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ORIGINAL PAPER

Synthesis and characterization of monoaryl esters of L-tartaric acid and their process for fries rearrangement

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Abstract Chiral protected monoaryl esters (**2a–2h**) were synthesized from monoester of L-tartaric acid, having two asymmetric centers and C2 axis of symmetry. L-tartaric acid was protected and partially hydrolyzed to give the corresponding monoester. Monoester upon treatment with different substituted phenols gave desired monoaryl esters (**2a–2h**). Fries rearrangement of monoaryl esters was then tried under various conditions by using different Lewis acids. All the compounds were purified and characterized by using spectroscopic techniques like IR, ^{1}H-NMR, ^{13}C-NMR, HRMS-ESI, and elemental analysis. The structure of compound **2e** was obtained by X-ray crystallography.

Keywords L-Tartaric acid · Protection · Monoaryl esters · Fries rearrangement

Introduction

Tartaric acid is an important optically active compound. It has been used to study the stereochemistry. The different derivatives of tartaric acid have wide applications in the synthesis of numerous chiral building blocks [1–3]. In addition, it is also used as a precursor of chiral ligands, auxiliaries, and resolving agents [4–8]. Among the derivatives of tartaric acid, its dialkyl esters are most frequently used, not only for the preparation of other tartaric acid derivatives but also in asymmetric catalysis, for example, as chiral ligands in the Sharpless asymmetric epoxidation [9, 10], kinetic resolution of racemic allyl alcohols [11, 12], asymmetric synthesis of sulfoxides by the Kagan-Modena method [13–16], asymmetric Simmons-Smith reaction [17–20], asymmetric allylation [21–23], asymmetric allylboration developed by Roush [24, 25], and homoallenylboration of aldehydes developed by Brown [26].

Keeping in view the importance of L-tartaric acid derivatives, we planned to synthesize some new chiral substrates of potential value for synthetic and biological applications.

Experimental

Materials and methods

All chemicals were of highest purity available and used as supplied. Dry solvents like methanol, dichloromethane, chloroform, and *n*-hexane were obtained by distillation using standard procedures or by passage through a column of anhydrous alumina using equipment from anhydrous engineering (University of Bristol, UK) based on the Grubbs' design. Reactions were carried out under anhydrous conditions using three-way stopcock and rubber septa.

All reactions were monitored by TLC on Kieselgel 60 F254 (Merck), and ethyl acetate/*n*-Hexane and methanol/chloroform were used as eluents.

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Column chromatography was performed using silica gel [Merck, 230–400 mesh (40–63 μm)]. Melting points were determined in degree Celsius (°C) using Gallenkamp digital melting point apparatus and are uncorrected. IR spectra were recorded on Bruker IFS 66 (FT IR), Nicolet 205 FT IR; Nicolet 360 smart orbit (ATR); thermo scientific Nicolet 6700 FT IR and Schimadzu Fourier Transform Infrared Spectrophotometer Model 270. ^{1}H NMR spectra were recorded on NMR Bruker apparatus at 300 MHz and varian 400 MHz INOVA instrument. ^{13}C NMR spectra were recorded on NMR Bruker apparatus at 75 MHz and varian 100 MHz INOVA instrument. The optical rotations of the compounds were measured on ATAGO, AP-100 automatic polarimeter. Single-crystal X-ray diffraction data were collected on Bruker Smart APEX II, CCD 4-K area detector diffractometer [27]. Data reductions were performed by using SAINT program. The structure was solved by direct method [28] and refined by full-matrix least squares on F2 by using the SHELXTL-PC package [29]. The figures were plotted with the aid of ORTEP program [30].

General procedure for the synthesis of 1,3-dioxolane dimethyl-L-tartrate (1)

In a round bottom flask (250 ml), dimethyl-L-tartrate (35.60 g, 200 mmol) and catalytic amount of camphor sulfonic acid were placed under nitrogen. Dimethylformamide (DMF) (100 ml) was added through a syringe and stirred with a magnetic stirrer. 2-Methoxypropene (22.90 ml, 240 mmol,) was added drop wise over 1 h and left overnight. After completion of the reaction as monitored by TLC, water (300 ml) was added to the reaction mixture and extracted with ethyl acetate (100 ml × 3). The organic layer was washed with saturated $NaHCO_3$ (100 ml × 2), water, and brine (100 × 3). The combined organic layer was dried over anhydrous magnesium sulfate; the crude was purified by column chromatography using ethyl acetate: *n*-hexane (2:8) as eluent.

Light yellow oil. Yield: 89 %. IR (neat) cm^{-1}: 2928 (CH), 1738 (CO). ^{1}H NMR (300 MHz, $CDCl_3$): δ (ppm): 4.78 (s, 2H, CH), 3.80 (s, 6H, OCH_3) 1.47 (s, 6H, CH_3). ^{13}C NMR (75 MHz, $CDCl_3$): δ (ppm): 170.0 (C=O), 113.8 (qt C), 76.6 (CH), 52.7 (OCH_3), 26.2 (CH_3).

General procedure for the synthesis of monoester (2)

In a round bottom flask (250 ml), a solution of compound **1** (22.74 ml, 120 mmol) in methanol (30 ml) was added to a solution of NaOH (4.80 g, 120 mmol) in methanol (30 ml) over a period of 1 h. The reaction mixture was stirred at room temperature for an additional 1 h and methanol was evaporated under reduced pressure to give a residue. Water (30 ml) was added and extracted with Dichloromethane (DCM) (30 ml × 3) to recover some unreacted diester. The aqueous layer was acidified with $KHSO_4$ (1 M) and extracted with DCM (30 ml × 3). The solvent was evaporated and the crude was purified by column chromatography using methanol:dichloromethane (2:8) as eluent.

Colorless oil. Yield: 79 %. IR (neat) cm^{-1}: 3467 (OH), 2928 (CH), 1730 ($COOCH_3$), 1708 (COOH). ^{1}H NMR (300 MHz, $CDCl_3$): δ (ppm): 9.31 (bs, 1H, OH), 4.87 (d, J = 5.4 Hz, 1H, CH), 4.82 (d, J = 5.4 Hz, 1H, CH), 3.82 (s, 3H, OCH_3), 1.49 (s, 3H, CH_3), 1.47 (s, 3H, CH_3). ^{13}C NMR (75 MHz, $CDCl_3$): δ (ppm): 173.8 (COOH), 169.7 ($COOCH_3$), 114.1 (qt C), 76.5 (CH), 76.3 (CH), 52.8 (OCH_3), 26.1 (CH_3), 25.5 (CH_3). HRMS-ESI for $C_8H_{12}O_6$: (M-H) calcd: 203.0634, found: 203.0570. EI-MS *m/z* (%): 204.0 M^+ (10.6), 189.1 (35.9), 59.0 (100).

