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Base-promoted [3 + 3] cyclization of cyclopropenones and cyclopropenethiones with amides for the synthesis of 6*H*-1,3-oxazin-6-ones and 6*H*-1,3-thiazin-6-ones†

Ben Niu,^a Bo Jiang,^b Liu-Zhu Yu^a and Min Shi^{ID} *^{a,b,c}Received 26th January 2018,
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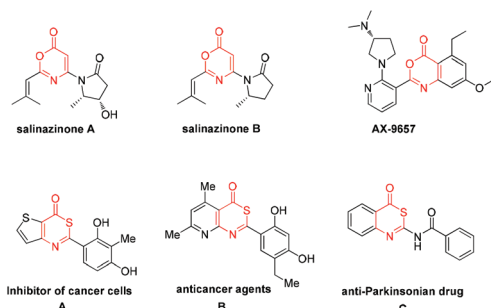
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A facile synthetic method to access 6*H*-1,3-oxazin-6-ones and 6*H*-1,3-thiazin-6-ones has been disclosed via a base-promoted [3 + 3] cyclization reaction of cyclopropenones and cyclopropenethiones with amides. These reactions exhibited excellent yields and good functional group tolerance under metal free and mild conditions.

6*H*-1,3-Oxazin-6-one frameworks have been recognized as important core structures that widely exist in medicinal agents, pharmaceuticals and biologically active molecules,¹ such as salinazinone A, salinazinone B and AX-9657, as shown in Scheme 1. Consequently, synthetic methods of 6*H*-1,3-oxazin-6-ones have garnered much attention over the past few years and various useful methods have been developed for the synthesis of 6*H*-1,3-oxazin-6-ones.² For example, in 2013,

Guan and co-workers achieved palladium-catalyzed oxidative carbonylation of enamides with equivalent Cu(OAc)₂ as an oxidant for the construction of 6*H*-1,3-oxazin-6-ones (Scheme 2, eqn (1)).^{2a} In 2015, Liu's group described a gold-catalyzed cycloaddition reaction of *tert*-butyl propiolates with nitriles (Scheme 2, eqn (2)).^{2b} More recently, Liu and co-



Scheme 1 Biologically active molecules containing 6*H*-1,3-oxazin-6-ones and 6*H*-1,3-thiazin-6-one.

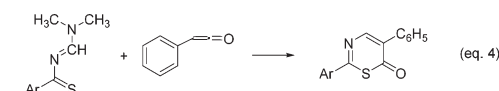
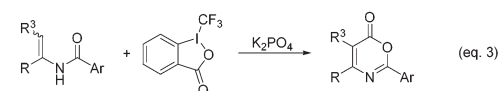
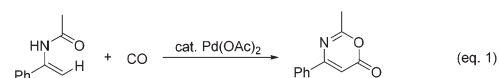
^aKey Laboratory for Advanced Materials and Institute of Fine Chemicals, School of Chemistry & Molecular Engineering, East China University of Science and Technology, Meilong Road No. 130, Shanghai, 200237, China

^bState Key Laboratory of Organometallic Chemistry, Center for Excellence in Molecular Synthesis, Shanghai Institute of Organic Chemistry, Chinese Academy of Sciences, 345 Lingling Road, Shanghai 200032, China. E-mail: mshi@mail.sioc.ac.cn

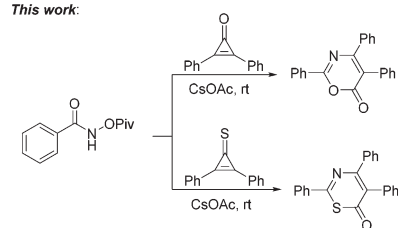
^cState Key Laboratory and Institute of Elemento-organic Chemistry, Nankai University, Tianjin 300071, P. R. China

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Previous work



This work:



Scheme 2 Previous work for the synthesis of 6*H*-1,3-oxazin-6-ones and 6*H*-1,3-thiazin-6-one.

