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Synthesis of α-Hydroxycarboxylic Acids from Various Aldehydes and Ketones by Direct Electrocarboxylation: A Facile, Efficient and Atom Economy Protocol

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In present work, the formation of α-hydroxycarboxylic acids have been described from various aromatic aldehydes and ketones *via* direct electrocarboxylation method with 80-92% of yield without any side product and can be purified by simple recrystallization using sacrificial Mg anode and Pt cathode in an undivided cell, CO_2 at (1 atm) was continuously bubbled in the cell throughout the reaction using tetrapropylammonium chloride as a supporting electrolyte in acetonitrile. The synthesized compounds obtained in fair to excellent yield with a high level of purity. The characterization of electrocarboxylated compounds was done with spectroscopic techniques like IR, NMR (^1H & ^{13}C), mass and elemental analysis.

Keywords: Electrocarboxylation, α-Hydroxycarboxylic acids, Ionic liquids, Tetrapropylammonium chloride.

INTRODUCTION

The carboxylic group has always drawn extensive attention from researchers owing to the widespread applications in the various pharmaceutical and food industries [1]. Many strategies have been adopted to achieve desired carboxylic acids, primarily by the oxidation of functional groups like –CHO, –OH and C–H bond or by the carbon nucleophile carboxylation with CO_2 [2]. The latter being the non-toxic, easily available and cost-effective source of the C1 building block in organic synthesis has aroused considerable interest in the researchers [3,4]. The other reason for being a highly preferred method is the utilization of this green-house gas, an act in the direction of protecting the environment [5,6]. In the traditional carboxylation methods, the kinetic and thermodynamic stability of carbon dioxide can impose an undesirable challenge, such as specific metal catalyst, generated waste and harsh reaction conditions [7]. However, organic electrochemical techniques have been developed to overcome these shortcomings. Electrocarboxylation can be achieved with an inert cathode (like nickel, stainless steel, platinum) [8] with a sacrificial anode (like magnesium or aluminum) [9,10]. Much more efforts are focused on sacrificial anode owing to the simplicity of electrolytic cell without any separating membrane, mild chemical and process conditions, high selectivity with inexpensive reagents and safer operation with easy control [11]. Electrocarboxylation with these electrodes have become highly efficient routes from organic halides [12], ketones [13], alkenes [14], alkynes [15], epoxides [16], amines [17] and other heterocyclic compounds under mild conditions [18].

The use of green ionic liquids as assisting electrolyte [19-21] gives an advantage to the electrocarboxylation method [22,23] over other traditionally available techniques [24-26]. Several different types of ionic liquids have been reported till now but still, the discoveries of the new and best combination of electrodes with supporting electrolyte are the need of the hour. In present work, authors reported the electrocarboxylation of various types of substituted aldehydes/ketones using Mg as sacrificial anode and Pt as an inert cathode in tetrapropylammonium chloride as a supporting electrolyte.

EXPERIMENTAL

All the chemicals utilized in this research were procured from Sigma-Aldrich and used as such without any sort of further purification. Acetonitrile (Merck), the commercially available

solvent was kept in 4A molecular sieves overnight. It was collected after distillation at 80-82 ºC. The distillate solution was kept in P_2O_5 for a night, then distilled again to get pure and dry CH_3CN. Double distilled water was employed for the preparation of all the aqueous solutions. Open capillary techniques were used for the determination of the melting point of all the synthesized compounds and are uncorrected. IR spectrum (Perkin-Elmer RXIFT IR) with a fixed scanning speed method was obtained as KBr disks. Bruker Advanced NMR spectrometer was used (both ^1H & ^{13}C NMR with $CDCl_3$ as internal standard TMS) at 500/400 MHz and 125/100 MHz, respectively. The MS were recorded on LC-MS spectrometer Model Q-ToF Micromass, Waters. Thin layer chromatography technique and a UV chamber were used for verifying the purity and visualization of the compounds.

Electrochemical instrumentation

Power source: In electrocarboxylation, direct current was supplied by an electrophoresis power supply (Toshniwal). It was fitted with a voltmeter in the range of 0-300 V and an ammeter capable of indicating 0-100 mA.

Undivided cell: For electrocarboxylation, an undivided cell was used which is made of pyrex glass. Both cathode and anode were suspended in the cell through two different openings and CO_2 was bubbled continuously throughout the reaction with a third opening in the cell. Magnesium electrode having dimensions (5 cm length & 1 cm diameter) and platinum gauze having dimensions (1 cm × 1 cm × 0.1 cm) were used as sacrificial anode and inert cathode, respectively. The circuit was completed by connecting the anode to +ve terminal and cathode to –ve terminal using DC power supply for the undivided cell.

General procedure: An undivided cell equipped with Mg as sacrificial anode and Pt as an inert cathode for electrocarboxylation. The two electrodes were cleaned with dilute HNO_3, rinsed with distilled water and dried. 4′-Isobutylacetophenone (0.54 mmol) were added to 100 mL of CH_3CN containing TPAC (5 mmol) as a supporting electrolyte. This electrolytic solution was electrolyzed at 20 ºC maintaining 15 mA/cm^2 constant current density. A regular stream of CO_2 was also supplied to this solution maintaining the requisite pressure (1 atm). This reaction was spread over a continual period of 10 h while providing a constant current density.

