

## Resin Tulsion-8052 MP – a novel and ecofriendly catalyst for Knoevenagel reaction in aqueous medium

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The novel catalyst resin Tulsion-8052 MP is an acid catalyst that promotes the Knoevenagel reaction of aldehydes with active methylene compounds in an ecofriendly way. The reaction was performed in an aqueous medium with a catalytic amount of resin. This method is advantageous, as the catalyst is easy to operate, recyclable, ecofriendly, and economical.

**Keywords:** Resin Tulsion-8052 MP catalyst, Aldehydes, Active methylene compounds, Knoevenagel reaction, Water, Recyclable catalyst.

### INTRODUCTION

In the past decades, the wave of catalytical transformation in the Knoevenagel reaction has peaked due to its unique carbon-carbon bond formation ability. This method is widely used and impacted on several fields such as pharmaceuticals, fine chemicals, functional polymers, and biologically active materials [1-5]. Knoevenagel reaction products or specially benzyldene malononitrile (BMN) derivatives are widely used pioneers in several areas of organic chemistry due to their biological activities [6-15].

Recently, due to the advantageous nature of BMN, there is an extensive need to focus on its synthesis using a greener approach. The best way to perform organic transformation is using water as a solvent due to its universal solvent property [16]. The aqueous medium is selective, environmentally friendly, cheap and non-hazardous [17-19]. For Knoevenagel condensation, recently scientists reported an aqueous medium reaction with different catalysts such as, zeolitic imidazolate framework-8 (ZIF-8) [20], acylhydrazone-linked COF catalyst (TH-MT-COF-OH) [21], chiral 4-MeO-pyridine (MOPY) [22], magnesium [23], boron carbon nitride (BCN) [24], amine-rich nickel(II)-xerogel [25], Pd nanoparticles supported on 2-(aminomethyl) phenol-modified boehmite [26], as well as catalyst-free reaction [27]. All the above methods show some drawbacks like use of expensive catalysts, tedious method of catalyst preparation, workups, and high-temperature reactions. To overcome these problems, our team introduced a simple, ecofriendly, cheap,

stable, and recyclable method for the Knoevenagel reaction using the resin Tulsion-8052 MP catalyst.

There are some review articles [28] that give brief details on catalysts for Knoevenagel condensation such as heterogeneous catalysts, nitrogen-based catalysts, and metal-free sustainable nitrogen-based catalysts.

Resins are versatile materials used in various industries like pharmaceuticals [29], petrochemicals [30], and polymers [31]. Resin catalysts almost never encompass the use of toxic solvents, which avoids environmental risks, endorses the efficiency of the reaction and decreases waste production [32-34]. The catalyst's acidic sulfonic functional group promotes the activation of the carbonyl group in the aldehydes to be involved in carbon-carbon bond formation. This mechanism ensures high selectivity and enables the carbon-carbon bond formation in excellent yields. Moreover, the resin Tulsion-8052 MP can be easily recycled, making it a cost-effective and bearable choice for large-scale synthesis.

In consideration of all the advantageous activities of the resin in organic transformation, we herein performed a Knoevenagel reaction of aldehydes with active methylene compounds using the resin Tulsion-8052 MP.

### EXPERIMENTAL

#### *General information*

All reagents, active methylene compounds, and aldehydes were obtained from commercial suppliers and were not purified. Tulsion-8052 MP

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resin was obtained from Thermax Limited. Melting points were recorded in open capillaries and were uncorrected. Thin-layer chromatography was performed on preparatory glass coated by silica gel 60F254 measuring 20×20 cm from Merck. IR spectra were recorded on an FT/IR-410 type (A) spectrophotometer in KBr. <sup>1</sup>H and <sup>13</sup>C NMR spectrum was measured in CDCl<sub>3</sub>/DMSO-d<sub>6</sub> solution on a Bruker spectrophotometer. Electron spray ionization mass spectra (ES-MS) were recorded on a Water-Micro mass Quattro-II spectrometer.

#### General procedure

Knoevenagel condensation reaction was carried out in a four-neck glass round-bottom flask of 100 mL volume on a magnetic stirrer. The stirrer speed was controlled by a speed regulator. The round-bottom flask was placed in a water bath at room temperature. In a typical run, 1.0 mmol of aromatic aldehyde (limiting reactant) and 1.0 mmol of active methylene group compound were charged in the round-bottom flask with water (5V) as solvent. The Tulsion-8052 MP catalyst loading was 10 mol%. The reaction mixture was stirred at room temperature. After completion of the reaction, the reaction mass was filtered and purified by using ethanol. Obtained wet purified product was dried and analysed.

#### Recovery of resin

After completion of Knoevenagel condensation reaction, the catalyst was undissolved and remained on the filter paper during ethanol purification of product. After ethanol washing (2×5 mL) of the recovered catalyst, the latter was collected, air dried to remove solvent traces of ethanol and used in further cycles.

#### Spectral data of the synthesized compounds

**2-Benzylidenemalononitrile (3a):** white solid, m. p. 80-82°C (ref. 39); FT-IR (KBr, cm<sup>-1</sup>): 3035, 2223, 1568; <sup>1</sup>H-NMR (400 MHz, CDCl<sub>3</sub>), δppm 7.88 (d, *J*=7.05 Hz, 2H), 7.76 (s, 1H), 7.61 (t, *J*=7.6 Hz, 2H); <sup>13</sup>C NMR (101 MHz, CDCl<sub>3</sub>) δppm 159.9, 134.5, 131.0, 130.5, 129.5, 113.8, 112.5, 82.8; MS: *m/z* = 154.05 (M<sup>+</sup>).