General procedure for the synthesis of monoaryl esters (2a–2h)

In a round bottom flask (100 ml), compound (**2**) (0.61 g, 3 mmol) in DCM (30 ml), 1-ethyl-3-(3-dimethylaminopropyl) carbodiimide (EDC) (0.68 g, 3.6 mmol), and catalytic amount of 4-dimethylaminopyridine (DMAP) were placed under nitrogen. After half an hour substituted phenol (3 mmol) was added and stirred for 4–12 h. After the completion of the reaction, by-product urea was removed by extraction with ethyl acetate or chloroform and water (30 × 3). Crude was purified by column chromatography using ethyl acetate: *n*-hexane (3:7) as eluent.

(4*R*,5*R*)-4-Methyl-5-phenyl-2,2-dimethyl-1,3-dioxolane-4,5-dicarboxylate (2a)

Yield: 78 %. Colorless oil. $[\alpha]_D^{25} = 72.58°$ (c = 24 mg/2 ml CH_2Cl_2). (IR υ cm^{-1}): 2992 (CH), 1756 (COOPh), 1732 ($COOCH_3$) 1592 (Ar), 1324 (C–O–C). ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm): 7.44–7.14 (m, 5H, Ar–H), 5.06 (d, 1H, J = 5.3 Hz, CH), 4.99 (d, 1H, J = 5.3 Hz, CH), 3.87 (s, 3H, O-CH_3), 1.58 (s, 3H, CH_3), 1.51 (s, 3H, CH_3). ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm): 170.7 (COOPh), 168.5 ($COOCH_3$), 150.8 (Ar–C–OR), 129.6, 126.5, 121.8 (Ar–C), 114.7 (qt, C), 76.5 (CH), 75.2 (CH), 53.4 (OCH_3), 26.3 (CH_3), 25.1 (CH_3). HRMS-ESI for $C_{14}H_{16}O_6$ Na: $[M+Na]^+$ calcd: 303.0945, found: 303.0845. Anal. Calc. For $C_{14}H_{16}O_6$: C, 59.99; H, 5.75; O, 34.25. Found C, 59.96; H, 5.77; O, 34.27.

(4*R*,5*R*)-4-Methyl-5-*p*-tolyl-2,2-dimethyl-1,3-dioxolane-4,5-dicarboxylate (2b)

Yield: 83 %. Yellow Oil. $[\alpha]_D^{25} = 70.51°$ (c = 24 mg/2 ml CH_2Cl_2). (IR υ cm^{-1}): 2994 (CH), 1751 (COOPh), 1730 ($COOCH_3$), 1590 (Ar), 1321 (C–O–C). ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm): 7.54 (d, J = 8.3 Hz, 2H, Ar–H), 6.99 (d, J = 8.4 Hz, 2H Ar–H), 5.03 (d, 1H,

J = 5.3 Hz, CH), 4.96 (d, 1H, J = 5.3 Hz, CH), 3.85 (s, 3H, O-CH_3), 2.35 (s, 3H, Ar–CH_3), 1.56 (s, 3H, CH_3), 1.46 (s, 3H, CH_3). ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm): 170.3 (COOPh), 169.4 ($COOCH_3$), 147.5 (Ar–C–OR), 136.4, 130.5, 120.9 (Ar–C), 113.7 (qt, C), 75.3 (CH), 74.3 (CH), 52.5 (O–CH_3), 26.6 (CH_3), 25.6 (CH_3), 20.4 (Ar–CH_3). HRMS-ESI for $C_{15}H_{18}O_6$ Na: $[M+Na]^+$ calcd: 317.1001, found: 317.0984. Anal. Calc. For $C_{15}H_{18}O_6$: C, 61.22; H, 6.16; O, 32.62 Found C, 61.25; H, 6.13; O, 32.66.

(4*R*,5*R*)-4-(3-Bromophenyl)-5-methyl-2,2-dimethyl-1,3-dioxolane-4,5-dicarboxylate (2c)

Yield: 85 %. Yellow Oil. $[\alpha]_D^{25}$ = 54.17° (c = 24 mg/2 ml CH_2Cl_2). (IR υ cm^{-1}): 2984 (CH), 1751 (COOPh), 1722 ($COOCH_3$), 1594 (Ar), 1311 (C–O–C), 563 (C–Br). ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm): 7.39 (s, 1H, Ar–H), 7.36–7.30 (m, 3H, Ar–H) 5.00 (d, 1H, J = 5.5 Hz, CH), 4.92 (d, 1H, J = 5.5 Hz, CH) 3.83 (s, 3H, O-CH_3), 1.55 (s, 3H, CH_3), 1.51 (s, 3H, CH_3). ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm): 170.5 (COOPh), 169.8 ($COOCH_3$), 150.5 (Ar–C–OR), 130.4, 129.6, 124.7, 122.5 (Ar–C), 114.1 (qt, C), 76.3 (CH), 75.6 (CH), 53.4 (OCH_3), 26.8 (CH_3), 25.4 (CH_3). HRMS-ESI for $C_{14}H_{15}BrO_6$ Na: $[M+Na]^+$ calcd: 380.9950, found: 380.9948. Anal. Calc. For $C_{14}H_{15}BrO_6$: C, 48.28; H, 4.59; Br, 21.41; O, 25.72 Found C, 48.30; H, 4.56; Br, 21.44; O, 25.70.

(4*R*,5*R*)-4-(3-Chloro-4-methylphenyl)-5-methyl-2,2-dimethyl-1,3-dioxolane-4,5-dicarboxylate (2d)

Yield: 87 %. Yellow oil. $[\alpha]_D^{25}$ = 60.35° (c = 24 mg/2 ml CH_2Cl_2). (IR υ cm^{-1}): 2983 (CH), 1747 (COOPh), 1723 ($COOCH_3$) 1581 (Ar), 1316 (C–O–C), 736 (C–Cl). ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm): 7.63 (s, 1H, Ar–H), 6.95 (d, J = 8.4 Hz, 2H, Ar–H), 5.01 (d, 1H, J = 4.9 Hz, CH), 4.94 (d, 1H, J = 4.9 Hz, CH), 3.85 (s, 3H, OCH_3), 2.35 (s, 3H, Ar–CH_3), 1.56 (s, 3H, CH_3), 1.46 (s, 3H, CH_3). ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm): 169.6 (COOPh), 168.2 ($COOCH_3$), 148.5 (Ar–C–OR), 134.4, 134.1, 131.3, 121.5, 119.7 (Ar–C), 114.6 (qt, C), 75.5 (CH), 74.3 (CH), 53.5 (O–CH_3), 26.8 (CH_3), 25.8 (CH_3), 19.7 (Ar-CH_3). HRMS-ESI for $C_{15}H_{17}ClO_6$ Na: $[M+Na]^+$ calcd: 351.0611, found: 351.0602. Anal. Calc. For $C_{15}H_{17}ClO_6$: C, 54.80; H, 5.21; Cl, 10.78; O, 29.20 Found C, 54.83; H, 5.24; Cl, 10.75; O, 29.17.