Post this process, the removal of excess solvent was done under reduced pressure and the solid residue was collected. To remove the ionic impurities, the solid extractions were performed with diethyl ether using a separating funnel and dry the product using anhydrous $MgSO_4$. The crude product was recrystallized from ethanol to afford the required compound.

2-Hydroxy-2-(4-isobutylphenyl)propionic acid (2a): Yield 92%, m.p.: 96-98 ºC. IR (ATR) (ν_{max}, cm^{-1}): 3220 (-OH), 1723 (C=O), 3019 (Ar C-H), 2832 (sp^3 C-H). ^1H NMR (500 MHz, $CDCl_3$): δ 12.67 (brs, 1H, COO**H**), 7.28 (d, 2H, H-2′,6′), 6.92 (d, 2H, H-3′,5′), 5.57 (brs, 1H, O-**H**), 2.53 (d, 2H, H-1″), 1.91 (m, 1H, H-2″), 1.41 (s, 3H, H-3), 0.91 (d, 6H, H-3″). ^{13}C NMR (100 MHz, $CDCl_3$): δ 197.9 (C-1), 147.6 (C-1′), 134.9 (C-2′ C-6′), 129.2 (C-3′ C-5′), 128.3 (C-4′), 70.2 (C-2), 45.3 (C-1″), 30.2 (C-2″), 26.5 (C-3), 22.3 (C-3″). MS-EI (*m/z*): 223 [M+1]. Elemental analysis calcd. (found) % for $C_{13}H_{18}O_3$: C, 70.24 (70.22); H, 8.10 (8.09).

2-Hydroxy-2-phenylpropionic acid (2b): Yield 80%, m.p.: 115.3 ºC. IR (ATR) (ν_{max}, cm^{-1}): 3480 (O-H), 1714 (C=O), 3021 (Ar C-H), 2824 (sp^3 C-H). ^1H NMR (500 MHz, $CDCl_3$): δ 12.60 (brs, 1H, COO**H**), 7.51 (d, 2H, H-2′,6′), 7.23-7.34 (m, 3H, H-3′,4′,5′), 5.55 (br, S, 1H, O-**H**), 1.60 (s, 3H, H-3). ^{13}C NMR (100 MHz, $CDCl_3$): δ 190.2 (C-1), 141.8 (C-1′), 128.4 (C-2′ C-6′), 128.1 (C-3′ C-5′), 125.2 (C-4′), 80.7 (C-2), 26.5(C-3). MS-EI (*m/z*): 167 [M+1]. Elemental analysis calcd. (found) % for $C_9H_{10}O_3$: C, 65.05 (65.03); H, 6.07 (6.02).

2-Hydroxy-2,2-diphenylacetic acid (2c): Yield 90%, m.p.: 151.4 ºC. IR (ATR) (ν_{max}, cm^{-1}): 3400 (O-H), 1720 (C=O), 3034 (Ar C-H), 2834 (sp^3 C-H). ^1H NMR (500 MHz, $CDCl_3$): δ 13.10 (brs, 1H, COO**H**), 7.36 (d, 2H, H-2′,6′), 7.30-7.24 (m, 3H, H-3′,4′,5′), 6.30 (brs, 1H, O-**H**). ^{13}C NMR (100 MHz, $CDCl_3$): δ 192.2 (C-1), 141.1 (C-1′), 128.4 (C-2′ C-6′), 128.2 (C-3′ C-5′), 127.3(C-4′), 82.1 (C-2). MS-EI (*m/z*): 229 [M+1]. Elemental analysis calcd. (found) % for $C_{14}H_{12}O_3$: C, 73.67 (73.43); H, 5.30 (5.21).

2-Hydroxy-2-(2-chlorophenyl)propionic acid (2d): Yield 84%, m.p.: 163 ºC. IR (ATR) (ν_{max}, cm^{-1}): 3429 (O-H), 1720 (C=O), 3022 (Ar C-H), 2836 (sp^3 C-H). ^1H NMR (500 MHz, $CDCl_3$): δ 12.43 (brs, 1H, COO**H**), 7.39 (d, 1H, H-2′), 7.12-7.21 (m, 3H, H-3′,4′,5′), 5.54 (br, S, 1H, O-**H**); 1.59 (s, 3H, H-3). ^{13}C NMR (100 MHz, DMSO-$CDCl_3$): δ 193.5 (C-1), 142.9 (C-2′), 140.3 (C-6′), 139.5 (C-1′), 138.7 (C-3′), 138.3 (C-5′), 137.3(C-4′), 81.7(C-2), 25.0 (C-3). MS-EI (*m/z*): 201 [M+1], 202 [M+2]. Elemental analysis calcd. (found) % for $C_9H_9O_3Cl$: C, 53.88 (2.92); H, 4.52 (4.49).

