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Cu(I)-catalyzed enantioselective and stereospecific borylative annulation of cyclic 1,3-dione-tethered 1,3-enynes†

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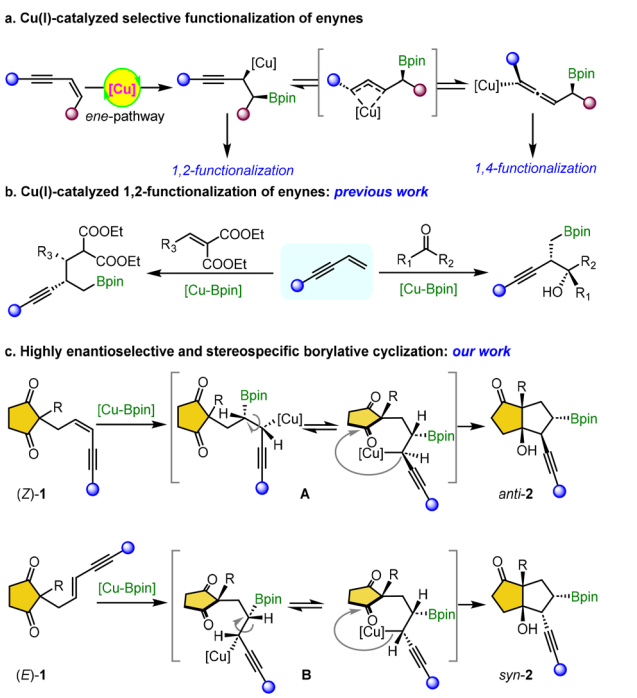
A copper(I)-catalyzed, highly enantioselective, and diastereoselective borylative cyclization of prochiral cyclic 1,3-dione-tethered 1,3-enynes is reported. This stereospecific transformation exhibits a broad substrate scope, enabling access to bicyclic organoboron products containing four contiguous stereocenters with excellent enantioselectivity. Notably, the reaction rate is significantly influenced by the substrate's stereochemistry, with the (*Z*)-isomer undergoing borylative cyclization much faster than the (*E*)-isomer due to reduced steric interactions during C–C bond formation. Furthermore, treatment of the resulting products with sodium perborate yields the corresponding alcohols without compromising enantiomeric excess.

Introduction

Conjugated enynes are highly reactive and valuable substrates in modern organic chemistry, widely utilized in the synthesis of complex aromatic molecules and materials.[1] While 1,3-enyne motifs can be readily accessed through several efficient methods, the catalytic cross-coupling of terminal alkynes stands out as the most convenient approach.[2] Recently, copper-catalyzed hydro- and borofunctionalizations, multicomponent reactions, radical functionalizations, and cyclizations of these π-systems have garnered significant attention from organic and medicinal chemists.[3] Among these methods, enantioselective Cu-catalyzed borylation of 1,3-enynes has also emerged as an elegant strategy, providing access to a diverse range of chiral organoboranes.[4] The resulting C–B bonds can be conveniently converted into C–C, C–O, and C–N bonds through stereospecific 1,2-migration.[5] However, achieving asymmetric chemo- and regioselective borylative difunctionalization of 1,3-enynes remains highly challenging due to the presence of multiple reactive sites.

In general, two pathways are possible for 1,3-enynes during hydro- or borofunctionalization. The reaction at the olefin can yield propargyl or allene products *via* the ene-pathway (Scheme 1a), whereas the reaction at the alkyne results in diene products through the yne-pathway.[3] In 2011, Ito and co-workers reported that the regioselectivity of borocupration is influenced by the nature of the ligand employed in the reaction and steric



Scheme 1 Cu(I)-catalyzed borylative functionalization of 1,3-enyes.

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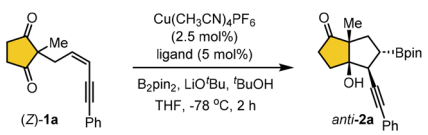
hindrance around the olefinic functionality of the enyne.[6] The first enantioselective Cu-catalyzed borylative 1,2-difunctionalization of 1,3-enynes was reported by the Hoveyda group in 2014 *via* the ene-pathway (Scheme 1b).[7] The borocupration of 1,3-enynes enables the formation of a chiral allenylcopper complex, which is readily captured by aldehydes to provide propargylated products with excellent diastereo- and enantioselectivities. In light of this report, Yin and co-workers disclosed similar consecutive protocols on ketones.[8] Later, Procter and co-workers disclosed a highly enantio- and diastereoselective borylative 1,2-coupling of 1,3-enynes with imines to provide chiral homopropargyl amines with excellent diastereo- and enantioselectivity.[9] Recently, Yun and co-workers reported a highly enantioselective 1,2-borylation/conjugate addition with β-substituted alkylidene malonates, enabling organoboranes bearing adjacent stereocentres.[10] In 2020, Hu, Wang, Liao, and co-workers developed a cooperative Cu/Pd-catalyzed 1,4-boroarylation, wherein arylation occurs *via* transmetalation with palladium to access chiral tri- and tetra-substituted allenes.[11] Shortly thereafter, Xu *et al.* reported the 1,4-boroprotonation of trifluoromethyl-substituted conjugated enynes to access enantioenriched homoallenyboronates.[12] Similarly, CuH-catalyzed hydrofunctionalization of 1,3-enynes also allows the generation of chiral allenylcopper intermediates, which are readily captured by various electrophiles to yield the corresponding propargylic products and allenes with excellent stereoselectivities.[13,14] Among these elegant methods, 1,2-borofunctionalization is generally limited to terminal 1,3-enynes, with only two reports[9,10] exploring internal enynes due to their lower reactivity and other challenges related to regioselectivity and stereoselectivity. Here, *E*/*Z*-selectivity of the double bond controls the diastereoselectivity of the corresponding product in a stereospecific manner.

