, Meldrum's acid, and 3-methyl-1*H*-pyrazol-5-amine using glycol (PEG)-400 [31], sonic waves [32], and Fe^{+3}-K10 montmorillonite [33].

Coumarin-3-carboxylic esters, which have been prepared using simple and cheaply available salicylaldehydes, Meldrum's acid, and alcohols in the presence of $FeCl_3$ [34], are some of Meldrum's acid-based heterocycles which function as a selective monoamine oxidase inhibitory [35] and are also used in chemotherapeutic studies on schistosomiasis [36]. Some substituted coumarin-3-carboxylatosilver(I) complexes also showed in vitro antibacterial and antifungal activities [37].

The solid-state reaction (or solvent-free reaction) possesses several advantages such as reduced pollution, low costs, simplicity in process and handling, and elimination of harmful organic solvents, which account for a great proportion of the waste materials [38]. These aspects make this protocol especially important from economic and ecological viewpoints.

Experimental

Materials and measurements

All chemicals were purchased from Merck, Aldrich, and Alfa Aesar and were used without further purification. Commercial nano-titania (anatase phase, average particle size of 25–30 nm, and 0.24 g/cm^3) has been purchased from Nanosany Corporation. FT-IR spectra were recorded from a KBr disk using an Bruker Tensor 27 FT-IR instrument. Melting points were determined on an Electrothermal 9200 analyzer and are uncorrected. Proton nuclear magnetic resonance (^{1}H NMR) spectra were recorded with a Bruker DRX (400 MHz) machine in DMSO-d_6 solvent. Elemental analyses were determined using a Thermo-Finnigan Flash EA 1112 Series. Mass spectroscopy was obtained using a GC-Mass 5973 network mass selective detector, GC 6690 Agilent device. The scanning electron microscope (FESEM, VEGA\\TESCAN-LMU) used to characterize the nano-structures. Thermogravimetric analysis were conducted using a Netzsch TGA 209 F1 apparatus. The potentiometric study was been using an Orion 620 pH meter. Ultrasonication was performed in a Wise clean bath with power of 90 W. Progress of the reaction was monitored by thin layer chromatography (TLC) technique using commercially available silica gel sheets. Preparative layer chromatography (PLC) was carried out on 20 × 20-cm^2 plates, coated with a 1-mm-thick layer of Merck silica gel PF$_{254}$, prepared by applying the silica as slurry and drying in air.

Preparation of nano-TiO_2@C_g

In order to activate the graphite surface, a mixture of graphite powder (5 g) and concentrated nitric acid (3 mL) in 20 mL of absolute ethanol was stirred for 5 h at room temperature. The solution was centrifuged and decanted followed with drying in an oven at 70 °C for 2 h. Then, nano-TiO_2 (1 g in 50 mL absolute ethanol) added to dried solid and sonicated for 30 min, followed by stirring at 70 °C within 5 h. After cooling, the suspension was centrifuged and rinsed with more absolute ethanol (10 mL). The resultant solid was again dried in a 60 °C oven for 3 h. The obtained black powder is nano-TiO_2@C_g that containing 20% (w/w) nano-titanium on the surface of graphite which has been characterized via FT-IR, EDX, TGA/DTG, FESEM), and potentiometric titration techniques.

General procedure for synthesis of 4-aryl-3,4-dihydroquinolin-2(1*H*)-ones and 3-methyl-4-aryl/alkyl-2,4,5,7-tetrahydropyrazolo[3,4-*b*]pyridin-6-ones

A mixture of Meldrum's acid **1** (1 mmol), amines **2a–d** or 5-methylpyrazol-3-amine **2e** (1 mmol), and aldehydes **3a–g** (1 mmol) in the presence of nano-$TiO_2@C_g$ powder (0.004 g) was magnetically stirred under solvent-free conditions at 90 °C for the desired reaction time monitored by TLC (*n*–hexane/ethylacetate eluent, 2:1 for 4-aryl-3,4-dihydroquinolin-2(1*H*)-ones and 1: 1 for 3-methyl-4-aryl/alkyl-2,4,5,7-tetrahydropyrazolo[3,4-*b*]pyridin-6-ones). After completion of the reaction, methanol (10 mL) was added and the catalyst separated through filtration. Purification of the products was gained by plate chromatography of the mixture to give the corresponding solid products **4a–n**.

