Barishal University Journal of Science and Engineering, Vol. 9: 93-101 (June 2024) ISSN 2411-247X

SYNTHESIS OF CHIRAL IONIC POLYMER AND THEIR APPLICATION AS POLYMERIC CHIRAL ORGANOCATALYST IN ASYMMTERIC BENZYLATION OF GLYCINE DERIVATIVE

Md. Masud Parvez[1, *], Shinichi Itsuno[2], Md. Alauddin[3], Gazi Jahirul Islam[1]

[1]*Department of Chemistry, University of Barishal, Bangladesh*
[2]*Department of Environmental and Life Sciences, Toyohashi University of Technology, Japan*
[3]*Department of Theoretical and Computational Chemistry, University of Dhaka*

Abstract

Chiral ionic polymer has been synthesized using ion exchange polymerization between newly designed dimer of cinchona alkaloid derivatives and different types of disulfonates. A total of 10 chiral ionic polymers have been synthesized and yields of the chiral ionic polymers were in the range 75% to 88%. The number average molecular weight (M_n) of the polymers were between 5200 to 5700. These chiral ionic polymers demonstrated higher catalytic activity than lower molecular weight chiral catalyst, when utilized in asymmetric benzylation of glycine derivative.

Keywords: Ion-exchange polymerization, cinchonidium dimer, Mizoroki-Heck reaction, Ionic polymers, Asymmetric benzylation, Glycine derivative.

Introduction

Quaternary ammonium salts derived from cinchonidine are important classes of organocatalyst for asymmetric transformation. Having multifunctionalities and multi chiral center, cinchonidines can be easily modified and used as chiral organocatalyst in various asymmetric transformations. There are several modifications including monomeric (O'Donnell, 1989; Corey 1997; Lygo, 1997), dimeric (Jew, 2001; Park, 2001 and 2002; Chinchilla, 2002; Lee, 2007) and polymer immobilized (Chinchilla, 2000; Thierry, 2001 and 2005; Arakawa, 2008; Shi, 2008; Haraguchi, 2011; Itsuno, 2012;) quaternary ammonium salts of cinchonidine have been reported by various groups. Due to the separation simplicity polymer immobilized chiral quaternary ammonium salts of chinchonidine are better choice for asymmetric synthesis.

Several research have been done with the polymer immobilized chiral quaternary ammonium salts of cinchonidine, but very few works have been reported for the designing and application of chiral polymer catalyst bearing main-chain chiral unit derived from cinchonidine. Main-chain chiral polymeric organocatalysts have sterically regular structure compare to polymer immobilized chiral catalysts. These polymeric organocatalysts can also be easily separated from reaction medium. Over the last few years, several main-chain chiral polymer catalysts have been prepared by different methods such as polyether formation (Itsuno, 2010 and 2011), ion exchange (Itsuno, 2010; Parvez, 2012; Haraguchi, 2012 and 2018; Parvez, 2019), quaternization (Haraguchi, 2012; Ahamed, 2013; Parvez, 2017), neutralization (Haraguchi, 2012). Nearly all main-chain chiral polymers demonstrated high level of catalytic activity in asymmetric transformation of glycine derivative compare to monomeric and dimeric chiral catalyst.

Mizoroki-Heck reaction has been useful for carbon-carbon bond formation reactions (Mizoroki, 1971; Heck, 1972; Heck, 1982) but not widely been applied for cinchonidine double bond modification. Very few works have been reported utilizing Mizoroki-Heck reaction for cinchonidine double bond modification or used in polymerization

*Corresponding author: Md. Masud Parvez (masud.chdu@yahoo.com)

(Ma, 2007; Parvez, 2014; Ullah, 2017 and 2018; Kumpuga, 2018; Chhanda, 2019; Parvez, 2019; Abdelkawy, 2021). All of these polymers were quite effective as polymeric organocatalyst when applied in asymmetric synthesis.

