



Cite this: *RSC Adv.*, 2017, 7, 38216

Highly efficient synthesis of chiral quaternary 3-aminooxindoles promoted by zinc(II) chloride via Et₂Zn-catalysed addition of Grignard reagents to isaltin-derived *N*-*tert*-butanesulfinyl ketimines†

Shiwei Yang,^{ab} Guangling Bian,^{id}*^a Zhongxiang Chen,^a Xiaohan Xia,^a Mi Zhou,^a Caiyan Cui^a and Ling Song^{*ab}

Received 13th July 2017
 Accepted 25th July 2017

DOI: 10.1039/c7ra07692d

rsc.li/rsc-advances

A highly efficient and practical approach to chiral quaternary 3-aminooxindoles was developed via Et₂Zn catalyzed diastereoselective addition of Grignard reagents to isaltin-derived *N*-*tert*-butanesulfinyl ketimines giving good to excellent yields and diastereoselectivities with broad substrates and reagent scopes promoted by zinc(II) chloride.

Introduction

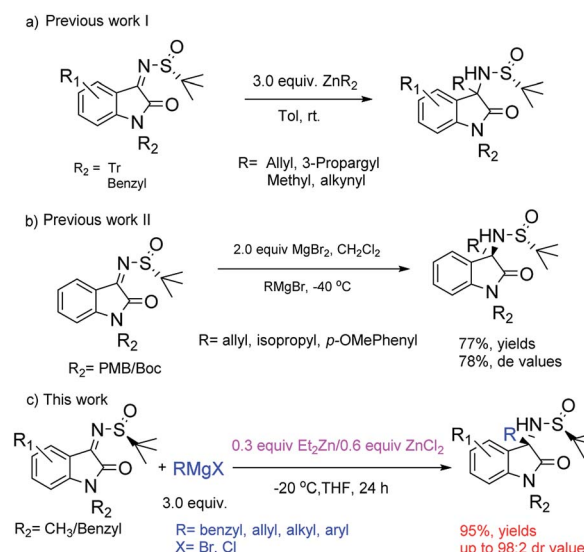
As a widely used chiral auxiliary due to its excellent stereoselectivity, facile preparation and low cost, the application of chiral *tert*-butanesulfinamide to build a chiral C–N center has been well documented.¹ Although constructing chiral quaternary C–N centers is still a challenging task in asymmetric synthesis,² using chiral *tert*-butanesulfinamide as a chiral auxiliary to construct tertiary chiral C–N centers via the addition of organometallic reagents to *N*-*tert*-butanesulfinyl aldimines has been reported.^{1a,3} The use of chiral *tert*-butanesulfinamide and organometallic reagents such as Grignard reagents provided a practical strategy to synthesize chiral quaternary carbon C–N bonds. For example, using isaltin-derived *N*-*tert*-butanesulfinyl ketimines to build quaternary C–N centers has been becoming a hot research topic in recent years.⁴ The core skeleton of chiral quaternary 3-aminooxindoles can be found in V1b receptor antagonist SSR-149415 (ref. 5) and the antimalarial drug candidate NITD609.⁶

To synthesize chiral quaternary 3-aminooxindoles, several methodologies via metal-mediated diastereoselective addition of isaltin-derived *N*-*tert*-butanesulfinyl ketimines have been developed. Among them, methylation/terminal alkynylation and allylation/propargylation via alkyl zinc reagent were carried out by Wang^{4g} and Xu^{4h} (Scheme 1a); and MgBr₂ mediated addition of the ketimines with Grignard reagents was first reported by Alessandra Silvani's group⁴ⁱ (Scheme 1b). Excessive

ZnMe₂, zinc powder and MgBr₂ were needed for these methodologies accordingly. Herein, we report an effective Et₂Zn catalyzed approach to chiral quaternary 3-aminooxindoles via diastereoselective addition of diverse Grignard reagents to a variety of *N*-*tert*-butanesulfinyl ketimines derived from isaltin in mild conditions, giving satisfactory yields and diastereoisomeric ratios promoted by zinc(II) chloride (yields up to 95% and dr up to 98 : 2) (Scheme 1c).

