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# Synthesis of enantiomerically enriched benzimidazole-triazoles: Application as organocatalyst for asymmertric Diels-Alder reaction

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4-(Benzimidazolylmethyl)-1,2,3-triazole derivatives **8a-g** and **9a-g** have been developed using click chemistry protocol in regioselective manner and in high yields. These compounds have geometry to behave as chiral tweezers due to the presence of flexibly bound pi-rich hetero-aryl rings in addition to a chiral center. The synthesized chiral benzimidazole-triazoles have been found to be useful as organocatalysts for the enantioselective Diels-Alder (DA) reaction between anthrone **10** and maleimide detivatives **11a-g**. Enantioselectivity levels have been found to be dependent on several factors including nature of substituents in benzimidazole-triazoles **8a-g** and **9a-g**.

**Keywords**: Enantiomerically enriched, click chemistry, tweezer, benzimidazole-triazoles, Diels-Alder adduct

Amines work as efficient Lewis bases in many reactions. Chiral heterocyclic amines, with presence of one or more polar functional groups, have found applications in variety of asymmetric transformations[1-9]. Cinchona alkaloids, a classic example of such features, have exhibited applications in many chiral discriminative processes, such as asymmetric synthesis, kinetic resolutions, *etc*.[10-15] Chiral molecular recognition is yet another important process which requires similar structural features as multiple binding sites, presence of aryl/heteroaryl rings, presence of polar groups, *etc*.[16a-d] Though these types of molecules have shown efficient chiral discriminating abilities, the exact mechanistic requirement remains un-clear in most cases and hence it is generally very difficult to propose a chiral molecule as the best for a given purpose. This has necessitated availability of a large number of enantiomerically enriched molecules to suit the plethora of asymmetric transformations.

Metal-based chiral catalysts[17] have dominated the field of asymmetric catalysis for many decades. This catalytic system offers wide range of metals available for soft and hard chiral ligands. Metals ensure a better bound transition states resulting in better stereoselectivities. While organo-catalysis[18] has to depend on multiple-ligating hetero-atoms or electron rich units such as presence of aryl groups for a rigid transition state species, needed for high levels of stereo-selections. There are some reports where excellent levels of stereoselections have been found, but in general, the results do not match the levels of chiral metal-based catalysis. Organo-catalysts however offer advantages such as cost effective, greener catalysis and less stringent reaction conditions. Therefore this continues to draw attention of the chiral community.

Base-catalysed Diels–Alder reaction is unusual and works in a different manner; the base catalytically activates the diene to give a higher energy HOMO. The cycloadditions of anthrones and *N*-substituted maleimides are prominent examples of asymmetric catalysis exerted by chiral Brønsted bases, the resultant DA adduct α,β-butenolides and α,β-unsaturated lactams have antipsoriatic and antiproliferative biological activities. However, many research groups, including our group, have developed the chiral base catalysed[19,20a,b] methodology with moderate to excellent enantioselectivity and good yield for DA adduct. Recently our group has employed benzimidazole based chiral tweezers[18a] for the asymmetric Diels-Alder reaction between anthrone and various maleimides; the methodology intriguingly gave reversal of enantioselectivity for obtained cyclo-adduct under the influence of different achiral part of the developed tweezers.

In continuation of our quest in this area[20a-e,21], we aimed to build a new chiral bi-heterocyclic system with benzimidazole-triazole as partners and its successful application as organocatalyst for the

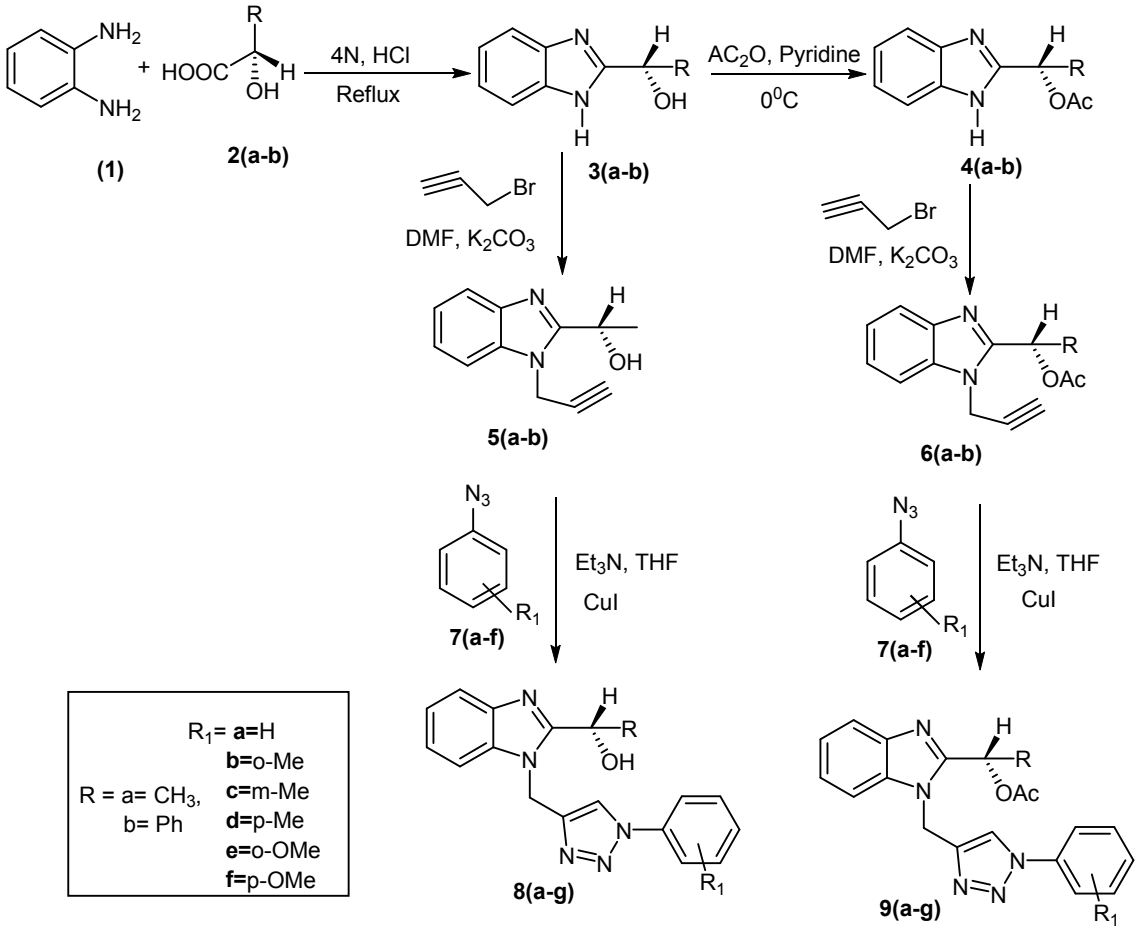
enantioselective Diels-Alder (DA) reaction between anthrone and maleimide.

## Results and Discussion

Philips condensation[22] and Click chemistry protocols were employed for synthesis of desired tweezers. The copper(I)-mediated 1,3-dipolar cycloaddition of azides and terminal alkynes[23] (CuAAC) represents useful strategy for regioselective synthesis of 1,4-substituted 1,2,3-traizoles. The special feature of this reaction is high yield, mild conditions, environmentally friendly, and above all, a regiospecific outcome.

