Supporting Information

Application of magnetic Fe_3O_4 nanoparticles as a reusable heterogeneous catalyst in the synthesis of β-lactams contain amino group

Aleme Moslehi and Maaroof Zarei*

General considerations

All required chemicals were purchased from Merck, Fluka and Acros chemical companies. The melting points were determined on an Electrothermal 9200 apparatus and are uncorrected. IR spectra were measured on a Galaxy series FT-IR 5000 spectrometer. NMR spectra were recorded in $CDCl_3$ using a Bruker spectrophotometer (^{1}H NMR 300 MHz, ^{13}C NMR 75 MHz) with tetramethylsilane as an internal standard and coupling constants were given in cycles per second (Hz). Elemental analyses were run on a Vario EL III elemental analyzer. The morphology of nanoparticles was investigated by TEM (Zeiss 906e HT-100kv). The phase composition of nanoparticles was considered by X-ray diffraction (XRD, D8, Advance, Bruker, axs). Thin-layer chromatography was carried out on silica gel 254 analytical sheets obtained from Fluka.

Fe_3O_4 preparation

In a typical procedure, 3.6 g of $FeCl_3 \cdot 6H_2O$ and 3.5 g of $FeSO_4 \cdot 7H_2O$ were dissolved in 30 ml of deionized water. Then 1 mL concentrated HCl 37% was added. The resulting clear solution was added dropwise to 300 mL NaOH (1.5 M) solution with the reaction mixture vigorously stirred at 75 °C for 3 hours. The mixture was then cooled to room temperature. The final products were collected and washed with deionized water and ethanol several times, and dried in air at 80 °C.

Synthesis of (4-nitrophenoxy)acetic acid 3d

Chloroacetic acid (0.05 mol, 4.72 g) was dissolved in water (20 mL). The solution was cooled in an ice bath and NaOH was added with stirring until the pH value was adjusted to 9–10, then a solution of sodium chloroacetate was obtained. 4-Nitrophenol (0.04 mol, 5.56 g) was slowly added under stirring to a mixture of NaOH (0.04 mol, 1.60 g), water (20 mL) and ethanol (20 mL). Then, sodium chloroacetate was added dropwise. The reaction solution was refluxed for 15 h. After cooling down, the pH value of the mixture was acidified to 2 with hydrochloric acid 15%. The white precipitate was filtered, recrystallized from petroleum ether and dried.

General procedure for the synthesis of β-lactams contain nitroaryl group 4a-p

The Vilsmeier reagent ((chloromethylene)dimethylammonium chloride) **1** (1.5 mmol) was added to a solution of substituted acetic acids (1.5 mmol), Schiff bases **2** (1.0 mmol) and triethylamine (5.0 mmol) in dry CH_2Cl_2 (20 ml) at room temperature and the mixture was stirred overnight. The reaction mixture was washed successively with saturated $NaHCO_3$ (20 ml) and brine (20 ml). The organic layer was dried (Na_2SO_4), filtered and the solvent was removed to give the crude product, which was purified by crystallization from 95% ethanol to give pure β-lactams **4a-p**.

1-(4-Methoxyphenyl)-3-(naphthalen-2-yloxy)-4-(4-nitrophenyl)azetidin-2-one (4e): Yield: 92%. Milky solid. m.p: 156-158 ^oC. IR (KBr) cm^{-1}: 1753 (CO, β-lactam); ^1H NMR (300 MHz, $CDCl_3$): δ 3.79 (OMe, s, 3H), 5.30 (H-4, d, 1H, J = 4.80), 5.62 (H-3, d, 1H, J = 4.80), 6.82-8.08 (ArH, m, 15H); ^{13}C NMR (75 MHz): δ 56.2 (OMe), 62.3 (C-4), 80.9 (C-3), 111.6, 114.0, 117.9, 121.1, 123.7, 124.5, 126.7, 127.3, 127.5, 128.5, 129.0, 130.9, 131.3, 135.5, 143.2, 144.1, 152.4, 156.8 (aromatic carbons), 164.1 (CO, β-lactam). Anal. Calcd for $C_{26}H_{20}N_2O_5$: C, 70.90; H, 4.58; N, 6.36. Found: C, 71.10; H, 4.73; N, 6.51.

4-(4-Chlorophenyl)-1-(3-nitrophenyl)-3-phenoxyazetidin-2-one (4g): Yield: 84%. Milky solid. m.p: 151-155 ^oC. IR (KBr) cm^{-1}: 1755 (CO, β-lactam); ^1H NMR (300 MHz, $CDCl_3$): δ 5.25 (H-4, d, 1H, J = 4.98), 5.58 (H-3, d, 1H, J = 4.98), 6.94-7.98 (ArH, m, 13H); ^{13}C NMR (75 MHz): δ 63.3 (C-4), 81.7 (C-3), 115.6, 116.4, 121.5, 122.8, 123.1, 127.9, 128.5, 129.4, 131.2, 132.9, 134.0, 143.2, 151.0, 155.7 (aromatic carbons), 163.5 (CO, β-lactam). Anal. Calcd for $C_{21}H_{15}ClN_2O_4$: C, 63.89; H, 3.83; N, 7.10. Found: C, 64.05; H, 3.92; N, 7.16.

4-(4-Chlorophenyl)-3-(2,4-dichlorophenoxy)-1-(4-nitro-phenyl)azetidin-2-one (4h): Yield: 82%. Milky solid. m.p: 161-163^oC. IR (KBr) cm^{-1}: 1755 (CO, β-lactam); ^1H NMR (300 MHz, $CDCl_3$): δ 5.16 (H-4, d, 1H, J = 4.71), 5.71 (H-3, d, 1H, J = 4.71), 6.90-7.97 (ArH, m, 11H); ^{13}C NMR (75 MHz): δ 60.9 (C-4), 82.1 (C-3), 113.9, 117.7, 125.2, 125.8, 126.7, 128.0, 128.4, 128.5, 129.1, 131.0, 133.2, 133.9, 146.9, 154.6 (aromatic carbons), 161.8 (CO, β-lactam). Anal. Calcd for $C_{21}H_{13}Cl_3N_2O_4$: C, 54.40; H, 2.83; N, 6.04. Found: C, 54.58; H, 3.01; N, 6.16.