Results and discussion

Ishihara⁷ showed that ZnCl₂ could catalyze the addition of Grignard reagents to varied imines efficiently. And Yu⁸ also



Scheme 1 Synthetic approaches to chiral quaternary 3-aminooxindoles.

^aThe Key Laboratory of Coal to Ethylene Glycol and Its Related Technology, Fujian Institute of Research on the Structure of Matter, Chinese Academy of Sciences, Fuzhou, Fujian 350002, P. R. China. E-mail: songling@fjirsm.ac.cn; glb@fjirsm.ac.cn
^bUniversity of Chinese Academy of Sciences, 100049, Beijing, P. R. China

† Electronic supplementary information (ESI) available: Experimental details and spectral data for new compounds. CCDC 1523303. For ESI and crystallographic data in CIF or other electronic format see DOI: 10.1039/c7ra07692d



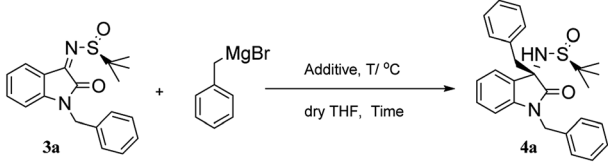
reported that stoichiometric amount of Et₂Zn could promote the addition of RMgBr to *N-tert*-butanesulfinyl aldimines, but few to ketimines. Surprisingly, we found that ZnCl₂ and Et₂Zn could have synergistic effect in the synthesis of chiral quaternary 3-aminooxindoles *via* the addition of Grignard reagents to isaltin-derived *N-tert*-butanesulfinyl ketimines.

Initially, we conducted the reaction in -78 °C without any additives. After the mixture was stirred for 3 days, good diastereoselectivity but low yield was obtained (Table 1, entry 1). When the temperature was increased to -55 °C, the product yield was enhanced a lot with decrease of the dr value. Surprisingly, when ZnCl₂ was added the diastereoselectivity of the reaction was improved obviously (Table 1, entry 3). When catalytic amount Et₂Zn was used respectively, the rate of reaction was greatly increased and 65% isolated yields after 48 hours (Table 1, entry 4). We then examined the efficiency of ZnCl₂ and Et₂Zn in the addition reaction between *N-tert*-butanesulfinyl ketimine **3a** and benzylmagnesium bromide separately in -40 °C (Table 1, entries 5 and 6). In the presence of 0.3 equiv. of ZnCl₂ only, although the reactivity was unsatisfied, the diastereoselectivity of the reaction was very high (>98 : 2 dr) at -40 °C for 24 h. Meanwhile, 0.3 equiv. of Et₂Zn gave the desired product with 80% yields and 98 : 2 dr value under the same conditions. As we expected, when combining Et₂Zn and ZnCl₂, the product yield was increased to 86% without reduction in diastereoselectivity (Table 1, entry 7). Elevating the reaction

temperature to -20 °C, the corresponding yield of the product was improved to 90%, but its dr value was decreased to 96 : 4 (Table 1, entry 8). Further increasing the loading amount of ZnCl₂ enhanced the de value of the product with lower yield (Table 1, entries 9 and 10). The loading amount of Et₂Zn was critical and 0.3 equiv. of Et₂Zn was shown to be the best (Table 1, entries 5, 11 and 12). Replacing ZnCl₂ by ZnBr₂, the product yields dropped a lot with slightly decreasing of the dr value (Table 1, entries 9 and 13). Using PhCH₂MgCl instead of PhCH₂MgBr in the presence of 0.3 equiv. of Et₂Zn and 0.6 equiv. of ZnCl₂ at -20 °C improved the yield to 92% and the dr value to 98.5 : 1.5 (Table 1, entries 9 and 14). Further elevating the reaction temperature to 0 °C resulted in the decrease of the dr value to 94.5 : 5.5 (Table 1, entry 15).