(4*R*,5*R*)-4-(3-Bromo-4-methylphenyl)-5-methyl-2,2-dimethyl-1,3-dioxolane-4,5-dicarboxylate (2e)

Yield: 78 %. White crystalline solid m.p 145–146 °C. $[\alpha]_D^{25}$ = 61.14° (c = 24 mg/2 ml CH_2Cl_2). (IR υ cm^{-1}): 2980 (CH), 1748 (COOPh), 1736 ($COOCH_3$), 1580 (Ar), 1326 (C–O–C), 559 (C–Br). ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm): 7.35 (s, 1H, Ar–H), 6.99 (d, J = 8.4 Hz, 2H Ar–H), 5.02 (d, 1H, J = 5.0 Hz, CH), 4.94 (d, 1H, J = 5.0 Hz, CH), 3.86 (s, 3H, OCH_3), 2.39 (s, 3H, Ar–CH_3), 1.55 (s, 3H, CH_3), 1.45 (s, 3H, CH_3). ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm): 169.9 (COOPh), 168.3 ($COOCH_3$), 148.5 (Ar–C–OR), 136.7, 131.8, 125.5, 124.3, 120.3 (Ar–C), 114.8 (qt, C), 76.1 (CH), 75.3 (CH), 53.6 (OCH_3), 26.7 (CH_3), 25.5 (CH_3), 22.3 (Ar–CH_3). HRMS-ESI for $C_{15}H_{17}BrO_6$ Na: $[M+Na]^+$ calcd: 395.0106, found: 395.0209. Anal. Calc. For $C_{15}H_{17}BrO_6$: C, 48.28; H, 4.59; Br, 21.41; O, 25.72 Found C, 48.30; H, 4.57; Br, 21.44; O, 25.70.

(4*R*,5*R*)-4-Methyl-5-*m*-tolyl-2,2-dimethyl-1,3-dioxolane-4,5-dicarboxylate (2f)

Yield: 80 %. Brown Oil. $[\alpha]_D^{25}$ = 74.51° (c = 24 mg/2 ml CH_2Cl_2). (IR υ cm^{-1}): 2983 (CH), 1753 (COOPh), 1733 ($COOCH_3$), 1581 (Ar), 1321 (C–O–C). ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm): 7.38 (s, 1H, Ar–H), 7.05–6.99 (m, 3H Ar–H), 5.03 (d, 1H, J = 5.3 Hz, CH), 4.96 (d, 1H, J = 5.3 Hz, CH), 3.85 (s, 3H, OCH_3), 2.36 (s, 3H, Ar–CH_3), 1.56 (s, 3H, CH_3), 1.46 (s, 3H, CH_3). ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm): 169.7 (COOPh), 168.6 ($COOCH_3$), 150.7 (Ar–C–OR), 139.7, 129.6, 127.6, 121.0, 118.2 (Ar–C), 114.6 (qt, C), 76.3 (CH), 75.5 (CH), 53.5 (OCH_3), 26.7 (CH_3), 25.7 (CH_3), 21.8 (Ar–CH_3). HRMS-ESI for $C_{15}H_{18}O_6$ Na: $[M+Na]^+$ calcd: 317.1001, found: 317.0984. Anal. Calc. For $C_{15}H_{18}O_6$: C, 61.22; H, 6.16; O, 32.62 Found C, 61.25; H, 6.18; O, 32.60.

(4*R*,5*R*)-4-(2-Bromophenyl)-5-methyl-2,2-dimethyl-1,3-dioxolane-4,5-dicarboxylate (2g)

Yield: 74 %. Brown Oil. $[\alpha]_D^{25}$ = 49.15° (c = 24 mg/2 ml CH_2Cl_2). (IR υ cm^{-1}): 2973 (CH), 1749 (COOPh), 1727 ($COOCH_3$), 1591 (Ar), 1311 (C–O–C), 567 (C–Br). ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm): 7.63–7.14 (m, 4H, Ar–H), 5.15 (d, 1H, J = 5.4 Hz, CH), 5.11 (d, 1H, J = 5.4 Hz, CH), 3.86 (s, 3H, O–CH_3), 1.55 (s, 3H, CH_3), 1.45 (s, 3H, CH_3). ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm): 169.9 (COOPh), 167.8 ($COOCH_3$), 147.9 (Ar–C–OR), 133.8, 128.7, 127.5, 123.6 (Ar–C), 114.6 (qt, C), 76.1 (CH), 75.3 (CH), 52.7 (OCH_3), 26.3 (CH_3), 25.7 (CH_3). HRMS-ESI for $C_{14}H_{15}BrO_6$ Na: $[M+Na]^+$ calcd: 380.9950, found: 380.9946. Anal. Calc. For $C_{14}H_{15}BrO_6$: C, 48.28; H, 4.59; Br, 21.41; O, 25.72 Found C, 48.31; H, 4.53; Br, 21.40; O, 25.70.

(4*R*,5*R*)-4-(2,4-Dichlorophenyl)-5-methyl-2,2-dimethyl-1,3-dioxolane-4,5-dicarboxylate (2h)

Yield: 69 %. Brown Oil. $[\alpha]_D^{25}$ = 61.15° (c = 24 mg/2 ml CH_2Cl_2). (IR υ cm^{-1}): 2983 (CH), 1748 (COOPh), 1724 ($COOCH_3$), 1581 (Ar), 1321 (C–O–C), 765 (C–Cl). ^{1}H

NMR (400 MHz, $CDCl_3$): δ (ppm): 7.48 (s, 1H, Ar–H), 7.13 (d, J = 8.1 Hz, 1H, Ar–H), 6.93 (d, J = 8.1 Hz, 1H, Ar–H), 5.12 (d, 1H, J = 5.0 Hz, CH), 5.02 (d, 1H, J = 5.0 Hz, CH), 3.86 (s, 3H, O-CH_3), 1.56 (s, 6H, CH_3). ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm): 170.6 (C=OOPh), 169.4 (C=OOCH_3), 145.7 (Ar–C–OR), 132.8, 130.5, 128.9, 127.4, 124.7 (Ar–C), 114.7 (qt, C), 75.8 (CH), 74.9 (CH), 53.8 (OCH_3), 26.3 (CH_3), 25.5 (CH_3). HRMS-ESI for $C_{14}H_{14}Cl_2O_6$ Na: $[M+Na]^+$ calcd: 371.0065, found: 371.0069. Anal. Calc. For $C_{14}H_{14}Cl_2O_6$: C, 48.16; H, 4.04; Cl, 20.31; O, 27.49 Found C, 48.13; H, 4.06; Cl, 20.35; O, 27.47.

General procedure for the synthesis of compounds (3a–3h)

In a round bottom flask (100 ml), solution of monoaryl ester (**2a–2h**) (1 eq) in DCM was stirred at 0 °C. $BF_3.Et_2O$ (2 eq) was added drop wise under nitrogen atmosphere. The reaction mixture was then allowed to warm to room temperature and stirred overnight. After the completion as indicated by thin layer chromatography (TLC), solvent was evaporated under reduced pressure. The crude was dissolved in ethyl acetate (30 ml), and then washed with water and brine (30 ml × 3). The organic layer was dried over anhydrous magnesium sulfate. The crude was further purified by column chromatography using methanol: chloroform (2:8) as eluent.