Table 2, when R¹ is an aromatic ring and the leaving group is the OPiv anion, we first examined the electronic effect at the *para*-position of the aromatic ring. As for substrates **1b–1f**, regardless of whether an electron-donating or electron-withdrawing substituent was introduced, the reaction proceeded smoothly, giving the desired products **3b–3f** in good to excellent yields ranging from 65 to 98%. In the case of the *ortho*-substituted substrate (2-methyl) or disubstituted substrate (3,5-dimethyl), the reaction also performed very well, providing the corresponding products **3g** and **3h** in 65% and 89% yields, respectively. Afterwards, we screened a set of leaving groups such as OBz, OMe, OBoc and OFmoc when R¹ is a phenyl group. As can be seen from Table 2, all of them afforded the desired product **3d** in good yields. The heteroaryl-substituted amide **1i** was also compatible, affording the corresponding product **3i** in 65% yield. The structure of **3a** was determined by X-ray diffraction and its ORTEP drawing is shown in Table 2.⁸

To make this cyclization reaction even more integrated, next, R¹ was switched from an aryl group to an alkyl group and R² was changed to a phenoxy group. We found that these substrates were also well tolerated when R¹ is a methyl, an ethyl or an isopropyl group, furnishing the target products **3d**, **3j**, **3k** and **3l** in excellent yields varying from 91–92% regardless of the electronic nature of the phenoxy leaving group.

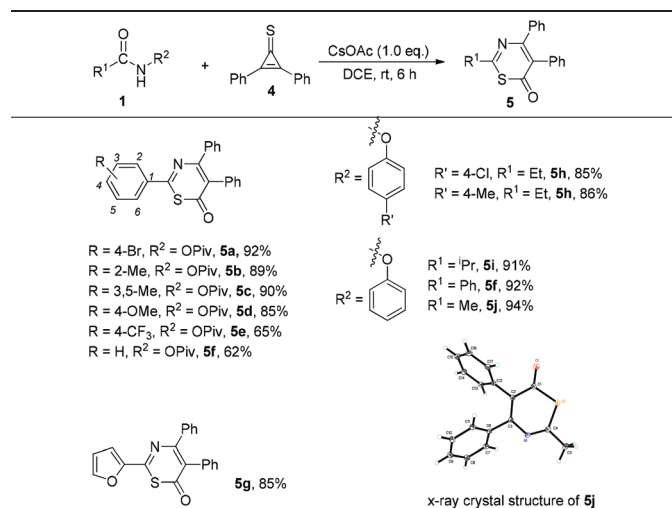
Encouraged by the above results, we next tried to replace the cyclopropenone with cyclopropenethione **4**. Initially, we commenced the investigation in the reaction of *N*-phenoxyacetamide **1j** (R¹ = Me, R² = OPh) with cyclopropenethione **4** under the optimal conditions. We found that 6*H*-1,3-thiazin-6-one **5j** was obtained in 94% yield and its structure was unambiguously determined by X-ray diffraction⁹ (Table 3). After that, we further explored the substrate scope of this cycloaddition reaction and the results are shown in Table 3. Firstly, when cyclopropenethione **4** was treated with various benza-

mides, the desired products **5a–5f** were obtained in 62–92% yields regardless of whether an electron-donating or electron-withdrawing substituent was introduced at different positions of the aromatic ring. The use of *N*-phenoxyacetamides **1h–1j** as substrates also gave the corresponding products **5h–5j** in good yields ranging from 85 to 92%. Heteroaryl-substituted amide was tolerated in this case, giving the desired product **5g** in 85% yield under the standard conditions.