With the optimized conditions in hand, we then investigated the substrate scope of the reaction system. As shown in Table 2, this system worked very well for a variety of substrates with H-, CH₃-, OCH₃-, Cl-, Br-substitution on 3-, 4-, 5-position of the aromatic ring and Bn-, CH₃-substitution on the nitrogen center

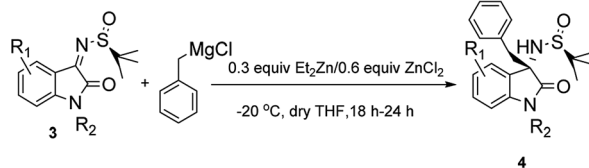
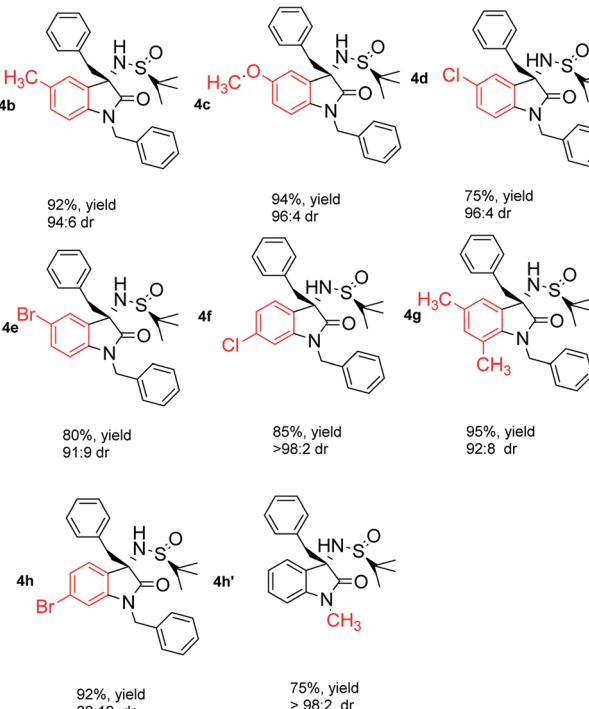
Table 1 Optimization of experimental conditions^{10a}



Entry	T/°C	Additive/equiv.		Time/h	Yield ^b %	Dr ^c
		Et ₂ Zn	ZnCl ₂			
1	-78	—	—	72 ^d	19	>98 : 2
2	-55	—	—	72 ^d	35	95.5 : 4.5
3	-55	—	0.3	72 ^d	42	98.5 : 1.5
4	-55	0.3	—	48 ^d	65	97.5 : 2.5
5	-40	—	0.3	24 ^d	39	>98 : 2
6	-40	0.3	—	24	80	98 : 2
7	-40	0.3	0.3	24	86	>98 : 2
8	-20	0.3	0.3	24	90	96 : 4
9	-20	0.3	0.6	24	88	97.5 : 2.5
10	-20	0.3	1.0	24	70	>98 : 2
11	-20	0.4	0.6	24	61	>98 : 2
12	-20	0.2	0.6	24 ^d	63	98.5 : 1.5
13 ^e	-20	0.3	0.6	24	79	96 : 4
14 ^f	-20	0.3	0.6	18	92	98.5 : 1.5
15 ^f	0	0.3	0.6	24	93	94.5 : 5.5

^a Reaction conditions: **3a** (0.2937 mmol), the Grignard reagents (0.8811 mmol), dried THF, N₂. ^b Isolated yields. ^c Analyzed by NMR and HPLC. ^d SM did not react completely detected by TLC. ^e ZnBr₂ was used instead of ZnCl₂. ^f Benzylmagnesium chloride was used instead of benzylmagnesium bromide.

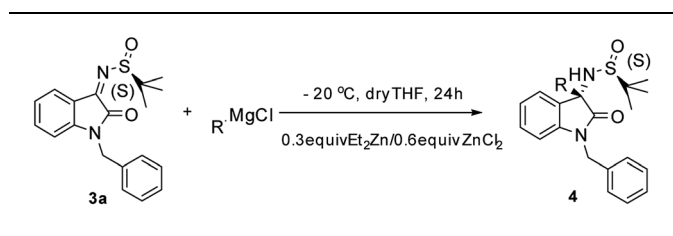
Table 2 Scope of ketimines derived from isaltin^a

Substrate	Yield (%)	dr
4b	92%	94:6
4c	94%	96:4
4d	75%	96:4
4e	80%	91:9
4f	85%	>98:2
4g	95%	92:8
4h	92%	88:12
4h'	75%	>98:2

^a Reaction conditions: the corresponding substrates **3** (0.2937 mmol), benzylmagnesium chloride (0.8811 mmol), Et₂Zn (0.08811 mmol), ZnCl₂ (0.1762 mmol), dried THF, N₂, -20 °C, 18–24 h. Yield is for isolated yields and dr is analyzed by NMR.