2-Hydroxy-2-(4-tolyl)propionic acid (2e): Yield 56%, m.p.: 106.4 ºC. IR (ATR) (ν_{max}, cm^{-1}): 3426 (O-H), 1722 (C=O), 3010 (Ar C-H), 2823 (sp^3 C-H). ^1H NMR (500 MHz, $CDCl_3$): δ 12.52 (brs, 1H, COO**H**), 7.37 (d, 2H, H-2′,6′), 7.12 (d, 2H, H-3′,5′), 5.67 (brs, 1H, O-**H**), 2.31 (s, 3H, H-1″), 1.59 (s, 3H, H-3). ^{13}C NMR (100 MHz, $CDCl_3$): δ 190.4 (C-1), 139.0 (C-1′), 137.9(C-2′ C-6′), 129.1 (C-3′ C-5′), 125.9 (C-4′), 79.6 (C-2), 26.4(C-3), 21.0 (C-1″). MS-EI (*m/z*): 181 [M+1]. Elemental analysis calcd. (found) % for $C_{10}H_{12}O_3$: C, 66.65 (66.22); H, 6.71 (6.59).

2-Hydroxy-2-(4-hydroxyphenyl)propionic acid (2f): Yield 83%, m.p.: 218-220 ºC. IR (ATR) (ν_{max}, cm^{-1}): 3481 (O-H), 1726 (C=O), 3018 (Ar C-H), 2839 (sp^3 C-H). ^1H NMR (500 MHz, $CDCl_3$): δ 12.25 (brs, 1H, COO**H**), 7.31 (d, 2H, H-2′,6′), 7.07 (d, 2H, H-3′,5′), 5.62 (brs, 1H, O-**H**), 4.53 (s, 1H, Ar-OH), 1.61 (s, 3H, H-3). ^{13}C NMR (100 MHz, $CDCl_3$): δ 191.3 (C-1), 137.3 (C-1′), 135.5 (C-2′ C-6′), 134.1 (C-3′ C-5′), 129.8 (C-4′), 80.7 (C-2), 25.7 (C-3). MS-EI (*m/z*): 183 [M+1]. Elemental analysis calcd. (found) % for $C_9H_{10}O_4$: C, 59.34 (59.23); H, 5.53 (5.39).

2-Hydroxy-2-(4-cyanophenyl)propionic acid (2g): Yield 85%, m.p.: 196-198 ºC. IR (ATR) (ν_{max}, cm^{-1}): 3462, (O-H), 1733 (C=O), 2234 (C-N), 3049 (Ar C-H), 2867 (sp^3 C-H). ^1H NMR (500 MHz, $CDCl_3$): δ 12.29 (brs, 1H, COO**H**), 7.56 (d, 2H, H-2′,6′), 7.25 (d, 2H, H-3′,5′), 5.75 (br, S, 1H, O-**H**), 1.78 (s, 3H, H-3). ^{13}C NMR (100 MHz, $CDCl_3$): δ 196.7 (C-1), 143.5 (C-1′), 141.2 (C-2′ C-6′), 142.6 (C-3′ C-5′), 144.6 (C-4′), 112.7

(C-N), 83.3 (C-2), 26.5(C-3). MS-EI (*m/z*): 192 [M+1]. Elemental analysis calcd. (found) % for $C_{10}H_9NO_3$: C, 62.82 (62.70); H 4.74 (4.71); N 7.33 (7.18).

2-Hydroxy-2-(4-nitrophenyl)propionic acid (2h): Yield 86%,mp 219-220 ºC. IR (ATR) (ν_{max}, cm^{-1}): 3468 (O-H), 1725 (C=O), 1353 (NO_2), 3041 (Ar C-H), 2858 (sp^3 C-H). ^{1}H NMR (500 MHz, $CDCl_3$): δ 12.31 (brs, 1H, COO**H**), 7.51 (d, 2H, H-2′,6′), 7.31 (d, 2H, H-3′,5′), 5.71 (brs, 1H, O-**H**), 1.77 (s, 3H, H-3). ^{13}C NMR (100 MHz, $CDCl_3$): δ 197.6 (C-1), 143.5 (C-1′), 141.8 (C-2′ C-6′), 140.4 (C-3′ C-5′), 143.7 (C-4′), 81.5 (C-2), 26.8(C-3). MS-EI (*m/z*): 212 [M+1]. Elemental analysis calcd. (found) % for $C_9H_9NO_5$: C, 51.19 (51.09); H, 4.30 (4.23); N, 6.63 (6.59).

2-Hydroxy-2-(4-anisyl)propionic acid (2i): Yield 88%, m.p.: 146.0 °C. IR (ATR) (ν_{max}, cm^{-1}): 3409 (O-H), 1715 (C=O), 3017 (Ar C-H), 2843 (sp^3 C-H). ^{1}H NMR (500 MHz, $CDCl_3$): δ12.45 (brs, 1H, COO**H**), 7.35 (d, 2H, H-2′,6′), 6.89 (d, 2H, H-3′,5′), 5.67 (brs, 1H, O-**H**), 3.74 (s, 3H, OC**H$_3$**), 1.52 (s, 3H, H-3). ^{13}C NMR (100 MHz, $CDCl_3$): δ 192.4 (C-1), 129.5 (C-1′), 128.5 (C-2′ C-6′), 126.5 (C-3′ C-5′), 125.4 (C-4′), 80.9 (C-2), 70.3 (OCH_3), 24.2 (C-3). MS-EI (*m/z*): 197 [M+1]. Elemental analysis calcd. (found) % for $C_{10}H_{12}O_4$: C, 61.22 (61.07); H, 6.16 (6.09).

