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Asymmetric cyclopropanation catalyzed by copper–Schiff's base complexes

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Abstract

The asymmetric cyclopropanation of styrene with alkyl diazoacetate were performed with copper complexes of Schiff bases, derived from substituted salicylaldehydes and a new chiral amino alcohol, as the catalysts. The electronic and steric properties, as well as the position of those substituents show obvious effects on the enantioselectivities, and ee higher than 98% were achieved under optimal conditions. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Cyclopropanation; Schiff base Cu(II) complex; Diazoacetate; Asymmetric catalysis; Styrene

1. Introduction

The asymmetric cyclopropanation of olefins with alkyl diazoacetate is becoming a powerful tool in the synthesis of chiral cyclopropanecarboxylates, and there have been many reports of successful use of metal–Schiff base complexes, metal–monooxazoline complexes and metal–bisoxazoline complexes as the catalysts [1–3]. Among the various catalysts applied to this kind of reaction, copper–Schiff base complexes derived from chiral amino alcohols are of particular importance. With this kind of catalyst, Aratani achieved high ee for the cyclopropanation of 2,5-dimethyl-2,4-hexadiene [4], which yields a valuable product in the synthesis of pesticides. However, the ee for the reaction of styrene is not as high as that with other kind of catalysts containing a C_2 symmetry reported in the last 15 years [5–17]. Recently, Co–Schiff base with a C_2 symmetry, derived from chiral 1,2-diaryl-1,2-ethanediamines and carbonyl compounds, including salicylaldehyde and diketone, and cobalt salts, were also reported as efficient catalysts for asymmetric cyclopropanation [12–16]. Although substituents in the carbonyl compounds play a key role on the ee of the products, to the best of our knowledge, there has been no report employing copper–amino alcohol–Schiff bases derived from substituted salicylaldehyde as catalysts in the asymmetric cyclopropanation except Cai reported in very recently binuclear copper–Schiff base complexes derived from substituted 2-hydroxy-1,3-benzenedialdehyde to catalyze the reaction [18]. Recently, we reported on an efficient catalyst, derived from a new chiral amino alcohol which does not contain an alkoxy group, for the asymmetric cyclopropanation [19]. We also introduce other group to the carbonyl moiety of Aratani's 1644 catalyst [20]. To further our study of derivatives of this amino alcohol, we synthesized some Schiff bases and their copper complexes from this amino alcohol and substituted salicylaldehyde. Here, we wish to report the catalytic properties of these copper–Schiff

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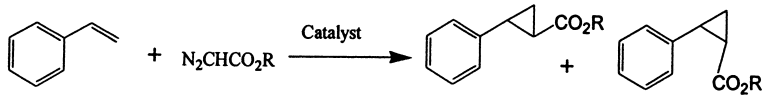
base complexes in the reaction of styrene with diazoacetate, yielding ee up to 98%.



2. Experimental

All reactions were carried out under an argon atmosphere. Optical rotations were measured by a SEPA-200 high sensitive polarimeter. NMR spectra were recorded by a Bruker DRX-400NMR spectrometer. The yields and ee values were determined by GC analyses with a chiral capillary column.

2.1. (S)-2-amino-1,1-di(3,5-di-t-butylphenyl)-propanol

This compound was prepared from methyl ester hydrochloride of L-alanine and Grignard reagent derived from 3,5-di-*t*-butylbromobenzene in a 42.8% yield [19]. ^{1}H NMR: 7.49 (s, 2H), 7.36 (s, 2H), 7.24 (s, 1H), 7.20 (s, 2H), 4.13 (q, $J = 6.03$ Hz, 1H), 2.18 (s, br, 3H), 1.30 (s, 9H), 1.28 (s, 9H), 0.98 (d, $J = 6.03$ Hz, 3H); ^{13}C NMR: 150.4, 149.8, 145.5, 143.5, 120.5, 120.0, 119.8, 79.2, 53.2, 34.9, 34.9, 31.5, 16.8.

2.2. The Schiff base

This kind of compounds was prepared in a similar method in literature from the condensation of (S)-2-amino-1,1-di(3,5-di-*t*-butylphenyl)propanol and substituted salicylaldehyde in a ethanol solution and was purified by a chromatographic column. Their structures were identified by their spectral data.