4-(4-Chlorophenyl)-3-methoxy-1-(4-nitrophenyl)azetidin-2-one (4i): Yield: 85%. White solid. m.p: 125-128 ^oC. IR (KBr) cm^{-1}: 1745 (CO, β-lactam); ^1H NMR (300 MHz, $CDCl_3$): δ 3.43 (OMe, s, 3H), 5.12 (H-4, d, 1H, J = 4.80), 5.38 (H-3, d, 1H, J = 4.80), 7.15-7.93 (ArH, m, 8H); ^{13}C NMR (75 MHz): δ 58.1 (OMe), 62.6 (C-4), 81.4 (C-3), 117.6, 125.8, 126.1, 128.6, 133.7, 142.0, 147.6, 152.5 (aromatic carbons), 163.8 (CO, β-lactam). Anal. Calcd for $C_{16}H_{13}ClN_2O_4$: C, 57.76; H, 3.94; N, 8.42. Found: C, 57.84; H, 4.11; N, 8.51.

1-(4-Nitrophenyl)-3-phenoxy-4-styrylazetidin-2-one (4j): Yield: 91%. Milky solid. m.p: 194-196^oC. IR (KBr) cm^{-1}: 1753 (CO, β-lactam); ^1H NMR (300 MHz, $CDCl_3$): δ 4.86 (H-4, dd, 1H, J = 4.41, 8.49), 5.39 (H-3, d, 1H, J = 4.41), 6.15 (H-5, dd, 1H, J = 8.49 , 15.81), 6.98-8.14 (CH=CH and ArH, m, 15H); ^{13}C NMR (75 MHz): δ 60.2 (C-4), 81.6 (C-3), 116.8, 123.0, 124.5, 125.5, 125.6, 127.3, 128.7. 128.9, 130.0, 134.8. 137.2, 143.8, 151.3, 155.6 (C=C, aromatic carbons), 162.3 (CO, β-lactam). Anal. Calcd for $C_{23}H_{18}N_2O_4$: C, 71.49; H, 4.70; N, 7.25. Found: C, 71.43; H, 4.77; N, 7.21.

3-(4-Nitrophenoxy)-1,4-diphenylazetidin-2-one (4k): Yield: 93%. Milky solid. m.p: 178-180 ^{o}C. IR (KBr) cm^{-1}: 1744 (CO, β-lactam); ^{1}H NMR (300 MHz, $CDCl_3$): δ 5.25 (H-4, d, 1H, J = 4.71), 5.58 (H-3, d, 1H, J = 4.71), 7.01-7.98 (ArH, m, 14H); ^{13}C NMR (75 MHz): δ 63.3 (C-4), 84.9 (C-3), 116.8, 120.3, 125.3, 126.2, 126.5, 128.0, 128.5, 128.9, 134.3, 137.7, 142.7, 156.6 (aromatic carbons), 162.8 (CO, β-lactam). Anal. Calcd for $C_{21}H_{16}N_2O_4$: C, 69.99; H, 4.48; N, 7.77. Found: C, 70.16; H, 4.52; N, 7.85.

4-(4-Chlorophenyl)-3-(4-nitrophenoxy)-1-phenylazetidin-2-one (4l): Yield: 88%. Milky solid. m.p: 163-165 ^{o}C. IR (KBr) cm^{-1}: 1758 (CO, β-lactam); ^{1}H NMR (300 MHz, $CDCl_3$): δ 5.38 (H-4, d, 1H, J = 4.50), 5.70 (H-3, d, 1H, J = 4.50), 7.14-7.93 (ArH, m, 13H); ^{13}C NMR (75 MHz): δ 63.0 (C-4), 83.9 (C-3), 117.3, 121.2, 125.5, 126.1, 127.6, 128.6, 129.0, 132.8, 133.6, 137.5, 143.1, 156.5 (aromatic carbons), 162.8 (CO, β-lactam). Anal. Calcd for $C_{21}H_{15}ClN_2O_4$: C, 63.89; H, 3.83; N, 7.10. Found: C, 64.01; H, 4.01; N, 7.19.

4-(4-Chlorophenyl)-1-(4-methoxyphenyl)-3-(4-nitrophenoxy)azetidin-2-one (4m): Yield: 90%. White solid. m.p: 208-210 ^{o}C. IR (KBr) cm^{-1}: 1747 (CO, β-lactam); ^{1}H NMR (300 MHz, $CDCl_3$): δ 3.72 (OMe, s, 3H), 5.32 (H-4, d, 1H, J = 4.50), 5.71 (H-3, d, 1H, J = 4.50), 7.02-7.84 (ArH, m, 12H); ^{13}C NMR (75 MHz): δ 55.9 (OMe), 62.3 (C-4), 81.5 (C-3), 113.8, 117.3, 120.1, 125.5, 128.7, 129.0, 130.4, 132.9, 133.9, 145.53, 151.4, 157.1 (aromatic carbons), 162.7 (CO, β-lactam). Anal. Calcd for $C_{22}H_{17}ClN_2O_5$: C, 62.20; H, 4.03; N, 6.59. Found: C, 62.34; H, 4.21; N, 6.71.