Herein, we describe synthesis of new chiral benzimidazole tweezers namely *N*-1-((1-phenyl-1H-1,2,3-triazol-4-yl)methyl)-(*S*)-(-)-2-(α-hydroxyethyl/benzyl) benzimidazole **(PT-HEB) 8a-g** and*N*-1-((1-phenyl-1H-1,2,3-triazol-4-yl)methyl)-(*S*)-(-)-2-(α-acetoxyethyl/benzyl) benzimidazole **(PT-AEB) 9a-g** (Scheme I). (*S*)-2-(α-hydroxyethyl/benzyl) benzimidazole (HEB/HBB) **3a-b** could be obtained from *o*-phenylenediamine (**1**) with respective (*S*)-lactic acid/mandelic acid **2a-b**[24]. Base-catalysed alkylation with propargyl bromide was carried out. Newly synthesized alkylated products **5a-b/6a-b** exhibited C≡C-H band at 2110-2130 $cm^{-1}$ and bridging $CH_2$ group resonated at around δ 4.7 ppm as dd with a large coupling constant value (around18 Hz) in $^1$H NMR.

The alkylated chiral benzimidazoles **5a-b/6a-b** serve as alkyne for click reaction. Aromatic azides could be synthesized from aromatic amines by diazotisation using reported procedure[25]. For synthesis of the benzimidazole-triazole tweezers click chemistry protocol, involving use of CuI-TEA in THF was employed, in a reaction between equimolar mixtures of alkylated chiral benzimidazoles **5a-b** and substituted aromatic azides **7a-f** at RT[26]. The *N*-1-((1-Aryl-1H-1,2,3-triazol-4-yl)methyl)-(*S*)-(-)-2-(α-hydroxyethyl) benzimidazole **(PT-HEB) 8a-g** was




Scheme I — Synthetic pathway for preparation of **8a-g** and **9a-g**

obtained as a fine white powder. The formation of compound **8a** by 1,3-dipolar cyclo-addition was evident by the disappearance of a C≡C stretching band at 2117 $cm^{-1}$ in IR and in $^1H$ NMR the methylene protons at δ 5.78 was seen as dd with *J* value of 8.1 Hz, indicating clearly geminal coupling and diasterotopic nature of the methylene protons.

Chiral identity was established for these cycloaddition products using normal phase HPLC and with use of Chiralpak IB as enantioselective stationary phase. The chiral tweezers with greater than 95% *ee* were obtained. Using the optimized reaction conditions, we next examined the scope and generality of this reaction with various types of substituted azides, and synthesized a small library of new chiral benzimidazole based triazoles **8a-f**. The yield and enantiopurity of products were uniformly very high. (refer entry **1-6** of Table I)

Based on our experience[17c,d] of better levels of chiral kinetic resolutions when acetyl derivatives rather than with free hydroxyls were employed involving chiral benzimidazoles, we decided to attempt similar strategy in the present investigations. Conversion of free hydroxyl group to their acetyl derivatives was therefore carried out to obtain *N*-1-((1-aryl-1H-1,2,3-triazol-4-yl)methyl)-(*S*)-(-)-2-(α-acetoxyethyl/benzyl) benzimidazole (PT-AEB) **9a-g** with very high enantiomeric excess of >96% *ee*.

The synthesized enantiopure heterocycle based tweezers **8a-e**, **8g** and **9a** were then evaluated as the organo-catalysts, as Bronsted bases, for asymmetric Diels-Alder reaction of anthrone **10** and *N*-ethyl maleimide **11b** at 0°C (Supporting Information 1.1).

Table I — Substrate scope of chiral tweezer benzimidazole-triazoles **8a-g** and **9a-g**

| Sr. No. | Compd | R | R1 | Yield[a] (%) | $[\alpha]^{25}_D$ (°) | *ee*[b] (%) |
|---|---|---|---|---|---|---|
| 1 | **8a** | $CH_3$ | H | 78 | +15 | 98 |
| 2 | **8b** | $CH_3$ | *o*-Me | 68 | +13 | 98 |
| 3 | **8c** | $CH_3$ | *m*-Me | 75 | +09 | 75 |
| 4 | **8d** | $CH_3$ | *p*-Me | 81 | +22 | 100 |
| 5 | **8e** | $CH_3$ | *o*-OMe | 66 | +24 | 95 |
| 6 | **8f** | $CH_3$ | *p*-OMe | 83 | +16 | 97 |
| 7 | **8g** | Ph | H | 82 | – | 98 |
| 8 | **9a** | $CH_3$ | H | 85 | –97 | 99 |
| 9 | **9b** | $CH_3$ | *o*-Me | 82 | –90 | 99 |
| 10 | **9c** | $CH_3$ | *m*-Me | 84 | –86 | 99 |
| 11 | **9d** | $CH_3$ | *p*-Me | 83 | –98 | 96 |
| 12 | **9e** | $CH_3$ | *o*-OMe | 80 | –88 | 99 |
| 13 | **9f** | $CH_3$ | *p*-OMe | 87 | –103 | 96 |
| 14 | **9g** | Ph | H | 76 | – | 99 |

[a] Represents isolated yield over three steps.
[b] Determined by chiral HPLC analysis.

The organo bases **8a-e**, **8g** and **9a** catalysed DA reaction gave good yields (83-91%), varied enantioselectivities (7-74% *ee*) and *(S,S)* configuration of Diels-Alder adduct. It was noticed that acetyl substituent on chiral centre **(PT-AEB) 9a** offered less enantioselectivity compared to free hydroxy group **PT-HEB 8a**. Substituents attached to phenyl ring at triazole seemed to be affecting steric and electronic properties and consequently differential enantioselectivities were found in different cases. Based on the overall better performance of catalyst **PT-HEB 8a** in the Diels-Alder reaction it was further selected for screening with regard to optimization of reaction conditions for the most suitable solvents and temperature.

Furthermore, the systematic studies of Asymmetric Diels-Alder reaction **PT-HEB 8a** as an organo-catalyst at RT in various solvents was carried out (Supporting Information 1.2). 1, 2-Dichloroethane (DCE) gave highest enantioselectivity with good conversion (89% yield, 37% *ee*), was selected as a best suitable solvent for the further screening of temperature.

Optimal temperature of the DA reaction have been evaluated using **PT-HEB 8a** as an organo-catalyst at different temperatures in 1,2-Dichloroethane as a solvent (Supporting Information 1.3). On lowering the temperature of the reaction from RT to −10°C extended the reaction time yet furnished better enantioselectivities up to 83%.

Under the optimized condition, we studied Asymmetric Diels-Alder reaction and anthrone **10** and various ranges of *N*-substituted maleimides **11a-g** (Scheme II) and the results are listed in Table II. *N*-alkyl substituted maleimides reacted smoothly giving

Table II — Substrate scopes of antrone **10** and maleimide **11a-g** for asymmetric Diels-Alder reaction

| Sr. No. | N-Substituted Maleimide **11a-g** | DA Adduct **12a-g** | Yield (%)[b] | *ee* (%)[c] | Configuration[d] |
|---|---|---|---|---|---|
| 1 | $CH_3$ (**11a**) | **12a** | 86 | 57 | (S, S) |
| 2 | $C_2H_5$ (**11b**) | **12b** | 82 | 83 | (S, S) |
| 3 | $C_3H_7$ (**11c**) | **12c** | 84 | 5 | (S, S) |
| 4 | *tert*-Butyl (**11d**) | **12d** | 82 | 28 | (S, S) |
| 5 | Benzyl (**11e**) | **12e** | 75 | 61 | (S, S) |
| 6 | Ph (**11f**) | **12f** | – | – | – |
| 7 | *p*-$OCH_3$Ph (**11g**) | **12g** | – | – | – |

[a] All reactions were carried out using 0.5 mmol of N-alkyl/aryl maleimide **11a-g**, 0.5 mmol of anthrone **10** in 5 mL of 1,2-dichlroethane at -10°C for 8-12 h.
[b] Isolated yield after column chromatography.
[c] Configuration was determined by optical rotation reported in literature[19c-d,27].

