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Synthesis of novel chiral monophosphine ligands derived from isomannide and isosorbide. Application to enantioselective hydrogenation of olefins

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ABSTRACT

A new class of monophosphine ligands has been prepared from natural chirality renewable source, 1,4:3,6-dianhydrohexitol compounds, via a nucleophilic substitution process, or a hydrophosphination reaction involving microwave activation. These ligands have been evaluated for the rhodium-catalyzed enantioselective hydrogenation of olefins giving good conversion and enantioselectivity up to 95% and 96% ee, respectively.

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The development of available, inexpensive, modular, and innovative catalysts from biomass products is expected to be one of the key procedures for expanding the reaction scope and the synthetic potential of metal-catalyzed enantioselective catalysis.

Isosorbide and isomannide, industrially obtained by dehydration of D-sorbitol or D-mannitol, represent commercially available and low cost chiral starting materials for the synthesis of sophisticated molecules including chiral ionic liquids,[1] phase-transfer catalysts,[2] and ligands (amino alcohols, amines, diphosphines, diphosphites, bis diaminophosphites, diamidophosphites).[3,4]

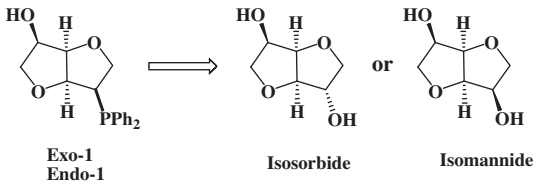
We have recently shown that this starting material provides easy and cost effective access to optically pure functionalized and stable amino alcohol, or diamine ligands.[5] The structure modification could be easily and efficiently obtained by classical organic transformations of diol groups.

Although isosorbide or isomannide were described as starting materials for the synthesis of phosphorus ligands, essentially bidentate ligands such as diphosphines, diphosphites, bis-diaminophosphites, or diamidophosphites,[6] no example of monophosphine derived from 1,4:3,6-dianhydrohexitol has been reported so far. Presently, the application field of monophosphine in organometallic catalysis has received much attention, particularly for organocatalysis.[7] We report herein the synthesis of chiral monophosphines **1** derived from isosorbide and isomannide and their use as ligand for enantioselective hydrogenation of olefins (Scheme 1).

First, our synthesis was inspired by our previous work on the synthesis of aminoalcohol ligands[5] including the selective monobenzylation of the hydroxyl group at the *endo* position C_3 of isosorbide and the activation of the free hydroxyl group at the *exo* position C_6 as its sulfonate **3** (Scheme 2). However, the substitution of **3** with the diphenylphosphine anion failed and produced only the alcohol **2**.

We then chose the isomannide as starting material. Indeed, benzylation of isomannide gave the monobenzylated compound **5** in 48% yield. Bromination of **5** afforded a mixture of **4a** and **4b** in 28% and 66% yields respectively.[4d] **4a** and **4b** were easily separated by flash chromatography on silica gel. At this point, the *exo* configuration of the carbon C6 for compound **4b** was confirmed by X-ray analysis (Scheme 3, see SI, Figure A).

Introduction of phosphine group consists of the nucleophilic substitution of **4a** or **4b.** Phosphine-borane complexes **6a** and **6b** were obtained from **4a** or **4b** respectively after protection with borane dimethylsulfide complex (Scheme 4).



Scheme 1. Structure of monophosphines.

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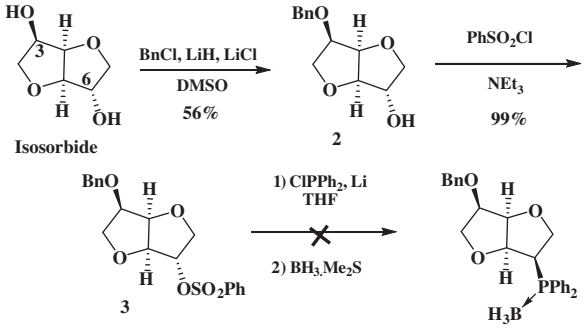
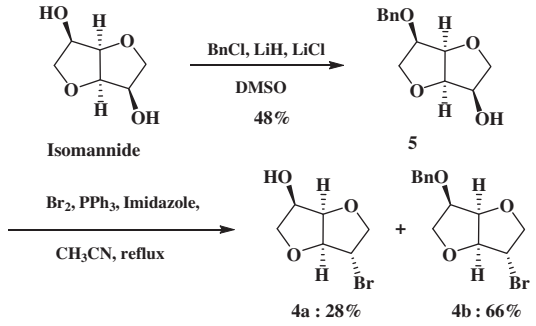
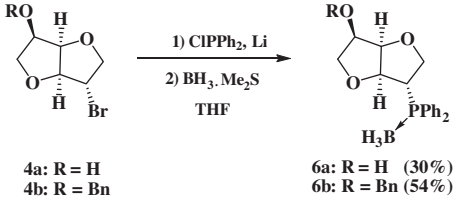


Scheme 2. Synthesis of monophosphine from isosorbide.