4-(3-Nitrophenyl)-3,4-dihydroquinolin-2(1H)-one (4g)

Viscous liquid. IR (KBr, cm^{-1}): 3240 (NH), 2924, 2854, 1711 (CO), 1622, 1475, 767 (N–H). ^1H NMR (400 MHz, DMSO-d_6): 9.37 (brs, 1H, NH), 8.52–7.82 (m, 5H, Ar), 7.77–7.71 (m, 3H, Ar), 7.70–7.69 (m, 2H, Ar), 4.18 (t, *J* = 10.2 Hz, 1H, CH), 2.54–2.25 (m, 2H, CH_2). m/z 318 [M^+], 193 [M^+]-$C_6H_5NO_2$, 185 [M^+]-C_6H_5, -NH_2COCH_3, 148 [naphthylamine]$^+$, 127 [naphthyl]$^+$, 74 [$C_2H_5CONH_2$]$^+$. Anal. calcd. for $C_{19}H_{14}N_2O_3$: C, 71.69; H, 4.43; N, 8.80%; found: C, 71.41; H, 4.22; N, 8.42%

1,4-{3-Methyl-6-oxo-4,5,6,7-tetrahydro-1H-pyrazol[3,4-b]pyridine-4-yl)}benzene (4n)

Melting point (Mp) 217–220 °C. IR (KBr, cm^{-1}): 3174 (NH), 2961, 1650 (CO), 1365, 734 (N–H), 486. ^1H NMR (400 MHz, DMSO-d_6): 11.75 (brs, 1H, NH), 10.11 (brs, 1H, NH), 7.30–7.29 (m, 1H, Ar), 6.19–6.17 (m, 1H, Ar), 3.50–3.47 (m, 1H, CH), 3.15 (s, 3H, CH_3), 2.42–2.18 (m, 2H, CH_2). m/z 376 [M^+], 329 [M^+]-NH_2CO, 265 [M^+]-$2C_2H_5$, $-2N_2$, 225 [M^+]-$C_7H_7NO_3$, 198 [M^+]-$C_7H_7NO_3$, −2Me, 109 [methylpyrazolyl]$^+$. Anal. calcd. for $C_{20}H_{20}N_6O_2$: C, 63.82; H, 5.35; N, 22.32%; found: C, 63.43; H, 5.12; N, 22.11%

General procedure for synthesis of coumarin-3-carboxylic esters

A mixture of Meldrum's acid **1** (1.2 mmol), alcohols **5a–c** (1 mmol), salicylaldehydes **6a–f** (1 mmol), and nano-$TiO_2@C_g$ (0.04 g) was stirred under solvent-free conditions at 100 °C. After completion of the reaction, the nano-catalyst was separated by addition of methanol and filtration; the pure adducts **7a–k** were obtained by pale chromatography (*n*-hexane/ethylacetate eluent, 2:1).

8-Methoxy-2-oxo-2H-chromene-3-carboxylate (7h)

Mp 220–223 °C. IR (KBr, cm^{-1}): 2956, 2855, 1749 (CO), 1474, 1417, 1272, 1102. ^1H NMR (400 MHz, DMSO-d_6): 8.65 (s, 1H, CH), 7.45–7.28 (m, 3H, Ar), 3.61 (s, 3H, CH_3), 3.15 (s, 3H, CH_3). m/z 234 [M^+], 203 [M^+]-OMe, 188 [M^+]-OMe, -Me, 159 [M^+]-C_6H_5, 120 [methoxytolyl]$^+$, 120 [anisolyl]$^+$. Anal. calcd. for $C_{12}H_{10}O_5$: C, 61.54; H, 4.30%; found: C, 61.28; H, 4.22%

3-Oxo-2H-bnzo[f]chromene-2-carboxylate (7i)

Viscous liquid. IR (KBr, cm^{-1}): 2930, 1739 (CO), 1601, 1434, 1334, 1276, 1161. ^{1}H NMR (400 MHz, DMSO-d_6): 8.58 (d, $J = 10.5$ Hz, 1H, Ar), 8.29 (d, $J = 10.41$ Hz, 1H, Ar), 8.03 (s, 1H, CH), 7.91–7.87 (m, 2H, Ar), 7.64–7.57 (m, 2H, Ar), 3.61 (s, 3H, CH_3). m/z 254 [M^+], 236 [M^+]-Me, 223 [M^+]-OMe, 210 [M^+]-CO_2, -Me, 139 [naphthyl]$^+$, 84 [methylacrylyl]$^+$. Anal. calcd. for $C_{15}H_{10}O_4$: C, 70.86; H, 10.08%; found: C, 70.48; H, 10.02%

Results and discussion

Characterization of the catalyst

The FT-IR spectrum of nano-$TiO_2@C_g$ is presented in Fig. 1. As can be seen, the stretching of C–H bonds of the graphite at 2922 cm^{-1} and 2853 cm^{-1} in addition to the Ti–O–Ti peak at 706 cm^{-1} with a shoulder at 522 cm^{-1} [39] confirmed successful embedding of nano-titania on the graphite surface. The broad band at 3647–3440 cm^{-1} belongs to the hydroxyl groups of adsorbed water on the nano-structure surface.

The TGA/DTG diagram is shown in Fig. 2. According to the results, the endothermic main weight loss of 83.3% took placed in one step which started at 580 °C and ended at 670 °C. The main weight lost displayed at 265–380 °C occurred in a single endothermic step. The degradation in one step confirmed that the synthesized nano-structure is a single system, not a binary system.