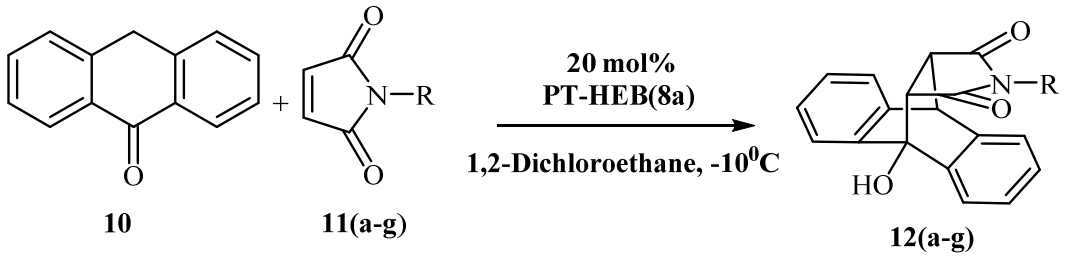
good yields (75-86%). But in case of *N*-aryl maleimides **11f-g,** the desired cycloadducts could not be formed. Formation of Diels-Alder adducts **12a-e** was confirmed by $^{1}$H NMR, and Mass Spectrum.

The enantioselectivities (Table II) of these adducts **12a-e** were analysed by HPLC using chiral stationary phase. All *N*-alkyl substituted maleimides reacted smoothly giving good yields (75-86%) and mixed enantioselectivities (5-83% *ee*) (Table II, Entries 1-5).

While with *N*-aryl maleimides **11f-g** desired cycloadducts were not obtained. Excellent level of enantioselectivity was furnished with *N*-ethyl maleimide **11b** upto 83% *ee* and 82 % yield (Table II, Entry 2).

**Plausible mechanism of asymmetric Diels-Alder reaction**

A plausible mechanism for this chiral base tweezers **8a-f, 9a** catalysed Diels-Alder reaction of anthrone **10** and *N*-substituted maleimides **11a-e** (Figure 1) is presented. It is proposed that the acidic proton of the anthrone was abstracted by the amine of triazole, converting anthrone to its dienolate form with protonated amine as its counter




Scheme II — Substrate scopes of antrone **10** and maleimide **11a-g** for asymmetric Diels-Alder reaction

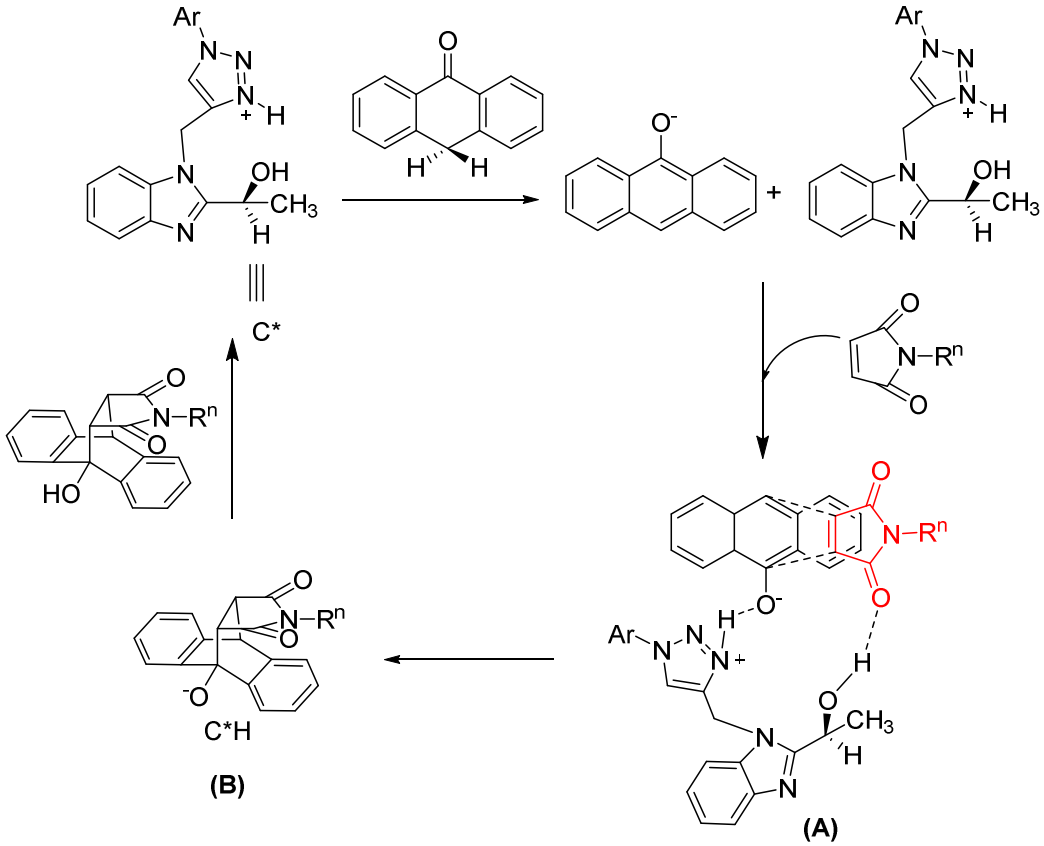



Figure 1 — A plausible mechanism for this chiral base tweezers **8a-f**, **9a** catalysed Diels-Alder reaction of anthrone **10** and *N*-substituted maleimides **11a-e**

ion. The chiral catalyst with a hydroxyl group present at the chiral center then formed additional H-bond with the maleimide. Thus the chiral amine was partially bonded to the diene part and the dienophile part to induce stereoselectivity. In case of approach of the maleimide from the right hand side *(S,S)* configuration was expected, on the other hand in case the approach of the maleimide from the left hand side *(R,R)* configuration could be expected.

The aromatic/heteroromatic methylene moiety attached to the '*N*' of benzimidazole was believed to be in the same plane of the benzimidazole ring and was believed to be away from the side arm of the benzimidazole ring with a chiral center. This made the approach of the maleimide difficult from the left hand side and hence due to the approach of the maleimide from the right hand side the predominant enantiomer obtained was (*S*, *S*) for the adduct.

## Experimental Section

All reagents and solvents of analytical grade were commercially available and used as received. The progress of the reaction was monitored by thin-layer chromatography (TLC) using silica gel of SDFCL Ltd. LR. $^{1}$H NMR, $^{13}$C NMR, COSY, NOESY, DEPT$^{135}$ spectra were scanned in $CDCl_3$ and DMSO-$d_6$ on Bruker (Avance II, 300MHz) spectrometers using TMS as an internal standard. IR spectra were recorded on Perkin-Elmer Frontier model. Optical rotations were recorded on Autopol IV-Ruldolph. Enantiomeric excess were determined by chiral HPLC analysis on Thermo Fisher spectra system UV1000 HPLC unit. GC-MS spectra were recorded in Thermo Fisher Polaris Q-Trace GC Ultra. Melting points are uncorrected and were recorded on Mel-Temp melting point apparatus.