To the best of our knowledge, there are no intramolecular cyclizations reported *via* Cu-catalyzed borylative 1,2-difunctionalization of 1,3-enynes with internal electrophiles. Based on our interest in the area of enantioselective Cu-catalysis,[15] herein, we report a stereospecific annulation of 1,3-enyne-tethered cyclic 1,3-enones (Scheme 1c). This work describes an unprecedented intramolecular Cu(I)-catalyzed borylative difunctionalization of 1,3-enynes, delivering products with excellent diastereo- and enantioselectivity. The *E*/*Z* configuration of the substrates significantly influences the reaction rate and diastereoselectivity of products. We envisioned that stereospecific *syn*-addition of a borylcopper(I) intermediate on the double bond of (*Z*/*E*)-**1** could provide intermediate A/B. Subsequent intramolecular nucleophilic attack of organocuprate A/B could afford the corresponding product *anti*-**2** or *syn*-**2**, respectively with the retention of the configuration at the C–B bond. Notably, the reaction proceeds through highly regioselective 1,2-borocupration on the double bond adjacent to the sterically demanding quaternary prochiral center.

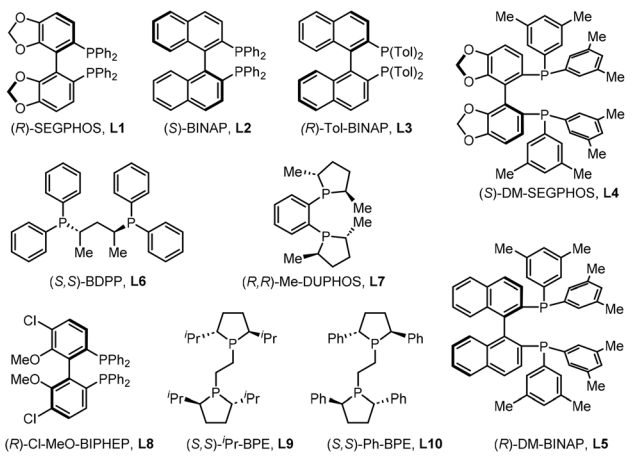
Results and discussion

We began our investigation on Cu(I)-catalyzed borylative cyclization of *Z*-selective 1,3-enyne **1a** as a model substrate in the presence of bis(pinacolato)diboron as the borylation source with various chiral bidentate phosphine ligands (Table 1). The reaction was initially conducted with 2.5 mol% of $Cu(CH_3CN)_4PF_6$, 5 mol% of ligand, and 2.0 equivalents of base in THF at −78 °C for 2 hours. Notably, the BINAP ligands provided the desired product *anti*-**2a** in moderate yield with enantioselectivity ranging from 37% to 92%, whereas SEGPHOS ligands resulted in only trace amounts of the product (entries 1–5). In addition, the BDPP ligand L6, DUPHOS ligand L7, BIPHEP ligand L8, and iPr-BPE ligand L9 proved ineffective in the model reaction, resulting in no product formation. Fortunately, the reaction with (*S*,*S*)-Ph-BPE ligand L10 afforded **2a** in high yield with excellent enantioselectivity (>99% ee). The exclusive diastereoselectivity suggests that the borylative cyclization of (*Z*)-**1a** proceeds with high stereocontrol. The relative stereochemistry of *anti*-**2a** was confirmed by single crystal X-ray diffraction analysis (see Table 2).[16]

Table 1 Optimization of reaction conditions[a,b,c,d]