The FESEM pattern of the synthesized catalyst is shown in Fig. 3, revealing the product consists of nano-spheres with the average diameter of 35–50 nm. It also demonstrates the morphology of the commercial nano-titania (average size of 25–30 nm) was not changed during the process.

EDAX results of nano-$TiO_2@C_g$ in Fig. 4 indicate that the catalyst is only made up of carbon, titanium, and oxygen. No impurity related to nitric acid usage during the activation of graphite has been observed.

The total acidity of the nano-catalyst was measured by potentiometric titration with *N*-hexylamine as a strong base. Its adsorption could be expected on the nano-structure sites related to its total solid acidity of nano-$TiO_2@C_g$. The potentiometric titration curves obtained for graphite, nano-titania, and the supported catalyst are shown in Fig. 5. This technique evaluated the total number of acid sites (meq *N*-hexylamine/g catalyst) and their strength (E) on the catalyst surface. According to the scales illustrated in the correlation diagram at the bottom of Fig. 5, graphite and nano-titania (with E values of -190 mV and -148 mV, respectively) are classified as very weak acids. The nano-catalyst showed an E of -10 mV which make it an acid with weak acidity power. The

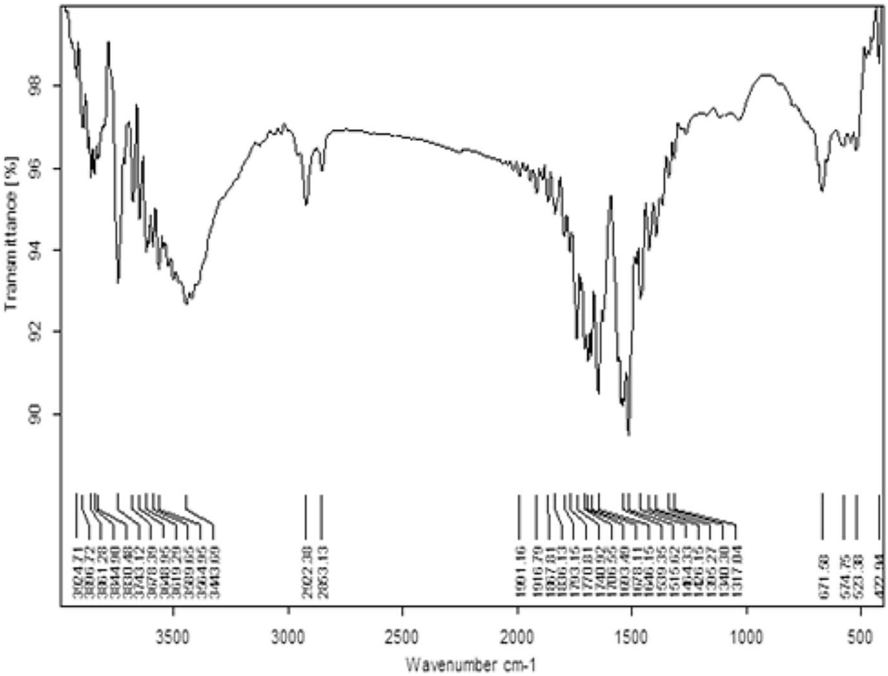


Fig. 1 FT-IR spectrum for nano-$TiO_2@C_g$

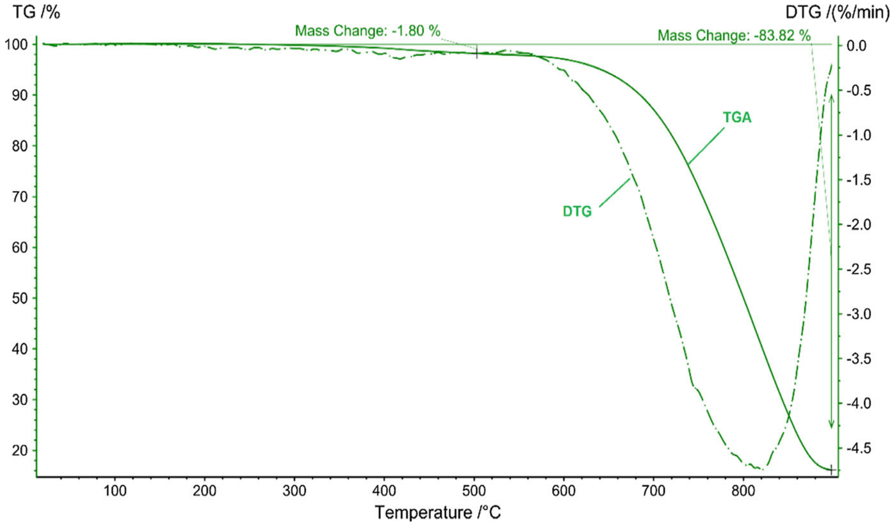


Fig. 2 TGA/DTG diagram of nano-$TiO_2@C_g$

data affirmed that supporting nano-titania on the graphite surface increased it total acid sites. It is observed that the strength of acid sites of nano-$TiO_2@C_g$ is stronger than each of its solid constituents [40].