Scheme 3. Synthesis of bromo derivatives from isomannide.



Scheme 4. Synthesis of monophosphines **6a** and **6b**.

Surprisingly, X-ray analysis of pure crystals from **6b** and **6a** confirms an *exo* position of phosphine group due to a total retention of configuration during the substitution step (Fig. 1 and SI, Figure B). This was already observed by Dervisi and co-workers when they carried out the synthesis of isomannide-based diphosphine from the corresponding dibromide.[6a] It was demonstrated that the choice of solvent had an important effect on stereochemistry. The presence of Et_2O favors the *endo* product, whereas THF gave the *exo* as the major product.

By adding $LiPPh_2$ formed by addition of *n*-BuLi on $HPPh_2$ in diethylether following by addition of $BH_3{\cdot}Me_2S$, we obtained a mixture of *endo*-**7b**/*exo*-**6b** (70/30) of desired phosphine boranes (Scheme 5). *Endo*-phosphine borane **7b** and *exo*-phosphine borane **6b** were isolated in 40% and 11% yields, respectively.

We thought that the obtaining of the compound **6b** with the unexpected *'exo'* configuration could be explained by a hydrophosphination of the alkene **8** which could be obtained in situ from **4b** by an elimination process in the presence of $LiPPh_2$ (Scheme 5).[8] The stereoselectivity could be easily explained by the attack of PPh_2 anion on the less hindered face of the alkene **8**. However, when performing the reaction of diphenylphosphine and alkene **8**[9] in Et_2O at 20 °C for 96 h, no conversion was observed (Table 1). In THF, only a trace of hydrophosphination product was detected

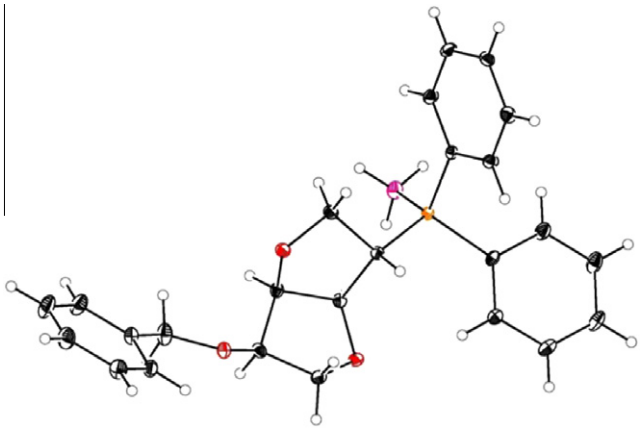
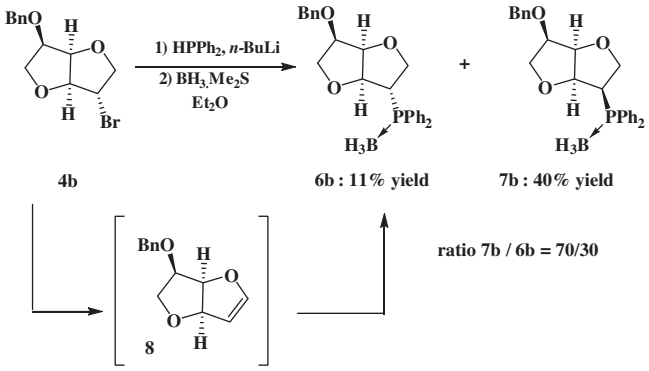
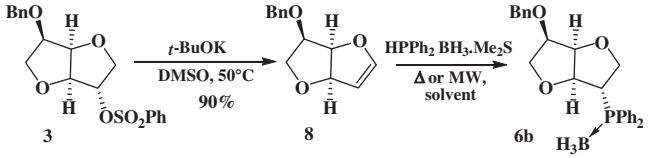


Figure 1. ORTEP drawing of **6b**. Ellipsoids are drawn at the 50% probability level.



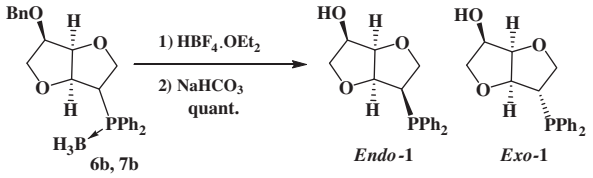
Scheme 5. Synthesis of monophosphines **6b** and **7b**.