### General procedure for preparation of *N*-propargyl derivatives of benzimidazoles, 5, 6a-b

(*S*)-2-(α-Hydroxyethyl/benzyl)benzimidazole **3a-b** (24.5 mmol) or (*S*)-2-(α-acetoxy ethyl/benzyl)benzimidazole **4a-b** and 24.5 mmol of propargyl bromide with 36.7 mmol of potassium carbonate ($K_2CO_3$) in round bottom flask was stirred at RT for 12 h. The course of reaction was monitored by Thin layer Chromatography (TLC). After complete disappearance of starting material the reaction mixture was poured in ice cold water. The obtained solid was filtered and air dried.

### General procedure for preparation of chiral benzimidazole based tweezers, 8a-g, 9a-g from alkylated benzimidazoles, 5, 6a-b

CuI (9.52 mg, 0.050 mmol) and triethylamine (TEA) (0.021 g, 0.050 mmol) were stirred in THF (4.5 cc) at RT for 20 min, after which a homogeneous solution was obtained. **5a-b** or **6a-b** (1.00 mmol) and **7a-f** (0.201 g, 1.00 mmol) were dissolved in THF (5 cc) and added in a single portion to the catalyst solution. The reaction mixture was allowed to stir for 6-8 h, and then quenched by adding 10 cc of 10% $NH_4OH$ solution. A precipitate formed upon vigorous stirring and was isolated by filtration, as a fine white powder.

### Characterization data of chiral benzimidazole-triazoles 8a-g and 9a-g

***N*-1-((1-Phenyl-1*H*-1,2,3-triazol-4-yl)methyl)-(*S*)-(-)-2-(α-hydroxy ethyl)benzimidazole (PT-HEB), 8a**: Yield 1.0 g (78%). m.p. 95°C. Specific rotation: $[\alpha]^{25}_{D}$= +15° (c 1, Ethanol); $^{1}$H NMR (300 MHz, MeOD): δ 1.76 (d, 3H, *J* = 4.2 Hz), 5.39 (unresolved siglet, 1H), 5.78 (m, 2H, *J* = 8.1 Hz), 7.24 (d, 2H, *J* = 6.6 Hz), 7.42-7.52 (m, 3H), 7.63-7.74 (m, 4H), 8.42 (s,1H); $^{13}$C NMR (75 MHz, MeOD): δ 21.90, 40.21, 64.22, 111.67, 119.92, 121.59, 122, 88, 123.67, 124.41, 130.14, 130.90, 138.23, 145.48; GC-MS: molecular ion ($C_{18}H_{17}N_5O$) *m/z* value at 317.11. Anal. Calcd for $C_{18}H_{17}N_5O$: C, 67.70; H, 5.37; N, 21.93. Found: C, 67.61; H, 5.22; N, 22.12%. Chiral HPLC: Column: Chiralpak IB column of diacel, Solvent system: DCM (20% ethanol) /Hexane 25:75, Flow rate = 0.8 cc/min, λ = 250 nm), $t_{major}$ =15.24 min, $t_{minor}$ =11.883 min, *ee* = 98%.

***N*-(1-((1-(*o*-Tolyl)-1*H*-1,2,3-triazol-4-yl)methyl)-(*S*)-(-)-2-(α-hydroxy ethyl) benzimidazole, 8b**: Yield 0.86 g (68%). m.p. 75°C. Specific rotation: $[\alpha]_{D}^{25}$ = +13° (c 1, Ethanol); $^{1}$H NMR (300 MHz, Acetone-$d_6$): δ 1.75 (d, 3H, $CH_3$, *J* = 5.7 Hz), 2.12 (s, 3H, $CH_3$), 5.44 (unresolved siglet, 1H), 5.76 (dd, 2H, *J* = 16.2 Hz ), 7.18-7.25 (m, 2H), 7.32-7.45 (m, 2H), 7.65-7.70 (m, 3H), 8.28 (s, 1H); $^{13}$C NMR (75 MHz, Acetone-$d_6$): δ 17.81, 22.16, 39.69, 111.35, 122.50, 123.23, 125.64, 126.81, 127.75, 130.68, 132.25, 134.37, 137.54; GC-MS: molecular ion ($C_{19}H_{19}N_5O$) *m/z* value at 331.19. Anal. Calcd for $C_{19}H_{19}N_5O$: C, 68.45; H, 5.74; N, 21.01. Found: C, 68.51; H, 5.63; N, 20.96%. Chiral HPLC: Column: Chiralpak IB column of diacel, Solvent system: DCM (20% ethanol)/Hexane 25: 75, Flow rate = 0.8 cc/min,

λ = 250 nm), $t_{major}$= 13.57 min, $t_{minor}$ = 8.96 min, *ee* = 98%.

**N-(1-((1-(*m*-Tolyl)-1*H*-1,2,3-triazol-4-yl)methyl)-(S)-(-)-2-(α-hydroxy ethyl) benzimidazole, 8c**: Yield 0.96 g (75%). m.p. 78°C. Specific rotation: $[\alpha]_D^{25}$= +09° (c 1, Ethanol); $^1$H NMR (300 MHz, Acetone-$d_6$): δ 1.76 (d, 3H, $CH_3$, *J* = 4.8 Hz), 2.39 (s, 3H, $CH_3$), 5.43 (unresolved siglet, 1H), 5.74 (q, 2H), 7.19 (d, 2H, *J* = 5.4 Hz), 7.26 (d, 2H, *J* = 7.8Hz), 7.39 (t,1H, *J* = 8.1 Hz), 7.59 (t, 2H, *J* = 8.4 Hz), 8.55 (s, 1H); $^{13}$C NMR (75 MHz, Acetone-$d_6$): δ 21.25, 110.20, 118.23, 121.62, 123.31, 130.21, 130.46, 134.40, 139.33; GC-MS: molecular ion ($C_{19}H_{19}N_5O$) *m/z* value at 331.19. Anal. Calcd for $C_{19}H_{19}N_5O$: C, 68.45; H, 5.74; N, 21.01. Found: C, 68.37; H,5.65; N, 21.15%. Chiral HPLC: Column: Chiralpak IB column of diacel, Solvent system: DCM (20% ethanol)/Hexane 25:75, Flow rate = 0.8 cc/min, λ = 250 nm), $t_{major}$ = 12.55 min, $t_{minor}$ = 9.14 min, *ee* = 99%.

***N*-(1-((1-(*p*-Tolyl)-1*H*-1,2,3-triazol-4-yl)methyl)-(*S*)-(-)-2-(α-hydroxy ethyl) benzimidazole, 8d**: Yield 1.04 g (81%). m.p. 103°C. Specific rotation: $[\alpha]^{25}_D$ = +22° (c 1, Ethanol); $^1$H NMR (300 MHz, Acetone-$d_6$): δ 1.74 (d, 3H, $CH_3$, *J* = 6Hz), 2.38 (s, 3H, $CH_3$), 5.03 (unresolved siglet,1H), 5.43 (s, 1H, OH), 5.73 (q, 2H, -$CH_2$), 7.19 (s, 1H), 7.34 (d, 2H, *J*=7.2 Hz), 7.59 (d, 2H, *J* = 6.9 Hz), 7.67 (d, 2H, *J* = 7.2 Hz), 8.53 (s, 1H); $^{13}$C NMR (75 MHz, Acetone-$d_6$): δ 20.94, 22.16, 39.66, 63.78, 111.25, 120.27, 121.05, 122.15, 122.54, 123.23, 131.06, 136.52, 139.65, 143.28, 145.17; GC-MS: molecular ion ($C_{19}H_{19}N_5O$) *m/z* value at 331.13. Anal. Calcd for $C_{19}H_{19}N_5O$: C, 68.45; H, 5.74; N, 21.01. Found: C, 68.40; H, 5.47; N, 21.11%. Chiral HPLC: Column: Chiralpak IB column of diacel, Solvent system: DCM (20% ethanol)/Hexane 25:75, Flow rate = 0.8 cc/min, λ = 250 nm), $t_{major}$ = 17.41min, $t_{minor}$ = 14.75 min, *ee* = 100%.