2-Hydroxy-2-(4-chlorophenyl)propionic acid (2j): Yield 81%, m.p.: 160-162 ºC; IR (ATR) (ν_{max}, cm^{-1}): 3423 (O-H), 1724 (C=O), 3031 (Ar C-H), 2835 (sp^3 C-H). ^{1}H NMR (500 MHz, $CDCl_3$): δ 12.52 (brs, 1H, COO**H**), 7.38 (d, 2H, H-2′,6′), 7.09 (d, 2H, H-3′,5′), 5.45 (br, S, ^{1}H, O-**H**), 1.52 (s, 3H, H-3). ^{13}C NMR (100 MHz, $CDCl_3$): δ 191.9 (C-1), 130.9 (C-1′), 129.9 (C-2′ C-6′), 127.3 (C-3′ C-5′), 125.9 (C-4′), 80.3 (C-2), 25.4 (C-3). MS-EI (*m/z*): 201 [M+1], 202 [M+2]. Elemental analysis calcd. (found) % for $C_9H_9O_3Cl$: C, 53.88 (52.24); H, 4.52 (4.39).

2-Hydroxy-2-(4-bromophenyl)propionic acid (2k): Yield 83%, m.p.: 170-171 ºC. IR (ATR) (ν_{max}, cm^{-1}): 3454 (O-H), 1732 (C=O), 3027 (Ar C-H), 2838 (sp^3 C-H). ^{1}H NMR (500 MHz, $CDCl_3$): δ 12.56 (brs, 1H, COO**H**), 7.41 (d, 2H, H-2′,6′), 7.13 (d, 2H, H-3′,5′), 5.47 (br, S, 1H, O-**H**), 1.53 (s, 3H, H-3). ^{13}C NMR (100 MHz, $CDCl_3$): δ 193.3 (C-1), 130.5 (C-1′), 129.9 (C-2′ C-6′), 127.7 (C-3′ C-5′), 125.1(C-4′), 81.6 (C-2), 25.3 (C-3). MS-EI (*m/z*): 246 [M+1], 247 [M+2]. Elemental analysis calcd. (found) % for $C_9H_9O_3Br$: C, 44.11 (44.01); H , 3.70 (3.55).

(4-Chlorophenyl)(hydroxy)phenylacetic acid (2l): Yield 89%, m.p.: 142-144 ºC. IR (ATR) (ν_{max}, cm^{-1}): 3464 (O-H), 1735 (C=O), 3020 (Ar C-H), 2846 (sp^3 C-H). ^{1}H NMR (500 MHz, $CDCl_3$): δ 12.54 (brs, 1H, COO**H**), 7.42 (d, 2H, H-2′,6′), 7.29 (d, 2H, H-3′,5′),7.19 (d, 2H, C-2″,6″), 7.06 (m, 3H, 3″, 4″,5″), 5.50 (brs, 1H, O-**H**). ^{13}C NMR (100 MHz, $CDCl_3$): δ 192.4 (C-1), 142.1 (C-2′ C-6′), 139.5 (C-1′), 138.7 (C-3′ C-5′), 137.3 (C-4′), 136.6 (C-1″), 132.8 (C-2″ C-6″), 130.4 (C-3″ C-5″), 129.3 (C-4″), 79.1 (C-2). MS-EI (*m/z*): 263 [M+1], 264 [M+2]. Elemental analysis calcd. (found) % for $C_{14}H_{11}O_3Cl$: C, 64.01 (63.94); H, 4.22 (4.12).

***bis*(4-Chlorophenyl)(hydroxy)acetic acid (2m):** Yield 90%, m.p.: 165 ºC. IR (ATR) (ν_{max}, cm^{-1}): 3476 (O-H), 1735 (C=O), 3044 (Ar C-H), 2847 (sp^3 C-H). ^{1}H NMR (500 MHz, $CDCl_3$): δ 12.42 (brs, 1H, COO**H**), 7.46 (d, 2H, H-2′,6′), 7.32 (d, 2H, H-3′,5′), 5.51 (brs, 1H, O-**H**). ^{13}C NMR (100 MHz, $CDCl_3$): δ 194.0 (C-1), 131.5 (C-1′), 129.5 (C-2′ C-6′), 127.1 (C-3′ C-5′), 125.6 (C-4′), 80.0 (C-2). MS-EI (*m/z*): 298 [M+1], 299 [M+2]. Elemental analysis calcd. (found) % for $C_{14}H_{10}O_3Cl_2$: C, 56.59 (56.20); H, 3.39 (3.28).

Hydroxy(phenyl)acetic acid (2n): Yield 90%, m.p.: 156-158 ºC, IR (ATR) (ν_{max}, cm^{-1}): 3399 (O-H), 1723 (C=O), 3019 (Ar C-H). ^{1}H NMR (500 MHz, $CDCl_3$): δ 12.59 (brs, 1H, COO**H**), 7.48 (d, 2H, H-2′,6′), 7.25-7.22 (m, 3H, H-3′,4′,5′) 5.91 (brs, 1H, O-**H**), 5.10 (s, 1H, H-2). ^{13}C NMR (100 MHz, $CDCl_3$): δ 174.4 (C-1), 140.4 (C-1′), 128.4 (C-2′ C-6′), 127.7 (C-3′ C-5′), 126.9(C-4′), 72.7(C-2). MS-EI (*m/z*): 153 [M+1]. Elemental analysis calcd. (found) % for $C_8H_8O_3$: C, 63.15 (63.02); H, 5.30 (5.19).

