Clean One-Pot Multicomponent Synthesis of Pyrans Using a Green and Magnetically Recyclable Heterogeneous Nanocatalyst

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License terms: © 2021. The Author(s). This is an open access article published by Thieme under the terms of the Creative Commons Attribution-NonDerivative-NonCommercial-License, permitting copying and reproduction so long as the original work is given appropriate credit. Contents may not be used for commercial purposes or adapted, remixed, further. However, because of their nanoscale size, separating them from the reaction mixture by conventional methods is not efficient, but use of magnetic nanoparticles (MNPs) can overcome this issue. These particles can be synthesized in various forms such as metal nanoparticles, iron oxides, and ferrites. Copper ferrite (CuFe$_2$O$_4$) is one member of the ferrite family that has been widely applied as a catalyst in organic transformations.

2-Amino-3-cyano-4H-pyran derivatives were synthesized via thermal decomposition and applied as a reusable and green catalyst in the synthesis of functionalized 4H-pyran derivatives using malononitrile, an aromatic aldehyde, and a β-ketoester in ethanol at room temperature. The nanoparticles were characterized by FT-IR, EDX, SEM, TGA, and DTG analysis. The catalyst was recovered from the reaction mixture by applying an external magnet and decanting the mixture. Recycled catalyst was reused for several times without significant loss in its activity. Running the one-pot three-component reaction at room temperature, using a green solvent under environmentally friendly reaction conditions, ease of catalyst recovery and recyclability, no need for column chromatography and good to excellent yields are advantages of this protocol.

Keywords green chemistry, multicomponent reactions, magnetic nanoparticles, pyran

In attempts to mitigate the greenhouse effect and environmental pollution, chemical and pharmaceutical companies look to environmentally friendly protocols to reduce environmental pollution using so-called green and sustainable chemistry. Multicomponent reactions (MCRs), in which one-pot reactions involving more than two reactants to produce a single product, represent one of the important strategies in green chemistry. These reactions produce multifunctionalized products using fewer steps compared to classical synthesis approaches. Strecker reported first MCR in 1850 for the synthesis of α-amino cyanides, and nowadays MCRs have been applied to the synthesis of a wide range of complex molecules. In this context, catalysts play a major role; in particular nanocatalysts provide a large surface-to-volume ratio, which increases their activity further. However, because of their nanoscale size, separating them from the reaction mixture by conventional methods is not efficient, but use of magnetic nanoparticles (MNPs) can overcome this issue. These particles can be synthesized in various forms such as metal nanoparticles, iron oxides, and ferrites. Copper ferrite (CuFe$_2$O$_4$) is one member of the ferrite family that has been widely applied as a catalyst in organic transformations.
CuFe₂O₄ magnetic nanoparticles as an efficient and green catalyst under mild reaction conditions in good to excellent yields (Scheme 1). To the best of our knowledge, this is the first time that copper ferrite magnetic nanoparticles have been applied as catalyst for the synthesis of this class of heterocycles.

The CuFe₂O₄ nanoparticles were prepared by thermal decomposition of copper(II) nitrate and iron(III) nitrate by a published method¹⁶,32 and characterized by FT-IR spectroscopy (Figure S11), EDX analysis (Figure S12), SEM analysis (Figure S13), and TGA/DTG analysis (Figure S15). To optimize conditions, the three-component reaction of 3-nitrobenzaldehyde (0.5 mmol), malononitrile (0.5 mmol), ethyl acetoacetate (0.5 mmol), and CuFe₂O₄ was run in various solvents at room temperature, as the model reaction for pyran derivative synthesis. Initially, the amount of CuFe₂O₄ catalyst was optimized. Best results were obtained with 20 mol% of the catalyst. No further increase in yield was observed with additional amounts of catalyst. Next, the role of the solvent was reconsidered with the best yield being obtained in ethanol³³ (Table 1). Following the optimization efforts, a range of reactions was run under optimized conditions, and the desired products were obtained in good to excellent yields (Table 2). Known compounds were identified by comparison of their physical data (melting points) with those of authentic samples. In addition, ¹HNMR and IR analyses were carried out. These data are provided in the Supporting Information.