4-(4-Methoxyphenyl)-3-(4-nitrophenoxy)-1-(*p*-tolyl)azetidin-2-one (4n): Yield: 92%. White solid. m.p: 172-174^{o}C. IR (KBr) cm^{-1}: 1753 (CO, β-lactam); ^{1}H NMR (300 MHz, $CDCl_3$): δ 2.28 (Me, s, 3H), 3.76 (OMe, s, 3H), 5.22 (H-4, d, 1H, J = 4.71), 5.58 (H-3, d, 1H, J = 4.71), 6.97-7.96 (ArH, m, 12H); ^{13}C NMR (75 MHz): δ 22.0 (Me), 55.8 (OMe), 63.5 (C-4), 83.2 (C-3), 113.2, 116.8, 124.7, 125.4, 125.8, 127.2, 130.6, 134.0, 135.7, 144.2, 158.5, 159.1 (aromatic carbons), 162.8 (CO, β-lactam). Anal. Calcd for $C_{23}H_{20}N_2O_5$: C, 68.31; H, 4.98; N, 6.93. Found: C, 68.42; H, 5.11; N, 7.03.

1,4-Bis(4-nitrophenyl)-3-phenoxyazetidin-2-one (4o): Yield: 76%. Light-yellow solid. m.p: 185-187 ^{o}C. IR (KBr) cm^{-1}: 1747 (CO, β-lactam); ^{1}H NMR (300 MHz, $CDCl_3$): δ 5.16 (H-4, d, 1H, J = 4.80), 5.61 (H-3, d, 1H, J = 4.80), 6.87-8.02 (ArH, m, 13H); ^{13}C NMR (75 MHz): δ 63.5 (C-4), 82.4 (C-3), 116.8, 122.6, 123.9, 125.5, 125.6, 127.2, 129.9, 135.4, 141.4, 143.1, 144.0, 156.1 (aromatic carbons), 163.4 (CO, β-lactam). Anal. Calcd for $C_{21}H_{15}N_3O_6$: C, 62.22; H, 3.73; N, 10.37. Found: C, 62.39; H, 3.92; N, 10.49.

General procedure for the synthesis of β-lactams contain aminoaryl group 5a-p

Fe_3O_4 nanoparticles (0.025 mmol) were added to a solution of β-lactams (0.25 mmol) and sodium hydroxide (0.25 mmol) in 5 mL of ethanol 95% and the mixture was stirred on oil-bath at 80 ^{o}C. The progress of reactions was monitored by thin layer chromatography. After completion and cooling of reaction, the catalyst was separated using magnetic separation. Then H_2O (5 mL) was added and the mixture extracted with $CHCl_3$ (10 mL). The organic layer was washed with 10% aqueous $NaHCO_3$ (10 mL) and brine (20 mL), and then dried over Na_2SO_4. After filtration and evaporation of the solvent, the crude residue was purified by recrystallization from ethyl acetate to give pure products **5a-p**.

4-(4-Aminophenyl)-3-methoxy-1-(4-methoxyphenyl)azetidin-2-one (5c): Yield: 62%. White solid. m.p: 153-155 ^{o}C. IR (KBr) cm^{-1}: 1736 (CO, β-lactam), 3361, 3446 (NH_2); ^{1}H NMR (300 MHz, $CDCl_3$): δ 3.41, 3.85 (2 OMe, 2s, 6H), 3.61 (NH_2, s, 2H), 5.04 (H-4, d, 1H, J = 4.70), 5.24 (H-3, d, 1H, J = 4.70), 6.60-7.17 (ArH, m, 8H); ^{13}C NMR (75 MHz): δ 55.8, 63.1 (2 OMe), 63.1 (C-4), 79.6 (C-3), 113.6, 115.5, 120.7, 121.8, 128.1, 130.6, 144.4, 157.1 (aromatic carbons), 163.9 (CO, β-lactam). Anal. Calcd for $C_{17}H_{18}N_2O_3$: C, 68.44; H, 6.08; N, 9.39. Found: C, 68.54; H, 6.22; N, 9.33.

4-(4-Aminophenyl)-1-(4-methoxyphenyl)-3-(naphthalen-2-yloxy)azetidin-2-one (5e): Yield: 88%. White solid. m.p: 177-180 ^{o}C. IR (KBr) cm^{-1}: 1763 (CO, β-lactam), 3382, 3429 (NH_2); ^{1}H NMR (300 MHz, $CDCl_3$): δ 3.57 (NH_2, s, 2H), 3.72 (OMe, s, 3H), 5.29 (H-4, d, 1H, J = 4.50), 5.68 (H-3, d, 1H, J = 4.50), 6.52-7.57 (ArH, m, 15H); ^{13}C NMR (75 MHz): δ 56.3 (OMe), 62.8 (C-4), 81.1 (C-3), 111.6, 114.4, 115.5, 118.3, 120.7, 121.7, 123.9, 127.2, 127.3, 128.1, 128.7, 129.2, 130.6, 131.1, 135.1, 144.4, 156.3, 156.7 (aromatic carbons), 163.6 (CO, β-lactam). Anal. Calcd for $C_{26}H_{22}N_2O_3$: C, 76.08; H, 5.40; N, 6.82. Found: C, 76.26; H, 5.57; N, 7.01.

1-(3-Aminophenyl)-4-(4-chlorophenyl)-3-phenoxyazetidin-2-one (5g): Yield: 84%. White solid. m.p: 160-163 ^{o}C. IR (KBr) cm^{-1}: 1753 (CO, β-lactam), 3381, 3419 (NH_2); ^{1}H NMR (300 MHz, $CDCl_3$): δ 3.51 (NH_2, s, 2H), 5.25 (H-4, d, 1H, J = 4.70), 5.70 (H-3, d, 1H, J = 4.59), 6.54-7.47 (ArH, m, 13H); ^{13}C NMR (75 MHz): δ 63.2 (C-4), 82.9 (C-3), 105.5, 111.2, 116.5, 117.3, 122.5, 127.9, 128.6, 129.9, 132.9, 133.7, 139.2, 143.9, 151.3, 156.5 (aromatic carbons), 162.7 (CO, β-lactam). Anal. Calcd for $C_{21}H_{17}ClN_2O_2$: C, 69.14; H, 4.70; N, 7.68. Found: C, 69.30; H, 4.88; N, 7.76.