1a: ^{1}H NMR: 12.86 (s, br, 1H), 8.12 (s, 1H), 7.40 (s, 2H), 7.33 (s, 2H), 7.27 (s, 1H), 7.22 − 7.17 (m, 2H), 7.02 (d, $J = 7.48$ Hz, 1H), 6.86 (d, $J = 8.24$ Hz, 1H), 6.77 (m, 1H), 4.38 (m, 1H), 2.68 (s, 1H), 1.33 (d, $J = 8.50$ Hz, 3H), 1.30 (s, 18H), 1.22 (s, 18H); ^{13}C NMR: 165.0, 160.8, 150.0 (4C), 144.2, 143.1, 132.1, 131.2, 120.6 (2C), 120.5 (2C), 120.4 (2C), 118.7, 118.4, 116.8, 80.7, 72.3, 34.9, 34.8, 31.5, 31.4, 17.3.

1b: mp 56–58°C; $[\alpha]_D = +50.83$ (c 1.20, benzene); ^{1}H NMR: 12.54 (s, br, 1H), 8.10 (s, 1H), 7.39 (s, 2H), 7.33 (s, 2H), 7.26 (s, 2H), 7.16 (s, 1H), 7.00 (s, 1H), 6.81 (d, $J = 8.83$ Hz, 1H), 4.37 (m, 1H), 2.69 (s, br, 1H), 1.36 (d, $J = 8.01$ Hz, 3H), 1.30 (s, 18H), 1.28 (2s, 9H), 1.22 (s, 18 H); ^{13}C NMR: 165.7, 158.4, 150.0 (4C), 144.3, 143.2, 141.1, 129.7, 127.8, 120.7 (2C), 120.6 (2C), 120.5 (2C), 118.0, 116.3, 80.8, 72.5, 34.9 (2C), 34.8 (2C), 33.8, 31.5 (^{t}Bu), 31.4 (^{t}Bu), 31.3, 17.3.

1c: mp 72–74°C; $[\alpha]_D = +74.53$ (c 0.966, benzene); ^{1}H NMR: 13.15 (s, br, 1H), 8.02 (s, 1H), 37 (s, 2H), 7.35 (s, 2H), 7.29 (s, 1H), 7.25 (s, 1H), 7.17 (s, 1H), 6.81 (s, 1H), 4.30 (m, 1H), 2.70 (s, br, 1H), 1.38 (s, 9H), 1.31 (d, $J = 6.12$ Hz, 3H), 1.30 (s, 18 H), 1.24 (s, 9H), 1.22 (s, 18H); ^{13}C NMR: 166.3, 157.6, 150.0 (4C), 144.1, 143.3, 139.9, 136.5, 126.8, 126.0, 120.9 (2C), 120.8 (2C), 120.5 (2C), 117.8, 81.1, 72.8, 34.9 (2C), 34.0 (2C), 31.5 (^{t}Bu), 31.4 (^{t}Bu), 29.4, 17.2.

1d: mp 63–64°C; $[\alpha]_D = +41.40$ (c 0.942, benzene); ^{1}H NMR: 13.05 (s, br, 1H), 8.01 (s, 1H), 7.36 (s, 2H), 7.29 (s, 3H), 7.17 (m, 2H), 6.99 (m, 1H), 6.80 (d, $J = 8.8$ Hz, 1H), 4.39 (q, $J = 6.2$ Hz, 1H), 2.59 (s, 1H), 1.34 (d, $J = 6.2$ Hz, 3H), 1.30 (s, 18H), 1.22 (s, 18H); ^{13}C NMR: 163.7, 159.7, 150.1 (4C), 143.9, 143.0, 132.0, 130.3, 122.9, 121.1 (2C), 120.7 (2C), 120.6 (2C), 119.5, 118.5, 80.9, 72.1, 34.9 (2C), 34.8 (2C), 17.2.