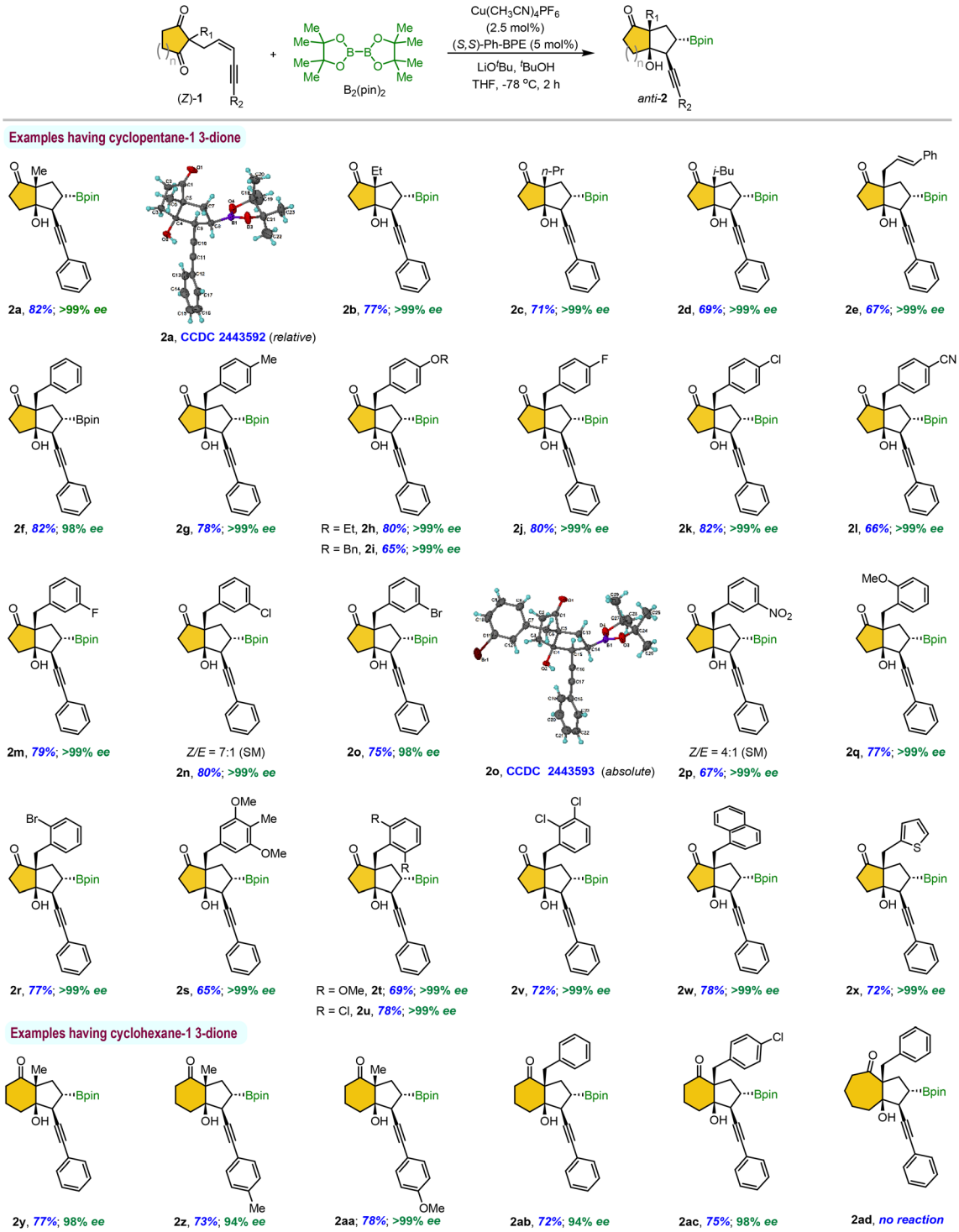


Entry	Ligand	Yield [%]	**2a** (ee)
1	(*R*)-SEGPHOS, **L1**	<5	—
2	(*S*)-BINAP, **L2**	54	92%
3	(*R*)-Tol-BINAP, **L3**	36	69%
4	(*S*)-DM-SEGPHOS, **L4**	<5	—
5	(*R*)-DM-BINAP, **L5**	31	37%
6	(*S*,*S*)-BDPP, **L6**	<5	—
7	(*R*,*R*)-Me-DUPHOS, **L7**	—	—
8	(*R*)-Cl-MeO-BIPHEP, **L8**	—	—
9	(*S*,*S*)-^{i}Pr-BPE, **L9**	—	—
10	**(*S*,*S*)-Ph-BPE-L10**	**82%**	**>99%**



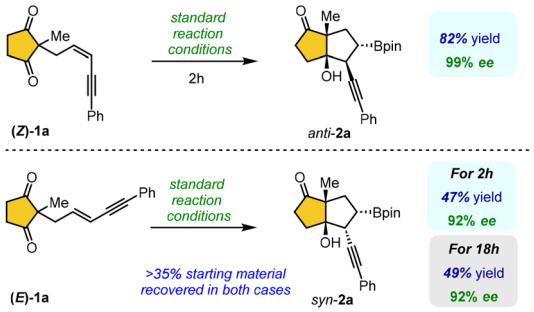
[a] Reaction conditions: **1a** (50 mg, 0.2 mmol), $B_2(pin)_2$ (60 mg, 0.24 mmol), $Cu(CH_3CN)_4PF_6$ (1.9 mg, 2.5 mol%), ligand (5.0 mol%), ^{t}BuOH (38 μL, 0.4 mmol), Li^{t}Bu (36 μL, 0.4 mmol, 1.0 M THF solution), in THF solvent (3 mL, 0.1 M). [b] Isolated yields. [c] Enantiomeric ratio (*er*) was determined by HPLC analysis using a chiral stationary phase. [d] >20 : 1 *dr* was observed from ^{1}H NMR analysis.