1-(4-Aminophenyl)-4-(4-chlorophenyl)-3-(2,4-dichlorophenoxy)azetidin-2-one (5h): Yield: 85%. White solid. m.p: 167-170 ^{o}C. IR (KBr) cm^{-1}: 1756 (CO, β-lactam), 3384, 3448 (NH_2); ^{1}H NMR (300 MHz, $CDCl_3$): δ 3.39 (NH_2, s, 2H), 5.20 (H-4, d, 1H, J = 5.01), 5.49 (H-3, d, 1H, J = 5.01), 6.71-7.38 (ArH, m, 11H); ^{13}C NMR (75 MHz): δ 63.2 (C-4), 81.3 (C-3), 117.1, 119.6, 120.5, 126.6, 126.9, 128.3, 128.4, 128.8, 129.0, 132.9, 141.8, 145.9, 152.0, 156.5 (aromatic carbons), 163.3 (CO, β-lactam). Anal. Calcd for $C_{21}H_{15}Cl_3N_2O_2$: C, 58.16; H, 3.49; N, 6.46. Found: C, 58.29; H, 3.64; N, 6.58.

1-(4-Aminophenyl)-4-(4-chlorophenyl)-3-methoxyazetidin-2-one (5i): Yield: 65%. White solid. m.p: 158-160 ^{o}C. IR (KBr) cm^{-1}: 1752 (CO, β-lactam), 3296, 3397 (NH_2); ^{1}H NMR (300 MHz, $CDCl_3$): δ 3.40 (OMe, s, 3H), 3.60 (NH_2, s, 2H), 5.02 (H-4, d, 1H, J = 4.89), 5.34 (H-3, d, 1H, J = 4.89), 6.77-7.24 (ArH, m, 8H); ^{13}C NMR (75 MHz): δ 57.9 (OMe), 63.78 (C-4), 82.2 (C-3), 117.0, 120.6, 126.3, 128.3, 128.5, 133.0, 133.8, 147.7 (aromatic carbons), 164.2 (CO, β-lactam). Anal. Calcd for $C_{16}H_{15}ClN_2O_2$: C, 63.48; H, 4.99; N, 9.25. Found: C, 63.63; H, 5.17; N, 9.32.

1-(4-Aminophenyl)-3-phenoxy-4-styrylazetidin-2-one (5j): Yield: 88%. White solid. m.p: 197-199^{o}C. IR (KBr) cm^{-1}: 1759 (CO, β-lactam), 3341, 3426 (NH_2); ^{1}H NMR (300 MHz, $CDCl_3$): δ 3.55 (NH_2, s, 2H), 4.73 (H-4, dd, 1H, J = 4.59, 8.61), 5.27 (H-3, d, 1H, J = 4.59), 6.11 (H-5, dd, 1H, J = 8.61, 15.99), 6.59-7.38 (CH=CH and ArH, m, 15H); ^{13}C NMR (75 MHz): δ 57.2 (C-4), 82.4 (C-3), 116.1, 116.9, 119.3, 122.7, 125.2, 127.1, 127.7, 128.6, 129.4, 129.9, 134.5, 137.1, 147.1, 157.6 (C=C, aromatic carbons), 162.4 (CO, β-lactam). Anal. Calcd for $C_{23}H_{20}N_2O_2$: C, 77.51; H, 5.66; N, 7.86. Found: C, 77.67; H, 5.81; N, 7.96.

3-(4-Aminophenoxy)-1,4-diphenylazetidin-2-one (5k): Yield: 93%. White solid. m.p: 187-190 ^{o}C. IR (KBr) cm^{-1}: 1760 (CO, β-lactam), 3373, 3424 (NH_2); ^{1}H NMR (300 MHz, $CDCl_3$): δ 3.59 (NH_2, s, 2H), 5.33 (H-4, d, 1H, J = 4.80), 5.69 (H-3, d, 1H, J = 4.80), 6.52-7.35 (ArH, m, 14H); ^{13}C NMR (75 MHz): δ 62.7 (C-4), 80.9 (C-3), 114.0, 118.7, 119.8, 126.1, 126.6, 128.4, 128.9, 134.6, 138.0, 144.1, 149.5, 153.2 (aromatic carbons), 161.6 (CO, β-lactam). Anal. Calcd for $C_{21}H_{18}N_2O_2$: C, 76.34; H, 5.49; N, 8.48. Found: C, 76.49; H, 5.66; N, 8.60.