(2*R*,3*R*)-1-Methyl-4-phenyl-2,3-dihydroxysuccinate (3a)

Yield: 86 %. White solid m.p 75–77 °C. $[\alpha]_D^{25}$ = 73.51° (c = 24 mg/2 ml CH_2Cl_2). (IR υ cm^{-1}): 3508 (OH), 2965 (CH), 1749 (COOPh), 1733 (C=OOCH_3), 1589 (Ar), 1314 (C–O–C). ^{1}H NMR (300 MHz, $CDCl_3$): δ (ppm): 7.45-7.15 (m, 5H, Ar–H), 4.84 (d, 1H, J = 5.5 Hz, CH), 4.80 (d, 1H, J = 5.5 Hz, CH), 3.91 (s, 3H, OCH_3), 3.25 (bs, 2H, OH). ^{13}C NMR (75 MHz, $CDCl_3$): δ (ppm): 171.3 (C=OOPh), 170.5 (C=OOCH_3), 150.7 (Ar–C–OR), 129.9, 126.3, 121.7 (Ar–C), 74.5 (CH), 73.5 (CH), 53.9 (OCH_3). Anal. Calc. For $C_{11}H_{12}O_6$: C, 55.00; H, 5.04; O, 39.96 Found C, 55.03; H, 5.07; O, 39.94.

(2*R*,3*R*)-1-Methyl-4-*p*-tolyl-2,3-dihydroxysuccinate (3b)

Yield: 78 %. White solid m.p 112-114 °C. $[\alpha]_D^{25}$ = 70.41° (c = 24 mg/2 ml CH_2Cl_2). (IR υ cm^{-1}): 3528 (OH), 2975 (CH), 1743 (COOPh), 1731 (C=OOCH_3), 1579 (Ar), 1311 (C–O–C). ^{1}H NMR (300 MHz, $CDCl_3$): δ (ppm): 7.43 (d, J = 8.9 Hz, 2H, Ar–H), 7.06 (d, J = 8.8 Hz, 2H, Ar–H), 4.82 (d, 1H, J = 5.4 Hz, CH), 4.79 (d, 1H, J = 5.4 Hz, CH), 3.92 (s, 3H, OCH_3), 3.28 (bs, 2H, OH), 2.37 (s, 3H, Ar–CH_3). ^{13}C NMR (75 MHz, $CDCl_3$): δ (ppm): 171.6 (C=OOPh), 170.1 (C=OOCH_3), 148.7 (Ar–C–OR), 136.8, 130.5, 120.3 (Ar–C), 75.1 (CH), 74.1 (CH), 53.7 (OCH_3), 20.7 (Ar–CH_3). Anal. Calc. For $C_{12}H_{14}O_6$: C, 56.69; H, 5.55; O, 37.76 FoundC, 56.64; H, 5.51; O, 37.73.

(2*R*,3*R*)-1-(3-Bromophenyl)-4-methyl-2,3-dihydroxysuccinate (3c)

Yield: 81 %. Colorless Oil. $[\alpha]_D^{25}$ = 51.25° (c = 24 mg/2 ml CH_2Cl_2). (IR υ cm^{-1}): 3538 (OH), 2985 (CH), 1748 (COOPh), 1724 (C=OOCH_3), 1569 (Ar), 1321 (C–O–C), 550 (C–Br).

^{1}H NMR (300 MHz, $CDCl_3$): δ (ppm): 7.41 (s, 1H, Ar–H), 7.37–7.31 (m, 3H, Ar–H) 5.06 (d, 1H, J = 4.9 Hz, CH), 4.96 (d, 1H, J = 4.9 Hz, CH), 3.86 (s, 3H, OCH_3), 3.27 (bs, 2H, OH). ^{13}C NMR (75 MHz, $CDCl_3$): δ (ppm): 171.5 (C=OOPh), 170.3 (C=OOCH_3), 148.8 (Ar–C–OR), 132.7, 130.4, 127.6, 126.2 (Ar–C), 75.4 (CH), 73.9 (CH), 52.6 (O–CH_3). Anal. Calc. For $C_{11}H_{11}BrO_6$: C, 41.40; H, 3.47; Br, 25.04; O, 30.08 Found C, 41.42; H, 3.49; Br, 25.01; O, 30.10.

(2*R*,3*R*)-1-(3-Chloro-4-methylphenyl)-4-methyl-2,3-dihydroxysuccinate (3d)

Yield: 77 %. Yellow Oil. $[\alpha]_D^{25}$ = 67.25° (c = 24 mg/2 ml CH_2Cl_2). (IR υ cm^{-1}): 3548 (OH), 2982 (CH), 1745 (COOPh), 1733 (C=OOCH_3), 1567 (Ar), 1323 (C–O–C), 766 (C–Cl).

^{1}H NMR (300 MHz, $CDCl_3$): δ (ppm): 7.33 (s, 1H, Ar–H), 7.12 (d, J = 8.4 Hz, 2H Ar–H), 5.11 (d, 1H, J = 5.5 Hz, CH), 4.92 (d, 1H, J = 5.5 Hz, CH), 3.87 (s, 3H, OCH_3), 3.30 (bs, 2H, OH), 2.35 (s, 3H, Ar–CH_3). ^{13}C NMR (75 MHz, $CDCl_3$): δ (ppm): 170.5 (C=OOPh), 169.8 (C=OOCH_3), 147.4 (Ar–C–OR), 134.9, 134.5, 131.4, 120.7, 117.3 (Ar–C), 74.7 (CH), 73.7 (CH), 53.6 (O–CH_3), 19.8 (Ar-CH_3). Anal. Calc. For $C_{12}H_{13}ClO_6$: C, 49.93; H, 4.54; Cl, 12.28; O, 33.25 Found C, 49.91; H, 4.51; Cl, 12.25; O, 33.27.

(2*R*,3*R*)-1-(3-Bromo-4-methylphenyl)-4-methyl-2,3-dihydroxysuccinate (3e)

Yield: 72 %. White solid. m.p = 176-177 °C. $[\alpha]_D^{25}$ = 68.15° (c = 24 mg/2 ml CH_2Cl_2). (IR υ cm^{-1}): 3541 (OH), 2980 (CH), 1747 (COOPh), 1731 (C=OOCH_3), 1568 (Ar), 1320 (C–O–C), 566 (C–Br). ^{1}H NMR (300 MHz, $CDCl_3$): δ (ppm): 7.57 (s, 1H, Ar–H), 7.13 (d, J = 8.4 Hz, 2H Ar–H), 5.13 (d, 1H, J = 5.4 Hz, CH),4.99 (d, 1H, J = 5.4 Hz, CH), 3.86 (s, 3H, OCH_3), 3.29 (bs, 2H, OH), 2.39 (s, 3H, Ar–CH_3). ^{13}C NMR (75 MHz, $CDCl_3$): δ (ppm): 170.3 (C=OOPh), 169.9 (C=OOCH_3), 149.7 (Ar–C–OR), 137.5, 133.1, 128.0, 124.9, 120.9 (Ar–C), 75.0 (CH), 74.6 (CH),

52.3 (O<u>C</u>H$_3$), 22.6 (Ar–<u>C</u>H$_3$). Anal. Calc. For $C_{12}H_{13}BrO_6$: C, 43.26; H, 3.93; Br, 23.99; O, 28.82 Found C, 43.25; H, 3.95; Br, 23.97; O, 28.84.