Table 2 Substrate scope of (*Z*)-isomer[a,b,c,d]



[a] Reaction conditions: **1** (0.3 mmol), $B_2(pin)_2$ (91 mg, 0.36 mmol), $Cu(CH_3CN)_4PF_6$ (2.8 mg, 2.5 mol%), (*S*,*S*)-Ph-BPE (7.6 mg, 5.0 mol%), ^{t}BuOH (57 μL, 0.6 mmol), LiO^tBu (54 μL, 0.6 mmol, 1.0 M THF solution), in THF solvent (3 mL, 0.1 M). [b] Isolated yields after column chromatography. [c] Enantiomeric ratio (*er*) was determined by chiral HPLC analysis. [d] >20 : 1 *dr* was observed (unless otherwise mentioned) through ^{1}H NMR analysis of a crude reaction mixture. SM = Starting material.

Under standard conditions, the borylative cyclization of 1,3-enyne (*Z*)-**1a** proceeded with complete *anti*-selectivity, affording the bicyclic product **2a** in 82% yield with >99% enantioselectivity (Scheme 2). In contrast, the reaction of 1,3-enyne (*E*)-**1a** yielded the *syn*-selective bicyclic product **2a** with moderate yield and 92% enantioselectivity. Besides, prolonging

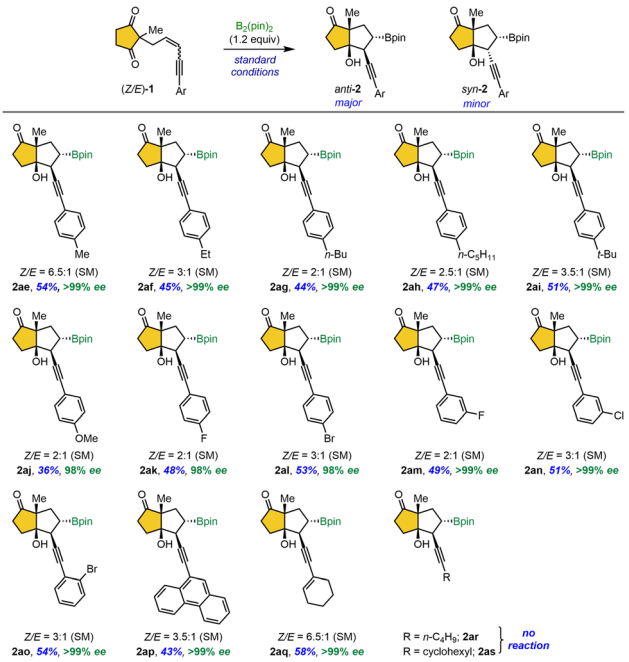


Scheme 2 Comparative study of reaction rates.

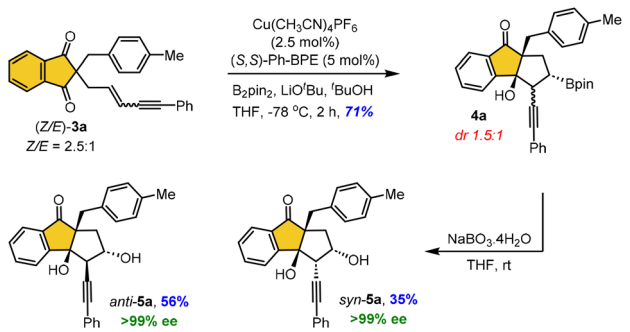
the reaction time did not enhance the conversion, and over 35% of the starting material (*E*)-**1a** remained unreacted in both cases. The reaction rates and *syn*/*anti* selectivity of the reaction were significantly influenced by the *E* or *Z* configuration of the 1,3-enyne substrates.[17] Notably, the borylative cyclization of (*Z*)-**1a** proceeded much faster than that of (*E*)-**1a**, affording the desired product in high yield with exclusive enantioselectivity. This enhanced reactivity is likely attributed to reduced steric interaction between the Bpin and alkyne groups in Int-A compared to Int-B during C–C bond formation (see Scheme 1c).

