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MgO Nanoparticles: an Efficient, Green and Reusable Catalyst for the One-pot Syntheses of 2,6-Dicyanoanilines and 1,3-Diarylpropyl Malononitriles under Different Conditions

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Abstract

This work described one pot syntheses of polysubstituted 2,6-dicyanoaniline and 2-(3-Oxo-1,3-diarylpropyl) malononitrile derivatives in the presence of MgO nanoparticles (NPs) under grinding conditions and microwave irradiation, respectively. The simple experimental procedure includes shorter reaction times, higher yields, lower cost and environmental friendliness. Other remarkable features are reusability of catalyst, MgO NPs can be reused at least five times without any obvious change in its catalytic activity.

1. Introduction

Ecofriendly organic syntheses are developed nowadays. A powerful tool for the generation of structurally diverse molecules is solvent-free conditions. It has advantages such as reduced pollution, mild reaction conditions, low costs, easy work-up, and easy purification. Therefore, in recent years, solvent-free organic reactions have attracted great interest [1]. Many reactions proceed efficiently without solvent and more selectively than does its solution counterpart, because molecules in a solid state are arranged tightly and regularly. Some solvent-free reactions can be carried out just by grinding [2].

Recently, metal oxides as efficient heterogeneous catalysts have been used in various organic transformations [3]. The development of new catalysts by nano-scale design has emerged as a fertile field for research and innovation [4,5]. The ability of nanotechnology to enhance catalytic

activity opens the potential to replace expensive catalysts with lower amounts of inexpensive nanocatalysts. Although metal oxide surface exhibits both Lewis acid and base properties, the nature of metal cation and surface area of the metal oxides have extensively amplify their catalytic properties. Magnesium oxide is a low-priced metal oxide which has been used in both industrial and nano type as a professional catalyst in various organic transformations [6,7].

3,5-Diaryl-2,6-dicyanoanilines are useful intermediates and act as building blocks for cyclophanes [8] to create a large molecular cavity [9] and host–guest complexes [10]. Some of these molecular systems are the basis for artificial photosynthetic systems [11], materials presenting semiconducting or nonlinear optical properties [12,13] and molecular electronic devices [14].

These compounds have been prepared from arylidenemalonodinitriles and 1 arylethylidenemalonodinitriles in the presence of piperidine[15].

The reaction between malononitrile and α,β-unsaturated ketones could also give 3,5-diaryl-2,6-dicyanoanilines, but the yields were very poor (5–20%) [16,17]. A literature survey showed that several methods have been reported for the synthesis of 3,5-diaryl-2,6-dicyanoanilines [18,19], but they suffer from several drawbacks, such as multistep reactions, long reaction times, an excess of volatile organic solvents, harsh refluxing conditions, and especially lower product yields. In continuation of our current studies on the application of solvent-free conditions using nanoparticle catalysts for the synthesis of organic compounds [20-23], we report a method that does not have those disadvantages. Herein we developed a practical and simple method to prepare polysubstituted 2,6-dicyanoaniline and 2-(3-Oxo-1,3-diarylpropyl)malononitrile derivatives by three component reaction of aromatic aldehyde, cyclic ketones, and malononitrile in the presence of MgO NPs (Scheme 1).
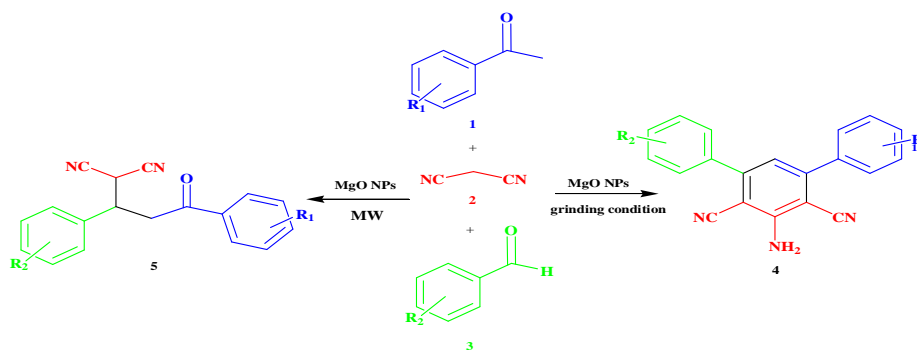
Scheme 1. Three-component reaction of aldehydes, acetophenone and malononitril catalyzed by MgO nanoparticles