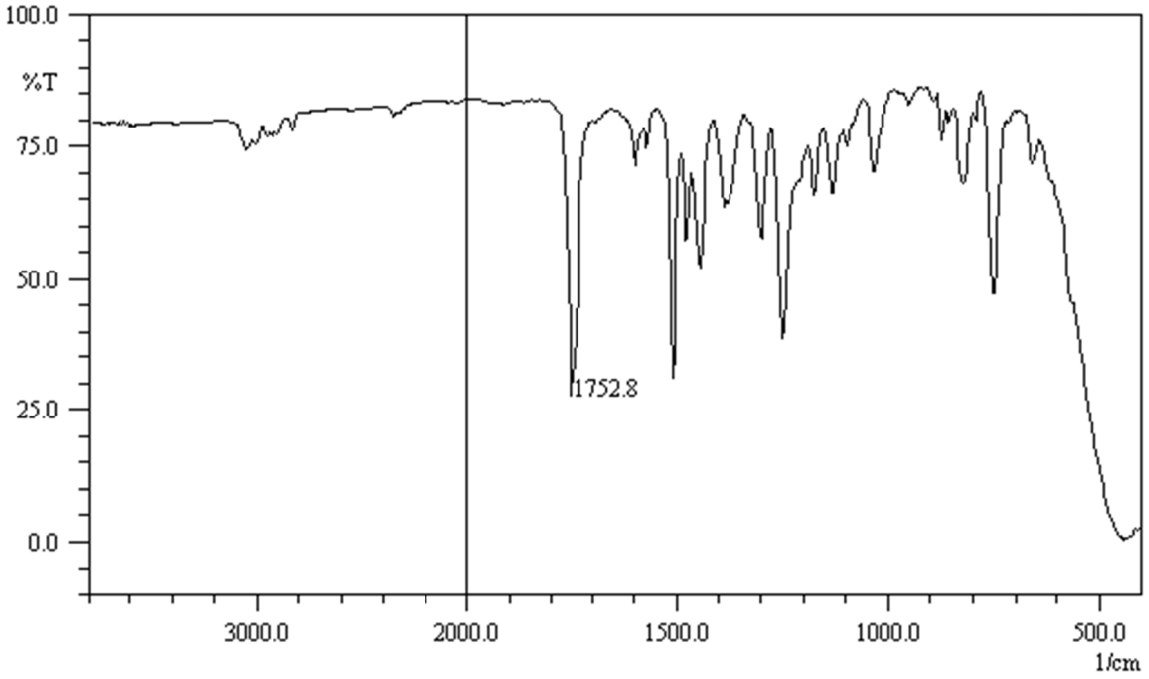
3-(4-Aminophenoxy)-4-(4-chlorophenyl)-1-phenylazetidin-2-one (5l): Yield: 92%. White solid. m.p: 178-180 ^{o}C. IR (KBr) cm^{-1}: 1758 (CO, β-lactam), 3380, 3421 (NH_2); ^{1}H NMR (300 MHz, $CDCl_3$): δ 3.43 (NH_2, s, 2H), 5.29 (H-4, d, 1H, J = 4.41), 5.72 (H-3, d, 1H, J = 4.41), 6.5-7.34 (ArH, m, 13H); ^{13}C NMR (75 MHz): δ 64.6 (C-4), 84.0 (C-3), 112.4, 114.4, 117.9, 120.5, 126.6, 127.9, 129.0, 134.1, 137.9, 144.7, 149.5, 154.1 (aromatic carbons), 162.9 (CO, β-lactam). Anal. Calcd for $C_{21}H_{17}ClN_2O_2$: C, 69.14; H, 4.70; N, 7.68. Found: C, 69.28; H, 4.81; N, 7.77.

3-(4-Aminophenoxy)-4-(4-chlorophenyl)-1-(4-methoxyphenyl)azetidin-2-one (5m): Yield: 89%. White solid. m.p: 212-215 ^{o}C. IR (KBr) cm^{-1}: 1753 (CO, β-lactam), 3387, 3445 (NH_2); ^{1}H NMR (300 MHz, $CDCl_3$): δ 3.49 (NH_2, s, 2H), 3.65 (OMe, s, 3H), 5.37 (H-4, d, 1H, J = 4.71), 5.73 (H-3, d, 1H, J = 4.71), 6.67-7.31 (ArH, m, 12H); ^{13}C NMR (75 MHz): δ 55.8 (OMe), 62.8 (C-4), 82.4 (C-3), 114.4, 114.8, 118.5, 121.1, 127.9, 128.5, 131.0, 133.4, 138.5, 144.7, 148.9, 155.9 (aromatic carbons), 163.1 (CO, β-lactam). Anal. Calcd for $C_{22}H_{19}ClN_2O_3$: C, 66.92; H, 4.85; N, 7.09. Found: C, 67.11; H, 5.02; N, 7.21.

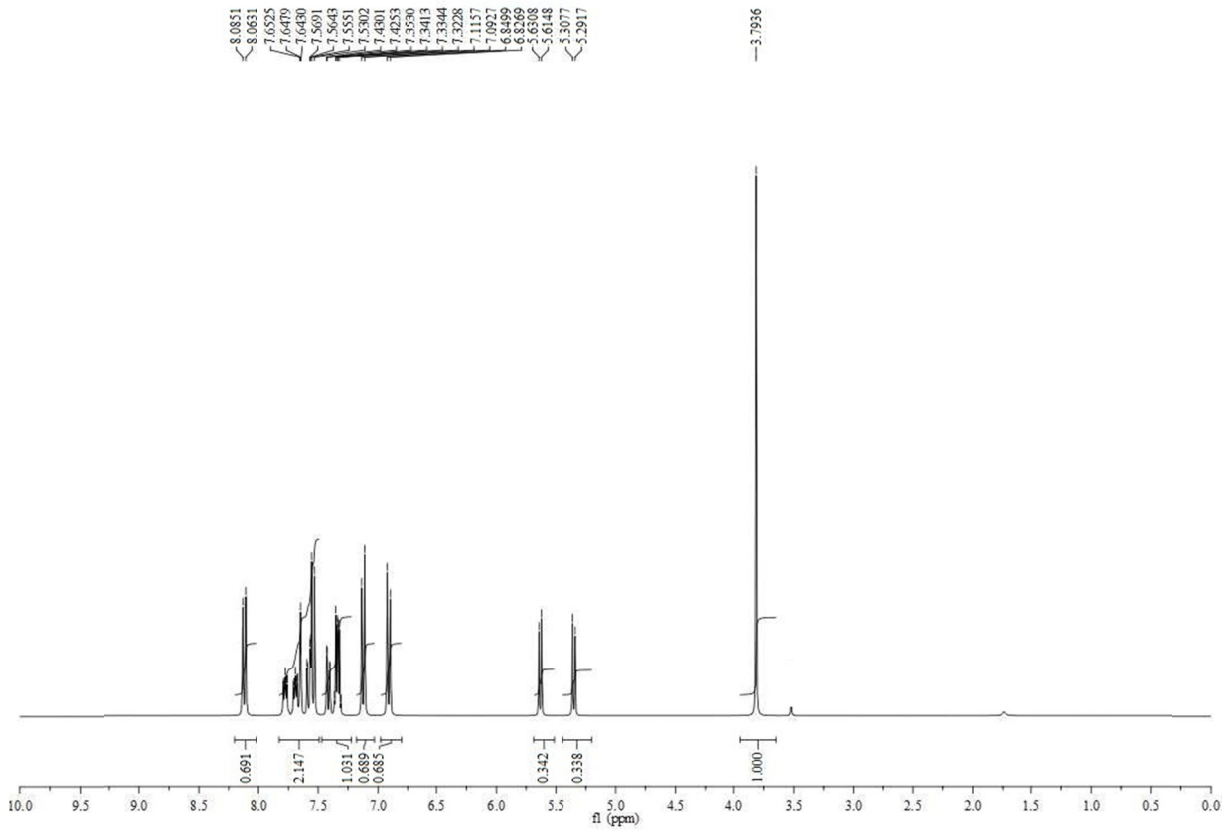
3-(4-Aminophenoxy)-4-(4-methoxyphenyl)-1-(p-tolyl)azetidin-2-one (5n): Yield: 95%. White solid. m.p: 175-177 ^{o}C. . IR (KBr) cm^{-1}: 1739 (CO, β-lactam), 3260 , 3392 (NH_2); ^{1}H NMR (300 MHz, $CDCl_3$): δ 2.29 (Me, s, 3H), 3.45 (NH_2, s, 2H), 3.68 (OMe, s, 3H), 5.18 (H-4, d, 1H, J = 4.95), 5.68 (H-3, d, 1H, J = 4.95), 6.58-7.27 (ArH, m, 12H); ^{13}C NMR (75 MHz): δ 20.6 (Me), 55.9 (OMe), 62.8 (C-4), 83.5 (C-3), 113.3, 114.6, 118.7, 124.9, 125.7, 127.2, 131.4, 133.8, 135.9, 144.7, 151.2, 158.0 (aromatic carbons), 162.3 (CO, β-lactam). Anal. Calcd for $C_{23}H_{22}N_2O_3$: C, 73.78; H, 5.92; N, 7.48. Found: C, 73.89; H, 6.10; N, 7.57.