In this work, modification of cinchonidine dimer using Heck coupling reaction was carried out and OH group of cinchonidine was further allylated (**scheme 1** and **scheme 2**). Finally, we used modified cinchonidine dimer in polymerization with different disulfonates to synthesize polymer catalyst **6A (a~e)-allyl** and **6B (a~e)-allyl** (**scheme 3**) using ion-exchange polymerization and employed these polymers in asymmetric benzylation of glycine derivative (**scheme 4**).

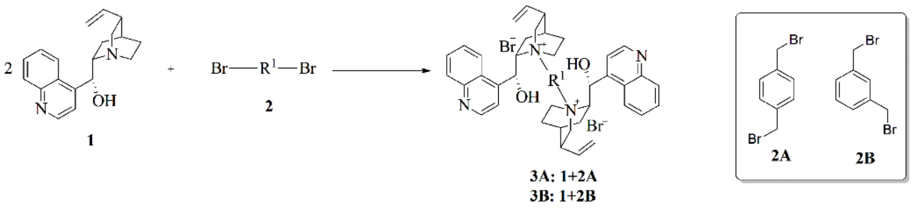
Experimental

Materials and Methods

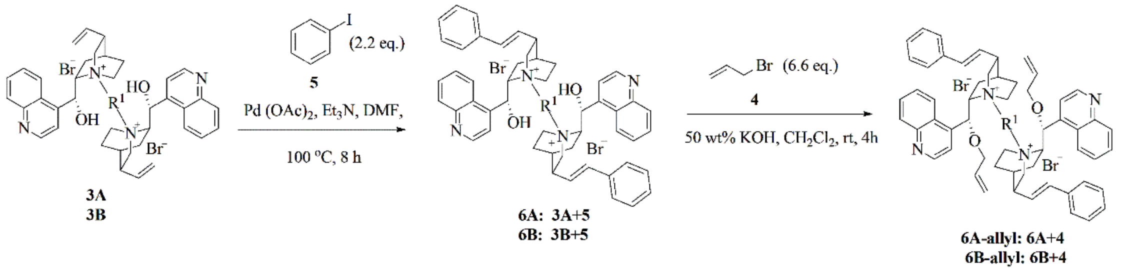
Chemical and solvents were bought from Wako Pure Chemical Industries, TCI, Sigma-Aldrich with highest purity and used unless noted otherwise. Dimer **3A** and **3B** were prepared (scheme 2) according to Jew, 2001. Modified dimer **6A** was prepared (scheme 3) according to Parvez, 2019. Modified dimer **6B** was prepared according to Parvez, 2014. Disulfonates **7d** and **7e** were prepared according to Parvez, 2012). Thin-layer chromatography (TLC) was used for reaction monitoring. ^{1}H NMR (400 MHz or 300 MHz) and ^{13}C NMR (100 MHz or 75 MHz) spectra were measured on Jeol ECS 400 Mercury 300 spectrometer. JASCO HPLC system was used which consist of an HPLC pump, column oven, degasser and a chiral column (CHIRALCEL ODH). Propanol/hexane was used as mobile phase. For peak detection UV detector was chosen. JASCO DIP-149 digital polarimeter was used for optical rotation measurement. Molecular weight was determined by GPC using Tosoh instrument with the help of UV or RI detector. DMF was selected as a carrier solvent and flow rate of 1.0 mLmin^{-1} was maintained while 40 ^{o}C temperature was selected for column. Calibration curve was made with polystyrene standards to determine number-average molecular weight (M_n) and molecular weight distribution (M_w/M_n). Yanaco melting instrument was used for melting point determination.

General Method for Dimer and Polymer Synthesis

Before synthesizing polymeric organocatalyst, we synthesized cinchonidium dimer **3A** and **3B** (Scheme 1) (Jew, 2001). Cinchonidine double bond in **3** was modified by reacting aryliodide **5** to obtain dimer **6** (scheme 2) by Mizoroki-Heck reaction according to reported procedure (Parvez, 2014 and 2019). Treating dimer **6** with allyl bromide resulted dimer **6A-allyl** and **6B-allyl** (Scheme 2). Ion exchange polymerization of dimer **6A-allyl** or **6B-allyl** with disulfonate **7** proceeded readily in THF-H_2O system to produce the polymer **6A (a~e)-allyl** and **6B (a~e)-allyl (**scheme 3).