2. Experimental

2.1. Materials and characterization

Chemicals were purchased from Fluka and Merck in high purity. All of the materials were of commercial reagent grade and were used without further purification. MgO nanoparticles were prepared according to the procedure reported by

Tang *et al*. [24]. All products were characterized by comparison of their FT-IR and NMR spectra and physical data with those reported in the literature. All yields refer to the isolated products. Progress of reactions was followed by TLC on silica-gel Polygram SILG/UV 254 plates. IR spectra were obtained on a Shimadzu FT-IR- 8300 spectrophotometer. NMR spectra were recorded on a Bruker Avance DRX instrument (400 MHz). The elemental analyses (C, H, N) were obtained from a Carlo ERBA Model EA 1108 analyzer. Microscopic morphology of products was visualized by SEM (LEO 1455VP). Powder X-ray diffraction (XRD) was carried out on a Philips diffractometer of X'pert Company with mono chromatized Cu Kα radiation (λ = 1.5406 Å). EIMS (70 eV) was performed by Finnigan-MAT-8430 mass spectrometer in m/z.

2.2. Synthesis of Magnesium oxide nanoparicles

In a typical procedure, to a solution of Mg $(NO_3)_2.6H_2O$ (2 g) and PVP (0.5 g) in 30 ml deionized water was added dropwise 1.0 M of NaOH under ultrasound. After it being sonicated about 30 min, the resulting gel was washed several times with deionized water and ethanol. Finally, MgO nanoparticles with different sizes could be obtained through calcining at $600^{\circ}C$ for 2h. The prepared MgO NPs have been structurally characterized by SEM and XRD analysis.

The crystalline nature of the synthesized MgO nanoparticles was further verified by X-ray diffraction pattern (XRD). The XRD pattern of the MgO NPs is shown in Figure 1. All of the reflection peaks in Figure 1 can be easily indexed to pure cubic phase of MgO (JCDPS No. 75-0447). The crystallite size diameter (D) of the MgO nanoparticles has been calculated by Debye–Scherrer equation ($D = K\lambda/\beta\cos\theta$), where β FWHM (full-width at half-maximum or half-width) is in radian and θ is the position of the maximum of diffraction peak, K is the so-called shape factor, which usually takes a value of about 0.9, and λ is the X-ray wavelength (1.5406 Å for Cu Kα). Crystallite size of MgO has been found to be 18 nm.
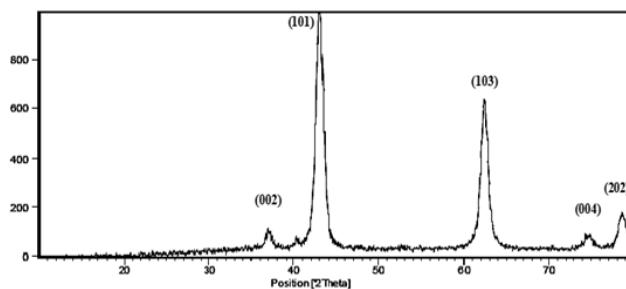

Fig. 1. The XRD pattern of MgO nanoparticles.