***N*-(1-((1-(2-Methoxyphenyl)-1*H*-1,2,3-triazol-4yl)methyl)-(*S*)-(-)-2-(α-hydroxyethyl) benzimidazole, 8e**: Yield 0.84 g (66%). m.p. 60°C. Specific rotation: $[\alpha]^{25}_D$= +24° (c 1, Ethanol); $^1$H NMR (300 MHz, Acetone-$d_6$): δ 1.761 (d, 3H, $CH_3$, *J* = 5.1 Hz), 3.86 (s, 3H, $CH_3$), 5.74 (q, 2H), 7.08-7.19 (m, 2H), 7.20-7.65 (m, 7H, Ar), 8.45 (s, 1H); $^{13}$C NMR (75 MHz, Acetone-$d_6$): δ 56.51, 113.64, 121.62, 121.80, 122.50, 123.21, 126.12, 131.30, 143.77, 152.452; GC-MS: molecular ion ($C_{19}H_{19}N_5O_2$) *m/z* value at 347.1. Anal. Calcd for $C_{19}H_{19}N_5O_2$: C, 65.32; H, 5.48; N, 20.04. Found: C, 65.38; H, 5.41; N, 20.13%. Chiral HPLC: Column: Chiralpak IB column of diacel, Solvent system: DCM (20% ethanol) /Hexane 25:75, Flow rate = 0.8 cc/min, λ = 250 nm), $t_{major}$= 21.22 min, $t_{minor}$ = 12.50 min, *ee* = 95%.

**Preparation of *N*-(1-((1-(4-methoxyphenyl)-1*H*-1,2,3-triazol-4-yl)methyl)-(*S*)-(-)-2-(α-hydroxyethyl) benzimidazole, 8f**: Yield 1.06 g (83%). m.p. 89°C. Specific rotation: $[\alpha]^{25}_D$ = +16° (c 1, Ethanol); $^1$H NMR (300 MHz, Acetone-$d_6$): δ 1.744 (d, 3H, $CH_3$, *J* = 6.6 Hz), 3.85 (s, 3H, $CH_3$), 5.42 (d, 1H), 5.72 (q, 2H, *J* = 15.9 Hz), 7.05-7.23 (m, 4H), 7.59-7.73 (m, 4H, Ar), 8.47 (s, 1H); $^{13}$C NMR (75 MHz, Acetone-$d_6$): δ 22.16, 39.65, 56.01, 63.76, 111.25, 115.62, 120.29, 122.23, 122.51, 122.80, 123.20, 145.04, 160.85; GC-MS: molecular ion ($C_{19}H_{19}N_5O_2$) *m/z* value at 347.1. Anal. Calcd for $C_{19}H_{19}N_5O_2$: C, 65.32; H, 5.48; N, 20.04. Found: C, 65.43; H, 5.52; N, 20.06%. Chiral HPLC: Column: Chiralpak IB column of diacel, Solvent system: DCM (20% ethanol) /Hexane 25:75, Flow rate = 0.8 cc/min, λ = 250 nm), $t_{major}$ = 9.42 min, $t_{minor}$ = 14.64 min, *ee* = 99%.

***N*-1-((1-Phenyl-1*H*-1,2,3-triazol-4-yl)methyl)-(*S*)-(+)-2-(α-hydroxybenzyl) benzimidazole (PT-HBB), 8g**: Yield 1.51 g (82%). m.p. 114°C. Specific rotation: $[\alpha]^{25}_D$ = +21° (c 1, Ethanol); $^1$H NMR (300 MHz, $CDCl_3$): δ 5.92 (s, 2H), 7.38-7.50 (m, 8H), 7.52-7.70 (m, 3H), 7.90-7.97 (m, 2H), 8.373 (s, 1H), 8.377 (d, 2H, *J* = 7.2Hz); $^{13}$C NMR (75 MHz, $CDCl_3$): δ 29.68, 41.0, 111.76, 120.63, 121.75, 122.01, 124.08, 128.45, 128.84, 129.68, 131.34, 133.76, 135.91, 136.68, 136.94, 141.93, 144.33; GC-MS: molecular ion ($C_{16}H_{16}N_2O$) *m/z* value at 380.28. Anal. Calcd for $C_{16}H_{16}N_2O$: C, 72.42; H, 5.02; N, 18.36. Found: C, 72.30; H, 5.16; N, 18.27%. Chiral HPL: Column: Chiralpak IB column of diacel, Solvent system: DCM (20% ethanol) /Hexane 25:75, Flow rate = 0.5 cc/min, λ = 254 nm), $t_{major}$ =16.18 min, $t_{minor}$ = 13.30 min, *ee* = 98%.

***N*-1-((1-Phenyl-1*H*-1,2,3-triazol-4-yl)methyl)-(*S*)-(-)-2-(α-acetoxy ethyl) benzimidazole (PT-AEB), 9a**: Yield 1.24 g (85%). m.p. 107°C. Specific rotation: $[\alpha]^{25}_D$ = −97° (c 1, Ethanol); $^1$H NMR (300 MHz, $CDCl_3$): δ 1.81 (d, 3H, *J* = 6.6 Hz), 2.039 (s, 3H), 5.53 (d, 1H, *J* = 16.8Hz), 5.72 (d, 1H, *J* = 16.8Hz), 6.26 (q, 1H, *J* = 6.6 Hz), 7.26-7.49 (m, 6H), 7.62-7.7 (m, 2H), 7.78-7.9 (m, 2H); $^{13}$C NMR (75 MHz, $CDCl_3$): δ 19.35, 20.94, 39.53, 64.60, 109.93,

120.24, 120.28, 120.48, 122.86, 123.63, 129.01, 129.78, 134.65, 136.71, 142.16, 143.95, 152.32, 170.48; GC-MS: molecular ion ($C_{20}H_{19}N_5O_2$) *m/z* value at 361.25. Anal. Calcd for $C_{20}H_{19}N_5O_2$: C, 66.47; H, 5.30; N, 19.38. Found: C, 66.53; H, 5.19; N, 19.47%. Chiral HPLC: Column: Chiralpak IB column of diacel, Solvent system: DCM (10% ethanol) /Hexane 25:75, Flow rate = 0.5cc/min, λ = 250 nm), $t_{major}$ = 26.42 min, $t_{minor}$ =14.95min, *ee* = 99%.

***N*-(1-((1-(*o*-Tolyl)-1*H*-1,2,3-triazol-4-yl)methyl)-(*S*)-(-)-2-(α-acetoxy ethyl) benzimidazole, 9b**: Yield 1.18 g (82%). m.p. 80°C. Specific rotation: $[\alpha]^{25}_D$ = −90° (c 1, Ethanol); $^1$H NMR (300 MHz, $CDCl_3$): δ 1.91 (d, 3H, *J* = 5.4Hz), 2.13 (s, 3H), 2.168 (s, 3H), 5.60 (d, 1H, *J* = 15.9Hz), 5.80 (d, 1H, *J* = 14.7 Hz), 6.30 (unresolved siglet, 1H), 7.16-7.26 (m, 6H), 7.28-7.61 (m, 2H), 7.89 (s, 1H); $^{13}$C NMR (75 MHz, $CDCl_3$): δ 17.80, 21.08, 39.79, 123.44, 124.23, 125.86, 126.92, 130.14, 131.36, 131.58, 133.58, 170.56; GC-MS: molecular ion ($C_{21}H_{21}N_5O_2$) *m/z* value at 375.21. Anal. Calcd for $C_{21}H_{21}N_5O_2$: C, 67.18; H, 5.64; N, 18.65. Found: C, 67.11; H, 5.57; N, 18.71%. Chiral HPLC: Column: Chiralpak IB column of diacel, Solvent system: DCM (10% ethanol) /Hexane 25:75, Flow rate = 0.5cc/min, λ = 250 nm), $t_{major}$ = 20.65min, $t_{minor}$ =12.74 min, *ee* = 99%.