1e: $[\alpha]_D = +96.27$ (c 0.966, benzene); ^{1}H NMR: 14.26 (s, br, OH), 7.88 (s, 1H), 7.33 − 7.31 (m, 4H), 7.26 − 7.23 (m, 2H), 7.20 (s, 1H), 6.86 (s, 1H), 4.43 (m, 1H), 2.61 (s, 1H), 1.31 (s, 18H), 1.28 − 1.24 (m, 3H), 1.22 (s, 18H); ^{13}C NMR: 163.0, 158.8, 150.3 (2C), 150.2 (2C), 143.5, 142.4, 132.4, 128.8, 123.7, 121.2, 118.5, 120.9 (2C), 120.8 (2C), 120.7, 120.6, 80.8, 70.6, 34.9 (2C), 34.9 (2C), 31.5 (^{t}Bu), 31.4 (^{t}Bu), 17.0.

1f: mp 138–139°C; $[\alpha]_D = +85.51$ (c 0.994, $CHCl_3$); ^{1}H NMR ($CDCl_3$) 14.55 (s, 1H), 8.01 (m, 1H), 7.92 (d, $J = 2.76$ Hz, 1H), 7.75 (s, 1H), 7.32 (m, 2H), 7.21 (d, $J = 6.32$ Hz, 1H), 6.63 (m, 2H), 4.52 (m, 1H), 3.53 (s, br, 1H), 1.42 (d, $J = 6.52$ Hz, 3H), 1.28 (s, 18H), 1.18 (s, 18H).

1g: mp 163–164°C; $[\alpha]_D = +362.39$ (c 0.952, benzene); ^{1}H NMR: 14.16 (s, br, 1H), 8.90 (d, $J = 2.76$ Hz, 1H), 8.15 (d, $J = 2.37$ Hz, 1H), 7.81 (s, 1H),

7.39 (s, 2H), 7.27 (s, 2H), 7.24 (s, 2H), 4.75 (m, 1H), 2.89 (s, 1H), 1.50 (d, $J = 6.52$ Hz, 3H), 1.31 (s, 18 H), 1.19 (s, 18H); ^{13}C NMR: 170.7, 165.1, 151.1 (2C), 150.8 (2C), 141.7, 140.7, 140.1, 136.1, 131.1, 128.3, 121.9 (2C), 120.6 (2C), 120.3 (2C), 116.5, 80.7, 66.4, 34.9 (4C), 31.4 (^{t}Bu), 31.3 (^{t}Bu), 15.6.

2.3. The catalyst

The catalysts were synthesized by the coordination of the Schiff base with copper acetate monohydrate in a ethanol solution, and were purified by usual work up.

2.4. Cyclopropanation

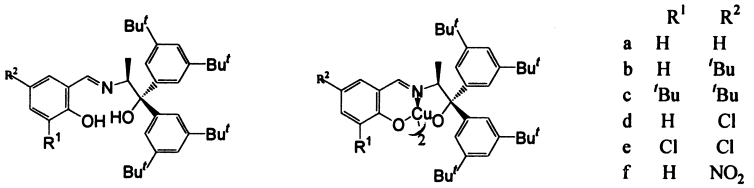
This reaction was performed as the standard procedure. The reaction mixture was concentrated in vacuum and passed a short silica column to remove the catalyst, and was analyzed by GC (permethyl β-cyclodextrin chiral capillary column, 30 m × 0.25 mm i.d., 0.25 μm film, column temp. 130°C) using the internal method with ethyl adipate as a standard. Configurations of the enantiomers were determined by comparison of the GC elution order with an authentic sample prepared according to the literature [21].

3. Results and discussion

The structure of the catalysts is shown in Scheme 1. They were easily synthesized via the coordination of copper acetate monohydrate with new chiral Schiff bases which were derived from (S)-2-amino-1,1-di(3,5-di-*t*-butylphenyl)-propanol and substituted salicylaldehydes.

Since the bulkiness of 3,5-di-*t*-butylphenyl in the ligand, configurations of its Schiff bases may be different form those with a small substituent. For instance, the conformation of the Schiff base derived (S)-2-amino-1,1-di(3,5-di-*t*-butylphenyl)propanol and salicylaldehyde is different from its analogue from 2-amino-1,1-diphenylpropanol as shown in Fig. 1. It can be deduced that this kind of catalyst with different steric demanding group should have different conformations, i.e. they have different chiral environments. Furthermore, when other substituents are introduced to the aldehyde moiety of the Schiff base, the corresponding conformations have some change, too. Consequently, they may show different catalytic properties, especially in stereoselectivities.