1,4-Bis(4-aminophenyl)-3-phenoxyazetidin-2-one (5o): Yield: 91%. Light-yellow solid. m.p: 190-192 ^{o}C. IR (KBr) cm^{-1}: 1754 (CO, β-lactam), 3357, 3411 (NH_2); ^{1}H NMR (300 MHz, $CDCl_3$): δ 3.49, 3.70 ($2NH_2$, 2s, 4H), 5.32 (H-4, d, 1H, J = 4.59), 5.71 (H-3, d, 1H, J = 4.59), 6.58-7.28 (ArH, m, 13H); ^{13}C NMR (75 MHz): δ 62.3 (C-4), 80.8 (C-3), 115.1, 116.9, 117.1, 120.6, 122.0, 123.0, 126.2, 128.2, 130.0, 144.6, 146.1, 157.3 (aromatic carbons), 162.8 (CO, β-lactam). Anal. Calcd for $C_{21}H_{19}N_3O_2$: C, 73.03; H, 5.54; N, 12.17. Found: C, 73.19; H, 5.72; N, 12.31.

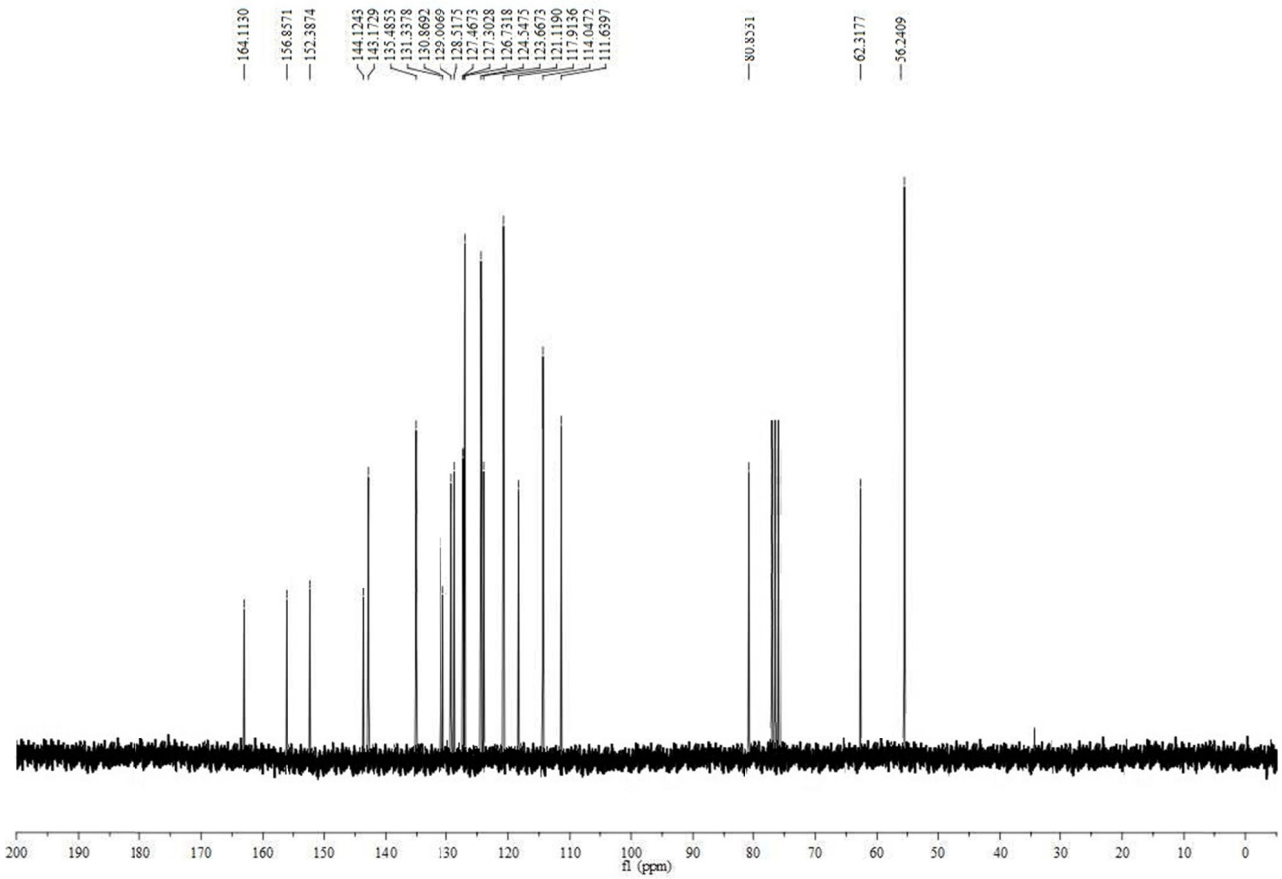
4-(4-Aminophenyl)-1-(2-chloropyridin-3-yl)-3-phenoxy-azetidin-2-one (5p): White solid. mp: 201-203 ^{o}C. IR (KBr) cm^{-1}: 1615 (C=N, pyridine ring), 1749 (CO), 3342, 3430 (NH_2),; ^{1}H NMR δ 3.38 (NH_2, s, 2H), 5.21 (H-4, d, 1H, J = 4.9), 5.58 (H-3, d, 1H, J = 4.9), 6.79-8.02 (ArH, m, 12H); ^{13}C NMR δ 61.5 (C-4), 82.9 (C-3), 116.4, 119.2, 122.0, 124.6, 126.0, 128.4, 128.8, 134.7, 138.3, 142.1, 145.9, 151.7, 153.2 (aromatic carbons), 162.6 (CO, *β*-lactam), Anal. Calcd for $C_{20}H_{16}ClN_3O_2$: C, 65.67; H, 4.41; N, 11.49. Found: C, 65.71; H, 4.58; N, 11.56.