**2-(2-Nitrobenzylidene) malononitrile (3b):** yellow solid, m. p. 138-140°C (ref. 40); FT-IR (KBr, cm<sup>-1</sup>): 3062, 2951, 2226, 1728, 1623, 1579, 1524; <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>), δppm 8.45 (s, 1H), 8.32 (d, 1H, *J*=8 Hz), 7.90-7.88 (m, 1H), 7.86 – 7.82 (m, 2H); <sup>13</sup>C NMR (101 MHz, CDCl<sub>3</sub>) δppm 158.2, 146.9, 134.5, 133.3, 130.8, 126.4, 125.6, 112.2, 110.1, 88.2; MS: *m/z* = 200 (M<sup>+</sup>).

**2-(4-Nitrobenzylidene) malononitrile (3c):** light yellow solid, m. p. 160-162°C (ref. 39); FT-IR (KBr, cm<sup>-1</sup>): 3030, 2262, 1622, 1536, 989; <sup>1</sup>H-NMR (400MHz, CDCl<sub>3</sub>): δppm 8.40 (d, *J*= 8.7 Hz, 2H), 8.77 (d, *J*= 8.8 Hz, 2H), 7.90 (s, 1H); <sup>13</sup>C NMR (101 MHz, CDCl<sub>3</sub>) δppm 159.8, 137.7, 134.5, 133.8, 117.5, 112.2, 111.7, 88.0; MS: *m/z* = 200 (M<sup>+</sup>).

**2-(4-Methylbenzylidene) malononitrile (3d):** white solid, m. p. 132-134°C (ref. 39); FT-IR (KBr, cm<sup>-1</sup>): 3030, 2982, 2852, 2220, 1605, 1571, 1557, 1513; <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>), δppm 7.88 (d, 2H, *J*=8 Hz), 7.77 (s, 1H), 7.36 (d, 2H, *J*=8 Hz), 2.43 (s, 3H); <sup>13</sup>C NMR (101 MHz, CDCl<sub>3</sub>) δppm 159.4, 146.3, 130.5, 130.8, 128.1, 114.2, 112.3, 81.4, 22.2; MS: *m/z* = 169 (M<sup>+</sup>).

**2-(4-Methoxybenzylidene) malononitrile (3e):** white solid, m. p. 112-114°C (ref. 39); FT-IR (KBr, cm<sup>-1</sup>): 3032, 2986, 2848, 2218, 1615, 1566, 1549, 1510; <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>), δppm 7.94 (d, 2H, *J*=8.8 Hz), 7.68 (s, 1H), 7.11 (d, 2H, *J*=8.8 Hz), 3.96 (s, 3H); <sup>13</sup>C NMR (101 MHz, CDCl<sub>3</sub>), δppm 165.0, 158.8, 133.0, 124.2, 114.9, 114.3, 113.1, 78.0, 56.1; MS: *m/z* = 185 (M<sup>+</sup>).

**2-(2-Chlorobenzylidene) malononitrile (3f):** light beige solid, m. p. 96-98°C (ref. 39); FT-IR (KBr, cm<sup>-1</sup>): 3047, 2224, 1638, 1585, 1164, 757; <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>), δppm 8.25 (s, 1H), 8.19 (d, *J* = 7.9 Hz, 1H), 7.58 – 7.52 (m, 2H), 7.48 – 7.40 (m, 1H); <sup>13</sup>C NMR (101 MHz, CDCl<sub>3</sub>) δppm: 158.4, 133.1, 131.8, 129.9, 129.6, 113.4, 112.3, 83.5; MS: *m/z* = 190 (M<sup>+</sup>).

**2-(4-Chlorobenzylidene) malononitrile (3g):** White solid, m. p. 161-163°C (ref. 39); FT-IR (KBr, cm<sup>-1</sup>): 3033, 2923, 2227, 1636, 1585, 1407; <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>), δppm 7.89 (d, 2H, *J* = 8.4 Hz), 7.76 (s, 1H), 7.54 (d, 2H, *J* = 8.7 Hz); <sup>13</sup>C NMR (101 MHz, CDCl<sub>3</sub>) δppm: 158.7, 141.6, 132.2, 130.5, 129.6, 113.8, 112.7, 83.7; MS: *m/z* = 190 (M<sup>+</sup>).

**2-(4-Fluorobenzylidene) malononitrile (3h):** Brown solid, m. p. 125-127°C (ref. 41); FT-IR (KBr, cm<sup>-1</sup>): 3038, 2920, 2229, 1596, 1575; <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>), δppm 7.8 (s, 1H), 6.76–6.71 (m, 2H), 7.2–7.4 (m, 2H); <sup>13</sup>C NMR (101 MHz, CDCl<sub>3</sub>) δppm: 165.0, 158.7, 134.0, 128.1, 117.1, 113.6, 112.6, 81.8; MS: *m/z* = 172 (M<sup>+</sup>).

**2-(4-Hydroxybenzylidene) malononitrile (3i):** pale yellow solid, m. p. 187-189°C (ref. 39); FT-IR (KBr, cm<sup>-1</sup>): 3353, 3080, 2922, 2226, 1611, 1581; <sup>1</sup>H NMR (400 MHz, DMSO-d<sub>6</sub>) δppm 11.05 (s, 1H), 8.30 (s, 1H), 7.89 (d, *J*= 8.5 Hz, 2H), 6.97 (d, *J*= 8.5 Hz, 2H); <sup>13</sup>C NMR (101 MHz, DMSO-d<sub>6</sub>) δppm 164.5, 161.0, 134.4, 123.2, 117.1, 115.6, 114.7, 75.4; MS: *m/z* = 171 (M<sup>+</sup>).