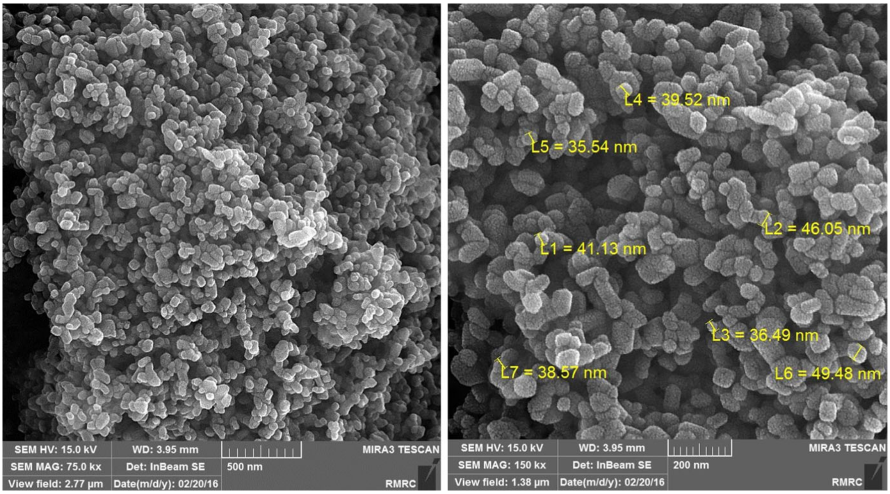


Fig. 3 FESEM image of nano-$TiO_2@C_g$

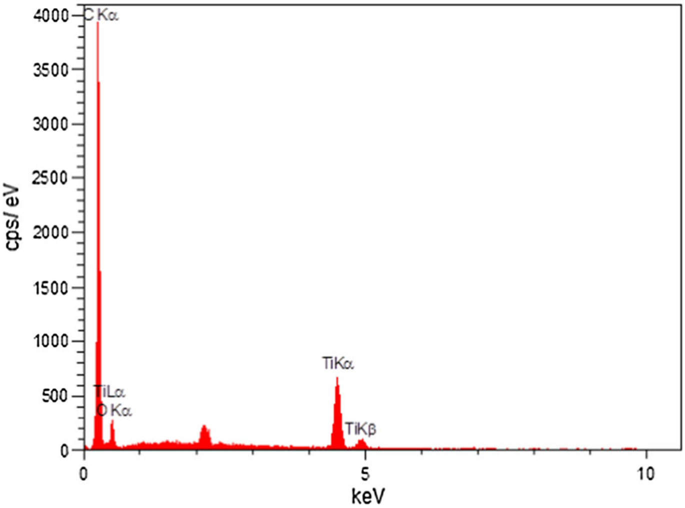
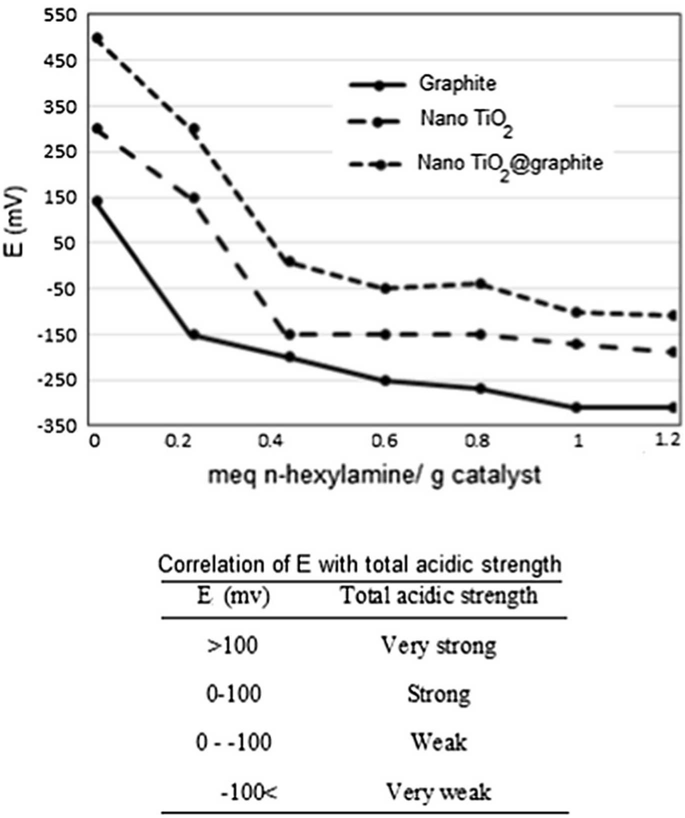