(4-Chlorophenyl)(hydroxy)acetic acid (2o): Yield 89%, m.p.: 189-190 ºC. IR (ATR) (ν_{max}, cm^{-1}): 3452 (O-H), 1728 (C=O), 3023 (Ar C-H). ^{1}H NMR (500 MHz, $CDCl_3$): δ 12.63 (brs, 1H, COO**H**), 7.48 (d, 2H, H-2′,6′), 7.29-7.21 (m, 3H, H-3′,4′,5′), 5.46 (brs, 1H, O-**H**), 5.14 (s, 1H, H-2). ^{13}C NMR (100 MHz, $CDCl_3$): δ 189.6 (C-1), 141.5 (C-1′), 129.9(C-2′ C-6′), 127.3 (C-3′ C-5′), 125.8 (C-4′), 80.4(C-2). MS-EI (*m/z*): 187 [M+1], 188 [M+2]. Elemental analysis calcd. (found) % for $C_8H_7O_3Cl$: C, 51.49 (51.37); H, 3.78 (3.60).

(4-Bromophenyl)(hydroxy)acetic acid (2p): Yield 88%, m.p.: 192-194 ºC. IR (ATR) (ν_{max}, cm^{-1}): 3448 (O-H), 1726 (C=O), 3029 (Ar C-H). ^{1}H NMR (500 MHz, $CDCl_3$): δ 12.60 (brs, 1H, COO**H**), 7.42 (d, 2H, H-2′,6′), 7.27-7.20 (m, 3H, H-3′,4′,5′), 5.49 (br, S, 1H, O-**H**), 5.16 (s, 1H, H-2). ^{13}C NMR (100 MHz, $CDCl_3$): δ 190.3 (C-1), 142.3 (C-1′), 130.3 (C-2′ C-6′), 126.9 (C-3′ C-5′), 126.3 (C-4′), 80.4 (C-2). MS-EI (*m/z*): 232 [M+1], 233 [M+2]. Elemental analysis calcd. (found) % for $C_8H_7O_3Br$: C, 41.59 (41.32); H, 3.05 (2.99).

(3*E*)-2-Hydroxy-4-phenylbut-3-enoic acid (2q): Yield 78%, m.p.: 177 ºC. IR (ATR) (ν_{max}, cm^{-1}): 3462 (O-H), 1722 (C=O), 3027 (Ar C-H). ^{1}H NMR (500 MHz, $CDCl_3$): δ 12.71 (brs, 1H, COO**H**), 7.39 (d, 2H, H-2′,6′), 7.20-7.15 (m, 3H, H-3′,4′,5′), 5.51 (brs, 1H, O-**H**), 5.15(s, 1H, H-2), 3.43 (s,1H, H-3), 3.25 (s, 1H, H-4). ^{13}C NMR (100 MHz, $CDCl_3$): δ 188.8 (C-1), 140.5 (C-1′), 130.7 (C-2′ C-6′), 127.6 (C-3′ C-5′), 126.1 (C-4′), 116.4 (C-3), 112.6 (C-4), 81.9(C-2). MS-EI (*m/z*): 179 [M+1]. Elemental analysis calcd. (found) % for $C_{10}H_{10}O_3$: C, 67.41 (67.22); H, 5.66 (5.61).

2-(Furan-2-yl)-2-hydroxyacetic acid (2r): Yield 85%, m.p.: 192 ºC. IR (ATR) (ν_{max}, cm^{-1}): 3442 (O-H), 1722 (C=O), 3031 (Ar C-H). ^{1}H NMR (500 MHz, $CDCl_3$): δ 12.66 (brs, 1H, COO**H**), 7.35 (d, 1H, J= 7.67, H-3′), 7.22 (d, 1H, J= 7.48, H-5′), 7.06 (m, 1H, H-4′), 5.38 (brs, 1H, O-**H**), 5.02 (s, 1H, H-2). ^{13}C NMR (100 MHz, $CDCl_3$): δ 189.4 (C-1), 151.3 (C-1′), 149.1 (C-3′), 123.7 (C-5′), 120.4 (C-4′), 83.4(C-2). MS-EI (*m/z*): 143 [M+1]. Elemental analysis calcd. (found) % for $C_6H_6O_4$: C, 50.71 (50.68); H, 4.26 (4.21).