**2-(4-Bromo-2-fluorobenzylidene) malononitrile (3j):** off white solid, m. p. 150-152°C (no ref.); FT-

IR (KBr,  $\text{cm}^{-1}$ ): 3100, 2225, 1589, 963, 956, 816;  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  8.15 (t,  $J=8.0$  Hz, 1H), 8.00 (s, 1H), 7.46 (dd,  $J=21.0, 9.2$  Hz, 2H);  $^{13}\text{C}$  NMR (101 MHz,  $\text{CDCl}_3$ )  $\delta$ ppm 162.04, 159.42, 149.97, 130.52, 129.13, 128.95, 120.4, 120.22, 118.35, 113.11, 112.03, 84.96; MS:  $m/z = 252$  ( $\text{M}^+$ ).

*Ethyl 2-cyano-3-(2-nitrophenyl)acrylate (3k)*: white solid, m. p. 99-101°C (ref. 39); FT-IR (KBr,  $\text{cm}^{-1}$ ): 3097, 3032, 2989, 2944, 2225, 1721, 1618, 1590, 1568, 1496;  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$ ppm 8.69 (s, 1H), 8.25 (d,  $J=8.1$  Hz, 1H), 7.84-7.76 (dd,  $J_1=7.5$  Hz,  $J_2=7.5$  Hz, 2H), 7.69 (t,  $J=7.5$  Hz, 1H), 3.39 (q,  $J=7.0$  Hz, 2H), 1.39 (t,  $J=7.2$  Hz, 3H);  $^{13}\text{C}$  NMR (101 MHz,  $\text{CDCl}_3$ )  $\delta$ ppm 178.5, 161.0, 153.4, 147.2, 134.3, 132.4, 130.5, 127.9, 125.3, 108.8, 72.0, 14.2; MS:  $m/z = 247$  ( $\text{M}^+$ ).

*Ethyl 2-cyano-3-(4-nitrophenyl)acrylate (3l)*: white solid, m. p. 167-169°C (ref. 39); FT-IR (KBr,  $\text{cm}^{-1}$ ): 3092, 3045, 2996, 2942, 2224, 1723, 1615, 1588, 1550, 1493;  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$ ppm 8.34 (d,  $J=9.0$  Hz, 2H), 8.29 (s, 1H), 8.12 (d,  $J=8.7$  Hz, 2H), 4.43 (q,  $J=3.6$  Hz, 2H), 1.42 (t,  $J=7.0$  Hz, 3H);  $^{13}\text{C}$  NMR (101 MHz,  $\text{CDCl}_3$ )  $\delta$ ppm 161.1, 151.5, 149.7, 137.0, 131.1, 124.0, 114.5, 107.1, 63.4, 14.1; MS:  $m/z = 247$  ( $\text{M}^+$ ).

*Ethyl-2-cyano-3-(p-tolyl)acrylate (3m)*: white solid, m. p. 88-90°C (ref. 39); FT-IR (KBr,  $\text{cm}^{-1}$ ): 3028, 2216, 1724, 1595, 1298, 847;  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$ ppm 8.19 (s, 1H), 7.88 (d,  $J=8.0$  Hz, 2H), 7.28 (d,  $J=7.9$  Hz, 2H), 4.35 (q,  $J=7.1$  Hz, 2H), 2.41 (s, 3H), 1.37 (t,  $J=7.1$  Hz, 3H);  $^{13}\text{C}$  NMR (101 MHz,  $\text{CDCl}_3$ )  $\delta$ ppm 162.6, 155.4, 144.7, 131.4, 130.3, 129.1, 115.9, 101.0, 62.4, 21.6, 14.3; MS:  $m/z = 216$  ( $\text{M}^+$ ).

*Ethyl-2-cyano-3-(4-methoxyphenyl)acrylate (3n)*: white solid, m. p. 75-77°C (ref. 39); FT-IR (KBr,  $\text{cm}^{-1}$ ): 3028, 2217, 1718, 1590, 1325, 1191, 825;  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$ ppm 8.18 (s, 1H), 7.33-8.03 (m, 4H), 4.2-4.46 (q,  $J=7.20$  Hz, 2H), 2.35 (s, 3H), 1.35-1.41 (2t,  $J=7.20$  Hz, 6H);  $^{13}\text{C}$  NMR (101 MHz,  $\text{CDCl}_3$ )  $\delta$ ppm 163.3, 154.2, 132, 131.86, 127, 119.41, 115.5, 101.83, 61.42, 14.0; MS:  $m/z = 232$  ( $\text{M}^+$ ).

*Ethyl-3-(2-chlorophenyl)-2-cyanoacrylate (3o)*: off-white solid, m. p. 52-55°C (ref. 39); FT-IR (KBr,  $\text{cm}^{-1}$ ): 3038, 2222, 1728, 1609, 1285, 760;  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$ ppm 8.55 (s, 1H), 7.78 (d,  $J=8.1$  Hz, 1H), 7.52 (m,  $J=7.6$  Hz, 2H), 7.22 (m, 1H), 4.31 (q,  $J=7.1$  Hz, 2H), 1.30 (t,  $J=7.1$  Hz, 3H);  $^{13}\text{C}$  NMR (101 MHz,  $\text{CDCl}_3$ )  $\delta$ ppm 162.3, 153.1, 139.6, 132.0, 129.8, 129.7, 115.4, 103.3, 62.9, 14.1; MS:  $m/z = 236$  ( $\text{M}^+$ ).