In order to investigate the morphology and particle size of MgO nanoparticles, SEM images of the magnetic nanoparticles were taken and the images are presented in Figs. 2. These results show that MgO nanoparticles were obtained with an average size between 20–30 nm.
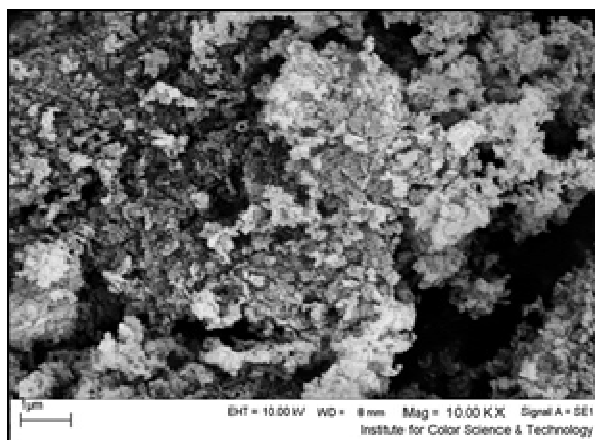

Fig. 2. SEM images of MgO nanoparticles

2.3. General procedure for the preparation of Polysubstituted 2,6-Dicyanoaniline derivatives (4a-f)

To a mixture of 1 mmol aryl aldehyde, 1 mmol acetophenone, and 2.5 mmol malononitrile and

0.3 mol% MgO NPs were added to a mortar. The mixture was ground with a pestle at room temperatures. The reaction was completed in 5 – 10 min, and the reaction mixture was poured into water. The crude product thus separated was filtered and washed with water. The dried solid residue was treated with dichloromethane and filtered to get MgO which could be reused. The filtrate was then evaporated to get the desired solid polysubstituted 2,6-dicyanoaniline which was recrystallized from 95% ethanol to get the pure product.

2.4. General procedure for the preparation of (3-Oxo-1,3-diarylpropyl)malononitrile derivatives (5a-f)

A mixture of 1 mmol aryl aldehyde, 1 mmol acetophenone, 1.5 mmol malononitrile and 0.3 mol% MgO NPs in ethanol is submitted to MW irradiation. For work-up the mixture was cooled to room temperature, dichloromethane added and the mixture stirred for 5 min. Then catalyst filtrated and the solvent was removed under reduced pressure and the product was dried and recrystallized from 95% ethanol.

All of the products were characterized and identified with m.p., ^{1}H NMR, ^{13}C NMR and FT-IR spectroscopy techniques. Spectral data of new compounds are given below:

2-[1-(4-Methylphenyl)-3-oxo-3-(4-Chlorophenyl)propyl]malononitrile (5e):

Yellow solid; ^{1}H NMR (400 MHz, CDCl$_3$): δ (ppm) 2.35 (3H, CH$_3$), 3.66 (2H, m, CH$_2$), 3.92 (1H, dt , CH), 4.29 (1H, CH), 7.53 (2H, t, Ar-H), 7.65(2H, t, Ar-H), 7.98(2H, d, Ar-H), 8.31(2H, Ar-H). ^{13}C NMR (100 MHz, CDCl$_3$): δ (ppm) 21.3, 28.32, 39.73, 41.0, 111.14, 111.30, 124.51, 128.13, 129.0, 129.31, 134.54, 135.41, 143.36,

148.35, 195.62. FT-IR (KBr): 2259, 1678, 1592, 1331 cm-1. MS (EI, 70 eV): m/z 321(M+), Anal. Calcd for C$_{19}$H$_{15}$N$_2$ClO: C, 70.80; H, 4.65; N, 8.69%. Found: C, 70.77; H, 4.61; N, 8.72%.