***N*-(1-((1-(*m*-Tolyl)-1*H*-1,2,3-triazol-4-yl)methyl)-(*S*)-(-)-2-(α-acetoxy ethyl) benzimidazole, 9c**: Yield 1.22 g (84%). m.p. 72°C. Specific rotation: $[\alpha]^{25}_D$ = −86° (c 1, Ethanol); $^1$H NMR (300 MHz, $CDCl_3$): δ 1.84 (d, 3H, *J* = 6.6Hz), 2.09 (s, 3H), 2.39 (s, 3H), 5.55 (d,1H, *J* = 16.8 Hz), 5.76 (d,1H, *J* = 14.7 Hz), 6.28 (d,1H, *J* = 6.6 Hz), 7.26-7.34 (m, 6H), 7.50-7.53 (d, 3H), 7.80 (s, 1H); $^{13}$C NMR (75 MHz, $CDCl_3$): δ 19.75, 21.08, 39.79, 110.20, 120.14, 120.45, 123.47, 124.19, 130.31, 134.40, 139.33, 170.56; GC-MS: molecular ion ($C_{21}H_{21}N_5O_2$) *m/z* value at 375.20. Anal. Calcd for $C_{21}H_{21}N_5O_2$: C, 67.18; H, 5.64; N, 18.65. Found: C, 67.08; H, 5.69; N, 18.75%. Chiral HPLC: Column: Chiralpak IB column of diacel, Solvent system: DCM (10% ethanol)/Hexane 25:75, Flow rate = 0.5cc/min, λ = 250 nm), $t_{major}$ = 24.45min, $t_{minor}$ =13.89 min, *ee* = 99%.

***N*-(1-((1-(*p*-Tolyl)-1*H*-1,2,3-triazol-4-yl)methyl)-(*S*)-(-)-2-(α-acetoxy ethyl) benzimidazole, 9d**: Yield 1.20 g (83%). m.p. 60°C. Specific rotation: $[\alpha]^{25}_D$ = −98° (c 1, Ethanol); $^1$H NMR (300 MHz, $CDCl_3$): δ 1.83 (d, 3H, *J* = 6.6Hz), 2.053 (s, 3H), 2.38 (s, 3H), 5.57 (d,1H, *J* = 16.5 Hz), 5.77 (d, 1H, *J* = 16.5 Hz), 6.29 (q, 1H, *J* = 6.6), 7.24-7.32 (m, 4H), 7.46-7.76 (m, 2H), 7.87 (s, 1H), 7.88 (d,1H); $^{13}$C NMR (75 MHz, $CDCl_3$): δ 19.58, 21.04, 21.07, 39.80, 64.79, 110.08, 120.26, 120.42, 123.16, 123.93, 125.84, 130.00, 130.28, 134.39, 139.28, 141.70, 143.60, 152.62, 170.46; GC-MS: molecular ion ($C_{21}H_{21}N_5O_2$) *m/z* value at 375.11. Anal. Calcd for $C_{21}H_{21}N_5O_2$: C, 67.18; H, 5.64; N, 18.65. Found: C, 67.14; H, 5.52; N, 18.60%. Chiral HPLC Column: Chiralpak IB column of diacel, Solvent system: DCM (10% ethanol)/Hexane 25:75, Flow rate = 0.5cc/min, λ = 250 nm), $t_{major}$ = 25.92min, $t_{minor}$ =14.86 min, *ee* = 96%.

**N-(1-((1-(2-Methoxyphenyl)-1*H*-1,2,3-triazol-4-yl)methyl)-(S)-(-)-2-(α-acetoxyethyl) benzimidazole, 9e**: Yield 1.16 g (80%). m.p. 80°C. Specific rotation: $[\alpha]^{25}_D$ = −88° (c 1, Ethanol); $^1$H NMR (300 MHz, $CDCl_3$): δ 1.84 (d, 3H, *J* = 6.0 Hz), 2.07 (s, 3H), 3.75 (s, 3H), 5.65 (unresolved siglet, 1H), 5.80 (d, 1H, *J* = 16.8 Hz), 6.26 (q, 1H, *J* = 6.6 Hz), 7.25-7.36 (m, 5H), 7.50-7.70 (m, 2H), 7.88 (s, 1H); $^{13}$C NMR (75 MHz, $CDCl_3$): δ 19.55, 20.99, 39.88, 55.70, 64.81, 110.31, 120.18, 120.85, 123.17, 123.91, 125.40, 130.44, 132.44, 151.04, 154.17, 170.42; GC-MS: molecular ion ($C_{21}H_{21}N_5O_3$) *m/z* value at 391.14. Anal. Calcd for $C_{21}H_{21}N_5O_2$: C, 64.44; H, 5.41; N, 17.89. Found: C, 64.30; H, 5.53; N, 17.85%. Chiral HPLC: Column: Chiralpak IB column of diacel, Solvent system: DCM (10% ethanol)/Hexane25:75, Flow rate = 0.5cc/min, λ = 250 nm), $t_{major}$ =29.68 min, $t_{minor}$ =15.59min, *ee* = 99%.

***N*-(1-((1-(4-Methoxyphenyl)-1*H*-1,2,3-triazol-4-yl)methyl)-(*S*)-(-)-2-(α-hydroxyethyl) benzimidazole, 9f**: Yield 1.26 g (87%). m.p. 91°C. Specific rotation: $[\alpha]^{25}_D$ = −102° (c 1, Ethanol); $^1$H NMR (300 MHz, $CDCl_3$): δ 1.87 (Unresolved Singlet, 3H), 2.101 (s, 3H), 3.83 (s, 3H), 5.66- 6.48 (Unresovled aliphatic signals), 6.954-7.039 (m, 2H), 7.34-7.93 (m, 7H); $^{13}$C NMR (75 MHz, $CDCl_3$): δ 21.04, 21.07, 39.80, 55.65, 114.57, 114.86, 122.22, 124.35, 127.44, 160.11, 161.01, 170.52; GC-MS: molecular ion ($C_{21}H_{21}N_5O_3$) *m/z* value at 391.06. Anal. Calcdfor $C_{21}H_{21}N_5O_3$:C, 64.44; H, 5.41; N, 17.89. Found: C, 64.37; H,5.36; N, 17.76%. Chiral HPLC: Column: Chiralpak IB column of diacel, Solvent system: DCM (10% ethanol) Hexane 25:75, Flow rate = 0.5cc/min, λ = 250 nm), $t_{major}$ = 22.76 min, $t_{minor}$ =13.33 min, *ee* = 96%.