Table 3 Scope of the Grignard reagents^a

Entry	No.	R-	Time/h	Yield ^b /%	Dr ^c
1	4i	Isopropyl-	24	84	>98 : 2
2	4j	Allyl-	24	92	>98 : 2
3	4k	Phenyl-	24	85	88 : 12
4	4l	<i>p</i> -Methylphenyl-	24	88	94 : 6
5	4m	Ethyl-	24	95	>98 : 2
6 ^d	4n	Methyl-	24	94	>98 : 2

^a Reaction conditions: **3a** (0.2937 mmol), the Grignard reagents (0.8811 mmol), Et₂Zn (0.08811 mmol), ZnCl₂ (0.1762 mmol), dried THF, N₂, -20 °C, 24 h. ^b Isolated yields. ^c Analyzed by NMR. ^d Only methyl addition product was isolated. The reason might be that Et₂Zn was the catalytic amount and no or less ethyl addition product could be isolated.

of **3** giving 75–95% yields and up to 98 : 2 dr value of the desired products. Furthermore, our methodology was also applicable for diverse Grignard reagents, containing aryl, benzyl, alkyl and allyl Grignard reagents (Table 3).

The S configuration of the new generated stereocenters of **4** was assigned on the basis of **4n** and **4m**. The relative configuration of the quaternary C–N center of **4n** was confirmed by chemical transformation to a known compound **5** (ref. 4g) and the absolute configuration of **4m** was determined by X-ray crystal structure (Fig. 1).¹¹

Based on our studies and previous published results by other groups,^{4i,7–9} we proposed the possible catalytic mechanism as follows (Fig. 2): catalytic Et₂Zn reacted with ZnCl₂ and RMgCl to generate active triorganozincate REt₂ZnMgCl and MgCl₂. The Lewis acid MgCl₂ activated *N*-*tert*-butanesulfinyl ketimine **3a** by

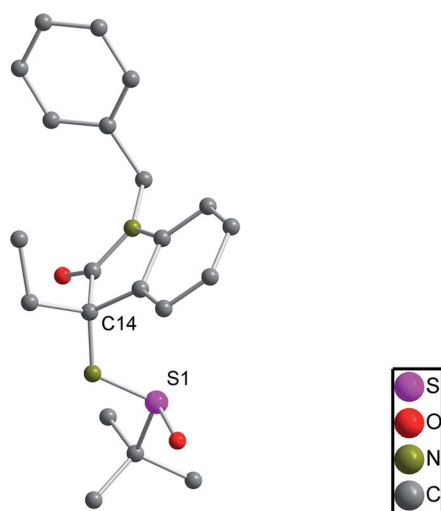
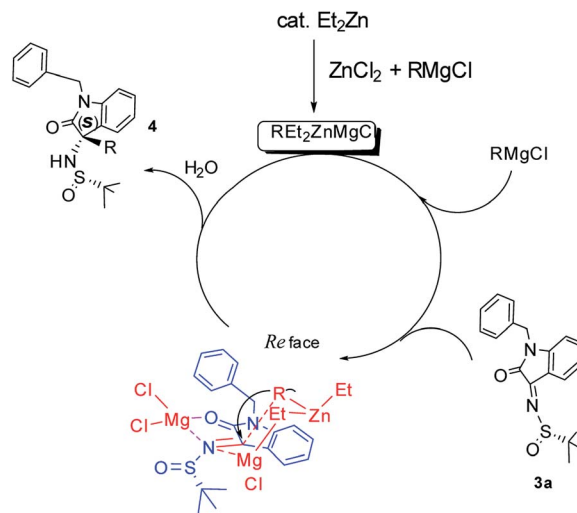
Fig. 1 X-ray structure of **4m**. Hydrogen was omitted for clarity.