Fig. 4 EDAX diagram of nano-$TiO_2@C_g$

Investigation the catalytic activity

In the next step, the catalytic activity of nano-$TiO_2@C_g$ was examined in the preparation of 4-aryl-3,4-dihydroquinolin-2(1*H*)-ones. In order to optimize the reaction conditions, the reaction of Meldrum's acid **1**, aniline **2a**, and 4-chlorobenzaldehyde **3b**, in a 1:1:1 molar ratio, was considered as a model reaction to determine the effect of various parameters. According to Table 1, the model reaction proceeded in the presence of different solvents as well as solvent-free situations. The best results obtained were in the absence of solvent. The results



Correlation of E with total acidic strength

E (mv)	Total acidic strength
>100	Very strong
0-100	Strong
0 - -100	Weak
-100<	Very weak

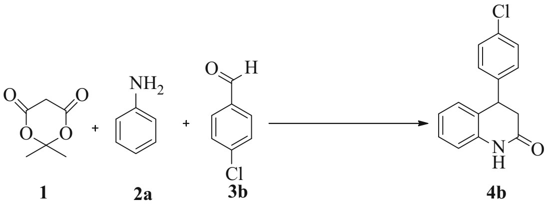
Fig. 5 Investigation of acidic strength of nano-TiO_2@C_g via potentiometric titration curves

(entries 3–5) affirmed that the best temperature is 70 °C and elevating up to 90 °C didn’t affect the progress of the reaction. Examination of the catalyst amount revealed that 0.004 g is the best amount (Table 1, entries 6–8). In addition, in order to affirm the strengthened catalytic activity of the synthesized nano-structure in comparison with the pure nano-titania or graphite, the model reaction has also been performed with each of them separately (entries 9 and 10). As can be seen, embedding nano-TiO_2 on the graphite surface increased it catalytic efficacy (entries 5, 9, and 10). The reaction without catalyst didn’t produce any by-products and the substrate stayed intact (entry 11). All the entries of Table 1 have been examined in a one-pot and one-step mode.

Based on optimized conditions, the reaction of Meldrum’s acid (**1**), aniline derivatives (**2a–e**), and benzaldehydes (**3a–d**) proceeded in the presence of nano-TiO_2@C_g (0.004 g) at 90 °C under solvent-free conditions. The results are summarized in Table 2.

According to the observed data in Table 2, aniline **2a** and its electron-donating as well as electron-withdrawing substituents reacted with Meldrum’s acid **1** and

Table 1 Summary of the reaction conditions in the synthesis of 4-(4-chlorophenyl)-3,4-dihydroquinolin-2(1*H*)-one **4b**



Entry	Conditions Nano-TiO_2@C_g amount (g)/solvent (5 mL)/temperature (°C)	Time (h)	Yield[a] (%)
1	0.004/H_2O/reflux	3	5
2	0.004/EtOH/reflux	4	45
3	0.004/–/rt	4.5	–
4	0.004/–/70	4.5	52
5	0.004/–/90	4	90
6	0.004/–/100	3	65
7	0.002/–/90	4	57
8	0.008/–/90	4	67
9	0.004[b]/–/90	4	53
10	0.004[c]/–/90	4	12
11	–/–/90	4	–

[a] Isolated yields

[b] The utilized catalyst was pure nano-TiO_2

[c] The utilized catalyst was graphite

different benzaldehyde derivatives **3a–c** to obtain the corresponding products successfully (entries 1–6). 1-Naphthylamine **2e,** as a dense candidate of aromatic amine, performed the same transformations well (entry 7). Utilizing 5-methylpyrazol-3-amine **2f**, as a potent pharmaceutically heteroaromatic amine with different benzaldehydes, also yielded 3-methyl-4-aryl/alkyl-2,4,5,7-tetrahydropyrazolo[3,4-*b*]pyridin-6-ones **4h–l** very well (entries 8–12). This condensation has also performed well with butyraldehyde as an aliphatic model (entry 13). No significant substituent effect relationship has been observed in the case of electron-donating and electron-withdrawing benzaldehydes or amines.

The condensation of **1**, **2f**, and terephthaldehyde **3g**, as a bifunctional aromatic aldehyde, obtained the corresponding product **4n** in good yield (entry 14). This observation affirmed the interesting regiospecific condensation in both aldehydic moieties without obtaining any byproduct of the one-moiety condensation reaction. All the products were isolated and characterized by their Mp and spectroscopic data (FT-IR, ^1H NMR, and mass spectroscopy) in comparison with their authentic samples.