The substrate scope of cyclopropenones was also explored, using two representative amides, 4-bromo-*N*-(pivaloyloxy)benzamide **1a** and *N*-phenoxyacetamide **1j** (R¹ = Me, R² = OPh), for this cyclization reaction. Upon treatment of 4-bromo-*N*-(pivaloyloxy)benzamide **1a** with 2-ethyl-3-phenylcyclopropenone **2b** at 60 °C under the standard conditions provided the desired product **6ab** in 71% yield. Its crystal structure has been determined by X-ray diffraction and the ORTEP drawing is shown in Table 4.¹⁰ On the other hand, the reaction of **1j** with **2b** proceeded smoothly at room temperature, affording the target product **6jb** in 75% yield. However, the reaction of **1j** with 2,3-dibutylcyclopropenone **2c** should be carried out at 60 °C, giving the desired product **6jc** in 51% yield, suggesting that the phenoxy group might be a better leaving group in this transformation. When R³ and R⁴ are different aryl groups, a cycloadduct mixture is formed under the standard conditions. All these results indicated a wide substrate scope in this base-promoted cyclization reaction.

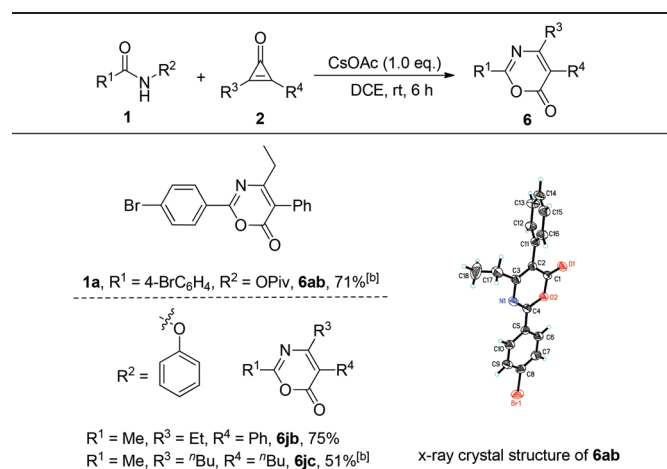
Based on the above results, a plausible mechanism has been outlined in Scheme 3. As for the synthesis of 6*H*-1,3-oxazin-6-ones (X = O), it is commonsense that the intermediate **A** is formed upon treatment of **1d** with CsOAc, which undergoes an isomerization to give the intermediate **B**. The reaction of the intermediate **B** with **2a** provides the intermediate **C**, which undergoes a ring-opening process to yield the intermediate **D**. Then, the desired product **3d** is formed through an intramolecular nucleophilic attack reaction along with the

Table 3 Reaction scope for the synthesis of thiazinones 5^a



^a Reaction conditions: **1** (0.2 mmol), **4** (0.2 mmol), CsOAc (1.0 equiv.), DCE (2.0 mL). NR = no reaction.

Table 4 Substrate scope for cyclopropenones^a



^a Reaction conditions: **1** (0.2 mmol), **4** (0.2 mmol), CsOAc (1.0 equiv.), DCE (2.0 mL). NR = no reaction. ^b T = 60 °C.



Scheme 3 A plausible reaction mechanism.

release of the OPiv anion. On the other hand, as for the synthesis of 6*H*-1,3-thiazin-6-one ($X = S$), we believe that the intermediate **E** undergoes a Newman–Kwart rearrangement¹¹ to produce a thermodynamically more stable product **5f**.

In summary, we have developed a novel and efficient synthetic protocol to easily access 6*H*-1,3-oxazin-6-ones and 6*H*-1,3-thiazin-6-ones *via* a base-promoted [3 + 3] cyclization reaction of cyclopropenones and cyclopropenethiones with amides. The reaction exhibits a wide substrate scope using easily available starting materials, excellent yields and good functional group tolerance under metal free and mild conditions. The potential utilization and extension of the scope of this new synthetic methodology are currently under investigation in our laboratory.

Conflicts of interest

There are no conflicts to declare.