*Ethyl-3-(4-chlorophenyl)-2-cyanoacrylate (3p)*: white solid, m. p. 90-92°C (ref. 39); FT-IR (KBr,  $\text{cm}^{-1}$ ): 3036, 2220, 1725, 1564, 795;  $^1\text{H}$  NMR (400 MHz,

$\text{CDCl}_3$ )  $\delta$ ppm 8.20 (s, 1H), 7.94 (d,  $J=8.8$  Hz, 2H), 7.48 (d,  $J=8.8$  Hz, 2H), 4.39 (q,  $J=7.2$  Hz, 2H), 1.40 (t,  $J=7.2$  Hz, 3H);  $^{13}\text{C}$  NMR (101 MHz,  $\text{CDCl}_3$ )  $\delta$ ppm 162.2, 129.9, 115.3, 103.0, 139.1, 153.2, 129.5, 132.3, 62.6, 14.3; MS:  $m/z = 236$  ( $\text{M}^+$ ).

*Ethyl-2-cyano-3-(2,4-dichlorophenyl) acrylate (3q)*: white solid, m. p. 79-81°C (ref. 39); FT-IR (KBr,  $\text{cm}^{-1}$ ): 3031, 2223, 1728, 1614, 1585, 826, 775;  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$ ppm 8.61 (s, 1H), 8.25 (d, 1H,  $J=8.8$  Hz), 7.58 (d,  $J=1.6$  Hz, 1H), 7.40-7.38 (m, 1H), 4.34 (q,  $J=7.2$  Hz, 2H), 1.44 (t,  $J=7.2$  Hz, 3H);  $^{13}\text{C}$  NMR (101 MHz,  $\text{CDCl}_3$ )  $\delta$ ppm 161.5, 149.6, 139.3, 137.2, 130.4, 130.2, 128.2, 127.9, 114.6, 106.3, 63.0, 14.0; MS:  $m/z = 270$  ( $\text{M}^+$ ).

*Ethyl (E)-2-cyano-3-(4-hydroxyphenyl) acrylate (3r)*: light yellow solid, m. p. 170-174°C (ref. 39); FT-IR (KBr,  $\text{cm}^{-1}$ ): 3279, 2987, 2230, 1722, 1586;  $^1\text{H}$  NMR (300 MHz,  $\text{DMSO-d}_6$ )  $\delta$ ppm 10.87 (s, 1H), 8.24 (s, 1H), 7.99-8.02 (d,  $J=9$  Hz, 2H), 6.95-6.98 (d,  $J=9$  Hz, 2H), 4.26-4.33 (q,  $J=9$  Hz, 2H), 1.28-1.33 (t,  $J=6$  Hz, 3H);  $^{13}\text{C}$  NMR (101 MHz,  $\text{DMSO-d}_6$ )  $\delta$ ppm 163.5, 163.1, 155.2, 134.5, 123.0, 117.0, 116.9, 97.5, 62.4, 14.5; MS:  $m/z = 218$  ( $\text{M}^+$ ).

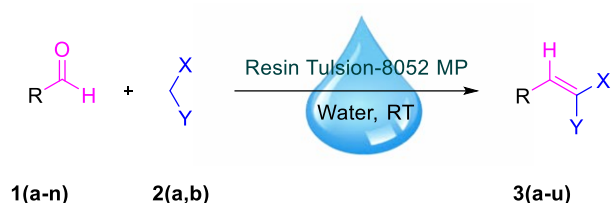
*2-(Furan-2-ylmethylene)malononitrile (3s)*: White solid, m. p. 68-70°C (ref. 42); FT-IR (KBr,  $\text{cm}^{-1}$ ): 3431, 3015, 2220, 1685, 1609, 1418, 1214, 1066, 761;  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ):  $\delta$ ppm 7.55 (s, 1H), 7.37 (d,  $J=3.7$  Hz, 1H), 7.83 (d,  $J=1.6$  Hz, 1H), 6.74 (q,  $J=2.2$  Hz, 1H);  $^{13}\text{C}$  NMR (101 MHz,  $\text{CDCl}_3$ ):  $\delta$ ppm 149.2, 148.5, 143.0, 130.3, 115.8, 112.1, 80.2; MS:  $m/z = 145$  ( $\text{M}^+$ ).

*2-(Thiophen-2-ylmethylene)malononitrile (3t)*: brown solid, m. p. 96-98°C (ref. 43); FT-IR (KBr,  $\text{cm}^{-1}$ ): 3429, 3020, 2219, 1675, 1431;  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ):  $\delta$ ppm 7.93 (s, 1H), 7.50 (d,  $J=4.8$  Hz, 1H), 7.16 (d,  $J=3.6$  Hz, 1H), 6.60 (t,  $J=4.3$  Hz, 1H);  $^{13}\text{C}$  NMR (101 MHz,  $\text{CDCl}_3$ ):  $\delta$ ppm 150.1, 141.5, 135.3, 129.8, 128.1, 113.7, 112.5, 76.2; MS:  $m/z = 161$  ( $\text{M}^+$ ).

*2-(Pyridin-4-ylmethylene) malononitrile (3u)*: off white solid, m. p. 99-101°C (ref. 41); FT-IR (KBr,  $\text{cm}^{-1}$ ): 3029, 2223, 1610, 1548, 1403;  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ):  $\delta$ ppm 7.69 (d,  $J=5.3$  Hz, 2H), 7.83 (s, 1H), 8.88 (d,  $J=5.3$  Hz, 2H);  $^{13}\text{C}$  NMR (101 MHz,  $\text{CDCl}_3$ ):  $\delta$ ppm, 157.6, 151.7, 137.2, 123.4, 113.3, 112.4, 85.0; MS:  $m/z = 155$  ( $\text{M}^+$ ).