Later, the scope of the borylative cyclization in the presence of B_2pin_2 was explored using various prochiral (*Z*)-selective 1,3-enyne-tethered cyclic 1,3-diones **1** under optimized reaction conditions, unless otherwise specified for the *Z*/*E* ratio of the substrate. Our initial investigation focused on phenyl-substituted enynes with various substituents at the all-carbon prochiral center, and the results are summarized in Table 2. Substrates bearing sterically diverse alkyl groups and a cinnamyl group at the quaternary center were well-tolerated, undergoing borylative enantioselective desymmetrization to afford the corresponding products **2a–2e** in 67–82% yield with excellent enantioselectivity. Next, a range of benzyl groups with electronically and sterically tuned substituents at the prochiral center were evaluated. These 1,3-enyne-tethered cyclopenta-1,3-diones proved to be highly suitable, delivering bicyclo[3.3.0] octane products **2f–2v** in good yields with uniformly >99% ee across all cases. Particularly, the reaction was carried out on the substrates as an inseparable mixture of (*Z*/*E*)-isomers, with the major (*Z*)-1,3-enyne predominantly yielding the corresponding products *anti*-**2n** and *anti*-**2p**, along with trace amounts of *syn*-products derived from the (*E*)-isomer. Beyond benzyl groups, a similar range of yields and enantioselectivities was observed with other substituents, including 1-naphthyl and thiophen-2-ylmethylene groups at the quaternary prochiral center, furnishing products **2w** and **2x**, respectively. Next, the generality of the present approach was evaluated using *Z*-selective enyne-tethered cyclohexa-1,3-diones under standard conditions, which provided the corresponding products **2y–2ac** in comparable yields and enantioselectivities. However, the cycloheptane-1,3-dione substrate failed to afford the desired product (**2ad**), and most of the starting material was recovered. The absolute stereochemistry of the bicyclic ketone *anti*-**2o** was unambiguously established by single-crystal X-ray diffraction

Table 3 Substrate scope of the (*Z*/*E*)-isomer[a,b,c,d,e]



[a] Reaction conditions same as in Table 2. [b] Isolated yields of the major product *anti*-**2**. [c] Diastereoselectivity was observed to be >20 : 1 for the major isomer, which was confirmed by ^{1}H NMR analysis. [d] Unable to find the ratio of major and minor products in the crude ^{1}H NMR analysis. [e] Enantioselectivity of the major isomer. SM = starting material.



Scheme 3 Borylative cyclization of 1,3-indandiones.

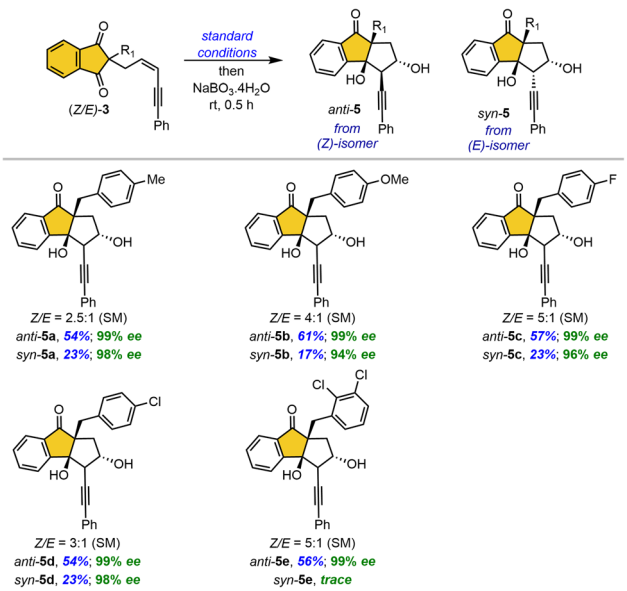
analysis.[16] The stereochemical assignments of the remaining products were assumed by analogy.

Next, we explored the scope of 1,3-enynes bearing various aromatic substituents (Table 3). The reaction was carried out on a mixture of (*Z*/*E*)-isomers under standard conditions, yielding product *anti*-**2** predominantly from (*Z*)-1,3-enyne as the major diastereomer due to its higher reaction rate. Only trace amounts of the *syn*-product **2** (<5% yield) were identified from (*E*)-**1** in a few examples, highlighting the strong stereochemical influence on the reaction outcome. The transformation proceeded with good diastereoselectivity, and excellent enantioselectivity. Aromatic 1,3-enynes with diverse substituents, regardless of their electronic properties, were well-tolerated under the standard conditions. Substituents such as alkyl, alkoxy, and halogen groups at the para-, meta-, or ortho-positions of the phenyl ring afforded the corresponding products (**2ae–2ao**) in moderate yields with excellent enantioselectivity (97–99% ee). Additionally, 9-phenanthryl and 1-cyclohexenyl groups on 1,3-enynes were readily converted into the desired products (**2ap** and **2aq**) in good yields with >99% enantioselectivity. Unfortunately, 3-enyne substrates bearing aliphatic substituents failed to afford the desired products, and most of the starting material was recovered (entries **2ar** and **2as**).