(2*R*,3*R*)-1-Methyl-4-*m*-tolyl-2,3-dihydroxysuccinate (3f)

Yield: 79 %. Colorless oil. $[\alpha]_D^{25} = 74.51°$ (c = 24 mg/2 ml CH_2Cl_2). (IR υ cm^{-1}): 3531 (OH), 2960 (CH), 1750 (COOPh), 1732 (COOCH$_3$), 1569 (Ar), 1310 (C–O–C). ^{1}H NMR (300 MHz, $CDCl_3$): δ (ppm): 7.32 (s, 1H, Ar–H), 7.12-6.99 (m, 3H Ar–H), 4.83 (dd, J = 6.9, 2.4 Hz, 1H, CH), 4.80 (dd, J = 6.9, 2.4 Hz, 1H, CH), 3.91 (s, 3H, OCH$_3$), 3.40 (d, J = 6.9 Hz, 1H, OH), 3.35 (d, J = 7.2 Hz, 1H, OH), 2.38 (s, 3H, Ar–CH$_3$). ^{13}C NMR (75 MHz, $CDCl_3$): δ (ppm): 171.3 (<u>C</u>OOPh), 170.2 (<u>C</u>OOCH$_3$), 150.9 (Ar–<u>C</u>–OR), 139.5, 129.1, 127.8, 121.2, 118.5 (Ar–<u>C</u>), 74.6 (<u>C</u>H), 73.3 (<u>C</u>H), 53.8 (O–<u>C</u>H$_3$), 21.7 (Ar–<u>C</u>H$_3$). Anal. Calc. For $C_{12}H_{14}O_6$: C, 56.69; H, 5.55; O, 37.76 Found C, 56.66; H, 5.57; O, 37.73.

(2*R*,3*R*)-1-(2-Bromophenyl)-4-methyl-2,3-dihydroxysuccinate (3g)

Yield: 76 %. Yellow oil. $[\alpha]_D^{25} = 57.15°$ (c = 24 mg/2 ml CH_2Cl_2). (IR υ cm^{-1}): 3521 (OH), 2980 (CH), 1748 (COOPh), 1725 (COOCH$_3$), 1579 (Ar), 1313 (C–O–C), 559 (C–Br).

^{1}H NMR (300 MHz, $CDCl_3$): δ (ppm): 7.65–7.19 (m, Ar–H), 5.16 (d, J = 5.4 Hz, 1H, CH),5.13 (d, J = 5.4 Hz, 1H, CH), 3.87 (s, 3H, OCH$_3$), 3.25 (bs, 2H, OH). ^{13}C NMR (75 MHz, $CDCl_3$): δ (ppm): 170.5 (<u>C</u>OOPh), 168.9 (<u>C</u>OOCH$_3$), 145.8 (Ar–<u>C</u>–OR), 136.9, 134.1, 129.0, 127.7 (Ar–<u>C</u>), 76.3 (<u>C</u>H), 75.2 (<u>C</u>H), 52.5 (O–<u>C</u>H$_3$). Anal. Calc. For $C_{11}H_{11}BrO_6$: C, 41.40; H, 3.47; Br, 25.04; O, 30.08 Found C, 41.43; H, 3.49; Br, 25.01; O, 30.10.

(2*R*,3*R*)-1-(2,4-Dichlorophenyl)-4-methyl-2,3-dihydroxysuccinate (3h)

Yield: 70 %. White crystalline solid. m.p = 103–105 °C. $[\alpha]_D^{25} = 66.15°$ (c = 24 mg/2 ml CH_2Cl_2). (IR υ cm^{-1}): 3531 (OH), 2970 (CH), 1744 (COOPh), 1725 (COOCH$_3$), 1569 (Ar), 1311 (C–O–C), 768 (C–Cl). ^{1}H NMR (300 MHz, $CDCl_3$): δ (ppm): 7.51 (s, 1H, Ar–H), 7.19 (d, J = 7.7 Hz, 1H, Ar–H), 6.89 (d, J = 7.7 Hz, 1H Ar–H), 5.14 (d, J = 5.5 Hz, 1H, CH), 5.08 (d, J = 5.5 Hz, 1H, CH), 3.88 (s, 3H, OCH$_3$), 3.29 (bs, 2H, OH). ^{13}C NMR (75 MHz, $CDCl_3$): δ (ppm): 171.4 (<u>C</u>O–O–Ph), 170.7 (<u>C</u>O–O–CH$_3$), 146.9 (Ar–<u>C</u>–OR), 134.6, 133.4, 129.3, 128.2, 126.8 (Ar–<u>C</u>), 73.2 (<u>C</u>H), 53.6 (O–<u>C</u>H$_3$). Anal. Calc. For $C_{11}H_{10}Cl_2O_6$: C, 42.74; H, 3.26; Cl, 22.94; O, 31.06 Found C, 42.76; H, 3.28; Cl, 22.99; O, 31.08.

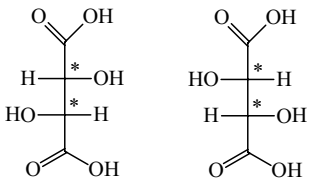


Fig. 1 L-(+)-tartaric acid D-(−)-tartaric acid

Results and discussion

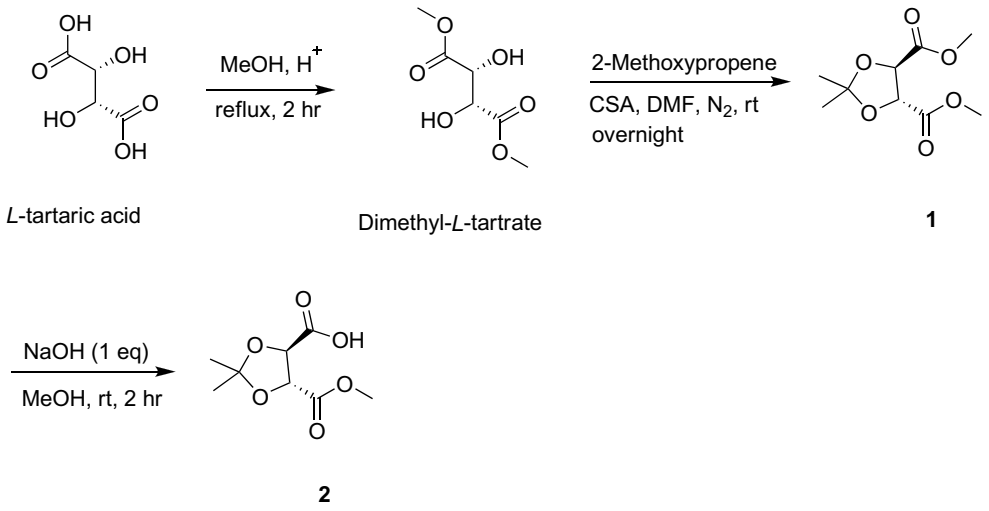
Synthesis of monoaryl esters (1a–1h)

For the designing and synthesis of monoaryl esters, we have started research work with selection of an inexpensive and commercially available starting material L-(+)-tartaric acid which has two chiral centers (Fig. 1).