2-[1-(4-Nitrophenyl)-3-oxo-3-(4 Nitrophenyl)propyl]malononitrile (5f):

Yellow solid; ^{1}H NMR (400 MHz, CDCl$_3$): δ (ppm) 3.62 (2H, m, CH$_2$), 3.94 (1H, dt, CH), 4.31 (1H, CH), 7.53 (2H, t, Ar-H), 7.65(2H, t, Ar-H), 7.96(2H, d, Ar-H), 8.31(2H, Ar-H). ^{13}C NMR (100 MHz, CDCl$_3$): δ (ppm) 28.29, 39.73, 41.0, 111.1, 111.28, 124.52, 128.15, 129.0, 129.31, 134.54, 135.42, 143.36, 148.38, 195.59. FT-IR (KBr): 2259, 1682, 1590, 1330 cm-1. MS (EI, 70 eV): m/z 347(M+), Anal. Calcd for C$_{18}$H$_{12}$N$_4$O$_4$: C, 62.07; H, 3.44; N, 16.09%. Found: C, 62.03; H, 3.41; N, 16.12%.

3. Results and discussion

In the present work, we report efficient and rapid three-component reactions catalyzed by MgO NPs. Reaction of aromatic aldehyde, cyclic ketones, and malononitrile afforded two various products under two different conditions. 2,6-Dicyanoaniline derivatives are produced under grinding conditions, and 2-(3-Oxo-1,3-diarylpropyl)malononitrile derivatives produced under microwave conditions. To determine optimum reaction conditions, a model reaction including treatment of 4-chlorobenzaldehyde, malononitrile and acetophenone was conducted. We started our investigations with the optimization of the type and amount of catalyst. The results are listed in Table 1 and as you can see, 0.3 mol% MgO NPs have achieved the best performance.

Table 1. Optimization of model reaction by using various catalysts and amount of MgO nanoparticle.

Entry	Catalyst	mol% of cat.	Time (min)		Yield[a] (%)	
			4a	5a	4a	5a
1	FeCl$_3$	0.2	50	30	42	38
2	CuI	0.2	40	35	55	43
3	SnCl$_2$	0.2	55	40	48	39
4	MgO	0.2	20	15	66	69
5	MgO NPs	0.1	20	10	75	77
6	MgO NPs	0.15	15	10	76	75
7	MgO NPs	0.2	15	8	81	83
8	MgO NPs	0.3	8	3	82	85
9	MgO NPs	0.4	8	3	83	85

[a] Isolated yields.

It should be noted that the model reaction for preparation of 2-(3-Oxo-1,3-diarylpropyl)malononitriles was achieved in different organic solvents including polar and non-polar. Ethanol was found much better than organic solvents and poor yields, long reaction time and by-products were observed by using non-polar organic solvents.

Using the optimized reaction conditions (Table 1, entry 8), the scope of the reaction was tested by extending the reaction to different aldehydes and acetophenones and it was found that, all the aldehydes and acetophenones displayed high reactivity and generated the products in good to excellent yields. The results in table 2 indicate that the aromatic aldehydes bearing both electron-donating and electron-withdrawing groups gave excellent yield of the desired products. The suggested mechanism for the synthesis of 2,6-dicyanoaniline and 2-(3-Oxo-1,3-diarylpropyl)malononitrile compounds in the presence of MgO NPs is shown in Scheme 2. We proposed that these reactions could be realized in a one-pot, two-step manner. Initially, acetophenone (1) and aldehyde (3) react to form the intermediate (I) in the presence of MgO NPs, then reaction of intermediate I and malononitrile afforded product 5. Also on the other path, condensation of aldehyde (3) and malononitrile produced intermediate (II) and afterwards this intermediate and acetophenone resulted product 5. In order to preparation of 2,6-dicyanoaniline products, the reaction proceeds by a similar route and finally Thorpe–Ziegler cyclization of compound 5 and malonitrile to give product 4 after tautomerization (Scheme 2).

Table 2. Synthesis of Polysubstituted 2,6-Dicyanoanilines (4) and 2-(3-Oxo-1,3-diarylpropyl)malononitriles (5) by MgO nanoparticles.