2-Hydroxy-2-(thiophen-2-yl)acetic acid (2s): Yield 83%, m.p.: 187-188 ºC. IR (ATR) (ν_{max}, cm^{-1}): 3452 (O-H), 1729 (C=O), 3033 (Ar C-H). ^{1}H NMR (500 MHz, $CDCl_3$): δ 12.74 (brs, 1H, COO**H**), 7.54 (d, 1H, J_o=7.67, H-3′), 7.27 (d, 1H, J= 7.48, H-5′), 7.11 (m, 1H, H-4′), 5.45 (brs, 1H, O-**H**), 5.14 (s, 1H, H-2). ^{13}C NMR (100 MHz, $CDCl_3$): δ 191.5 (C-1), 149.7

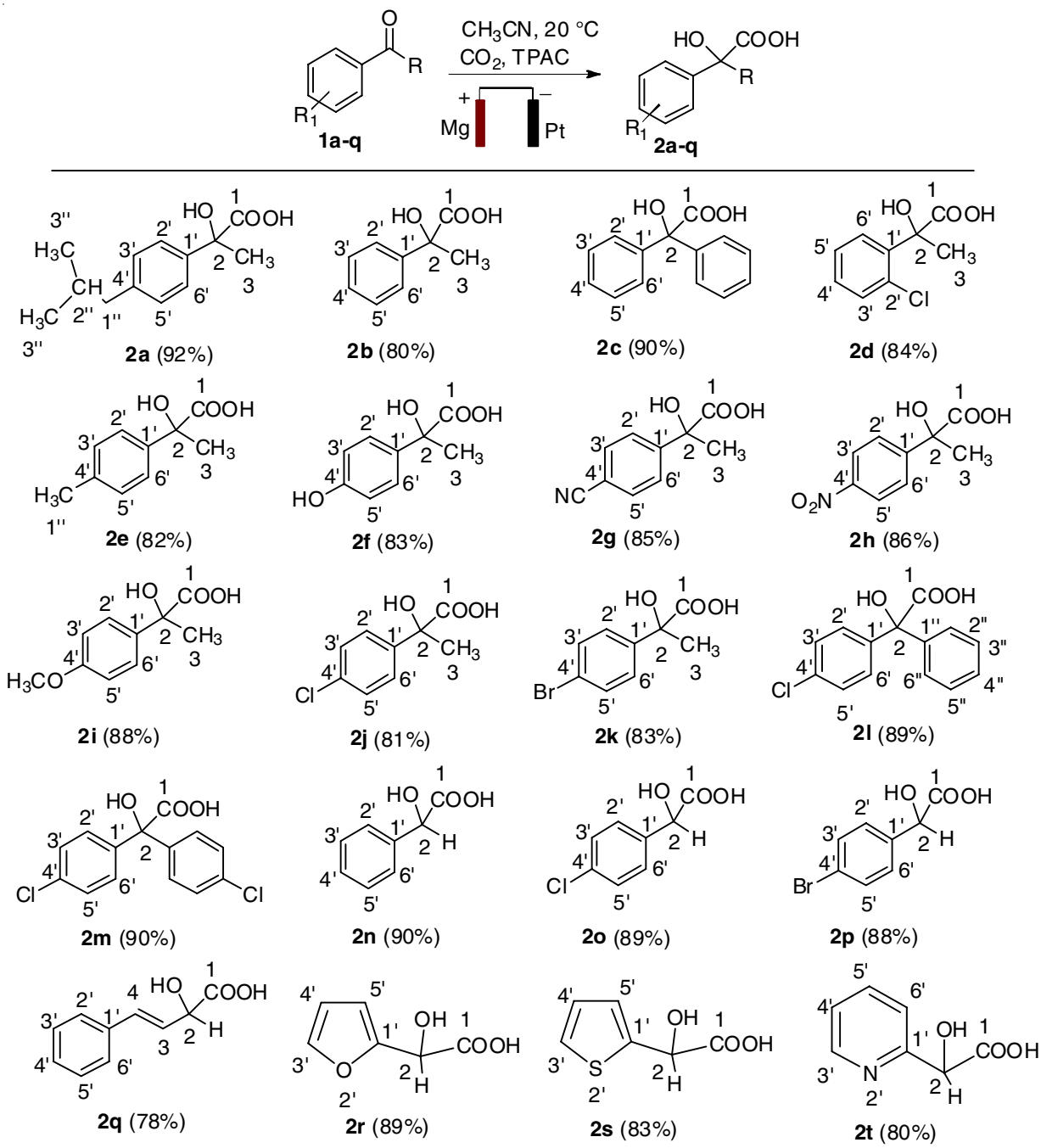
(C-1′), 146.2 (C-3′), 123.4 (C-5′), 120.3(C-4′), 81.2 (C-2). MS-EI (*m/z*): 159 [M+1]. Elemental analysis calcd. (found) % for $C_6H_6O_3S$: C, 46.56 (46.42); H, 3.82 (3.79).

2-Hydroxy-2-(pyridin-2-yl)acetic acid (2t): Yield 77%, m.p.: 197 ºC. IR (ATR) (ν_{max}, cm^{-1}): 3459 (O-H), 1726 (C=O), 3022 (Ar C-H). ^1H NMR (500 MHz, $CDCl_3$): δ 12.78 (brs, 1H, COO**H**), 7.64 (d, 1H, *J* = 7.49, H-3′), 7.41 (d, 1H, *J* = 7.25, H-6′), 7.05 (t, 1H, H-4′), 7.13 (m, 1H, H-5′), 5.57 (br, S, 1H, O-**H**), 5.21(s, 1H, H-2). ^{13}C NMR (100 MHz, $CDCl_3$): δ 189.8 (C-1), 152.6 (C-1′), 149.8 (C-3′), 139.4 (C-5′), 128.0 (C-4′), 122.3 (C-6′), 80.7 (C-2). MS-EI (*m/z*): 154 [M+1]. Elemental analysis calcd. (found) % for $C_7H_7NO_3$: C, 54.90 (54.82); H, 4.61 (4.53).