![Scheme 1](image)

**Figure 1** The structures of some biologically active molecules with 4H-pyran cores

<table>
<thead>
<tr>
<th>Entry</th>
<th>Catalyst (mol%)</th>
<th>Solvent</th>
<th>Time (h)</th>
<th>Yield (%)</th>
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<tr>
<td>1</td>
<td>–</td>
<td>EtOH</td>
<td>6</td>
<td>53</td>
</tr>
<tr>
<td>2</td>
<td>–</td>
<td>EtOH</td>
<td>3</td>
<td>trace</td>
</tr>
<tr>
<td>3</td>
<td>–</td>
<td>EtOH</td>
<td>3</td>
<td>70</td>
</tr>
<tr>
<td>4</td>
<td>–</td>
<td>EtOH</td>
<td>2</td>
<td>75</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>EtOH</td>
<td>3</td>
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<td>EtOH</td>
<td>3</td>
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<tr>
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<td>EtOH</td>
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<td>86</td>
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<tr>
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<td>EtOH</td>
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<td>EtOH</td>
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<td>–</td>
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<td>23</td>
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<td>H₂O</td>
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<td>13</td>
<td>20</td>
<td>MeCN</td>
<td>4</td>
<td>25</td>
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</tbody>
</table>

* Room temperature unless otherwise temperature is mentioned.
* Reactions were followed by TLC.
* Isolated yields.
* Optimization studies of this entry are omitted, and just highest yield in the shortest time is noted.
* This reaction was run at 40 °C.
* This reaction was run at 60 °C.

To investigate the catalyst reusability, the catalyst was recovered and washed with distilled water and ethanol, and the model reaction was run again in the presence of recycled...
catalyst. The results shown in Figure 2 indicate that very slight decreases in yields were observed after 3 cycles and after the 5th cycle, catalyst activity was still satisfying.

In order to demonstrate the advantages of this methodology, some other methods for the synthesis of 4H-pyran (4e) were compared with the present protocol. Some of the methods need an external source of energy such as heating or ultrasonic radiation. In some cases, the catalysts are expensive or may not be recyclable. Typical results are gathered in Table 3.

In summary, we have represented clean, efficient, one-pot methodology for the synthesis of highly functionalized 4H-pyran using CuFe$_2$O$_4$ magnetic nanoparticles as a reusable and green nanocatalyst. Reactions are run at room temperature in ethanol providing a green synthesis of...
4H-pyran heterocycles. Short reaction times, nontoxic catalyst, ease of catalyst separation by using an external magnet, catalyst recyclability, no need for heating, good to excellent yields, and mild conditions are advantages of the reported protocol. Moreover, the high tolerance of this procedure towards various functional groups, easy and simple work-up procedure, exceptionally high yields of the desired products, and scalability are the added advantages.

Conflict of Interest

The authors declare no conflict of interest.

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Supporting Information

Supporting information for this article is available online at https://doi.org/10.1055/a-1469-6721.

References and Notes

(32) Preparation of Copper Ferrite Nanoparticles Fe(NO3)3·9H2O (3.34 g, 8.2 mmol) and Cu(NO3)2·3H2O (1.0 g, 4.1 mmol) were dissolved in distilled water (75 ml), then NaOH (3.0 g, 75 mmol) dissolved in distilled water (15 ml) was added at room temperature over 10 min, during which time a reddish-black precipitate was formed. Then the reaction mixture was warmed to 90 °C with stirring under ultrasonic irradiation for 2 h and then cooled to room temperature. The magnetic particles so formed were separated by an external magnet then washed with distilled water (3 × 30 ml) and kept in an oven at 80 °C overnight. The powder was further ground in a mortar, heated at 700 °C for 5 h, and then cooled to room temperature.
(33) A mixture of aryl aldehyde (1 mmol), malononitrile (1 mmol), methyl/ethyl acetoacetate (1 mmol), and CuFe2O4 (20 mol%) was stirred in ethanol (5 ml) at room temperature until completion, the catalyst was removed from the reaction mixture via an external magnet and the product allowed to precipitate. The mixture was filtered and washed with distilled water (3 × 30 mL) and kept in an oven at 80 °C overnight. The so formed were separated by external magnet then washed with distilled water (3 × 30 mL) and kept in an oven at 80 °C overnight. The powder was further ground in a mortar, heated at 700 °C for 5 h, and then cooled to room temperature.
(34) A mixture of aryl aldehyde (1 mmol), malononitrile (1 mmol), methyl/ethyl acetoacetate (1 mmol), and CuFe2O4 (20 mol%) was stirred in ethanol (5 mL) at room temperature until completion of the reaction as indicated by TLC. After completion of the reaction, the catalyt was removed from the reaction mixture via an external magnet and the product allowed to precipitate. The solid product was filtered and recrystalized from ethanol. All the products are known compounds that were identified by comparison of their physical data (melting points) with those authentic samples.