Scheme 1 Synthesis of dimer **3** (Jew, 2001)



Scheme 2 Synthesis of dimer **6** (Parvez 2014 and 2019) and **6-allyl**

Preparation of 6A-allyl

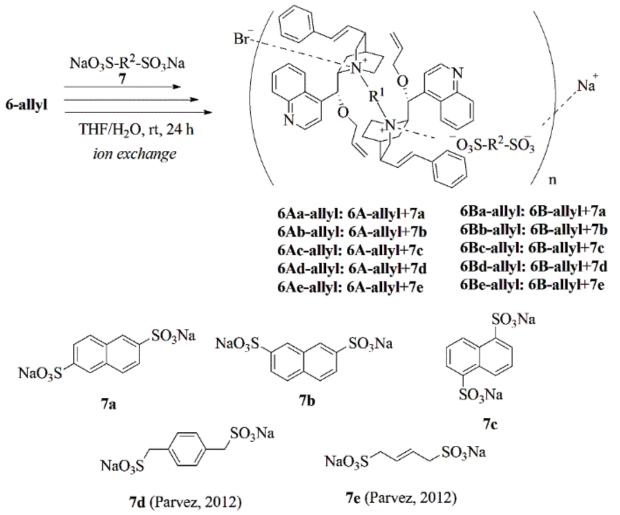
A suspension of dimer **6A** (1.76 mmol, 1.77 g) in CH_2Cl_2 (5mL), allyl bromide (11.56 mmol, 1 mL) and 50% aqueous KOH (17.6 mmol, 2 mL) were mixed together and stirred (300 rpm) at rt for 4 hours. After 4 hours, reaction mixture became homogeneous. The product was extracted with CH_2Cl_2 (3 x 20 mL) following the addition of H_2O (5 mL). The combined organic extracts were dried over $MgSO_4$. Then filtered by filter paper and filtrate was evaporated by rota evaporator to obtain crude product. Finally, crude was purified by reprecipitation from CH_2Cl_2-hexane to obtain dimer **6A-allyl** (1.55 g, 81% yield) as a light yellow solid. IR (KBr) υ 856, 926, 993, 1068, 1164, 1235, 1357, 1450, 1492, 1507, 1590, 1644, 2932, 3339. mp=150~152 °C. $[\alpha]_D^{25} = +0.83\ (c\ 0.1, \mathrm{DMSO})$. ^{1}H NMR ($d_6$-DMSO, 400 MHz) δ 1.26~1.19 (m, 3H), 1.80~1.39 (m, 1H), 2.21~2.05 (m, 1H), 3.25~3.19 (m, 1H), 4.07~3.90 (m, 5H), 4.58~4.22 (m, 1H), 5.08~4.85 (m, 1H), 5.51~5.15 (m, 3H), 5.80~5.59 (m, 2H), 6.25~5.99 (m, 2H), 6.51~6.43 (m, 1H), 7.44~7.02 (m, 4H), 7.93~7.70 (m, 5H), 8.37~8.07 (m, 2H), 9.02 (d, J = 26.0 Hz, 1H). ^{13}C NMR (d_6-DMSO, 100 MHz) δ 7.28, 20.59, 24.46, 26.61, 52.15, 52.83, 59.25, 62.21, 69.51, 70.61, 72.01, 116.56, 117.63, 125.32, 125.52, 126.02, 127.00, 127.65, 128.35, 129.59, 129.63, 129.88, 134.01, 135.06, 136.41, 141.29, 147.11, 150.15.