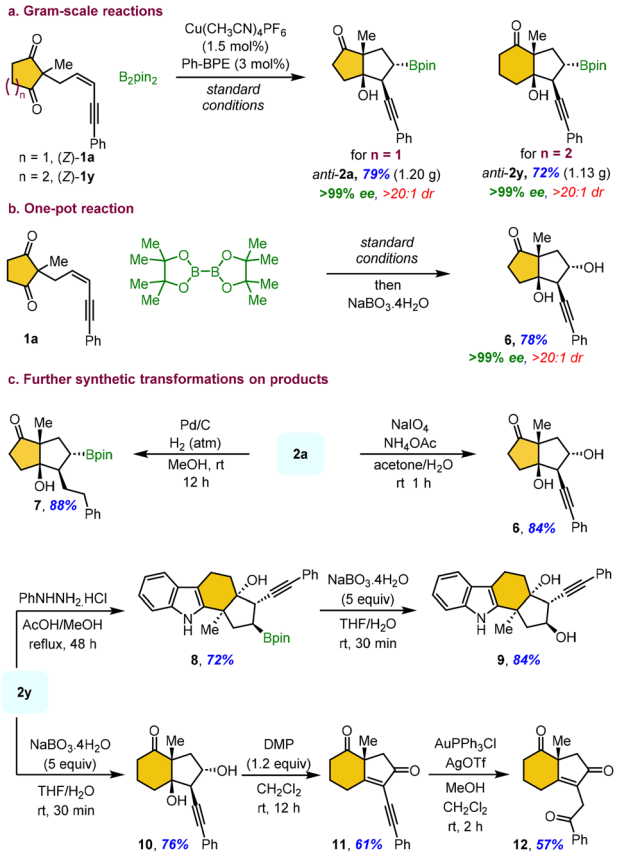
The enantioselective desymmetrization of α,α-disubstituted 1,3-indandione (*Z*/*E*)-**3a** (dr = 2.5 : 1) proceeded efficiently under the optimized reaction conditions, affording the desired product **4a** as a mixture of inseparable diastereomers in a 1.5 : 1 ratio with a 71% yield (Scheme 3). Subsequent oxidation of the Bpin group using $NaBO_3 \cdot 4H_2O$ yielded the corresponding alcohols *anti*-**5a** (56%) and *syn*-**5a** (35%) as separable diastereomers, which were easily purified *via* simple column chromatography. It is interesting to observe that the (*E*)-isomer of the 1,3-indandione substrate reacts just as effectively as the (*Z*)-isomer.

For ease of handling, we performed a one-pot borylative cyclization/oxidation of 1,3-indandiones under standard reaction conditions, followed by the sequential addition of $NaBO_3 \cdot 4H_2O$ (Table 4). We briefly screened this reaction with substrates featuring various benzyl groups at the prochiral quaternary center, yielding separable diastereomeric products *anti*-**5** and *syn*-**5**. Electronically diverse substituents on the benzyl group provided high yields and excellent enantioselectivities (**5a–5d**). However, a sterically demanding ortho-substituted benzyl group resulted in only a trace amount of *syn*-product from the (*E*)-isomer and predominantly *anti*-**5e** from the (*Z*)-isomer.

Table 4 One-pot borylative cyclization/oxidation of 1,3-indandiones[a,b,c,d]



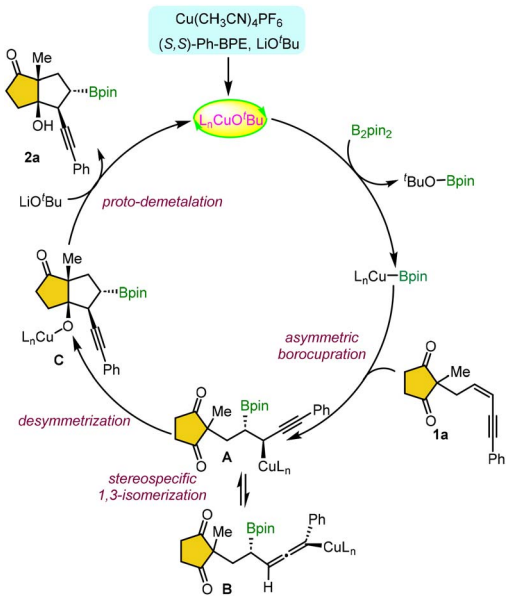
[a] Reaction conditions: Same as in Table 2 and then $NaBO_3 \cdot 4H_2O$ (150 mg, 1.5 mmol, 5.0 equiv.) was added in the same reaction. [b] Isolated yields of respective diastereomers. [c] Enantiomeric excess (ee) was determined by chiral HPLC analysis. [d] The dr was observed from ^1H NMR analysis of the crude reaction mixture. SM = starting material.



Scheme 4 Large-scale reactions and further transformations.