## RESULTS AND DISCUSSION

The resin Tulsion-8052 MP catalyzed the Knoevenagel reaction and contributed to its ecofriendly profile due to the aqueous media used. By eliminating the need for organic solvents, this method significantly reduces waste generation and eliminates potential environmental hazards. This green approach aligns with the principles of sustainable chemistry, making it an attractive option for researchers and industries alike. In continuation with our current research contribution in the field of green chemistry [35-38], herein we introduce the resin Tulsion-8052 MP for Knoevenagel reaction as a novel, recyclable, economical, and green catalyst (Scheme 1).



**Scheme 1.** Schematic diagram of Knoevenagel reaction using resin Tulsion-8052 MP catalyst in aqueous medium.

Resin Tulsion-8052 MP catalyst has a unique operating behavior in both aqueous and organic media making it preferred over other reported catalysts. The nature of the catalyst is granular with light brown in color. This catalyst has an active sulphonic acid functional group which participates in reaction to promote reaction. Resin Tulsion-8052 MP catalysts have a wide operating temperature range from 0-80°C. This catalyst has a large pore structure with a high exchange capacity (1.95 meq/ml.min). At the outset of the research, the first step is to benchmark Tulsion-8052 MP for condensation of benzaldehyde with malononitrile with another resin catalyst, to verify the catalyst's activity. The reaction was carried out in an aqueous medium at room temperature using Tulsion-8052 MP resin, and the results obtained are summarized in Table 1.

Tulsion-8052 MP resin was the best-performing resin for the Knoevenagel condensation between benzaldehyde and malononitrile in terms of yields, moreover, other acidic resins required longer reaction times. Basic ion exchange resin showed a lower yield in Knoevenagel condensation in aqueous medium.

**Table 1.** Comparative data of resin catalysts in Knoevenagel reaction of benzaldehyde and malononitrile.<sup>a</sup>

| Entry | Catalyst          | Main functional group    | Total exchange capacity (meq/mL) | Reaction Time (h) | Yield (%) <sup>b</sup> |
|-------|-------------------|--------------------------|----------------------------------|-------------------|------------------------|
| 1     | Indion 225 H      | Sulfonic acid            | 1.8                              | 2.0               | 90                     |
| 2     | Dowex 50WX2       | Sulfonic acid            | 0.6                              | 5.0               | 85                     |
| 3     | Dowex 50WX8       | Sulfonic acid            | 1.7                              | 2.0               | 89                     |
| 4     | Amberlite IR120 H | Sulfonic acid            | 1.8                              | 1.5               | 92                     |
| 5     | Amberlite IRC-50  | Carboxylic acid          | 3.5                              | 1.0               | 90                     |
| 6     | Amberlite FPA53   | Tertiary amines          | 1.6                              | 2.5               | 88                     |
| 7     | Amberlite IRA-96  | Tertiary amine           | 1.3                              | 4                 | 86                     |
| 8     | Amberlite IRA-410 | Dimethylethanol ammonium | 1.25                             | 4                 | 84                     |
| 9     | Tulsion-8052 MP   | Sulfonic acid            | 1.95                             | 1.0               | 95                     |
| 10    | Tulsion-A-74 MP   | Quaternary ammonium      | 1.0                              | 6.0               | 75                     |

<sup>a</sup> Reaction conditions: benzaldehyde 1a (1 mmol), malononitrile 2a (1mmol), catalyst (10 mol%), water (5V), <sup>b</sup> isolated yields.

Amberlite IR120 H showed comparatively decent results but not as good as Tulsion-8052 MP resin in aqueous medium. Hence, we chose Tulsion-8052 MP resin for reaction.

Further, various solvents' impact on the condensation of benzaldehyde with malononitrile as a model reaction in the presence of resin Tulsion-8052 MP catalyst (10 mol%) was studied. The solvent-free reaction takes a longer reaction conversion time and yields a sluggish reaction mass. After isolation, the obtained yield is 89% in solvent-free condensation. Then the reaction was carried out in the aprotic solvent acetonitrile and the realized

reaction worked at room temperature but afforded slightly longer reaction time. In protic solvents ethanol and methanol used for condensation reactions the reaction goes well within 4 h and yield was optimum. Based on the solvent study, we moved to carry out a reaction using water. In this practice it was found that the reaction goes well with higher yield and shorter reaction time under stirring at room temperature. Further, we studied the impact of applied temperature on reaction and carried out reactions at 45-50°C, 60-65°C, 75-80°C, which showed no drastic change in reaction time, as well as in yield. Whereas at reflux temperature the reaction

time was shorter, a slight decrease in yield was observed due to catalyst deactivation, as shown in Table 2. Based on Table 2, there is no need for a higher temperature to carry out the reaction using water as a solvent and the reaction can go smoothly at room temperature without loss of product. Also, there is no big change in reaction time by increasing the reaction temperature up to 80°C.

Further, the concentration of the resin Tulsion-8052 MP catalyst in condensation reaction was optimized. In trial run experiments with benzaldehyde (1mmol), malononitrile (1 mmol), and water (5V) were used and the reaction was performed with different concentrations of resin catalyst under stirring at room temperature and the obtained results are summarized in Table 3.