Catalytic properties of **2a–2g** for asymmetric cyclopropanation of styrene with ethyl diazoacetate (EDA) are summarized in Table 1. When **2a** was employed as the catalyst, a 37.6/62.4 ratio of *cis/trans* with 81.9% ee for *cis* isomer and 69.6% ee for *trans* isomer was obtained. The ee's were higher than those when a catalyst derived from 2-amino-1,1-diphenylpropanol was used as reported by Cai et al. [18]. The ee of *cis* isomer in the products was higher than that of *trans* isomer when **2a–2g** were used as the catalysts, which rarely occurs when copper complexes, as well as Co–Schiff's bases complexes derived from chiral diamines, were used as the catalysts, as reported in the literature [1,3,5,6]. A similar phenomenon has been reported with copper–bisoxazoline complexes derived from tartrates as the catalysts and was ascribed to the steric repulsion [22]. Results in Table 1 are also different to the results of copper–Schiff base of amino alcohol catalyzed cyclopropanation of 2,5-dimethyl-2,4-hexadiene, in which the ee of *cis* isomer is lower than that of the *trans* isomer. Catalyst



	R^1	R^2
a	H	H
b	H	^{t}Bu
c	^{t}Bu	^{t}Bu
d	H	Cl
e	Cl	Cl
f	H	NO_2
g	NO_2	NO_2

1 **2**

Scheme 1. Structure of ligand **1a–1g** and catalysts **2a–2g**.

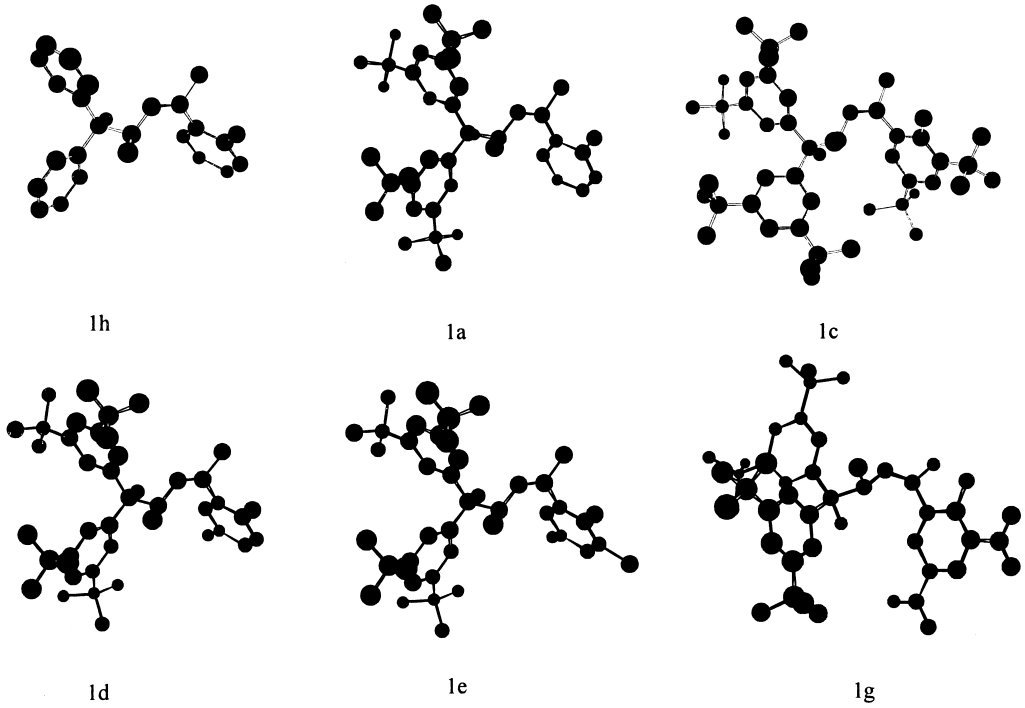


Fig. 1. 3D structure of some ligands optimized by MOPAC.