In contrast to the availability of dialkyl tartrates, which are readily synthesized by Fischer esterification of tartaric acid or by transesterification of a tartrate with the use of excess alcohols, di or monoaryl tartrates remained until now virtually unknown. We carried out many synthesis procedures for acid activation toward the synthesis of aryl esters; however, they did not afford any aryl esters on reaction with tartaric acid. Cysewski et al. [31] have reported the synthesis of diaryl esters from dimethyl-2,3-*O*-benzylidene-L-tartrate and addressed the difficulties for direct esterification of tartaric acid with aryl alcohols.

Herein we report a facile synthesis of monoaryl esters of L-tartaric acid. The monoester of L-tartaric acid is not commercially available; however, we synthesized up to 30 g scale in good yield [32]. In the synthetic sequence, the first step was to protect the diacid functionality as dimethyl ester and diol as 1,3-dioxolane. Different protecting groups can be used to avoid unwanted side reactions of hydroxyl groups. We chose 2-methoxypropene as a protecting group to furnish 1,3-dioxolane. 1,3-Dioxolanes are widely used in natural product syntheses as protecting groups for ketones, aldehydes, and 1,2-diols. It is stable in basic condition. It is also an important intermediate and end product in different pharmaceutical, fragrance, and polymer industries [33–36]. Kucuk et al. [36] have reported the synthesis of 1,3-dioxolane derivatives of L- and D-tartaric acid using 2,2-dimethoxy propane.

First, the dimethyl-L-tartrate was prepared from L-tartaric acid and methanol [37] (Scheme 1). 1,3-Dioxolane dimethyl-L-tartrate (**1**) was prepared from dimethyl-L-tartrate following the literature procedure [32–38]. The initial yield was poor and once the reaction conditions were optimized, the yield was improved to 89 %. The product was purified through column chromatography.



Scheme 1 Synthesis of 1,3-dioxolane dimethyl-L-tartrate (**1**) and monoester (**2**)

Our next step was to partially hydrolyze compound (**1**) using sodium hydroxide (1 eq.) in methanol [32, 39]. Initial attempts to prepare the desired monoester resulted in low yield. When the reaction time was increased from one to two hours and when the drop wise addition of sodium hydroxide solution was increased, the yield was further improved. The resultant salt was acidified with aqueous $KHSO_4$ (1 M). To remove some of the unreacted starting material and diacid, the product was purified with column chromatography to get the monoester (**2**) as colorless oil, in 79 % yield.

The compounds (1) and (2) were characterized using IR, ^{1}H NMR, ^{13}C NMR, and EI-MS

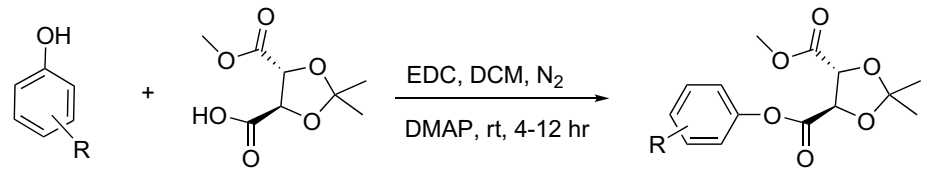
The IR absorption spectrum of the compound (**1**) showed characteristic bands at 2928 and 1738 cm^{-1}. These absorptions were attributed to C-H and CO, respectively. In ^{1}H NMR spectrum, a singlet at 4.45 ppm with integration of two protons was attributed to CH, singlet at 3.82 ppm with integration of six protons was assigned to two methoxy groups, and another singlet at 1.57 ppm with integration of six protons was assigned to two methyl groups of 1,3-dioxolane. In ^{13}C NMR spectrum, peak at 170.3 ppm was assigned to CO of ester group. Another peak at 113.5 ppm was attributed to quaternary carbon. The chiral methine carbon appeared at 76.4 ppm. The two carbon of the methoxy groups appeared at 52.3 ppm. The methyl carbon of 1,3-dioxolane appeared at 25.7 ppm, respectively.

The IR spectral data of compound (**2**) showed characteristic stretching bands at 3467, 2928, 1730, and 1708 cm^{-1}. These absorptions were assigned to OH, C-H, CO (ester), and CO (acid), respectively. In ^{1}H NMR, a broad singlet at 9.32 ppm with integration of one proton was attributed to OH group. The two methine protons appeared as doublets in 4.87–4.72 ppm with coupling constant of 5.4 Hz in each. The two methyl groups of 1,3-dioxolane appeared as singlets at 1.49 and 1.48 ppm with integration of three protons for each singlet. In ^{13}C NMR spectrum, peak at 173.8 ppm was assigned to CO (acid) and 169.7 to CO (ester). Methine carbons appeared at 76.8 and 75.7 ppm, respectively. EI-MS described in the experimental protocol also confirmed the synthesis of monoester, the molecular ion (*m/z*) appeared in the mass spectrum was in agreement with the molecular weight of the compound.

After the monoester in hand, it was coupled with different substituted phenols using EDC as dehydrating agent to afford compounds (**2a–2h**) in 69–87 % yields (Scheme 2).

All the compounds were purified and characterized by spectral analysis.

IR spectral data of the monoaryl esters (**2a–2h**) exhibited characteristic CO stretching bands in the range of 1756–1743 and C–O–C in 1324–1311 cm^{-1}. ^{1}H NMR spectral data show doublets in *para*-substituted phenol (**2b**), while *ortho*- and *meta*-substituted phenols (**2g, 2f**) showed multiplets and singlets, respectively. In ^{13}C NMR, peaks in 170.7–169.3 and 168.2–167.7 ppm were assigned to CO (aryl) and CO (methyl), respectively; the aromatic carbons appeared in the range of 150.8–121.8 ppm. Elemental analysis of these compounds, described in the experimental protocol further supported the structures of all the compounds. Formation of monoaryl esters was also confirmed by high-resolution mass analysis. Observed HRMS-ESI of the $[M+Na]^+$ and calculated values were in agreement with each other. Finally, the synthesis of monoaryl ester derivatives was supported by the crystal structure of (4*R*,5*R*)-4-(3-Bromo-4-methylphenyl)-5-methyl-2,2-dimethyl-1,3-dioxolane-4,5-dicarboxylate (**2e**) by X-ray crystallography (Fig. 2).