Acknowledgements

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Notes and references

- (a) M. C. Kim, J. H. Lee, B. Shin, L. Subedi, J. W. Cha, J.-S. Park, D.-C. Oh, S. Y. Kim and H. C. Kwon, *Org. Lett.*, 2015, **17**, 5024; (b) P. Fu, S. La and J. B. MacMillan, *J. Nat. Prod.*, 2016, **79**, 455; (c) R. L. Jarvest, M. J. Parratt, C. M. Debouck, J. G. Gorniak, L. J. Jennings, H. T. Serafinowska and J. E. Strickler, *Bioorg. Med. Chem. Lett.*, 1996, **6**, 2463; (d) M. Gütschow and U. Neumann, *Bioorg. Med. Chem.*, 1997, **5**, 1935; (e) U. Neumann, N. M. Schechter and M. Gütschow, *Bioorg. Med. Chem.*, 2001, **9**, 947; (f) P. Kopelman, A. Bryson, R. Hickling, A. Rissanen, S. Rossner, S. Toubro and P. Valensi, *Int. J. Obes.*, 2007, **31**, 494; (g) Y. Yamada, T. Kato, H. Ogino, S. Ashina and K. Kato, *Horm. Metab. Res.*, 2008, **40**, 539; (h) R. Padwal, *Curr. Opin. Invest. Drugs*, 2008, **9**, 414.
- (a) M. Chen, Z.-H. Ren, Y.-Y. Wang and Z.-H. Guan, *Angew. Chem., Int. Ed.*, 2013, **52**, 14196; (b) S. N. Karad, W.-K. Chung and R.-S. Liu, *Chem. Sci.*, 2015, **6**, 5964; (c) P. Song, P. Yu, J.-S. Lin, Y. Q. Li, N.-Y. Yang and X.-Y. Liu, *Org. Lett.*, 2017, **19**, 1330; (d) C. Zhang, S. Li, F. Bureš, R. Lee, X. Ye and Z. Jiang, *ACS Catal.*, 2016, **6**, 6853; (e) X. F. Wu, J. Schranck, H. Neumann and M. Beller, *Chem. – Eur. J.*, 2011, **17**, 12246; (f) Q. Liu, P. Chen and G. Liu, *ACS Catal.*, 2013, **3**, 178; (g) W. Li and X. F. Wu, *J. Org. Chem.*, 2014, **79**, 10410; (h) S. Munusamy, S. Venkatesan and K. I. Sathiyarayanan, *Tetrahedron Lett.*, 2015, **56**, 203; (i) J. Yu, D. Zhang-Negrerie and Y. Du, *Eur. J. Org. Chem.*, 2016, 562; (j) A. Verma and S. Kumar, *Org. Lett.*, 2016, **18**, 4388; (k) D. L. Boger and R. J. Wysocki, *J. Org. Chem.*, 1989, **54**, 714; (l) K. Liu, M. Z. Zou and A. W. Lei, *J. Org. Chem.*, 2016, **81**, 7088.
- (a) J. Matysiak, M. Juszczak, M. M. Karpińska, E. Langner, K. Walczak, M. K. Lemieszek, A. Skrzypek, A. Niewiadomy and W. Rzeski, *Mol. Diversity*, 2015, **19**, 725; (b) A. Stöfel, M. Schlenk, S. Hinz, P. Küppers, J. Heer, M. Gütschow and C. E. Müller, *J. Med. Chem.*, 2013, **56**, 4580; (c) C. Landreau, D. Deniaud, F. Reliquet, A. Reliquet and J. C. Meslin, *Heterocycles*, 2000, **53**, 2667; (d) A. Niewiadomy, J. Matysiak and M. M. Karpińska, *Arch. Pharm. Chem. Life Sci.*, 2011, **11**, 224; (e) C. B. Vicentine, S. Guccione, L. Giurato, R. Ciaccio, D. Mares and G. Forlani, *J. Agric. Food Chem.*, 2005, **53**, 3848.
- (a) J. C. Meslin and H. Quiniou, *Tetrahedron*, 1975, **31**, 3055; (b) C. Landreau, D. Deniaud, F. Reliquet, A. Reliquet and J. C. Meslin, *Heterocycles*, 2000, **53**, 2667; (c) H. Sheibania, M. H. Mosslemin, S. Behzadi, M. R. Islami, H. Foroughi and K. Saidi, *ARKIVOC*, 2005, 88–96; (d) H.-G. Häcker, F. Grundmann, F. Lohr, P. A. Ottersbach, J. Zhou, G. Schnakenburg and M. Gütschow, *Molecules*, 2009, **14**, 378; (e) S. Leistner, M. Gütschow and G. Wagner, *Synthesis*, 1986, 466; (f) J. W. Lown and K. Matsumo, *Can. J. Chem.*, 1972, **50**, 584.
- (a) I. Nakamura, B.-H. Oh, S. Saito and Y. Yamamoto, *Angew. Chem., Int. Ed.*, 2001, **40**, 1298; (b) J. P. Markham, S. T. Staben and F. D. Toste, *J. Am. Chem. Soc.*, 2005, **127**, 9708; (c) M. Murakami, N. Ishida and T. Miura, *Chem. Commun.*, 2006, 643; (d) G. Bhargava, B. Trillo, M. Araya, F. López, L. Castedo and J. L. Mascareñas, *Chem. Commun.*, 2010, **46**, 270; (e) B. Yao, Y. Li, Z. Liang and Y. Zhang, *Org. Lett.*, 2011, **13**, 640; (f) S. Li, Y. Luo and J. Wu, *Org. Lett.*, 2011, **13**, 3190; (g) L.-Z. Yu, K. Chen, Z.-Z. Zhu and M. Shi, *Chem. Commun.*, 2017, **53**, 5935; (h) C. L. Ladd and A. B. Charette, *Org. Lett.*, 2016, **18**, 6046.