**N-1-((1-Phenyl-1*H*-1,2,3-triazol-4-yl)methyl)-(*S*)-(-)-2-(α-acetoxybenzyl) benzimidazole (PT-**

**ABB), 9g**: Yield 1.51 g (76%). m.p. 121°C. Specific rotation: $[\alpha]^{25}_D = -45°$ (c 1, Ethanol); $^1$H NMR (300 MHz, $CDCl_3$): δ 2.21 (s, 3H), 5.91 (unresolved singlet, 2H), 6.12 (s, 1H), 7.00-7.56 (m, 7H), 7.62-7.69 (m, 2H), 7.90-8.25 (m, 2H), 8.362 (s, 1H), 8.367 (d, 2H, *J* = 7.2); $^{13}$C NMR (75 MHz, $CDCl_3$): δ 40.99, 111.76, 120.27, 120.62, 121.74, 122.0, 124.10, 126.0, 126.35, 127.66, 128.36, 128.46, 128.86, 129.03, 129.32, 129.69, 131.33, 133.79, 141.89; GC-MS: molecular ion ($C_{25}H_{21}N_5O_2$) *m/z* value at 423.17. Anal. Calcd for $C_{25}H_{21}N_5O_2$: C, 70.91; H, 5.00; N, 16.54. Found: C, 70.70; H, 5.03; N, 16.60%. Chiral HPLC: Column: Chiralpak IB column of diacel, Solvent system: DCM (20% ethanol)/Hexane 25:75, Flow rate = 0.5 cc/min, λ = 254 nm), $t_{major}$ =26.94 min, $t_{minor}$ =22.56 min, *ee* = 100%.

**Representative procedure for chiral base [PT-HEB, 8a] mediated enantioselective Diels-Alder reactions**

To a 50 mL RBF containing **PT-HEB 8a** (10 mol %), anhydrous 1,2-Dichloroethane at -10°C, anthrone **10** (97 mg, 0.5 mmol) and *N*-substituted maleimide **11a-e** (0.5 mmol) were added in this sequence. The reaction was carried out under dry condition and monitored with TLC. After stirring at −10°C for 8 h, on completion reaction mixture acidified with dilute hydrochloric acid and extracted with chloroform. The organic extracts were washed with brine, dried over sodium sulphate and filtered. The solvent was removed in vacuum, purified by using silica column chromatography (gradient elution with chloroform / pet. ether mixtures; 80:20).

**Characterization data of Diels-Alder adduct, 12a-e**

**4-Hydroxy-2-methyl-3a,4,9,9a-tetrahydro-4,9[1',2']-benzeno-1*H*-benz[f]isoindole-1,3(2*H*)-dione, 12a**: Yield 125.1 mg (86%). m.p. 218-220°C. Specific rotation:$[\alpha]^{25}_D$ = +44.1° (c 1, $CHCl_3$); $^1$H NMR (300 MHz, $CDCl_3$): δ 2.49 (s, 3H), 3.11 (d, 1H, *J* = 8.4 Hz), 3.32 (dd, 1H, *J* = 3.6, *J* = 8.5 Hz), 4.42 (s, 1H), 4.72 (d, 1H, *J* = 3.3Hz), 7.10-7.34 (m, 5H), 7.36 (m, 1H) 7.48 (m, 1H), 7.69 (m, 1H); GC-MS:molecular ion ($C_{19}H_{15}NO_3$) *m/z* value at 304.95; Chiral HPLC: Column: Chiralpak IB column of diacel, Solvent system: iPrOH/Hexane 10/90, Flow rate = 0.6 mL/min, λ = 230 nm, $t_{major}$ =23.28 min, $t_{minor}$ =19.59min, *ee*= 57%.

**Preparation of 4-hydroxy-2-ethyl-3a,4,9,9a-tetrahydro-4,9[1',2']-benzeno-1*H*-benz[f]isoindole-1,3(2*H*)-dione, 12b**: Yield 130.7 mg (82%). m.p. 213-215°C. Specific rotation:$[\alpha]^{25}_D$ =+33.7° (c 1, $CHCl_3$); $^1$H NMR (300 MHz, $CDCl_3$): δ 0.40 (t, 3H, *J* = 7.2 Hz), 3.07 (d, 1H, *J* = 8.7 Hz), 3.14 (q, 2H), 3.29 (dd, 1H, *J* = 3.6 Hz, *J* = 8.5 Hz), 4.53 (s, 1H), 4.73 (d, 1H, *J* = 3.6 Hz), 7.13-7.27 (m, 5H), 7.36 (m, 1H), 7.50 (m, 1H), 7.69 (m, 1H); GC-MS:molecular ion *m/z* value ($C_{20}H_{17}NO_3$) at 318.96; Chiral HPLC: Column: Chiralpak AD column of diacel, Solvent system: iPrOH: Hexane 10:90, Flow rate = 0.6 mL/min, λ = 230 nm, $t_{major}$ =26.84 min, $t_{minor}$ =24.07 min, *ee*= 83%.

**Preparation of 4-hydroxy-2-propyl-3a,4,9,9a-tetrahydro-4,9[1',2']-benzeno-1*H*-benz[f]isoindole-1,3(2*H*)-dione, 12c**: Yield 139.81 mg (84%). m.p. 208-210°C. Specific rotation:$[\alpha]^{25}_D$ =+ 5.7° (c 1, $CHCl_3$);$^1$H NMR (300 MHz, $CDCl_3$): δ 0.54 (t, 3H, 7.5 Hz), 0.79 (m, 2H), 3.01 (d, 1H), 3.08 (q, 2H), 3.29 (dd, 1H, *J* = 3.6 Hz, *J* = 8.5Hz), 4.52 (s, 1H), 4.72 (d, 1H, *J* = 3.6Hz), 7.13-7.27 (m, 5H), 7.34 (m, 1H), 7.50 (m, 1H), 7.69 (m, 1H); GC-MS: molecular ion *m/z* value ($C_{21}H_{19}NO_3$) at 333.38; Chiral HPLC: Column: Chiralpak IB column of diacel, Solvent system: iPrOH:Hexane 10:90, Flow rate = 0.6 mL/min, λ = 230 nm, $t_{major}$ =20.07 min, $t_{minor}$ =15.71min, *ee*= 5%.

**Preparation of 4-hydroxy-2-butyl-3a,4,9,9a-tetrahydro-4,9[1',2']-benzeno-1*H*-benz[f]isoindole-1,3(2*H*)-dione, 12d**: Yield142.2 mg (82%). m.p. 217-219°C. Specific rotation:$[\alpha]^{25}_D$ = +12°(c 1, $CHCl_3$); $^1$H NMR (300 MHz, $CDCl_3$):δ 1.14 (s, 9H), 2.95 (d, 1H, *J* = 9.0 Hz), 3.17 (dd, 1H, *J* = 3.6 Hz, *J* = 9.0 Hz), 4.69 (d, *J* = 3.6 Hz, 1H), 4.72 (s,1H), 7.17-7.27 (m, 5H), 7.37 (dd, 1H,) 7.87 (m, 1H), 8.34 (m, 1H); GC-MS:molecular ion ($C_{22}H_{21}NO_3$) *m/z* value at 346.82; Chiral HPLC: Column: Chiralpak IB column of diacel, Solvent system: iPrOH/Hexane 10/90, Flow rate = 0.6 mL/min, λ = 230 nm, $t_{major}$ =16.28 min, $t_{minor}$ =10.79 min, *ee*= 28%.