In the second part of the research, the catalytic activity of the newly prepared nano-catalyst was examined in the preparation of coumarin-3-carboxylic acid ester

Table 2 Synthesis of 4-aryl-3,4-dihydroquinolin-2(1*H*)-one and 3-methyl-4-aryl/alkyl-2,4,5,7-tetrahydropyrazolo[3,4-*b*]pyridin-6-ones in the presence of nano-$TiO_2@C_g$ under solvent-free conditions at 90 °C[a]

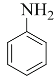
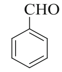
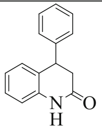
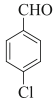
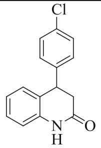
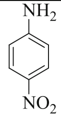
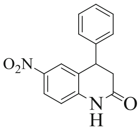
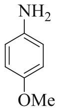
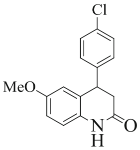
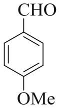
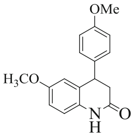
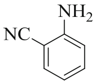
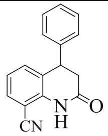
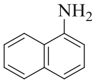
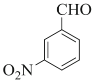
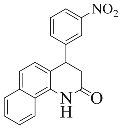
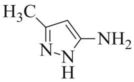
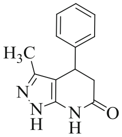
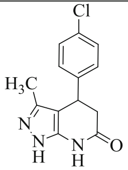
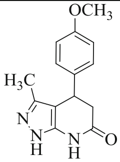
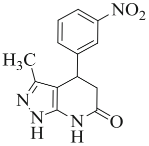
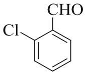
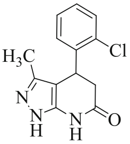
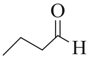
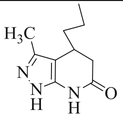
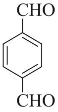
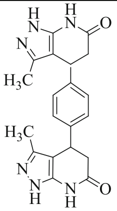
Entry	Amine	Aldehyde	Product		Time (h)	Yield (%)	Mp (°C)
1	 **2a**	 **3a**		**4a**	4	57	192-194 [41]
2	**2a**	 **3b**		**4b**	4	90	213-215 [41]
3	 **2b**	**3a**		**4c**	4	75	188-189 [41]
4	 **2c**	**3b**		**4d**	4.5	57	200-201 [42]
5	**2c**	 **3c**		**4e**	2.5	96	149-151 [42]
6	 **2d**	**3a**		**4f**	4.5	73	147-149 [41]
7	 **2e**	 **3d**		**4g**	5.5	91	Viscous New
8	 **2f**	**3a**		**4h**	5	63	303-305 [43]

Table 2 continued

9	**2f**	**3b**		**4i**	5	94	>300 [43]
10	**2f**	**3c**		**4j**	5	72	>300 [43]
11	**2f**	**3d**		**4k**	3	93	266-268 [43]
12	**2f**	 **3e**		**4l**	3.5	98	>300 [43]
13	**2f**	 **3f**		**4m**	5	92	258-260 [43]
14[b]	**2f**	 **3g**		**4n**	5	97	217-220 New

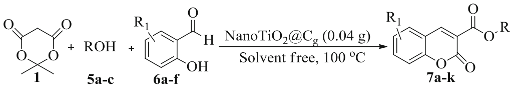
[a] Amine (1 mmol), aldehyde (1 mmol), Meldrum's acid (1 mmol), nano-$TiO_2@C_g$ (0.004 g)

[b] **1**: **2f**: **3g** molar ratio of 2:1:2 in the presence of nano-$TiO_2@C_g$ (0.008 g)

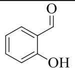
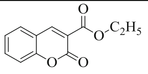
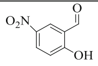
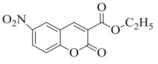
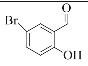
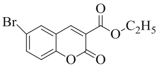
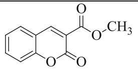
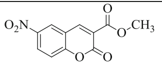
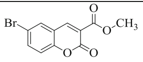
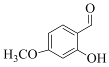
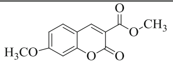
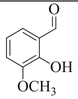
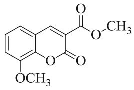
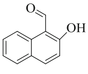
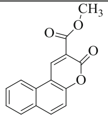
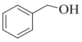
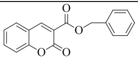
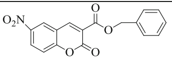
via the one-pot, three-component condensation of Meldrum acid **1**, alcohols **5a–c**, and salicylaldehydes **6a–f** in the presence of 0.04 g of the nano-$TiO_2@C_g$ at 100 °C under solvent-free conditions. It is interesting to mention that this class of compounds has been studied very rarely (Table 3).