- 6 (a) K. T. Potts and J. S. Baum, *Chem. Rev.*, 1974, **74**, 189; (b) K. Komatsu and T. Kitagawa, *Chem. Rev.*, 2003, **103**, 1371; (c) D. K. Nielsen and A. G. Doyle, *Angew. Chem., Int. Ed.*, 2011, **50**, 6056; (d) Y.-L. Yang, Z. Zhang, X.-N. Zhang, D. Wang, Y. Wei and M. Shi, *Chem. Commun.*, 2014, **50**, 115; (e) A. Brandi, S. Cicchi, F. M. Cordero and A. Goti, *Chem. Rev.*, 2014, **114**, 7317; (f) Y. Liang, L. Jiao, Y. Wang, Y. Chen, L. Ma, J. Xu, S. Zhang and Z.-X. Yu, *Org. Lett.*, 2006, **8**, 5877.
- 7 (a) P. A. Wender, T. J. Paxton and T. J. Williams, *J. Am. Chem. Soc.*, 2006, **128**, 14814; (b) P. A. O'Gorman, T. Chen, H. E. Cross, S. Naeem, A. Pitard, M. I. Qamar and K. Hemming, *Tetrahedron Lett.*, 2008, **49**, 6316; (c) Y.-L. Yang, Z. Zhang, X.-N. Zhang, D. Wang, Y. Wei and M. Shi, *Chem. Commun.*, 2014, **50**, 115.
- 8 The crystal data of **3a** have been deposited at CCDC with the number 1535814.†
- 9 The crystal data of **5j** have been deposited at CCDC with the number 1045751.†
- 10 The crystal data of **6ab** have been deposited at CCDC with the number 1576769.†
- 11 (a) G. C. Lloyd-Jones, J. D. Moseley and J. S. Renny, *Synthesis*, 2008, 661; (b) H. Kwart and E. R. Evans, *J. Org. Chem.*, 1966, **31**, 410; (c) M. S. Newman and H. A. Karnes, *J. Org. Chem.*, 1966, **31**, 3980.