Preparation of 6B-allyl

A suspension of dimer **6B** (1.76 mmol, 1.77 g) in CH_2Cl_2 (5mL), allyl bromide (11.56 mmol, 1 mL) and 50% aqueous KOH (17.6 mmol, 2 mL) were mixed together and stirred (300 rpm) at rt for 4 hours. After 4 hours, reaction mixture became homogeneous. The product was extracted with CH_2Cl_2 (3 x 20 mL) following the addition of H_2O (5 mL). The combined organic extracts were dried over $MgSO_4$. Then filtered by filter paper and filtrate was evaporated by rota evaporator to obtain crude product. Finally, crude was purified by reprecipitation from CH_2Cl_2-hexane to obtain dimer **6B-allyl** (1.65 g, 86% yield) as a light yellow solid. IR (KBr) υ 993,1067,1164, 1235, 1360, 1450, 1491, 1507, 1590, 1645, 2931, 3395. mp =140~142 °C. $[\alpha]_D^{25} = +0.45\ (c\ 0.1, \mathrm{DMSO})$. ^{1}H NMR ($d_6$-DMSO, 400 MHz) δ 0.83~0.77 (m,1H), 1.23~1.14 (m, 1H), 1.87~1.54 (m,1H), 2.08~1.99 (m,1H), 2.33~2.23 (m,2H), 4.06~3.83 (m, 4H), 5.26~4.81 (m,7H), 5.51~5.36 (m,1H), 5.76~5.53 (m,2H), 6.28~5.99 (m, 1H), 6.48~6.34 (m, 1H), 7.45~7.13 (m, 7H), 7.85~7.64 (m,3H), 8.31~7.91 (m, 2H), 8.99 (d, J = 3.6 Hz, 1H). ^{13}C NMR (d_6-DMSO, 100 MHz) δ20.91, 24.22, 26.48, 36.51, 52.83, 59.25, 64.61, 68.26, 69.31, 71.95, 109.51, 117.59, 119.64, 125.05, 125.51, 126.05, 127.04, 127.39, 127.63, 128.37, 128.54, 129.60, 129.90, 130.96, 134.20, 136.38, 140.75, 141.32, 147.79, 147.99, 150.21.

General synthesis of polymer catalyst 6A(a~e)-allyl and 6B(a~e)-allyl

A suspension of dimer **6A-allyl/6B-allyl** (1 mmol) in THF (10 mL) and a solution of disulfonates **7** (1 mmol) in water (8 mL) were stirred together for 24 hours at rt. After that reaction mixture was filtered through a glass filter. The solid was washed with H_2O and hexane to obtain polymer **6A (a-e)-allyl** and **6B (a~e)-allyl** (**Scheme 3**). **Table 1** demonstrates overall data of characterization obtained for polymer.



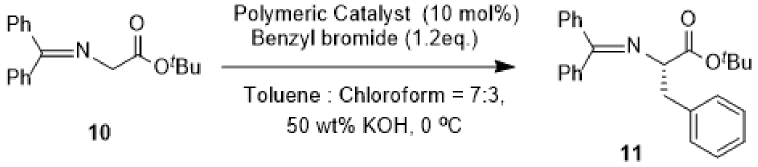
Scheme 3 Synthesis of main-chain chiral polymer **6A (a~e)-allyl** and **6B (a~e)-allyl**

Table 1 Characterization of the synthesized chiral polymers

Polymer	Yield and appearance	IR (KBr) data (cm^{-1})	M_n	M_w/M_n
6Aa-allyl	80% yield as brown solid.	3420, 2936, 1645, 1588, 1507, 1491, 1422, 1353, 1267, 1195, 1067, 993, 923.	5500	1.07
6Ab-allyl	85% yield as brown solid.	3421, 2938, 1942, 1684, 1645, 1588, 1507, 1451, 1422, 1385, 1203, 1134, 1066, 994.	5300	1.02
6Ac-allyl	88% yield as brown solid.	3420, 2937, 1942, 1645, 1588, 1507, 1493, 1453, 1422, 1385, 1237, 1188, 1095, 1066, 994, 924.	5500	1.05
6Ad-allyl	76% yield as brown solid.	3407, 2933, 1943, 1685, 1646, 1589, 1508, 1491, 1456,1422, 1384, 1351, 1213, 1184, 1094, 994, 935.	5600	1.08
6Ae-allyl	80% yield as brown solid.	3420, 2937, 1684, 1645, 1588, 1507, 1492, 1421, 1352, 1210, 1132, 1066, 993, 924.	5500	1.07
6Ba-allyl	80% yield as brown solid.	3418, 2937, 1708, 1646, 1589, 1507, 1490, 1361, 1220, 1068, 1028, 994.	5700	1.07
6Bb-allyl	82% yield as brown solid	3431, 2935, 1645, 1590, 1507, 1490, 1361, 1267, 1101, 1026, 993	5200	1.05
6Bc-allyl	85% yield as brown solid.	3421, 2937, 1942, 1645, 1589, 1507, 1491, 1361, 1238, 1066, 1030, 994.	5600	1.15
6Bd-allyl	76% yield as brown solid	3396, 2931, 1645, 1588, 1507, 1491, 1384, 1210, 1066, 1032, 993.	5700	1.06
6Be-allyl	75% yield as brown solid.	3397, 2932, 1943, 1646, 1588, 1507, 1491, 1353, 1209, 1066, 1028, 993.	5700	1.05