Gram-scale reactions using (*Z*)-**1a** and (*Z*)-**1y** were carried out with reduced catalyst loading under standard conditions, affording the desired products *anti*-**2a** and *anti*-**2y**, respectively, without any significant loss in yield or enantioselectivity (Scheme 4a). The one-pot borylative cyclization, followed by the sequential addition of the mild oxidizing agent sodium perborate, afforded the corresponding alcohol **6** in a similar yield with exclusive enantioselectivity (Scheme 4b). Interestingly, the reaction with the strong oxidizing agent sodium periodate also afforded alcohol 6 in high yield, instead of undergoing boronic ester hydrolysis (Scheme 4c). The Pd/C-catalyzed hydrogenolysis of compound **2a** successfully reduces the triple bond, providing bicyclic ketone **7** in 88%yield. The Fischer cyclization of compound **2y** with phenylhydrazine furnished a highly functionalized tetracyclic fused indole **8** in 72% yield. Subsequent oxidation of **8** with sodium perborate afforded the corresponding alcohol **9** in 84% yield. Interestingly, direct oxidation of **2y** with sodium perborate yielded alcohol **10**, which upon Dess–Martin periodinane (DMP) oxidation provided the α-alkynyl enone **11** *via* sequential alcohol oxidation and *tert*-alcohol elimination in good yield. This highly reactive, fused, electron-deficient enyne **11** serves as a promising intermediate for diverse cycloaddition reactions. In addition, Au(I)-catalyzed hydration of enyne **11** in methanol afforded arylketone **12** in 57% yield.

Based on the proposed copper catalytic cycle, the ligated copper alkoxide complex LnCuOtBu is generated *in situ* in the presence of a chiral ligand and base (Scheme 5). This complex



Scheme 5 Plausible reaction mechanism.

undergoes σ-bond metathesis with a diboron reagent, yielding the LnCu–Bpin species. The enantioselective and regioselective 1,2-*syn*-addition of LnCu–Bpin to the 1,3-enyne-tethered cyclic-1,3-dione **1a** leads to the formation of a propargylic copper intermediate A. This intermediate exists in equilibrium with an axially chiral allenyl–copper intermediate B *via* a stereospecific isomerization. Subsequent desymmetrization through annulation of propargylic intermediate A furnishes the desired product **2a**, while the catalytic cycle is completed by regenerating LnCu–OtBu *via* a copper alkoxide intermediate C in the presence of a base.

Conclusions

In summary, we have developed a stereospecific, enantioselective copper(I)-catalyzed borylative cyclization of prochiral 1,3-enyne-tethered cyclic-1,3-diones with excellent diastereoselectivity. This asymmetric desymmetrization reaction efficiently delivers highly functionalized chiral octahydropentalenes bearing four contiguous stereocenters. Notably, the use of a BPE-ligand resulted in >99% ee for most examples. Additionally, (*Z*)-1,3-enyne substrates react more rapidly than their (*E*)-isomers, affording borylation products in high yields under standard reaction conditions. Ongoing studies in our laboratory are focused on further Cu(I)-catalyzed stereoselective transformations.

Data availability

The data supporting this article have been included as part of the ESI.†

Author contributions

G. R. and V. B. P. performed the experiments and analyzed the experimental data; J. B. N. conducted the single X-ray

crystallographic analysis; R. C. designed and supervised the project and wrote the manuscript with the assistance of co-authors.

Conflicts of interest

There are no conflicts to declare.

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Notes and references

1 (*a*) S. Saito and Y. Yamamoto, *Chem. Rev.*, 2000, **100**, 2901–2916; (*b*) P. Wessig and G. Müller, *Chem. Rev.*, 2008, **108**, 2051–2063; (*c*) K. Campbell, C. J. Kuehl, M. J. Ferguson, P. J. Stang and R. R. Tykwinski, *J. Am. Chem. Soc.*, 2002, **124**, 7266–7267.

2 (*a*) B. M. Trost and J. T. Masters, *Chem. Soc. Rev.*, 2016, **45**, 2212–2238; (*b*) E.-i. Negishi and L. Anastasia, *Chem. Rev.*, 2003, **103**, 1979–2018.

3 Q. Dherbassy, S. Manna, F. J. T. Talbot, W. Prasitwatcharakorn, G. J. P. Perry and D. J. Procter, *Chem. Sci.*, 2020, **11**, 11380–11393.

4 (*a*) A. Whyte, A. Torelli, B. Mirabi, A. Zhang and M. Lautens, *ACS Catal.*, 2020, **10**, 11578–11622; (*b*) M. Holmes, L. A. Schwartz and M. J. Krische, *Chem. Rev.*, 2018, **118**, 6026–6052; (*c*) for the Cu-catalyzed borylative difunctionalization of π-systems, see: S. K. Dorn and M. K. Brown, *ACS Catal.*, 2022, **12**, 2058–2063; (*d*) W. Xue and M. Oestreich, *ACS Cent. Sci.*, 2020, **6**, 1070–1081; (*e*) G. J. P. Perry, T. Jia and D. J. Procter, *ACS Catal.*, 2020, **10**, 1485–1499; (*f*) D. Hemming, R. Fritzemeier, S. A. Westcott, W. L. Santos and P. G. Steel, *Chem. Soc. Rev.*, 2018, **47**, 7477–7494; (*g*) for other selected asymmetric functionalizations on 1,3-enynes, see: J. W. Han, N. Tokunaga and T. Hayashi, *J. Am. Chem. Soc.*, 2001, **123**, 12915–12916; (*h*) N. J. Adamson, H. Jeddi and S. J. Malcolmson, *J. Am. Chem. Soc.*, 2019, **141**, 8574–8583; (*i*) Y. Zhang, J. Yang, Y. L. Ruan, L. Liao, C. Ma, X. S. Xue and J. S. Yu, *Chem. Sci.*, 2023, **14**, 12676; (*j*) L. Li, S. Wang, A. Jakhar and Z. Shao, *Green Synth. Catal.*, 2023, **4**, 124–134.