**Preparation of 4-hydroxy-2-benzyl-3a,4,9,9a-tetrahydro-4,9[1',2']-benzeno-1*H*-benz[f]isoindole-1,3(2*H*)-dione, 12e**: Yield142.8 mg (75%). m.p. 204-207°C. Specific rotation:$[\alpha]^{25}_D$ =+36.5° (c 1, $CHCl_3$); $^1$H NMR (300 MHz, $CDCl_3$): δ 3.23 (d, 1H, *J* = 8.7 Hz), 3.40 (dd, 1H, *J* = 3.3, *J* = 8.1 Hz), 4.25 (s, 2H), 4.56 (s, 1H), 4.71 (d, 1H, *J* = 3.3 Hz), 6.32 (m, 2H), 7.03-7.21 (m, 8H), 7.40 (m, 1H), 7.49 (m, 1H), 7.587 (m, 1H); GC-MS:molecular ion ($C_{25}H_{19}NO_3$) *m/z* value at 380.86; Chiral HPLC: Column: Chiralpak IB column of diacel, Solvent system: iPrOH:Hexane 20:80, Flow rate = 0.6 mL/min, λ = 230 nm, $t_{major}$ = 21.16 min, $t_{minor}$ = 25.75 min, *ee*= 61%.

## Conclusions

An efficient Cu(I) catalysed procedure to synthesize benzimidazole based triazole tweezers has been developed. The compounds were obtained in highly enantiomerically enriched states and possess several structural features which are generally desired for an efficient chiral organo-catalysts and systems for exhibiting chiral molecular recognition. These tweezers **8a-f, 9a** were shown to be potent chiral Brønsted base catalysts for Diels-Alder reaction of N-substituted maleimides **11a-g** and anthrone **10**. Diels-Alder adducts **12a-e** with *(S,S)* configuration and moderate to good enantioselectivities were obtained. The developed enantioselective methodology for DA were more suitable for *N*-alkyl substituted maleimides giving good yields (75-86%) and moderate to excellent enantioselectivities (5-83% *ee*) while for aryl substituted maleimides **11f-g,** no corresponding Diels-Alder adducts were obtained.

## Supplementary Information

Supplementary information is available in the website http://nopr.niscair.res.in/handle/123456789/60.

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## References

1 France S, Guerin D J, Miller S J & Lectka T, *Chem Rev*, 103 (2003) 2985.
2 Chelucci G & Thummel R P, *Chem Rev*, 102 (2002) 3129.
3 Kizirian J, *Chem Rev*, 108 (2008) 140.
4 Lin J, Hua T, Jiang Y, Zheng H L & Zhang S, *Tetrahedron*: *Asymmetry*, 22 (2011) 1434.
5 Bhowmick S & Bhowmick K C, *Tetrahedron*: *Asymmetry*, 22 (2011) 1945.
6 Li P, Fang F, Chen J & Wanga J, *Tetrahedron*: *Asymmetry*, 25 (2014) 98.
7 Takizawa S, Horii A & Sasai H, *Tetrahedron*: *Asymmetry*, 21 (2010) 891.
8 Nakadai M, Saito S & Yamamoto H, *Tetrahedron*, 58 (2002) 8167.
9 Mark I E, Giles P R & Hindley N J, *Tetrahedron*, 53 (1997) 1015.
10 Doyle A G & Jacobsen E N, *Chem Rev*, 107 (2007) 5713.
11 Alemán J, Parra A, Jiang H & Jorgensen K A, *Chem Eur J*, 17 (2011) 6890.
12 Xie J W, Chem W, Li R, Zeng M, Du W, Yue L, Chen Y C, Wu Y, Zhu J & Deng J G, *Angew Chem Int Ed*, 46 (2007) 389.
13 Melchiorre P, *Angew Chem Int Ed*, 51 (2012) 9748.
14 Jiang L & Chen Y C, *Catal Sci Technol*, 1 (2011) 354.
15 Manoni F & Connon S J, *Angew Chem Int Ed*, 53 (2014) 2628.
16 (a) Yu S & Pu L, *Tetrahedron*, 71 (2015) 745; (b) Pu L, *Chem Rev*, 104 (2004) 1687; (c) Hembury G A, Borovkov V V & Inoue Y, *Chem Rev*, 108 (2008) 1; (d) Legouin B, Gayral B, Uriac P, Tomasi M & Weghe P, *Tetrahedron*: *Asymmetry*, 21 (2010) 1307.
17 (a) Li Y, Yu S, Shen W & Jing-Xing G, *Acc Chem Res*, 48 (2015) 2587; (b) Giovanni D, Giuseppe F, Karl A & Jorgensen K, *Chem Rev*, 111 (2011) PR284-437; (c) Serafino G, Elisabetta A, Kathrin J & Matthias B, *Chem Soc Rev*, 40 (2011) 3744.
18 (a) Carmen N, Jose M S & Enrique G B, *Pure Appl Chem*, 88 (2016) 561; (b) Carmen N & Miguel Y, *Tetrahedron Lett*, 56 (2015) 2623; (c) Thomas J, Manuel G & Benjamin L, *Chem Rev*, 115 (2015) 9388.
19 (a) Riant O, Kagan H B & Ricard L, *Tetrahedron*, 50 (1994) 4543; (b) Riant O & Kagan H B, *Tetrahedron Lett*, 30 (1989) 7403; (c) Uemae K, Masuda S & Yamamoto Y, *J Chem Soc Perkin Trans 1*, 9 (2001) 1002; (d) Tokioka K, Masuda S, Fijii T, Hata Y & Yamamoto Y, *Tetrahedron*: *Asymmetry*, 8 (1997) 101; (e) Hau C K, He H, Lee A, Chik D, Cai Z & Wong H, *Tetrahedron*, 66 (2010) 9860; (f) Akalay D G, Durner J W, Bats D & Gobel M W, *Beilstein J Org Chem*, 4:28 (2008); (g) Zea A, Valerao G, Alba A, Moyano A & Rios R, *Adv Synth Catzal*, 352 (2010) 1102; (h) Zea A, Alba A, Bravo N, Moyano A & Rios R, *Tetrahedron*, 67 (2011) 2513; (i) Kumagai J, Otsuki T, Reddy U V, Kohari Y, Seki C, Uwai K, Okuyama Y, Kwon E, Tokiwa M, Takeshita M & Nakano H, *Tetrahedron*: *Asymmetry*, 26 (2015) 1423.
20 (a) Tawde T S, Wagh S J, Sapre J V, Khose V N, Badani P M & Karnik A V, *Tetrahedron*: *Asymmetry*, 27 (2016) 130; (b). Mirgane N A & Karnik A V, *Chirality*, 23 (2011) 404; (c) Upadhyay S P, Pissurlenkar R S, Coutinho E C & Karnik A V, *J Org Chem*, 72 (2007) 5709; (d) Kamath S S & Karnik A V, *J Org Chem*, 72 (2007) 7435; (e) Kamath S S & Karnik A V, *Tetrahedron*: *Asymmetry*, 19 (2008) 45.
21 Pandey A, Mohammed H & Karnik A V, *Tetrahedron*: *Asymmetry*, 24 (2013) 706.
22 Phillips M A, *J Chem Soc*, (1928) 2393.
23 (a) Rostovtsev V V, Green L G, Fokin V V & Sharpless K B, *Angew Chem Int Ed*, 41 (2002) 2596; ( b) Tornoe C W, *J Org Chem*, 67 (2002) 3057.
24 Mirgane N A, Mohammed H & Karnik A V, *Lett Org Chem*, 7 (2010) 343.
25 Mallory F B, Smith P & Boyer J H, *Org Synth*, 37 (1957) 1.
26 Hein J E, Tripp J C & Fokin V, *Angew Chem Int Ed*, 48 (2009) 8018.
27 (a) Knapp S, Ornaf R M & Rodriques K E, *J Am Chem Soc*, 105 (1983) 5494; (b) Bunnage M E & Nicolaou K C, *Angew Chem Int Ed*, 35 (1996) 1110.