

K₂S as Sulfur Source and DMSO as Carbon Source for the Synthesis of 2-Unsubstituted Benzothiazoles

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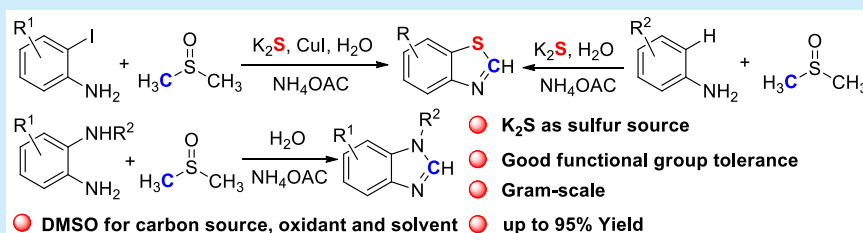
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ABSTRACT: We describe a three-component reaction of *o*-iodoanilines with K₂S and DMSO that provides 2-unsubstituted benzothiazoles in moderate to good isolated yields with good functional group tolerance. Electron-rich aromatic amines and *o*-phenylenediamines instead of *o*-iodoanilines provided 2-unsubstituted benzothiazoles and 2-unsubstituted benzimidazoles with and without K₂S under similar conditions. Notably, DMSO plays three vital roles: carbon source, solvent, and oxidant.

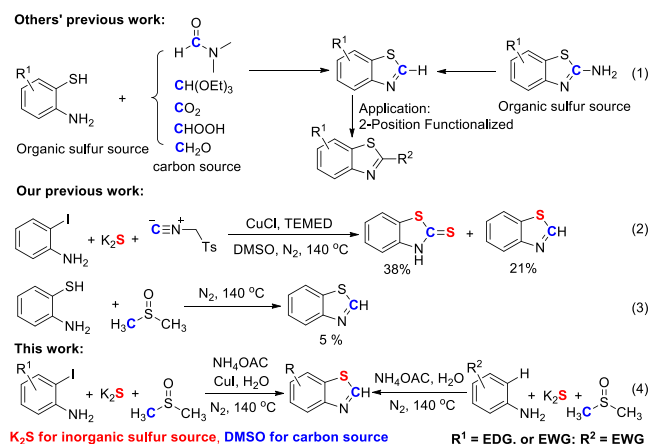
The 2-unsubstituted benzothiazoles are vital core structures for functional molecules applied in biology, pharmacy, and material science.¹ They are also very important precursors for synthesizing 2-substituted benzothiazoles via C2–H functionalization.² Accordingly, considerable efforts have been made toward the development of diverse synthetic methods for 2-unsubstituted benzothiazoles.^{3,4} Traditionally, synthetic strategies for 2-substituted benzothiazoles involved the condensation of *o*-aminobenzenethiols with suitable carbon sources such as DMF,^{3a–c} CH(OEt)₃,^{3d–f} CO₂,^{3g–i} CHOOH,^{3j,k} and CH₂O^{3l,m} and the deamination reaction of the 2-aminobenzothiazoles (Scheme 1, eq 1).⁴ However, their application is limited by instability and easy oxidation of *o*-

aminobenzenethiols as well as poor availability of starting materials and harsh reaction conditions. Recently, an efficient strategy involving inorganic sulfurating reagents was employed to assemble sulfur-containing heterocycles, particularly 2-substituted benzothiazoles.^{5,6} However, using easily available inorganic sulfurating reagents as sulfur source for a simple and effective method for the synthesis of 2-unsubstituted benzothiazoles has not been described.

During this synthesis of thiobenzothiazoles, a small amount of benzothiazole formation was observed (Scheme 1, eqs 2 and 3).⁷ Based on this unexpected finding and our interest in synthesis of sulfur-containing heterocycles using inorganic sulfurating reagents,^{7,8} we studied the synthesis of 2-unsubstituted benzothiazoles from *o*-iodoanilines, K₂S, and DMSO (Scheme 1, eq 4).