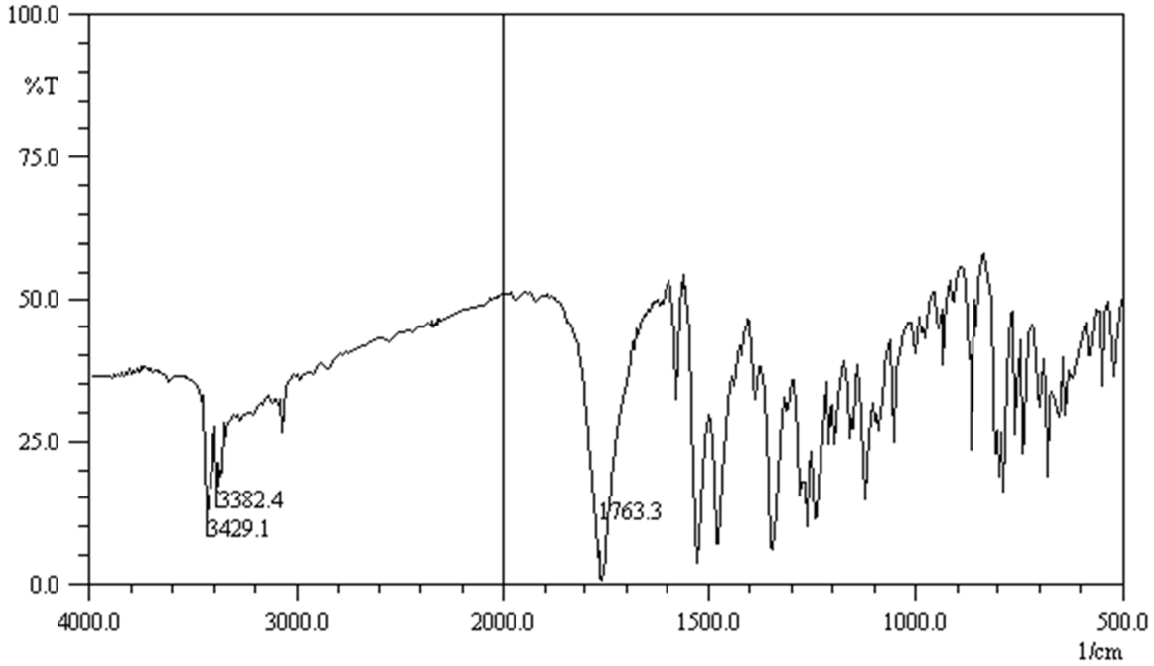
FT-IR: 1-(4-Methoxyphenyl)-3-(naphthalen-2-yloxy)-4-(4-nitrophenyl)azetidin-2-one **(4e)**