General procedure for asymmetric transformation of 10 using polymer catalyst 6Ba-allyl

Polymer catalyst **6Ba-Allyl** (10 mol %) and **10** (1.78 mmol, 0.53 g) were mixed to **10** mL solvent of toluene:chloroform (7:3). After that 2.5 mL KOH (50 wt% aqueous) was combined to the above mixture. 0 °C temperature was maintained and (2.14 mmol, 0.37 g) benzyl bromide was further added slowly to the mixture. Then, the reaction mixture was run for 5 hours. Organic layer was extracted with EtOAc following the addition of 10 mL NaCl (Saturated) and evaporated by rota evaporator and obtained colorless oil as crude product. Then, it was purified using a column packed with silica (hexane-ether = 10:1 as mobile phase) and finally pure **11** was obtained. The enantiomeric excess (90% ee) was determined by HPLC using OD-H (Chiralcel) column, 2-propanol: hexane=1:100, flow rate = 0.3 mL min^{-1}, retention time: enantiomer S = 47.9 min, enantiomer R = 27.6 min,). Absolute configuration of the final product was confirmed by comparing the retention time of the reported data (O'Donnell 1989).



Scheme 4 Asymmetric benzylation of *N*-diphenylmethylene glycine *tert*-butyl ester

Results and Discussion

Dimer **3**, originally synthesized and utilized by Jew, 2001. Later, dimer **3** was modified by Parvez, 2014 and 2019 to synthesize dimer **6A** and **6B** which was quite effective in asymmetric transformation of **10** (Table 2 and Table 3). When dimer **6A** and **6B** were further modified to obtain **6A-allyl** and **6B-allyl** and applied in asymmetric transformation of **10**, **6A-allyl** showed slightly lower activity (Table 2, entry 2) than **6A** and **6B-allyl** showed higher activity (Table 3, entry 2) than **6B.**

Table 2. Asymmetric transformation of **10** in presence of chiral polymer **6A(a~e)-allyl** to obtain **11**.

Entry	Catalyst	Time (h)	Yield[a] (%)	ee[b,c] (%)
1[d]	**6A**	5	85	88
2	**6A-allyl**	3	56	79
3	**6Aa-allyl**	4	71	85
4	**6Ab-allyl**	5	81	81
5	**6Ac-allyl**	5	95	86
6	**6Ad-allyl**	5	94	90
7	**6Ae-allyl**	5	96	85

[a]Determined by proton NMR [b]Determined by HPLC using OD-H column (Chiralcel). [c]*S* configuration. [d]Parvez et al. 2014.

Newly designed chiral ionic polymers **6A(a-e)-allyl** bearing *p*-xylene spacer in the polymer chain and various disulfonates were utilized in asymmetric transformation of **10** (scheme 4) to obtain **11**. The values obtained are summarized in Table 2. Many cases, ionic polymeric catalysts demonstrated higher yield and same level of enantioselectivity in comparison to dimeric catalyst **6A** and **6A-allyl** (Table 2, entry 3 to entry 7). Applying polymer catalyst **6Ad-allyl,** 96% yield and 90% ee was obtained (Table 2, entry 6) which is better than dimeric catalyst **6A** and **6A-allyl**. The polymeric chiral catalyst might have induced better chiral microenvironment than low molecular weight chiral catalyst, which resulted higher enantioselectivity.