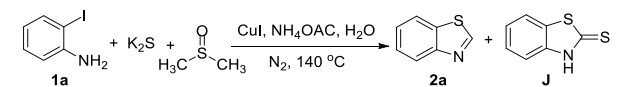
The initial evaluation of the reaction used *o*-iodoaniline (1a), K₂S, and DMSO to optimize the reaction conditions, and the results are summarized in Table 1. The desired benzothiazole product 2a could be obtained in 83% yield using CuI, H₂O, and NH₄OAc at 140 °C under nitrogen atmosphere (entry 1). Some control experiments were carried out to investigate the role of each component in the reaction. The results showed that CuI, NH₄OAc, and K₂S were indispensable for this reaction (entries 2–4), and a small

Scheme 1. Synthesis of 2-Unsubstituted Benzothiazoles



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Table 1. Optimization of the Reaction Conditions^a


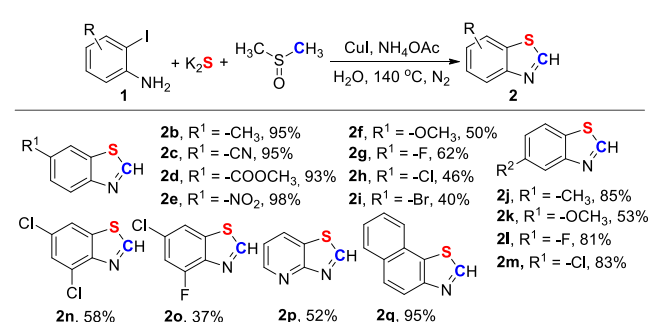
entry	variation from the standard conditions	yield of 2a (%)	yield of 2ae (%)
1	none	83	0
2	without CuI	trace	0
3	without NH ₄ OAc	trace	29
4	without K ₂ S	0	0
5	without H ₂ O	44	0
6	K ₂ CO ₃ instead of K ₂ S	0	0
7	NMP instead of DMSO	0	0
8	KOAc instead of NH ₄ OAc	16	25
9	NH ₄ OOCH instead of NH ₄ OAc	72	0
10	NH ₄ I instead of NH ₄ OAc	0	0
11	HOAc (6.equiv) instead of NH ₄ OAc	0	0
12	NH ₃ ·H ₂ O (6 equiv) instead of NH ₄ OAc and H ₂ O	12	0
13	KOH (2 equiv)	60	0
14	HOAc (2 equiv)	44	0
15 ^b	none	32	0
16 ^c	none	trace	0
17 ^d	none	82	0

^aReaction conditions: **1a** (0.2 mmol), K₂S (3 equiv), CuI (20 mol %), NH₄OAc (6 equiv), H₂O (80 μL), and DMSO (2 mL) in a sealed Schlenk tube at 140 °C for 10 h under N₂ atmosphere; isolated yields. ^bAir. ^cO₂. ^d**1a** (5 mmol).

amount of water could promote the reaction (entry 5). Product **2a** could not be obtained when the reaction was conducted using K₂CO₃ instead of K₂S (entry 6) and NMP instead of DMSO (entry 7). These results indicated that K₂S and DMSO served as the sulfur source and carbon source, respectively. The yield of **2a** did not improve when KOAc, NH₄OOCH, NH₄I, or HOAc was used in place of NH₄OAc and NH₃·H₂O instead of NH₄OAc and H₂O (entries 8–12). These results implied that NH₄OAc played an important role in this reaction. When KOH (2 equiv) or HOAc (2 equiv) was added, the yield of **2a** was reduced to 60% and 44%, respectively (entries 13 and 14). These results showed the effect of acid on the reaction was greater than base. Conducting the reaction under air atmosphere or in the presence of oxygen did not improve the yield. However, **2a** was formed in 82% yield when done on a 5 mmol scale (entry 17, see the Supporting Information (SI) for details).

With the optimal reaction conditions in hand, the substrate scope of *o*-iodoanilines (**1**) was next investigated (Scheme 2). The *o*-iodoanilines (**1b–1i**) with various functional groups were successfully applied to react with K₂S and DMSO, and the corresponding products were obtained in moderate to good yields (**2b–2i**). The efficiency of the three-component reaction was not affected by the electronic properties of the substituents. For example, the electron-rich groups such as methyl and electron-deficient groups such as ester-, cyano-, and nitril-substituted benzothiazoles were obtained in excellent yields (**2b–2e**). However, the electron-donating groups such as methoxyl as well as electron-withdrawing groups such as fluorine-, chlorine-, and bromine-substituted benzothiazoles led to only moderate yields (**2f–2i**). This might be due to the instability of these groups.