According to the obtained results, methanol and ethanol condensed with different benzaldehydes successfully (entries 1–8). 2-Hydroxy-1-naphatldehyde, as a bicyclic sterically hindered candidate, performed the reaction well (entry 9). Benzyl alcohol,

Table 3 Synthesis of coumarin-3-carboxylic acid esters in the presence of nano-TiO$_2$@C$_g$[a]



1 **5a-c** **6a-f** **7a-k**

Entry	Alcohol	Salicylaldehyde	Product	Time (h)	Yield (%)	Mp (°C)
1	C_2H_5OH **5a**	 **6a**	 **7a**	3	73, 71, 69[b]	90–91 [33]
2	**5a**	 **6b**	 **7b**	5	82	192–193 [33]
3	**5a**	 **6c**	 **7c**	6	81	175–177 [33]
4	CH_3OH **5b**	**6a**	 **7d**	6	86	118–120 [33]
5	**5b**	**6b**	 **7e**	6	74	222–224 [33]
6	**5b**	**6c**	 **7f**	6	71	184–185 [33]
7	**5b**	 **6d**	 **7g**	6	87	226–228 [33]
8	**5b**	 **6e**	 **7h**	5	82	220–223 New
9	**5b**	 **6f**	 **7i**	5	74	Viscose New
10	 **5c**	**6a**	 **7j**	5	97	88–91 [44]
11	**5c**	**6b**	 **7k**	5	74	236–237 [33]

[a] Meldrum's acid (1 mmol), salicylaldehydes (1 mmol), alcohols (1 mmol) and nano-TiO$_2$@C$_g$ (0.04 g) in the absence of solvent at 100 °C

[b] Yields of 3 runs

as another selection, produced the desired coumarin carboxylic ester analogues in good yield (entries 10–11).

Finally, the reusability and recovery of the synthesized nano-catalyst was also examined in the preparation of **7a**. After completion of the reaction, methanol (10 mL) was added to reaction mixture and the catalyst was filtered and washed with further methanol (2 × 5 mL). With evaporation of the solvent followed by air drying, the solid residue was utilized for another run. The results in Table 3 (entry 1) showed the catalyst could be recovered and reused simply at least for three runs without activity loss.

Conclusions

In conclusion, we have explored a simple, efficient, and eco-friendly protocol for the synthesis of 4-aryl-3,4-dihydroquinol-2-(1*H*)-ones and 3-methyl-4-aryl/alkyl-2,4,5,7-tetrahydropyrazolo[3,4-*b*]pyridin-6-ones via a one-pot, three-component reaction employing nano-$TiO_2@C_g$ as a novel, nontoxic, and efficient catalyst. The newly synthesized nano-powder also promoted preparation of coumarin-3-carboxylic acid esters successfully. The procedure offers several advantages, including mild and neutral conditions, good yields of the products, elimination of solvent, operational simplicity, minimum environmental impact, and easy workup.

Acknowledgements The authors thank Alzahra University for financial support of this research.

References

1. D. Astruc, F. Lu, J.R. Aranzaes, Angew. Chem. Int. Ed. **44**, 7852 (2005)
2. R. Ahmad, M. Sardar, Int. J. Innov. Res. **2**, 3569 (2013)
3. N. Rajalakshmi, N. Lakshmi, K.S. Dhathathreyan, Int. J. Hydrog. Energy **33**, 7521 (2008)
4. F. Sayilkan, M. Asilturk, S. Sener, S. Erdemoglu, M. Erdemoglu, H. Sayilkan, Turk. J. Chem. **31**, 219 (2007)
5. R.K. Saini, D. Singh, S. Bhagwan, V. Nishal, I. Singh, J. Nanoelectron. Optoelectron. **11**, 715 (2016)
6. M. Tajbakhsh, E. Alaee, H. Alinezhad, M. Khanian, F. Jahani, S. Khaksar, P. Rezaee, M. Tajbakhsh, Chin. J. Catal. **33**, 151 (2012)
7. B.B.F. Mirjalili, A. Akbari, Chin. Chem. Lett. **22**, 753 (2011)
8. A. Khazaei, A.R. Moosavi-zare, Z. Mohamadi, V. Khakhizadeh, J. Afshar, J. Chin. Chem. Soc. **63**, 165 (2016)
9. M. Rahimizadeh, Z. Bakhtiarpoor, H. Eshghi, M. Pordel, G. Rajabzadeh, Monatsh. Chem. **140**, 1465 (2009)
10. F.C. Cowlard, J.C. Lewis, J. Mater. Sci. **2**, 507 (1967)
11. R. Zacharia, H. Ulbricht, T. Hertel, Phys. Rev. B Condens. Matter Mater. Phys. **69**, 155406 (2004)
12. M. d'Halluin, Th Mabit, N. Fairley, V. Fernnandez, M.B. Gawwande, E. Le Grognec, F. Felpin, Carbon **93**, 974 (2015)
13. A. Schaetz, M. Zeltner, W.J. Stark, ACS Catal. **2**, 1267 (2012)
14. R. Jamatia, A. Gupta, B. Dam, M. Saha, A. Kumar Pal, Green Chem. **19**, 1576 (2017)
15. ZhK Lei, X. Li, X. Lu, H. Huang, ChJ Liu, Molecules **18**, 1653 (2013)
16. U.N. Gupta, H. Alshammari, N.F. Dummer, R.L. Jenkins, D. Bethell, G.J. Hutchings, Catal. Sci. Technol. **5**, 1307 (2015)
17. K.N. Naeesh, G.M. Raghavendra, C.N. Revanna, T.A. Jenifer Vijay, K.S. Rangappa, K. Mantelingu, Synth. Commun. **44**, 1103 (2014)
18. S.B. Parsekar, S. Naik, M.M. Naik, S.G. Tilve, Monatsh. Chem. **146**, 691 (2015)