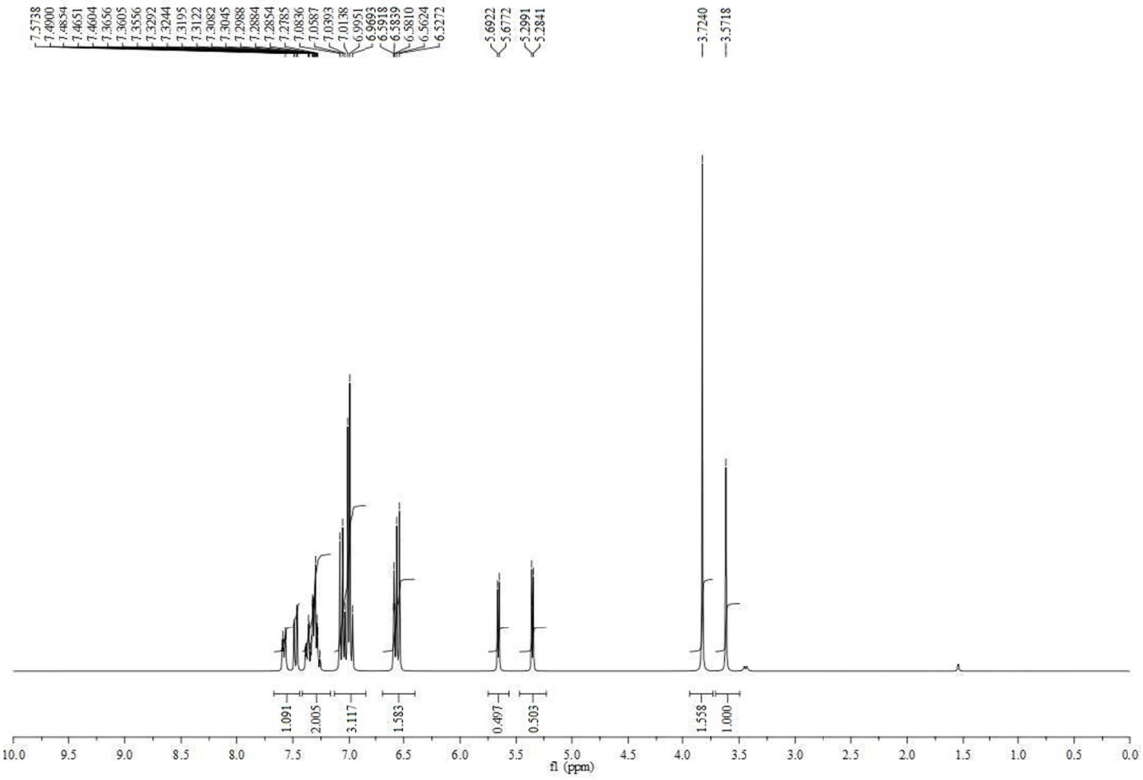
^{1}H NMR: 1-(4-Methoxyphenyl)-3-(naphthalen-2-yloxy)-4-(4-nitrophenyl)azetidin-2-one **(4e)**



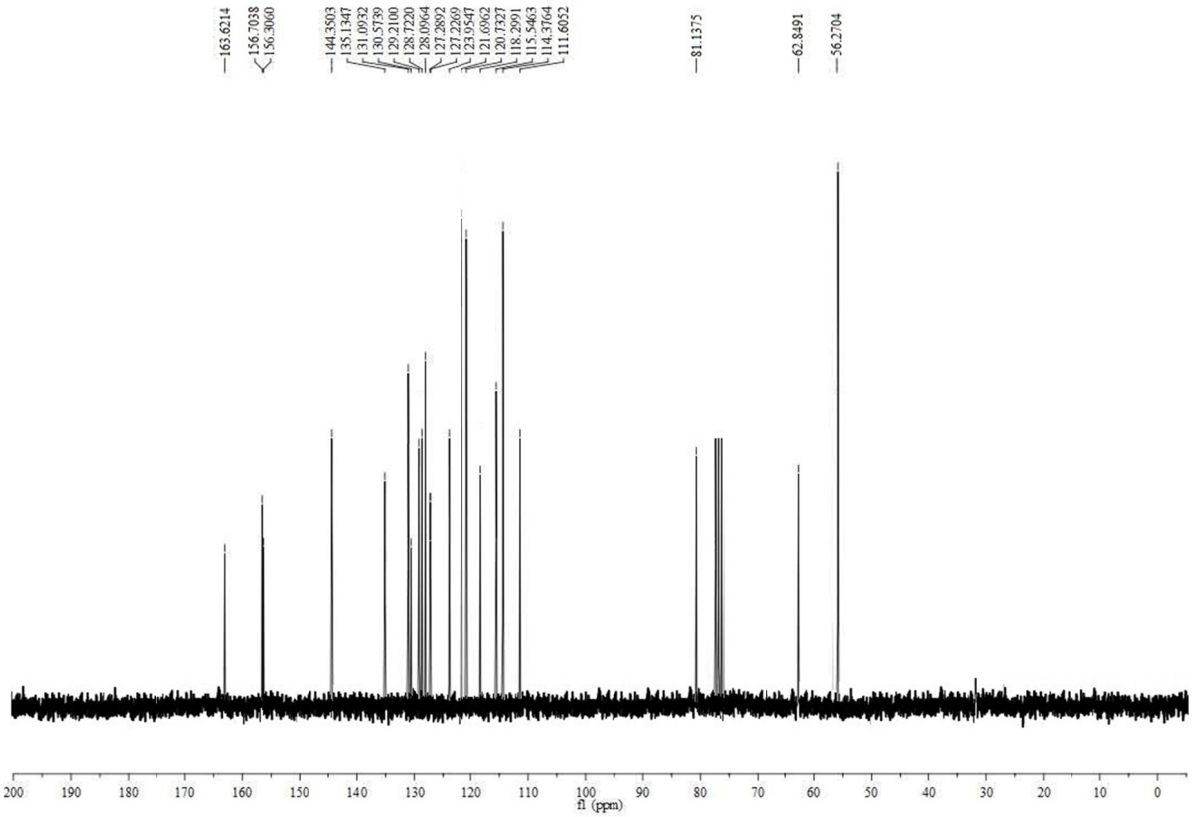
^{13}C NMR: 1-(4-Methoxyphenyl)-3-(naphthalen-2-yloxy)-4-(4-nitrophenyl)azetidin-2-one **(4e)**



FT-IR: 4-(4-Aminophenyl)-1-(4-methoxyphenyl)-3-(naphthalen-2-yloxy)azetidin-2-one **(5e)**



^{1}H NMR: 4-(4-Aminophenyl)-1-(4-methoxyphenyl)-3-(naphthalen-2-yloxy)azetidin-2-one **(5e)**



^{13}C NMR: 4-(4-Aminophenyl)-1-(4-methoxyphenyl)-3-(naphthalen-2-yloxy)azetidin-2-one **(5e)**