2 **2a-2h**

S. No.	Code	R	R_f values*	Yield (%)
1	**2a**	H	0.62	78
2	**2b**	4-Methyl	0.74	83
3	**2c**	3-Bromo	0.69	85
4	**2d**	3-Chloro-4-methyl	0.68	87
5	**2e**	3-Bromo-4-methyl	0.57	78
6	**2f**	3-Methyl	0.66	80
7	**2g**	2-Bromo	0.75	74
8	**2h**	2,4-Di-chloro	0.64	69

*Solvent system: Ethyl acetate:Hexane (3:7)

Scheme 2 Synthesis of monoaryl esters (**2a–2h**)

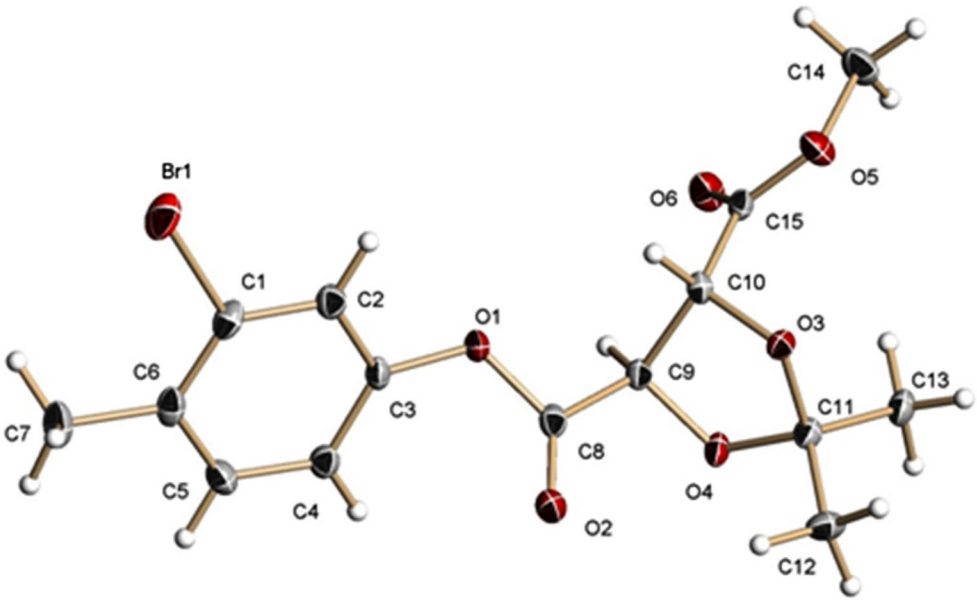
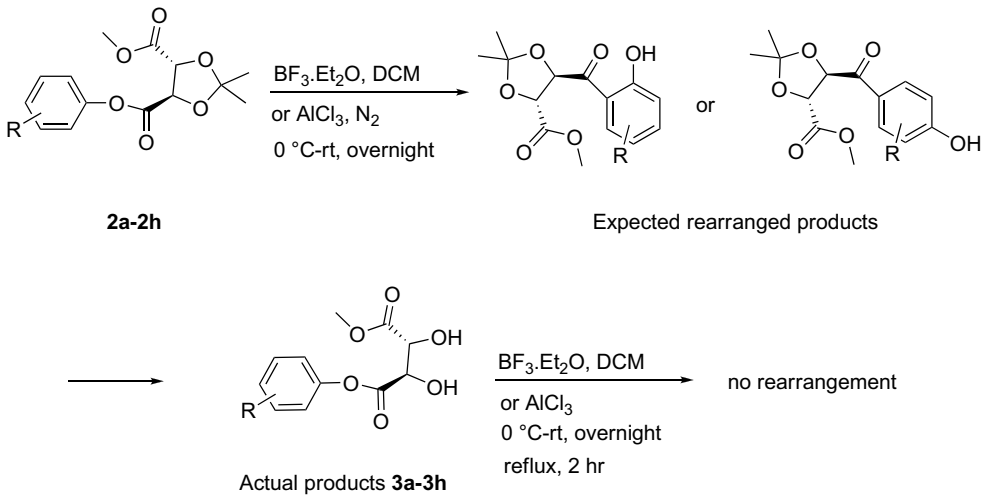


Fig. 2 Crystal structure of (4*R*,5*R*)-4-(3-bromo-4-methylphenyl)-5-methyl-2,2-dimethyl-1,3-dioxolane-4,5-dicarboxylate (**2e**). Thermal ellipsoids are shown at the 50 % probability level

On the basis of IR, ^{1}H NMR, ^{13}C NMR, HRMS-ESI, and single-crystal X-ray analysis, it was confirmed that the monoaryl ester derivatives were synthesized successfully.

Attempted Fries rearrangement of monoaryl esters (2a–2h)

The selective Fries rearrangement of esters of aromatic alcohols serves as a valuable synthesis step in the production of industrial pharmaceuticals, dyes and agrochemicals [40]. The reaction involves acylium ion intermediates that are generated from the ester by interaction with an acid catalyst. More specifically, the Fries rearrangement of phenyl acetate (PAc) yields *ortho*- and *para*-hydroxyacetophenones (*o*-HAP and *p*-HAP) which are very valuable precursors in the pharmaceutical industry, being this reaction the first step of the Hoechst Celanese manufacturing process of paracetamol [41]. Classical Fries rearrangement



Scheme 3 Attempted Fries rearrangement of monoaryl esters (**2a–2h**)

is generally catalyzed by acids like hydrofluoric acid (HF) [42], the most frequently used $AlCl_3$ [43], BF_3 [44], $TiCl_4$, or $SnCl_4$ [45].

In our ongoing effort to generate new C–C bond and chiral substrates, monoaryl esters (**2a–2h**) were processed following the literature procedures for the Fries rearrangement.

The Fries rearrangement of compound (**2a**) was first tried using $BF_3{\cdot}Et_2O$ in DCM (Scheme 2).

After overnight stirring and purification of new product as indicated by TLC, no rearrangement occurs; instead we got the deprotected product which was confirmed by ^{1}H NMR.

The reaction was then tried with $AlCl_3$. After purification and characterization with ^{1}H NMR, we got compound **2a** with free diol. The reactions were then tried for rest of the compounds (**2b–2h**) using different Lewis acids but all the products obtained were only the deprotected analog and no rearrangement occurs as confirmed by spectral analysis. The deprotected compounds (**3a–3h**) obtained were also tried using the same reaction conditions and with additional reflux for **2h** but no reactions occur (Scheme 3).

All the deprotected compounds were purified and characterized by spectral analysis.

IR spectral data of the compounds (**3a–3h**) showed characteristic OH stretching bands in the range of 3548–3508, CO at 1749–1743, and C–O–C in 1323–1312 cm^{-1}. ^{1}H NMR spectral data show the disappearance of signals for six methyl protons. The OH protons appeared as broad singlets in the range of 3.28–3.24 ppm, respectively. In ^{13}C NMR, peaks due to quaternary and two methyl carbons of the 1,3-dioxolane also disappeared which confirm only the deprotection of 1,3-dioxolane and no rearrangement. Elemental analysis of the deprotected compounds, described in the experimental protocol further supported the structures of all the compounds.