19. S. Luqman, A. Meena, P. Singh, T.P. Jondratyuk, L.E. Marler, J.M. Pezzuto, A.S. Negi, Chem. Biol. Drug Des. **80**, 616 (2012)
20. J.M. Singer, B.M. Barr, L.L. Coughenour, T.F. Gregory, M.A. Walters, Bioorg. Med. Chem. Lett. **15**, 4560 (2005)
21. J. Krapcho, J. Schwartz, E.R. Squibb, US Patent 3994900
22. T. Ozturk, A. McKillop, Can. J. Chem. **78**, 1158 (2000)
23. K. Li, L.N. Foresee, J.A. Tunge, J. Org. Chem. **70**, 2881 (2005)
24. J. Wang, R.P. Discordia, G.A. Crispino, J. Li, J.A. Grosso, R. Polniaszek, V.C. Truc, Tetrahedron Lett. **44**, 4271 (2003)
25. B. Li, Y. Park, S. Chang, J. Am. Chem. Soc. **136**, 1125 (2014)
26. E.F.M. Stephenson, *J. Chem. Soc*. **1956**, 2557 (1956)
27. I. Mieriņa, M. Jure, A. Stikute, Chem. Heterocycl. Compd. **52**, 509 (2016)
28. G.H. Elgemeie, M.A. Abu-Zaied, S.A. Loutfy, Tetrahedron **73**, 5853 (2017)
29. J. Feng, N. Haynes, J.C. Hermann, K. Kim, J. Liu, N.R. Scott, L. Yi, M.E. Zak, G. Zhao, US Patent (2013) US20130345215 A1
30. J.B. Cross, J. Zhang, Q. Yang, M.F. Mesleh, J.A.C. Romero, B. Wang, D. Bevan, K.M. Poutsiaka, F. Epie, T. Moy, A. Daniel, J. Shotwell, B. Chamberlain, N. Carter, J. Barker, M.D. Ryan, ChA Metcalf, J. Silverman, K. Nguyen, B. Lippa, R.E. Dolle, A.C.S. Med, Chem. Lett. **7**, 374 (2016)
31. X. Zhong, G. Dou, D. Wang, Molecules **18**, 13139 (2013)
32. A. Azimi Roshan, M. Mamaghani, N.O. Mahmoodi, F. Shirini, Chin. Chem. Lett. **23**, 399 (2012)
33. M. Mamaghani, F. Shirini, N.O. Mahmoodi, A. Azimi-Roshan, H. Hashemlou, J. Mol. Struct. **5**, 169 (2013)
34. X. He, Y. Shang, Y. Zhou, Zh Yu, G. Han, W. Jin, J. Chen, Tetrahedron **71**, 863 (2015)
35. F. Chimenti, D. Secci, A. Bolasco, P. Chimenti, A. Granese, O. Befani, P. Turini, S. Alcaro, F. Ortuso, Bioorg. Med. Chem. Lett. **14**, 3697 (2004)
36. Y.L. Zhang, B.Z. Chen, K.Q. Zheng, M.L. Xu, L.Z. Zhang, X.H. Lei, Yao Xue Xue Bao **17**, 17 (1982)
37. B.S. Creaven, D.A. Egan, K. Kavanagh, M. McCann, A. Noble, B. Thati, M. Walsh, Inorg. Chim. Acta **359**, 3976 (2006)
38. K. Tanaka, F. Toda, Chem. Rev. **100**, 1025 (2000)
39. X. Zhang, F. Zhang, K.-Y. Chan, Appl. Catal. A **284**, 193 (2005)
40. R. Cid, G. Pecci, Appl. Catal. **14**, 15 (1985)
41. D. Azarifar, D. Sheikh, Synth. Commun. **43**, 2517 (2013)
42. I. Mieriņa, A. Stikute, M. Jure, Chem. Heterocycl. Compd. **50**, 1137 (2014)
43. H. Veisi, A. Maleki, S. Jahangard, Tetrahedron Lett. **56**, 1882 (2015)
44. M. Sova, A. Perdih, M. Kotnik, K. Kristan, T.L. Rižner, T. Solmajer, S. Gobec, Bioorg. Med. Chem. **14**, 7404 (2006)

Affiliations

Kobra Nikoofar[1] · Fatemeh Molaei Yielzoleh[1]

✉ Kobra Nikoofar
kobranikoofar@yahoo.com; k.nikoofar@alzahra.ac.ir

[1] Department of Chemistry, Faculty of Physics and Chemistry, Alzahra University,
Vanak, Tehran 1993893973, Iran