Fig. 2 Proposed the possible catalytic mechanism.

coordinating with the oxygen of C=O and the nitrogen of C=N in the ketimine. It facilitated the R-group transfer of REt₂ZnMgCl and favored the equilibrium of E configuration of the imine which preferred the Re attack of R-group of REt₂ZnMgCl to obtain the S configuration on the quaternary C–N center of the final product.

Conclusions

To summarize briefly, we developed a new and effective methodology for the diastereoselective addition of diverse Grignard reagents to a variety of *N*-*tert*-butanesulfinyl ketimines derived from isatin in good to excellent yields and diastereoselectivities. We provided a very practical synthetic approach to chiral quaternary 3-aminooxindoles. The rate of reaction and yield was greatly increased through the use of Et₂Zn. The dr values of products were promoted obviously by zinc(II) chloride. The *in situ* generated active triorganozincate and rigid transition state are the key factors for the high reactivity and diastereoselectivity of the reaction.

Acknowledgements

The authors gratefully acknowledge financial supports from the Strategic Priority Research Program of the Chinese Academy of Sciences (Grant No. XDB20000000); The Key Laboratory of Coal to Ethylene Glycol and Its Related Technology, Fujian Institute of Research on the Structure of Matter, Chinese Academy of Sciences.

Notes and references

- For reviews on the application of (R/S)-*tert*-butanesulfinamide, see: (a) M. T. Robak, M. A. Herbage and J. A. Ellman, *Chem. Rev.*, 2010, **110**, 3600; (b) F. Ferreira, C. Botuha, F. Chemla and A. Pérez-Luna, *Chem. Soc. Rev.*, 2009, **38**, 1162; (c) J. A. Ellman, *Pure Appl. Chem.*,