Chiral ionic polymers **6B(a-e)-allyl** bearing *m*-xylene spacer in the polymer chain and various disulfonates were also applied in asymmetric transformation of **10** (scheme 4) and obtained values are summarized in Table 3. Mostly, they demonstrated high level of catalytic activity compare to dimeric catalyst **6B** and **6B-allyl**. Up to 97% yield and 90% ee value was obtained.

Table 3. Asymmetric transformation of **10** in presence of chiral polymer **6B(a~e)-allyl** to obtain **11**.

Entry	Catalyst	Time (h)	Yield[a] (%)	ee[b,c] (%)
1[d]	**6B**	7	79	81
2	**6B-allyl**	5	83	88
3	**6Ba-allyl**	5	96	90
4	**6Bb-allyl**	5	95	90
5	**6Bc-allyl**	5	94	90
6	**6Bd-allyl**	5	97	88
7	**6Be-allyl**	5	96	90

[a] Determined by proton NMR [b] Determined by HPLC using OD-H column (Chiralcel). [c] *S* configuration. [d] Parvez et al. 2019.

Conclusions

In this work, some novel chiral ionic polymers containing cinchonidine derived chiral quaternary ammonium unit in the polymer chain have been prepared by ion-exchange method. The polymers were characterized by IR, NMR, specific rotation and GPC analysis. The highest yield (88%) obtained was for ionic polymer **6Ac-allyl**. These polymers have been utilized as polymeric catalyst in asymmetric transformation of **10** to obtain phenylalanine derivative (*S* configuration) **11** up to 90% enantioselectivity. The polymers were nearly insoluble in the reaction system, which facilitated the working up step compare to low molecular weight catalyst.

Acknowledgments

This work was done in the Laboratory of Professor Shinichi Itsuno, Department of Environmental and life Sciences, Toyohashi University of Technology, Japan 441-8122.

References

Arakawa, Y., Haraguchi, N. and Itsuno, S. 2008. An Immobilization Method of Chiral Quaternary Ammonium Salts onto Polymer Supports. Angew. Chem. Int. Ed. 47, pp. 8232-8235.

Ahamed, P., Haque, M. A., Ishimoto, M., Parvez, M. M., Haraguchi, N. and Itsuno, S. 2013. Synthesis of chiral quaternary ammonium polymers for asymmetric organocatalysis application. Tetrahedron. 69, pp.3978-3983.

Abdelkawy, M. A., Davin, C., Aly, E.-S. A., El-Badawi, M. A. and Itsuno, S. 2021. Chiral Polyureas Derived Cinchona Alkaloids: Highly Efficient Bifunctional Organocatalysts for the Asymmetric Michael Addition Reaction. ChemistrySelect. 6(43), pp. 11971-11979.

Corey, E. J., Xu, F., and Noe, M. C. 1997. A Rational Approach to Catalytic Enantioselective Enolate Alkylation Using a Structurally Rigidified and Defined Chiral Quaternary Ammonium Salt under Phase Transfer Conditions. Journal of American Chemical Society. 119, pp.12414-12415.

Chinchilla, R., Mazón, P. and Nájera, C. 2000. Asymmetric synthesis of α-amino acids using polymer-supported *Cinchona* alkaloid-derived ammonium salts as chiral phase-transfer catalysts. Tetrahedron: Asymmetry. 11, pp.3277-3281.

Chinchilla, R., Mazon, P. and Najera, C. 2002. New dimeric anthracenyl derive Cinchona *quaternary* ammonium salts as phase-transfer catalysts for the asymmetric synthesis of α-amino acids. Tetrahedron: Asymmetry. 13, pp.927-931.

Chhanda, S.A. and Itsuno, S. 2019. Design and synthesis of chiral hyperbranched polymers containing cinchona squaramide moieties and their catalytic activity in the asymmetric Michael addition reaction. Journal of Catalysis. 377, pp.543-549.