RESULTS AND DISCUSSION

Screening of reaction conditions: The electrochemical synthesis of α-hydroxycarboxylic acids from aromatic aldehydes/ketones with CO_2 follows a simple protocol (**Scheme-I**). Extensive literature studies helped to build the background to optimize the conditions with 4′-isobutyl acetophenone for various parameters such as electrode material, supporting electrolyte in combination with a suitable solvent, pressure of CO_2 and temperature.

Behaviour of electrode matter and concentrations of substrate: Under the reaction conditions, 4′-isobutylaceto-



Scheme-I: Synthesis of α-hydroxycarboxylic acid derivatives *via* electrocarboxylation method

phenone (0.54 mmol), TPAC (5 mmol), MeCN (100 mL), CO_2 bubbling, 20 °C temperature, the impact of different sacrificial anodes Ni, Al, Mg against Pt as a cathode was critically investigated. Magnesium as sacrificial anode gave the final molecules, 2-hydroxy-2-phenylpropionic acid (**2a**) in an excellent yield of 92% (Table-1, entries 9), while the maximum of 60% and 70% obtained with Ni and Al, respectively (Table-1, entries 1 & 5). In present investigation, it was found that Mg anode with Pt inert cathode is the appropriate combination to proceed with considering other conditions.

TABLE-1
EFFECT OF SRP OF SACRIFICIAL ELECTRODES AND CONCENTRATION ON THE ELECTROCARBOXYLATION OF COMPOUND **2a**

Entry	Sacrificial anode	SRP (Volts)	Conc. (mmol/L)	Yield (%)
1	Ni	-0.23	0.54	60
2	Ni	-0.23	1.08	52
3	Ni	-0.23	1.63	40
4	Ni	-0.23	2.18	28
5	Al	-1.66	0.54	70
6	Al	-1.66	1.08	65
7	Al	-1.66	1.63	58
8	Al	-1.66	2.18	45
9	Mg	-2.36	0.54	92
10	Mg	-2.36	1.08	87
11	Mg	-2.36	1.63	78
12	Mg	-2.36	2.18	65

[a]Electrochemical carboxylation: 4'-Isobutylacetophenone (0.54 mmol), TPAC (5 mmol), MeCN (100 mL)

Relation of current density with temperature variation and pressure of carbon dioxide: To optimize the conditions for other parameters such as current density, temperature and CO_2 pressure. Current density is a crucial factor in electrocarboxylation (Table-2). The experiment was conducted at 10, 15 and 20 mA/cm^2, current density 10 and 20 mA/cm^2 resulted in a lower yield of ompound **2a** however at 15 mA/cm^2 higher Yields were obtained. The appropriate temperature in combination with appropriate carbon dioxide pressure provides better results. After testing with a temperature range from 0-25 ºC, it was found that the yield was low at lower temperature and current density of 10 mA/cm^2 (Table-2, entry-1), the results were better at a slightly higher temperature (20 ºC) and current density of 20 mA/cm^2 (Table-2, entry-17). However, the current density of 15mA/cm^2, CO_2 at 1 atm and temperature 20 ºC was best (Table-2, entries 11 & 12) to get higher yield 92% (Table-2, entry-11).

Effect of supporting electrolyte and solvents: The results of different supporting electrolytes (TPAB, TPAC and $TBABF_4$) with solvents (MeCN, *n*-butanol and *n*-pentanol) are summarized in Table-3 on the yield of reference ketone and aldehyde. Among these solvents, MeCN with the supporting electrolytes TPAC produced 92% of compound **2a** and 90% of compound **2n**. However, solvents like *n*-butanol and *n*-pentanol were difficult to remove, so it was assumed that the yields of the product also lost while evaporating such kinds of solvents.

To generalize the reaction, various substituted aldehydes and ketones were reacted with carbon dioxide under similar reaction conditions and observed that reactions proceed smoothly and desired molecules were collected in excellent Yield and purity. The compounds were further purified by simple crystallization in ethanol.

TABLE-2
OPTIMIZATION OF CURRENT DENSITY AND TEMPERATURE FOR THE SYNTHESIS OF COMPOUND **2a**

Entry	Current density (mA, cm^2)	Temperature (°C)	Yield[a] (%)
1	10	0	60
2	10	5	63
3	10	10	68
4	10	15	73
5	10	20	77
6	10	25	75
7	15	0	65
8	15	5	72
9	15	10	77
10	15	15	81
11	15	20	92
12	15	25	90
13	20	0	63
14	20	5	66
15	20	10	71
16	20	15	74
17	20	20	80
18	20	25	77

[a]Electrochemical carboxylation: 4'-Isobutylacetophenone (0.54 mmol), TPAC (5 mmol), MeCN (100 mL), Mg anode and Pt cathode