5 (*a*) N. Miyaura and A. Suzuki, *Chem. Rev.*, 1995, **95**, 2457–2483; (*b*) C. Sandford and V. K. Aggarwal, *Chem. Commun.*, 2017, **53**, 5481–5494.

6 Y. Sasaki, Y. Horita, C. Zhong, M. Sawamura and H. Ito, *Angew. Chem., Int. Ed.*, 2011, **50**, 2778–2782.

7 F. Meng, F. Haeffner and A. H. Hoveyda, *J. Am. Chem. Soc.*, 2014, **136**, 11304–11307.

8 (*a*) X.-C. Gan and L. Yin, *Org. Lett.*, 2019, **21**, 931–936; (*b*) X. C. Gan, Q. Zhang, X.-S. Jia and L. Yin, *Org. Lett.*, 2018, **20**, 1070–1073; (*c*) for 1,2-borylacylation, see: X.-L. Liu, L. Li, H.-Z. Lin, J.-T. Deng, X.-Z. Zhang and J.-B. Peng, *Chem. Commun.*, 2022, **58**, 5968–5971.

9 S. Manna, Q. Dherbassy, G. J. P. Perry and D. J. Procter, *Angew. Chem., Int. Ed.*, 2020, **59**, 4879–4882.

10 W. S. Yoon, W. J. Jang, W. Yoon, H. Yun and J. Yun, *Nat. Commun.*, 2022, **13**, 2570.

11 Y. Liao, X. Yin, X. Wang, W. Yu, D. Fang, L. Hu, M. Wang and J. Liao, *Angew. Chem., Int. Ed.*, 2020, **59**, 1176–1180.

12 C. Yang, Z.-L. Liu, D.-T. Dai, Q. Li, W.-W. Ma, M. Zhao and Y.-H. Xu, *Org. Lett.*, 2020, **22**, 1360–1367.

13 For CuH catalyzed 1,2-hydrofunctionalizations, see: (*a*) Y. Yang, I. B. Perry, G. Lu, P. Liu and S. L. Buchwald, *Science*, 2016, **353**, 144–150; (*b*) Y. Zhou, L. Zhou, L. T. Jesikiewicz, P. Liu and S. L. Buchwald, *J. Am. Chem. Soc.*, 2020, **142**, 9908–9914.

14 For CuH catalyzed 1,4-hydrofunctionalizations, see: (*a*) L. Bayeh-Romero and S. L. Buchwald, *J. Am. Chem. Soc.*, 2019, **141**, 13788–13794; (*b*) S. Yu, H. L. Sang, S.-Q. Zhang, X. Hong and S. Ge, *Commun. Chem.*, 2018, **1**, 64; (*c*) for enantioselective Cu-catalyzed hydroboration of 1,3-enynes, see: Y. Huang, J. Pozo, S. Torker and A.-H. Hoveyda, *J. Am. Chem. Soc.*, 2018, **140**, 2643–2655; (*d*) H.-J. Sang, S. Yu and S. Ge, *Org. Chem. Front.*, 2018, **5**, 1284–1287; (*e*) D.-W. Gao, Y. Xiao, M. Liu, M.-K. Karunananda, J.-S. Chen and K.-M. Engle, *ACS Catal.*, 2018, **8**, 3650–3654.

15 (*a*) S. Maurya, N. Navaneetha, P. Behera, J. B. Nanubolu, L. Roy and R. Chegondi, *Angew. Chem., Int. Ed.*, 2025, **64**, e202420106; (*b*) N. Navaneetha, S. Maurya, P. Behera, S. B. Jadhav, L. R. Magham, J. B. Nanubolu, L. Roy and R. Chegondi, *Chem. Sci.*, 2024, **15**, 20379–20387; (*c*) V. B. Patil, S. B. Jadhav, J. B. Nanubolu and R. Chegondi, *Org. Lett.*, 2022, **24**, 8233–8238; (*d*) S. B. Jadhav, S. R. Dash, S. Maurya, J. B. Nanubolu, K. Vanka and R. Chegondi, *Nat. Commun.*, 2022, **13**, 854.

16 CCDC-2443592 (compound **2a**) and CCDC-2443593 (compound **2o**) contain the supplementary crystallographic data for this paper.

17 (*a*) H. Ito, Y. Kosaka, K. Nonoyama, Y. Sasaki and M. Sawamura, *Angew. Chem., Int. Ed.*, 2008, **47**, 7424–7427; (*b*) H. Ito, T. Toyoda and M. Sawamura, *J. Am. Chem. Soc.*, 2010, **132**, 5990–5992.