Heck R. F. and Nolley**,** J. P. Jr. 1972. Palladium-catalyzed vinylic hydrogen substitution reactions with aryl, benzyl, and styryl halides**.** Journal of Organic Chemistry. 37, pp.2320-2322.

Haraguchi, N. and Itsuno, S. 2011. In Polymeric Chiral Catalyst Design and Chiral Polymer Synthesis, Ed. Itsuno, S. Wiley. 2, pp.17-61.

Haraguchi, N., Kiyono, H., Takemura, T. and Itsuno, S. 2012. Design of main-chain polymers of chiral imidazolidinone for asymmetric organocatalysis application. Chem. Commun. 48, pp. 4011-4013.

Haraguchi, N., Ahamed, P., Parvez, M. M. and Itsuno, S. 2012. Molecules. Synthesis of Main-Chain Chiral Quaternary Ammonium Polymers for Asymmetric Catalysis Using Quaternization Polymerization. 17, pp.7569-7583.

Haraguchi, N., Takenaka, N., Najwa, A., Takahara, Y., Mun, M. K. and Itsuno, S. 2018. Synthesis of Main-Chain Ionic Polymers of Chiral Imidazolidinone Organocatalysts and Their Application to Asymmetric Diels–Alder Reactions. Advanced Synthesis & Catalysis. 360 (1), pp.112-123.

Heck, R.F. 1982. Palladium-Catalyzed vinylation of organic halides. Org. React. 27, pp.345–390.

Itsuno, S., Paul, D. K., Salam, M. A. and Haraguchi, N. 2010. Main-Chain Ionic Chiral Polymers: Synthesis of Optically Active Quaternary Ammonium Sulfonate Polymers and Their Application in Asymmetric Catalysis. J. Am. Chem. Soc. 132, pp. 2864-2865.

Itsuno, S. and Haraguchi, N. 2012. In Science of Synthesis Asymmetric Organocatalysis 2, Ed. Maruoka, K. Thieme. 2.3.5, pp.673-695.

Itsuno, S., Paul, D. K., Ishimoto, M. and Haraguchi, N. 2010. Designing Chiral Quaternary Ammonium Polymers: Novel Type of Polymeric Catalyst for Asymmetric Alkylation Reaction. Chem. Lett., 39, pp.86-87.

Itsuno, S., Parvez, M. M. and Haraguchi, N. 2011. Polymeric chiral organocatalysts. Polym. Chem. 2, pp.1942-1949.

Jew, S.-S., Jeong, B.-S., Yoo, M.-S., Huh, H. and Park, H.-G. 2001. Synthesis and application of dimeric Cinchonaalkaloid phase-transfer catalysts: α, α′-bis[O(9)-allylcinchonidinium]-o,m, or p-xylene dibromide.Chemical Communications.14, pp. 1244-1245.

Kumpuga, B. T. and Itsuno, S. 2018. Synthesis of chiral polyesters of cinchona alkaloid catalysts for enantioselective Michael addition of anthrone to nitroalkenes. Journal of Catalysis. 361, pp.398-406.

Lygo, B. and Wainwright, P. G. 1997. A new class of asymmetric phase-transfer catalysts derived from Cinchona alkaloids-Application in the enantioselective synthesis of α-amino acids. Tetrahedron Letters. 38, pp.8595- 8598.

Lee, J.-H., Yoo, M.-S., Jung, J.-H., Jew, S.-S., Park, H.-G. and Jeong, B.-S. 2007. Polymeric chiral phase-transfer catalysts derived from cinchona alkaloids for enantioselective synthesis of α-amino acids. *Tetrahedron*. 63, pp.7906-7915.

Ma, B., Parkinson, J. L. and Castle, S. L. 2007. Novel cinchona alkaloid derived ammonium salts as catalysts for the asymmetric synthesis of α -hydroxy α-amino acids via aldol reactions. Tetrahedron Lett. 48, pp.2083-2086.

Mizoroki, T., Mori, K. and Ozaki, A. 1971. Arylation of Olefin with Aryl Iodide Catalyzed by Palladium. Bull. Chem. Soc. Jpn. 44, pp.581.