Table 1
Hydrophosphination of **8**



Conditions[a]	Solvent	T (°C)	T (h)	Conversion [b] (%)	Isolated yield (%)
—	Et_2O	20	96	0	—
—	THF	20	145	⩽5	—
Oil bath	$PhCH_3$	60	72	<10	nd[c]
MW	$PhCH_3$	50	5	>95	47

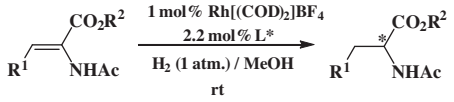
[a] Reaction was carried out using an oil bath or in a CEM microwave reactor.
[b] Determined by ^1H NMR.
[c] Not determined.



Scheme 6. Obtaining of momophosphines *endo*-and *exo*-**1**.

by ^{31}P NMR analysis after 145 h. On the other hand, using toluene as a solvent in classical heating conditions, very low conversion was observed (<10%) after 72 h of reaction. We turned our attention

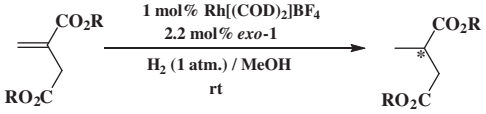
Table 2
Hydrogenation of activated olefins[a]



L*	R^1	R^2	$T_{1/2}$	Conversion[b] (%)	Ee[c] (%)
exo-**1**	Ph	Me	8 min	>95	(*S*)-57
exo-**1**	Ph	Me	24 h	85	(*S*)-71[d]
exo-**1**	Ph	H	17 min	>95	(*S*)-30
exo-**1**	H	Me	4 min	>95	(*S*)-72
exo-**1**	H	H	6 min	>95	(*S*)-70
endo-**1**	Ph	Me	No reaction		

[a] Reactions were carried out at room temperature under atmospheric pressure of dihydrogen with 1 mol % of $Rh(COD)_2BF_4$ and 2.2 mol % of ligand.
[b] Determined by ^1H NMR.
[c] Determined by chiral HPLC analysis.
[d] Reaction at −10 °C for 24 h.

Table 3
Hydrogenation of itaconic acid derivatives[a]



R	$T_{1/2}$ (min)	Conversion[b] (%)	Ee[c] (%)
H	47	>95	(*S*)-32
Me	55	>95	(*S*)-96

[a] Reactions were carried out under 1 atm of hydrogen at room temperature.
[b] Determined by ^1H NMR.
[c] Determined by chiral HPLC analysis.

to the use of microwave irradiation (MW). This technique was widely developed in our laboratory and in other research groups.[10] Under microwave activation, an excellent conversion was obtained after 5 h affording the regioselective *exo* phosphine **6b** in 47% yield after purification by flash chromatography.

Treatment of the phosphines-borane **6b** and **7b** with an excess of tetrafluoroboric acid dimethylether complex resulted in a quantitative formation of the phosphines *exo*-**1** and *endo*-**1** (Scheme 6).

Complexes formed in situ from $Rh[(COD)_2]BF_4$ and *exo*-**1** or *endo*-**1** ligand were examined as catalysts for the enantioselective hydrogenation of activated olefins (Table 2).

^1H NMR analysis showed that complete conversions were obtained in most of cases in few minutes at room temperature under the atmospheric pressure of dihydrogen. The products were obtained with satisfactory enantioselectivities when the catalyst was prepared with *exo*-**1** ligand. Surprisingly, no hydrogenation occurred in the presence of *endo*-**1** ligand. On the other hand, in the presence of Rh-*exo*-**1** catalyst, itaconic acid was hydrogenated quantitatively, but with a modest enantiomeric excess (32% ee), whereas, in the same reaction conditions, its corresponding dimethyl itaconate conducted a good enantioselectivity up to 96% ee (Table 3).

In summary, we have developed a synthesis of new monophosphine ligands derived from isosorbide and isomannide, natural renewable sources. The initial results in asymmetric catalysis such as hydrogenation of olefins showed good catalytic activity and enantioselectivity, up to 96% ee for dimethyl itaconic ester. Although the results are certainly still quite modest with respect to what can be achieved by using well-developed enantioselective hydrogenation catalysts, this represents the highest enantioselectivity to date for hydrogenation catalysts incorporating a monophosphine ligand. During our work, we have also reported a new way to conduct the phosphines using microwave-assisted olefin hydrophosphination. Development of theses phosphorus compounds as ligands or organocatalysts in asymmetric catalysis is currently underway in our laboratory.

Acknowledgments

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Supplementary data

Supplementary information (SI) available: experimental procedure, characterisation of all new compounds. CCDC 819788 (**6b**); 819789 (**4b**) and 819790 (**6a**) contain the supplementary crystallographic data for this paper. These data can be obtained free of charge from the Cambridge Crystallographic Data Centre via http://www.ccdc.cam.ac.uk/datarequest/cif.

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.tetlet.2012.07.035.

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