**Table 2.** Solvent with temperature comparison study for condensation of benzaldehyde and malononitrile in presence of resin catalyst.<sup>a</sup>

| Entry | Solvents <sup>b</sup> | Temp. (°C) | Reaction time (h) | Yield (%) <sup>c</sup>     |
|-------|-----------------------|------------|-------------------|----------------------------|
| 1     | --                    | RT         | 6.0               | 89                         |
| 2     | Acetonitrile          | RT         | 6.0               | 81                         |
| 3     | Ethanol               | RT         | 4.0               | 88                         |
| 4     | Methanol              | RT         | 4.0               | 86                         |
| 5     | Water                 | RT         | 1.0               | 95                         |
| 6     | Water                 | 45-50°C    | 1.0               | 95                         |
| 7     | Water                 | 60-65°C    | 1.0               | 96                         |
| 8     | Water                 | 75-80°C    | 1.0               | 97                         |
| 9     | Water                 | Reflux     | 0.5               | 90                         |
| 10    | Water                 | 65°C       | 2.0               | 94 <sup>[Ref. 44]</sup>    |
| 11    | Water                 | 50°C       | 2.0               | 99 <sup>[d, Ref. 45]</sup> |

<sup>a</sup> Reaction conditions: benzaldehyde 1a (1 mmol), malononitrile 2a (1mmol), resin Tulsion-8052 MP (10 mol%), <sup>b</sup>solvent volume (5V), <sup>c</sup>isolated yields, <sup>d</sup>use of excess of malononitrile (1.2 eq.) in reaction.

**Table 3.** Resin Tulsion-8052 MP concentration study in the condensation reaction of benzaldehyde and malononitrile under stirring<sup>a</sup> at room temperature.

| Entry | Catalyst conc. (mol%) | Reaction time (h) | Yield (%) <sup>b</sup> |
|-------|-----------------------|-------------------|------------------------|
| 1     | --                    | 2.0               | 14                     |
| 2     | 2.5                   | 2.0               | 46                     |
| 3     | 5.0                   | 2.0               | 78                     |
| 4     | 7.5                   | 2.0               | 87                     |
| 5     | 10                    | 1.0               | 95                     |
| 6     | 15                    | 1.0               | 95                     |
| 7     | 20                    | 1.0               | 97                     |

<sup>a</sup> Reaction conditions: benzaldehyde 1a (1 mmol), malononitrile 2a (1mmol), water (5V), <sup>b</sup>isolated yields.

By varying catalyst concentration, it was found that without a catalyst in an aqueous medium reaction performance is very poor and isolated yield is only 14%. With the increase in catalyst concentration in mol % an increase in yield was

observed which clearly points to the indispensable catalyst role. Based on the above observations, a 10 mol % catalyst concentration with respect to concerned aldehydes was chosen.

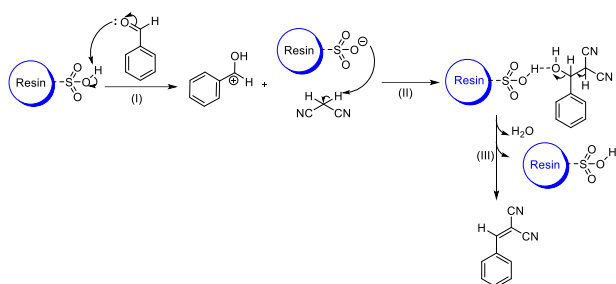
A similar procedure was applied to screen different derivatives for condensation reaction of aldehydes 1(a-k) and active methylene group compounds 2(a and b: CN/CN and CN/COOEt respectively) in the presence of resin Tulsion-8052 MP catalyst in water at room temperature to get condensed products 3(a-r) as shown in Table 4.

**Table 4.** Resin Tulsion-8052 MP catalysed Knoevenagel condensation reaction at room temperature in aqueous medium.

| Entry | R                      | X/Y      | Product | Reaction Time (h) | Yield (%) <sup>a</sup> |
|-------|------------------------|----------|---------|-------------------|------------------------|
| 1     | Ph                     | CN/CN    | 3a      | 1.0               | 95                     |
| 2     | 2-NO <sub>2</sub> Ph   | CN/CN    | 3b      | 1.0               | 91                     |
| 3     | 4-NO <sub>2</sub> Ph   | CN/CN    | 3c      | 1.0               | 93                     |
| 4     | 4-CH <sub>3</sub> Ph   | CN/CN    | 3d      | 1.0               | 96                     |
| 5     | 4-CH <sub>3</sub> O Ph | CN/CN    | 3e      | 1.0               | 98                     |
| 6     | 2-Cl Ph                | CN/CN    | 3f      | 1.0               | 95                     |
| 7     | 4-Cl Ph                | CN/CN    | 3g      | 1.0               | 96                     |
| 8     | 4-F Ph                 | CN/CN    | 3h      | 1.0               | 94                     |
| 9     | 4-OH Ph                | CN/CN    | 3i      | 1.0               | 97                     |
| 10    | 4-Br, 2-F Ph           | CN/CN    | 3j      | 1.5               | 92                     |
| 11    | 2-NO <sub>2</sub> Ph   | CN/COOEt | 3k      | 2.0               | 97                     |
| 12    | 4-NO <sub>2</sub> Ph   | CN/COOEt | 3l      | 2.0               | 99                     |
| 13    | 4-CH <sub>3</sub> Ph   | CN/COOEt | 3m      | 2.0               | 92                     |
| 14    | 4-CH <sub>3</sub> O Ph | CN/COOEt | 3n      | 2.0               | 93                     |
| 15    | 2-Cl Ph                | CN/COOEt | 3o      | 2.5               | 95                     |
| 16    | 4-Cl Ph                | CN/COOEt | 3p      | 2.5               | 95                     |
| 17    | 2,4-Cl Ph              | CN/COOEt | 3q      | 3.5               | 96                     |
| 18    | 4-OH Ph                | CN/COOEt | 3r      | 2.0               | 94                     |
| 19    | Furan-2-yl             | CN/CN    | 3s      | 4.0               | 95                     |
| 20    | Thien-2-yl             | CN/CN    | 3t      | 4.5               | 94                     |
| 21    | Pyrid-2-yl             | CN/CN    | 3u      | 4.0               | 91                     |

<sup>a</sup>Isolated yields.