Conclusions

Monoaryl esters (**2a–2h**) were synthesized from monoester of L-tartaric acid and processed further in Fries rearrangement to get chiral ketones. The rearrangement was tried under various conditions by using different Lewis acids. The actual products obtained were only the deprotected analog and no rearrangements occur. The structure of compound **2e** in the series was also confirmed by X-ray crystallography. The synthesized monoaryl esters have large optical rotations and will be served as lead compounds for further research in organic chemistry.

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References

1. J. Gawronski, K. Gawronska, *Tartaric and Malic Acids in Synthesis—A Source Book of Building Blocks, Ligands, Auxiliaries, and Resolving Agents* (Wiley, New York, 1999)
2. G.M. Coppola, H.F. Schuster, *Hydroxy Acids in Enantioselective Synthesis* (Wiley-VCH, Weinheim, 1997)
3. A.K. Ghosh, E.S. Koltun, G. Bilcer, Synthesis **9**, 1281 (2001)
4. A. Fernandez, L. Duhamel, J. Org. Chem. **61**, 8698 (1996)
5. N.A.J.M. Sommerdijk, T.H.L. Hoeks, M. Synak, M.C. Feiters, R.J.M. Nolte, B. Zwanenburg, J. Am. Chem. Soc. **119**, 4338 (1997)
6. A. Dondoni, D. Perrone, M. Rinaldi, Tetrahedron Lett. **39**, 2651 (1998)

7. B.S.J. Blagg, C.D. Poulter, J. Org. Chem. **64**, 1508 (1999)
8. D. Liu, B. Wang, G. Lin, J. Org. Chem. **65**, 9114 (2000)
9. T. Katsuki, K.B. Sharpless, J. Am. Chem. Soc. **102**, 5974 (1980)
10. M.G. Finn, M.K.B. Sharpless, in asymmetric synthesis, ed by J.D. Morrison (Academic Press, New York, 1985), vol. 5, pp. 247–308
11. V.S. Martin, S.S. Woodard, T. Katsuki, Y. Yamada, M. Ikeda, K.B. Sharpless, J. Am. Chem. Soc. **103**, 6337 (1981)
12. K.B. Sharpless, C.H. Behrens, T. Katsuki, A.W.M. Lee, V.S. Martin, M. Takatani, S.M. Viti, F.J. Walker, S.S. Woodard, Pure. Appl. Chem. **55**, 589 (1983)
13. P. Pitchen, H.B. Kagan, Tetrahedron Lett. **25**, 1049 (1984)
14. P. Pitchen, E. Dunach, M.N. Deshmukh, H.B. Kagan, J. Am. Chem. Soc. **106**, 8188 (1984)
15. H.B. Kagan, E. Dunach, C. Nemecek, P. Pitchen, O. Samuel, S.H. Zhao, Pure Appl. Chem. **57**, 1911 (1985)
16. S.H. Zhao, O. Samuel, H.B. Kagan, Tetrahedron **43**, 5135 (1987)
17. Y. Ukaji, M. Nishimura, T. Fujisawa, Chem. Lett. **21**, 61 (1992)
18. Y. Ukaji, K. Sada, K. Inomata, Chem. Lett. **22**, 1227 (1993)
19. A.B. Charette, H. Juteau, J. Am. Chem. Soc. **116**, 2651 (1994)
20. A.B. Charette, S. Prescott, C. Brochu, J. Org. Chem. **60**, 1081 (1995)
21. G.P. Boldrini, E. Tagliavini, C. Trombini, A. Umani-Ronchi, J. Chem. Soc. Chem. Commun. **9**, 685 (1986)
22. G.P. Boldrini, L. Lodi, E. Tagliavini, C. Tarasco, C. Trombini, A. Umani-Ronchi, J. Org. Chem. **52**, 5447 (1987)
23. M. Nishida, T. Tozawa, K. Yamada, T. Mukaiyama, Chem. Lett. **25**, 1125 (1996)
24. W.R. Roush, L. Banfi, J. Am. Chem. Soc. **110**, 3979 (1998)
25. W.R. Roush, P.T. Grover, J. Org. Chem. **60**, 3806 (1995)
26. R. Soundararajan, G. Li, H.C. Brown, J. Org. Chem. **61**, 100 (1996)
27. Siemens. SMART and SAINT. Siemens Analytical X-Ray Instruments Inc., Madison, Wisconsin, USA, 1996.
28. G. Altomare, C. Cascarano, A.Guagliardi Giacovazzo, J. Appl. Crystallogr. **26**, 343 (1993)
29. Sheldrick GM: SHELXTL-PC (Version 5.1), Siemens Analytical Instruments, Inc., Madison, WI, 1997.
30. C.K. Jhnson, *'ORTEPII', Report ORNL-5138* (Oak Ridge National Laboratory, Tennessee, 1976)
31. R. Cysewski, M. Kwit, B. Warzajtis, U. Rychlewska, J. Gawronski, J. Org. Chem. **74**, 4573 (2009)
32. S.W. Khan, J.H. Zaidi, S. Yousuf, K.M. Khan, N. Ambreen, M. Khan, S. Perveen, G.A. Miana, J. Chem. Soc. Pak. **35**, 875 (2013)
33. T.W. Greene, P.G.M. Wuts, *Protective Groups in Organic Synthesis*, 2nd edn. (Wiley, New York, 1991), pp. 129–133
34. P.J. Kociensky, *Protecting Groups* (Georg Thieme Verlag, New York, 1994)
35. A.L. Gemal, J.L. Luche, J. Org. Chem. **44**, 4187 (1979)
36. H.B. Kucuk, A. Yusufoglu, E. Mataraci, S. Dosler, Molecules **16**, 6806 (2011)
37. A.P. Kozikowski, V.I. Ognyanov, A.H. Fauq, S.R. Nahorski, R.A. Wilcox, J. Am. Chem. Soc. **115**, 4429 (1993)
38. K. Ilmarinen, K. Kriis, A. Paju, T. Pehk, M. Margus Lopp, Proc. Estonian. Acad. Sci. Chem. **50**, 147 (2001)
39. A. Dahlgren, J. Branalt, I. Kvarnstrom, I. Nilsson, D. Musil, B. Samuelsson. Bioorg. Med. Chem. Lett. **10**, 1567 (2002)
40. R. R. Kintner, the Chemistry of the Carbonyl Group, In: S. Patai (ed.), (Interscience, New York, 1996) 749.
41. K.G. Davenport, EP 251 552, to Celanese Corp. USA (1988)
42. M.B. Hocking, J. Chem. Technol. Biotechnol. **30**, 626 (1980)
43. Ramesh, B.B. IN 171 970, 1993, Shasun Chemicals (m) Ltd. India.
44. J.L. Boyer, J. Org. Chem. **65**, 4712 (2000)
45. R. Martin, Org. Prep. Proc. Int. **24**, 369 (1992)