O'Donnell M. J., Bennett, W. D. and, Wu, S. 1989. The stereoselective synthesis of alpha-amino acids by phase-transfer catalysis. Journal of American Chemical Society. 111, pp.2353-2355.

Park, H.-G., Jeong, B.-S., Yoo, M.-S., Park, M.-K., Huh, H and Jew, S.-S. 2001. Trimeric Cinchona alkaloid phase-transfer catalyst: α, α′, α″ -tris[O(9)-
Allyl cinchonidinium] mesitylene tribromide. *Tetrahedron Letters.*42, pp. 4645-4648.

Park, H.-G., Jeong, B.-S., Yoo, M.-S., Lee, J.-H., Park, M.-K., Lee, Y.-J. Kim M.-J. and Jew, S.-S. 2002. Highly Enantioselective and Practical Cinchona-Derived Phase-Transfer Catalysts for the Synthesis of α-Amino Acids. *Angewandte Chemie International Edition*. 41, pp.3036-3038.

Parvez, M. M., Salam, M. A., Haraguchi, N. and Itsuno, S. 2012. Synthesis of chiral ionic polymers containing quaternary ammonium sulfonate structure and their catalytic activity in asymmetric alkylation. J. Chinese Chem. Soc., 59, pp. 815-821.

Parvez, M. M., Haraguchi, N. and Itsuno, S. 2012. Molecular design of chiral quaternary ammonium polymers for asymmetric catalysis applications. Org. Biomol. Chem., 10: pp. 2870-2877.

Parvez, M. M., Haraguchi, N. and Itsuno, S. 2014. Synthesis of cinchona alkaloid-Derived chiral polymers by Mizoroki–Heck polymerization and their application to asymmetric catalysis. Macromolecules. 47, pp.1922-1928.

Parvez, M. M and Itsuno, S. 2017. Synthesis of chiral quaternary ammonium polymers from cinchonidine dimer and their applications in asymmetric benzylation of glycine derivative. Barishal University Journal Part 1, 4 (2), pp.291-297.

Parvez, M.M and Itsuno, S. 2019. Synthesis of main-chain chiral polymers using ion- exchange polymerization and their applications as polymeric organocatalyst in asymmetric reactions. Barishal University Journal Part 1, 6 (1), pp.13-23.

Shi, Q., Lee, Y. J. Song, H., Cheng, M., Jew, S. S., Park, H. G. and Jeong, B. S. 2008. Electronically Modified Polymer-supported Cinchona Phase-transfer Catalysts for Asymmetric Synthesis of α-Alkyl-α-amino Acid Derivatives. Chem. Lett. 37, pp.436-437.

Thierry, B., Plaquevent, J. C. and Cahard, D. 2001. New polymer-supported chiral phase-transfer catalysts in the asymmetric synthesis of α-amino acids: the role of a spacer. Tetrahedron: Asymmetry, 12, pp.983-986.

Thierry, B., Perrard, T., Audouard, C., Plaquevent, J.-C. and Cahard, D. 2001. Solution- and Solid-Phase Approaches in Asymmetric Phase-Transfer Catalysis by Cinchona Alkaloid Derivatives. Synthesis. 11, pp.1742-1746.

Thierry, B., Plaquevent, J.- C. and Cahard, D. 2005. Cinchona alkaloid-based polymer-bound phase-transfer catalysts: efficient enantioselective alkylation of benzophenone imine of glycine esters. Molecular Diversity, 9, pp.277-290.

Ullah, M. S. and Itsuno, S. 2017. Synthesis of cinchona alkaloid squaramide polymers as bifunctional chiral organocatalysts for the enantioselective Michael addition of -keto esters to nitroolefins. Molecular Catalysis. 438, pp.239-244.

Ullah, M. S. and Itsuno, S. 2018. Cinchona Squaramide-Based Chiral Polymers as Highly Efficient Catalysts in Asymmetric Michael Addition Reaction. ACS Omega, 3 (4), pp.4573–4582.