The activity of the catalyst was markedly better in the case of all synthesized aldehyde derivatives and the obtained results were excellent, compared to other reported methods. To understand the reaction pathway, the probable mechanism for Knoevenagel condensation reaction with resin Tulsion-8052 MP catalyst is illustrated in Scheme 2.



**Scheme 2.** Probable mechanistic pathway for the Knoevenagel condensation reaction of benzaldehyde and malononitrile catalyzed by the resin catalyst.

Based on the probable mechanism, the carbonyl functional group on benzaldehyde was activated by the resin sulphonyl acidic proton to proceed reaction of condensation (Scheme 2, step I). Afterward, the next step continues with the attack of the carbanionic anion on the polarized carbonyl group and a new intermediate was generated (Scheme 2, step II).

Meanwhile, with the recovery of the catalyst and loss of water molecules (Scheme 2, step III), the final product is obtained. Therefore, based on the proposed mechanism, one can say that the catalyst can be recycled and reused.

To confirm the reusability of the resin catalyst an experiment was performed with 4-methoxy benzaldehyde (1e) and malononitrile (2a) in water (5V) and Tulsion-8052 MP (10 mol%) at room temperature as shown in Table 5.

In the recycle experiment, after completion of reaction, crude product was isolated by filtration and the wet solid forwarded for crystallization using ethanol. During crystallization a clear solution was obtained which was filtered through filter paper to get recovered catalyst on the surface of the filter paper. After ethanol washing, the recovered catalyst was air dried to remove solvent traces of ethanol and used for the next cycles.

**Table 5.** Tulsion-8052 MP reusability experimental data<sup>a</sup>

| Entry | Catalyst cycles | Yield (%) <sup>b</sup> |
|-------|-----------------|------------------------|
| 1     | fresh           | 98                     |
| 2     | 1               | 98                     |
| 3     | 2               | 96                     |
| 4     | 3               | 95                     |
| 5     | 4               | 92                     |
| 6     | 5               | 91                     |

<sup>a</sup> Reaction conditions: 4-methoxy benzaldehyde 1e (1 mmol), malononitrile 2a (1mmol), water (5V). <sup>b</sup> Isolated yields.

According to the results in Table 5, the catalyst slightly lost its activity and yield after the 3<sup>rd</sup> run as compared to fresh use. Catalyst can be recycled for five sequential runs not losing much activity.

Representative condensates were structurally elucidated and confirmed. The developed method is easy to operate and provides products of high purity.

## CONCLUSION

Resin Tulsion-8052 MP catalyst is active, recyclable, economical and easy to operate in Knoevenagel condensation of aromatic aldehydes with active methylene compounds. The reaction proceeds at room temperature in aqueous medium, which makes it ecofriendly. This method has operationally simple work-up procedure, and completes within a shorter time to offer excellent yield. No toxic solvents were used which leads to a green approach for condensation reactions.

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## REFERENCES

- H. I. Aljaddua, M. S. Alhumaimess, H. M. Hassan, *Arab. J. Chem.* **15**, 103588 (2022).
- K. Cai, W. Tan, N. Zhao, H. He, *Cryst. Growth Des.* **20**, 4845 (2020).
- B. M. Trost, *Comp. Org. Syn., Pergamon Press, Oxford*, **2**, 341 (1991).
- S. Ramesh, F. Devred, D. P. Debecker, *Chemistry Select*, **5**, 300 (2020).
- F. Freeman, *Chem. Rev.*, **80**, 329 (1980).
- L. F. Tietze, *Chem. Rev.*, **96**, 115 (1996).
- Q. Hu, X. L. Shi, Y. Chen, X. Han, P. Duan, W. Zhang, *J. Ind. Eng. Chem.*, **54**, 75 (2017).
- S. S. Maltsev, M. A. Mironov, V. A. Bakulev, *Mendeleev Commun.*, **16**, 201 (2006).
- S. A. Khan, A. M. Asiri, R. M. Rahman, S. A. Elroby, F. M. S. Aqlan, M. Y. Wani, K. Sharma, *J. Hetero. Chem.*, **54**, 3099 (2017).
- A. Sidhu, J. R. Sharma, M. Rai, *Ind. J. Chem. Sect. B Org. Med. Chem.*, **49**, 247 (2010).
- R. K. Gopalakrishna Panicker, S. Krishnappillai, *Tetrahedron Lett.*, **55**, 2352 (2014).
- M. M. H. Bhuiyan, K. M. M. Rahman, M. A. Alam, M. M. Mahmud, *Pak. J. Sci. Ind. Res. A: Phys. Sci.*, **56**, 131 (2013).
- S. Alwarappan, S. Boyapalle, A. Kumar, C. Z. Li, S. Mohapatra, *J. Phys. Chem.*, **116**, 6556 (2012).
- A. S. Fouda, Y. A. El-Awady, O. M. Abo-El-Enein, F. A. Azizah, *Anti-Corros. Method. M.*, **55**, 317 (2008).
- M. Almasi, V. Zelenak, M. Opanasenko, J. Cejka, *Dalton Trans.*, **43**, 3730 (2014).
- M. Cortes-Clerget, J. Yu, J. R. A. Kincaid, P. Walde, F. Gallou, B. H. Lipshutz, *Chem. Sci.*, **12**, 4237 (2021).
- U. M. Lindstrom, *Chem. Rev.*, **102**, 2751 (2002).
- C. Wei, C. J. Li, *J. Am. Chem. Soc.*, **125**, 9584 (2003).