- 2003, 75, 39; (d) J. A. Ellman, T. D. Owens and T. P. Tang, *Acc. Chem. Res.*, 2002, 35, 984; for articles see: (e) C. Xie, Y. Dai, H. Mei, J. Han, V. A. Soloshonok and Y. Pan, *Chem. Commun.*, 2015, 51, 9149; (f) L. Wu, C. Xie, H. Mei, V. A. Soloshonok, J. Han and Y. Pan, *Org. Biomol. Chem.*, 2014, 12, 4620; (g) J. Cheng, L. Fu, C. Ling and Y. Yang, *Heterocycles*, 2010, 81, 2581; (h) C. H. Ko, D. Y. Jung, M. K. Kim and Y. H. Kim, *Synlett*, 2005, 02, 304; (i) D. R. Dragoli, M. T. Burdett and J. A. Ellman, *J. Am. Chem. Soc.*, 2001, 123, 10127; (j) H. B. Mei, C. Xie, J. L. Han and V. A. Soloshonok, *Eur. J. Org. Chem.*, 2016, 2016, 5917.
- 2 (a) S.-G. Wang, X.-J. Liu, Q.-C. Zhao, C. Zheng, S.-B. Wang and S.-L. You, *Angew. Chem., Int. Ed.*, 2015, 127, 15142; (b) Y. Liu and J. Zhou, *Chem. Commun.*, 2013, 49, 4421; (c) L.-N. Jia, J. Huang, L. Peng, L.-L. Wang, J.-F. Bai, F. Tian and L.-X. Wang, *Org. Biomol. Chem.*, 2012, 10, 236; (d) S. P. Marsden, E. L. Watson and S. A. Raw, *Org. Lett.*, 2008, 10, 2905; (e) Y. X. Jia, J. M. Hillgren, E. L. Watson, S. P. Marsden and E. P. Kundig, *Chem. Commun.*, 2008, 34, 4040; (f) P. Fu, M. L. Snapper and A. H. Hoveyda, *J. Am. Chem. Soc.*, 2008, 130, 5530; (g) T. Emura, T. Esaki, K. Tachibana and M. Shimizu, *J. Org. Chem.*, 2006, 71, 8559; (h) B. M. Trost and C. Jiang, *J. Am. Chem. Soc.*, 2001, 123, 12907; (i) T. Satoh, R. Matsue, T. Fujii and S. Morikawa, *Tetrahedron Lett.*, 2000, 41, 6495; (j) D. H. Hua, N. Lagneau, H. Wang and J. Chen, *Tetrahedron: Asymmetry*, 1995, 6, 349; (k) D. H. Hua, S. W. Miao, J. S. Chen and S. Iguchi, *J. Org. Chem.*, 1991, 56, 4.
- 3 (a) S. Kobayashi and H. Ishitani, *Chem. Rev.*, 1999, 99, 1069; (b) T. Vilaivan, W. Bhanthumnavin and Y. Sritana-Anant, *Curr. Org. Chem.*, 2005, 9, 1315.
- 4 (a) H. H. Jung, A. W. Buesking and J. A. Ellman, *Org. Lett.*, 2011, 13, 3912; (b) J.-P. Chen, W.-W. Chen, Y. Li and M.-H. Xu, *Org. Biomol. Chem.*, 2015, 13, 3363; (c) D. Chen and M.-H. Xu, *J. Org. Chem.*, 2014, 79, 7746; (d) V. B. Rao, A. P. Jadhav, D. Garad and R. P. Singh, *Org. Lett.*, 2014, 16, 648; (e) H. Takada, N. Kumagai and M. Shibasaki, *Org. Lett.*, 2015, 17, 4762; (f) S. Hajra, S. M. Aziz, B. Jana, P. Mahish and D. Das, *Org. Lett.*, 2016, 18, 532; (g) W. Yan, D. Wang, J. Feng, P. Li and R. Wang, *J. Org. Chem.*, 2012, 77, 3311; (h) D. Chen and M.-H. Xu, *Chem. Commun.*, 2013, 49, 1327; (i) G. Lesma, N. Landoni, T. Pilati, A. Sacchetti and A. Silvani, *J. Org. Chem.*, 2009, 74, 4537.
- 5 (a) H. Yin, T. Wang and N. Jiao, *Org. Lett.*, 2014, 16, 2302; (b) Y.-Q. Zhang, Y.-A. Yuan, G.-S. Liu and H. Xu, *Org. Lett.*, 2013, 15, 3910.
- 6 (a) H. Zheng, X. Liu, C. Xu, Y. Xia, L. Lin and X. Feng, *Angew. Chem., Int. Ed.*, 2015, 54, 10958; (b) T. N. Wells, *Science*, 2010, 329, 1153.
- 7 (a) M. Hatano, K. Yamashita and K. Ishihara, *Org. Lett.*, 2015, 17, 2412; (b) M. Hatano, R. Gouzu, T. Mizuno, H. Abe, T. Yamada and K. Ishihara, *Catal. Sci. Technol.*, 2011, 1, 1149; (c) M. Hatano, O. Ito, S. Suzuki and K. Ishihara, *Chem. Commun.*, 2010, 46, 2674; (d) M. Hatano, O. Ito, S. Suzuki and K. Ishihara, *J. Org. Chem.*, 2010, 75, 5008; (e) M. Hatano, S. Suzuki and K. Ishihara, *J. Am. Chem. Soc.*, 2006, 128, 9998; (f) M. Hatano, M. Mizuno and K. Ishihara, *Org. Lett.*, 2016, 18, 4462.
- 8 (a) R. Almansa, D. Guijarro and M. Yus, *Tetrahedron Lett.*, 2009, 50, 3198; (b) R. Almansa, D. Guijarro and M. Yus, *Tetrahedron: Asymmetry*, 2008, 19, 2484; (c) R. Almansa, D. Guijarro and M. Yus, *Tetrahedron: Asymmetry*, 2008, 19, 603.
- 9 (a) M. Hatano, K. Yamashita and M. Mizuno, *Angew. Chem., Int. Ed.*, 2015, 127, 2745; (b) F.-L. Li, H.-Y. Huang, H. Zong, G.-L. Bian and L. Song, *Tetrahedron Lett.*, 2015, 56, 2071; (c) H. Zong, H.-Y. Huang, J.-F. Liu, G.-L. Bian and L. Song, *J. Org. Chem.*, 2012, 77, 4645.
- 10 The diastereoisomers **4a** and **4a'** was separable, see: ¹HNMR, ¹³CNMR and HRMS in ESI.† The dr value of **4a** in optimization of experimental conditions was determined by NMR and HPLC.
- 11 The X-ray crystal structure of **4m** was confirmed by CCDC 1523303.†