TABLE-3
OPTIMIZATION OF SUPPORTING ELECTROLYTE AND SOLVENT FOR THE SYNTHESIS OF COMPOUNDS **2a** AND **2n**

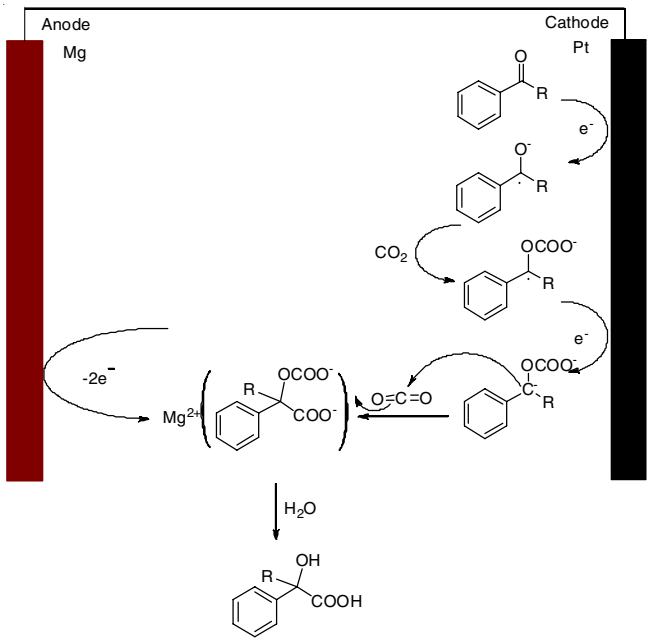
Entry	Supporting electrolyte	Solvent	Yield[a] (%)	
			Ketone (**2a**)	Aldehyde (**2n**)
1	TPAB	MeCN	78	75
2	TPAB	*n*-Butanol	73	73
3	TPAB	*n*-Pentanol	69	68
4	TPAC	MeCN	92	90
5	TPAC	*n*-Butanol	83	80
6	TPAC	*n*-Pentanol	76	75
7	$TBABF_4$	MeCN	85	84
8	$TBABF_4$	*n*-Butanol	81	77
9	$TBABF_4$	*n*-Pentanol	80	74

[a]Electrochemical carboxylation: 4'-Isobutylacetophenone (0.54 mmol), Mg anode and Pt cathode

Spectroscopic analysis: The structural analysis for the conformation of compound **2a** was done with the spectral techniques. In IR spectrum absorption at 3420 cm^{-1} represents the O-H stretching, absorption at 3019 and 2832 cm^{-1} for aromatic and sp^3 hybridized C-H bond, an absorption band at 1723 cm^{-1} corresponds to C=O stretching. In ^{1}H NMR spectra, two broad singlets at δ 12.67 and δ 5.57 ppm corresponds to COO**H** and O**H** protons respectively. Two doublets at δ 7.28 (for H-2′,6′) and δ 6.92 (for H-3′,5′) ppm were observed in the aromatic region, peaks for the alkyl substituent's were observed at their respective position. For example, a singlet for three hydrogens at δ 1.41 ppm for H-3, doublet at for two hydrogen δ 2.53 ppm for H-1″, multiplet for one hydrogen at δ 1.91 ppm for H-2″ and singlet for six hydrogens at δ 0.91 ppm. In the ^{13}C NMR

spectra, a peak at δ 197.9 ppm corresponds to the C-1 carbon atom. Peaks at δ 147.6, 134.9, 129.2 and 128.3 ppm belong to aromatic carbons C-1′, C-2′,6′, C-3′,5′ and C-4′, respectively. Peaks for the other carbon atoms observed at δ 70.2, 26.5, 45.3, 30.2 and 22.3 ppm for the carbon atoms C-2, C-3, C-1″, C-2″ and C-3″, respectively. Other spectral data like mass and elemental analysis of compound **2a** fully supports the structure assigned to it.

Mechanistic studies: Attempts have been made to explain the plausible mechanism of the synthesis of α-substituted carboxylic acid using Mg as sacrificial anode and Pt as an inert cathode (**Scheme-II**). Based on the literature survey [27,28] the mechanism has been drawn. In the beginning steps, ketone/aldehyde takes an electron from the cathode and reduces to anion radical, which had fewer tendencies to dimerize, due to the charge repulsion effect. Then oxygen anions fixed one molecule of CO_2 and the radical again captures one more electron to form carboanion which further captures one CO_2 molecule and gave the final product α-hydroxycarboxylic acid upon hydrolysis. At higher carbon dioxide concentration (1 atm), the intermediate radical was promptly trapped and getting converted into the favoured product. However, the product yield decreases with the decrease in pressure of the gas and there is not much impact on the yield with the increase in pressure beyond 1 atm.



Scheme-II: Plausible mechanism for electrocarboxylation of various substituted aldehydes and ketones

Conclusion

In conclusion, various α-hydroxycarboxylic acids have been prepared from different aldehydes and ketones with CO_2 in a single step by atom economy electrocarboxylation method with inherent flexibility and diversity. The targeted compounds are obtained in 80-92% of yield without any side product and can be purified by simple recrystallization with ethanol. Further, it was observed that the presence of electron withdrawing group enhance the rate of reaction and reduced by electron donating group.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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