19. S. Narayan, J. Muldoon, M. G. Finn, V. V. Fokin, H. C. Kolb, K. B. Sharpless, *Angew. Chem. Int. Edn.*, **44**, 3275 (2005).
20. M. Sayed, A. Soliman, H. N. Abdelhamid, *J. Solid State Chem.*, **332**, 124534 (2024).
21. Y. Xu, B. Tian, R. Zhang, P. Li, J. Hu, Z. Chen, *Micropor. Mesopor. Mat.*, **366**, 112959 (2024).
22. R. Kluga, A. Kinens, E. Suna, *A Eur. J.*, **30**(10), e202301136 (2024).
23. P. L. Kalar, K. Jain, S. Agrawal, S. Khan, R. Vishwakarma, A. Shivhare, M. M. Deshmukh, K. Das, *J. Org. Chem.*, **88**(24), 16829 (2023).
24. G. Xu, H. Zheng, X. Zhang, W. Li, L. Zhou, L. Qin, *Mol. Catal.*, **549**, 113447 (2023).
25. E. Saha, H. Jungi, S. Dabas, A. Mathew, R. Kuniyil, S. Subramanian, J. Mitra, *Inorg. Chem.*, **62**(37), 14959 (2023).
26. R. Zhang, T. Chen, G. Wang, Y. Guan, A. Reheman, Z. Chen, J. Hu, *Catal. Lett.*, **153**(6), 1807 (2023).
27. Q. Liu, X. Chen, N. Yu, Y. Li, K. He, W. Zheng, Y. Zhou, K. Jiang, L. Yang, Y. Wei, *Catalysis*, **13**(9), 5795 (2023).
28. (a) J. N. Appaturi, R. Ratti, B. L. Phoon, S. M. Batagarawa, I. U. Din, M. Selvaraj, R. J. Ramalingam, *Dalton Trans.*, **50**, 4445 (2021). (b) K. V. Beurden, S. D. Koning, D. Molendijk, J. V. Schijndel, *Green Chem. Lett. Rev.*, **13**(4), 349 (2020). (c) S. Johari, M. R. Johana, N. G. Khaligh, *Org. Biomol. Chem.*, **20**, 2164 (2022).
29. D. P. Elder, *J. Chem. Educ.*, **82**(4), 575 (2005).
30. M. J. Zohuriaan-Mehr, H. Omidian, *J. Macromolec. Sci. Part C- Polymer Rev.*, **40**(1), 23 (2000).
31. T. Ramakrishnan, M. D. M. Gift, S. Chitradevi, R. Jegan, P. S. H. Jose, H. N. Nagaraja, R. Sharma, P. Selvakumar, S. M. Hailegiorgis, *Adv. Mater. Sci. Eng.*, **2022**, 1 (2022).
32. Y. W. Rong, Q. H. Zhang, W. Wang, B. L. Li, *Bull. Kor. Chem. Soc.*, **35**(7), 2165 (2014).
33. H. Reymond, S. Vitas, S. Vernuccio, P. R. V. Rohr, *Ind. Eng. Chem. Res.*, **56**(6), 1439 (2017).
34. S. U. Tekale, S. S. Kauthale, R. P. Pawar, *J. Chil. Chem. Soc.*, **58**, 1619 (2013).
35. S. B. Sapkal, K. F. Shelke, B. B. Shingate, M. S. Shingare, *Tetrahedron Lett.*, **50**, 1754 (2009).
36. K. F. Shelke, S. B. Sapkal, G. K. Kakade, S. A. Sadaphal, B. B. Shingate, M. S. Shingare, *Green Chem. Lett. Rev.*, **3**, 17 (2010).
37. A. Sapkal, S. B. Sapkal, B. R. Madje, *Eur. Chem. Bull.*, **8**(11), 352 (2019).
38. S. S. Gadekar, R. A. Joshi, B. R. Madje, S. T. Salunke, S. B. Sapkal, *Results in Chem.*, **6**, 101074 (2023).
39. S. Wang, Z. Ren, W. Cao, W. Tong, *Synth. Commun.*, **31**(5), 673(2001).
40. R. Pal, T. Sarkar, *Int. J. Org. Chem.*, **4**, 106 (2014).
41. K. B. Badiger, K. Kamanna, *Org. Commun.*, **14**(1), 81 (2021).
42. H. B. Ammar, M. Chtourou, M. H. Frikha, M. Trabelsi, *Ultrason. Sonochem.*, **22**, 559 (2015).
43. P. Kudale, K. Gavali, D. Pinjari, G. Chaturbhuj, *Results in Chem.*, **5**, 100833 (2023).
44. F. Bigi, C. Quarantelli, *Curr. Org. Synth.*, **9**, 31 (2012).
45. V. Campisciano, F. Giacalone, M. Gruttadauria, *Chem. Cat. Chem.*, **14**, e202200696 (2022).