Entry	R_1	R_2	Product 4a-f Time(min)/Yield[a](%)	M.p/^{o}C[b]	Product 5a-f Time(min)/Yield[a](%)	M.p/^{o}C[b]
a	H	4-Cl	8/82	243-245[19]	3/85	115-117[25]
b	H	4-NO$_2$	8/80	243-245[26]	2/84	186-189[28]
c	H	4-Br	7/82	250-253[26]	2/85	176-179[28]
d	H	4-Me	5/80	200-202[27]	5/83	118-119[25]
e	4-Cl	4-Me	8/83	191-192[19]	3/85	122-125
f	4-NO$_2$	4-NO$_2$	10/85	348-350[27]	2/86	182-184

[a] Isolated yields.

[b]Literature references.
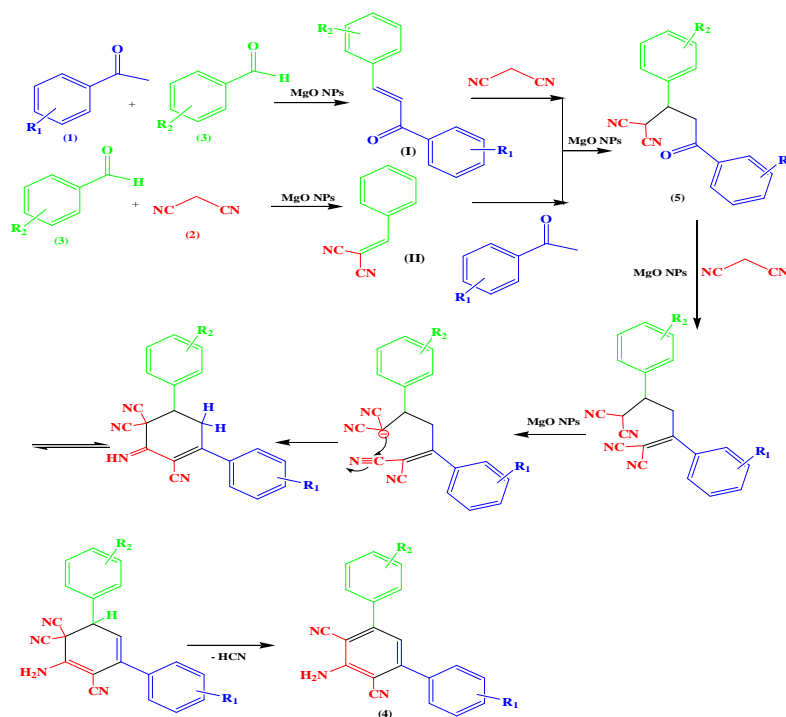
Scheme 2. Proposed reaction pathway for the synthesis of polysubstituted 2,6-dicyanoanilines And 2-(3-Oxo-1,3-diarylpropyl)malononitriles by MgO nanoparticles.

Catalyst recovery

The reusability of the catalyst was studied through the model reaction for preparation of product 4 and 5 under optimal conditions. After completion of the reaction, the reaction mixture was centrifuged at 2000–4000 rpm for 10 min, until the catalyst was deposited at the bottom of the centrifuge tube. The deposited catalyst was washed with acetone 3–4 times to confirm the complete removal of any organic residuals; the catalyst was reused for further catalytic reaction cycles. The same process was repeated after each reaction cycle to isolate and reuse the catalyst. The reaction proceeded smoothly with a yield of 82–79% (Table 3). This result indicates that the activity of the catalyst was not much affected on recycling.

Table 3. Catalyst recyclability study in model reaction for preparation of product 4 and 5.

Recycle time	1	2	3	4	5
Yield (%) of product 4	82	81	81	79	79
Yield (%) of product 5	85	85	84	83	83

4. Conclusion

In summary, we have reported a multicomponent reaction under two different conditions for the synthesis of polysubstituted 2,6-dicyanoaniline and 2-(3-Oxo-1,3-diarylpropyl)malononitrile derivatives. The desired products were formed in good yields upon mixing readily available substrates in the presence of MgO NPs. The broad scope, operational simplicity, practicability, high yields and mild reaction conditions render it an attractive approach for the generation of these derivatives.

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