2a, **2b**, **2d**, and **2f** having different atom or group at the 5-position of salicylaldehye and almost the same conformation, show different catalytic properties. Therefore, the electronic property of the substituents on the salicylaldehyde has a great influence upon the enantioselectivity of the reaction. Catalyst **2b**, which has a R^2 = *t*-butyl group, yields a lower ee than the catalyst **2a**, which has R^2 = H. Whereas, catalyst **2d** and **2f**, which have respectively, a chloro and nitro group at the same position, offered higher ee's than catalyst **2a** does. The use of **2e**, whose R^1 has an electron-withdrawing property, caused a further reducing of the electronic density in the salicylaldehyde ring of the catalyst and an increase of the ee. Therefore, an electron-withdrawing group is beneficial to this reaction. However, catalyst **2g**, which has one more nitro group than catalyst **2f**, results in a little higher for ee of the *cis* isomer and a little lower for ee of the *trans* isomer. It demonstrates that a bulky group of R^1 is disadvantage to the ee, even though it has a electron-withdrawing ability. It can also be seen from the difference of the results of **1a** and **1c** catalyzing the reaction. Introduction one *t*-butyl group to the carbonyl moiety results in 14% lower of ee for *cis* isomer, whereas introduction of two *t*-butyl groups results in 44% lower of the ee Table 2.

Table 1
Asymmetric cyclopropanation of styrene with ethyl diazoacetate using **2** as the catalysts[a]

Catalyst	Yield (%)	*cis*/*trans*	ee (%)[b]	
			cis	*trans*
2a	44.7	37.6/62.4	81.9	69.6
2b	44.5	39.1/60.9	68.0	46.5
2c	76.1	32.0/68.0	35.5	21.4
2d	55.0	45.6/54.4	72.0	63.0
2e	49.0	42.1/57.9	86.9	67.1
2f	63.4	42.5/57.5	89.1	80.5
2g	90.5	41.5/58.5	89.6	79.9

[a] Reactions were performed at 40°C with 1 mol% catalyst with a S configuration and the yields were based on EDA.

[b] 1R, 2S as the major enantiomer; 1R, 2R as the major enantiomer.

Considering the influence of the alkyl group in diazoacetate upon the ee, we use *i*-butyl diazoacetate

Table 2
Asymmetric cyclopropanation of styrene with *i*-butyl diazoacetate using **2** as the catalyst[a]

Catalyst	Yield (%)	*cis*/*trans*	ee (%)	
			cis[b]	*trans*[c]
2a	63.0	31.2/68.8	78.6	60.7
2b	73.7	33.5/66.5	70.8	44.6
2c	72.7	27.5/72.5	17.2	8.2
2d	63.9	29.8/70.2	>98.0	66.1
2e	59.4	33.3/66.7	64.6	39.4
2f		45.0/55.0	>98.0	85.5
2g	83.2	39.3/60.7	89.4	71.4

[a] Reaction conditions are the same as those in Table 1 except *i*-butyl diazoacetate was used instead of ethyl diaozacetate in Table 1.
[b] 1R, 2S as the major enantiomer.
[c] 1R, 2R as the major enantiomer.

instead of ethyl diazocetate. It is worthy to note that ee as high as 98% was achieved in this case. When catalyst with $R^1 = H$, a higher ee is obtained when *i*-butyl diazoacetate is used. It is consistent with the general result for this hind of reaction that high enantioselectivity is achieved by using diazoacetate with bulky alkyl moieties. However, when R^1 is not a hydrogen atom in the catalyst, a different phenomenon is observed. It is interesting that the ee obtained for the reaction of ethyl diazoacetate is higher than that of *i*-butyl diazoacetate in this cases with this kind of catalysts. When $R^1 = t$-Bu, which has the greatest size among *t*-Bu, Cl, and NO_2, the decrease is much higher than those when $R^1 = Cl$, and NO_2. Different to the increase of ee when **2e** instead of **2d** was used as the catalyst and ethyl diaozacetate was used, the ee when **2e** as the catalyst is lower than those when **2d** as the catalyst. It also demonstrates the setric repulsion of R^1 results in a low ee.

In conclusion, copper–Schiff base complexes of chiral amino alcohol are efficient for the asymmetric cyclopropanation of styrene. The electronic and steric properties and the position of the substituents on the substituted salicylaldehyde show obvious effects on the enantioselectivities, which may be used for reasonable design of catalysts.

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