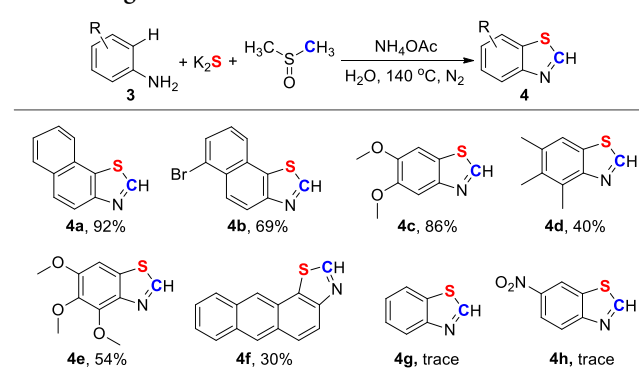
Substituents at different positions of the aromatic ring of *o*-iodoaniline were also investigated. These results indicated that

Scheme 2. Synthesis of 2-Unsubstituted Benzothiazoles from *o*-Iodoanilines^a

^aReaction conditions: **1** (0.2 mmol), K₂S (3 equiv), CuI (20 mol %), NH₄OAc (6 equiv), H₂O (80 μL), and DMSO (2 mL) in a sealed Schlenk tube at 140 °C for 10 h under N₂ atmosphere.

the electron-donating groups such as -CH₃ and -OCH₃ at the 4- and 5-positions of *o*-iodoaniline showed the same reactivity (**2b**, **2f**, **2j**, **2k**), whereas the response efficiency of electron-withdrawing groups such as fluorine and chlorine at 5-position of *o*-iodoaniline (**1l**, **1m**) was higher than that at the 4-position of *o*-iodoaniline (**1g**, **1h**). Notably, the disubstituted *o*-iodoanilines (**1n**, **1o**) could give the corresponding products in moderate yields (**2n**, **2o**). Gratifyingly, 3-iodopyridin-2-amine and 1-iodonaphthalen-2-amine could be smoothly transformed into the desired products in 52% and 95% yields, respectively.

In our preliminary work, 2-substituted benzothiazoles and 2-substituted naphtho[2,1-*d*]thiazoles compounds could be synthesized by breaking the C(sp²)-H bond of electron-rich aromatic amines.^{8b} An ideal strategy would prepare the 2-unsubstituted benzothiazoles via halogen-free aromatic amines instead of *o*-iodoanilines. To our delight, when the electron-rich aromatic amines (0.3 mmol) were treated with K₂S (3 equiv), NH₄OAc (4 equiv), H₂O (80 μL), and DMSO (2 mL) under transition-metal-free conditions, the corresponding 2-unsubstituted benzothiazoles and 2-unsubstituted naphtho[2,1-*d*]thiazoles products **4** were obtained in 30–92% yields (Scheme 3). Under these conditions, the naphtho[2,1-*d*]thiazole and 6-bromonaphtho[1,2-*d*]thiazole were afforded in 92% and 69% yields (**4a**, **4b**), respectively. Subsequently, the electron-rich anilines were examined. The results showed that

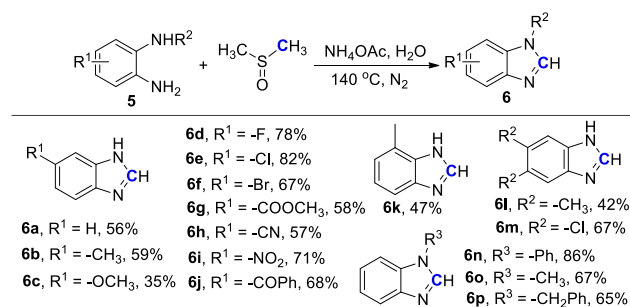
Scheme 3. Synthesis of 2-Unsubstituted Benzothiazoles from Halogen-Free Electron-Rich Aromatic Amines^a

^aReaction conditions **3** (0.3 mmol), K₂S (3 equiv), NH₄OAc (4 equiv), H₂O (80 μL), and DMSO (2 mL) in a sealed Schlenk tube at 140 °C for 10 h under N₂ atmosphere.

electron-donating groups such as methyl- and methoxy-substituted anilines could smoothly transform into the corresponding products in medium to good yields (**4c–4e**). Furthermore, when 2-aminoanthracene was employed as a substrate, the polycyclic anthra[2,1-*d*]thiazole **4f** was obtained in moderate yield. Unfortunately, the other anilines without electron-rich substituents such as aniline and *p*-nitroaniline were unsuccessful (**3g**, **3h**).

The 2-unsubstituted benzimidazoles are useful intermediates in fine chemicals¹⁰ and privileged scaffolds in medicinal chemistry.¹¹ Accordingly, we were curious about the possibility of applying this method to the synthesis of 2-unsubstituted benzimidazoles. Our further study indicated that the corresponding product **6** was obtained in 35–86% yields (Scheme 4) when the *o*-phenylenediamines (0.2 mmol) were

Scheme 4. Synthesis of 2-Unsubstituted Benzimidazoles from *o*-Phenylenediamines^a

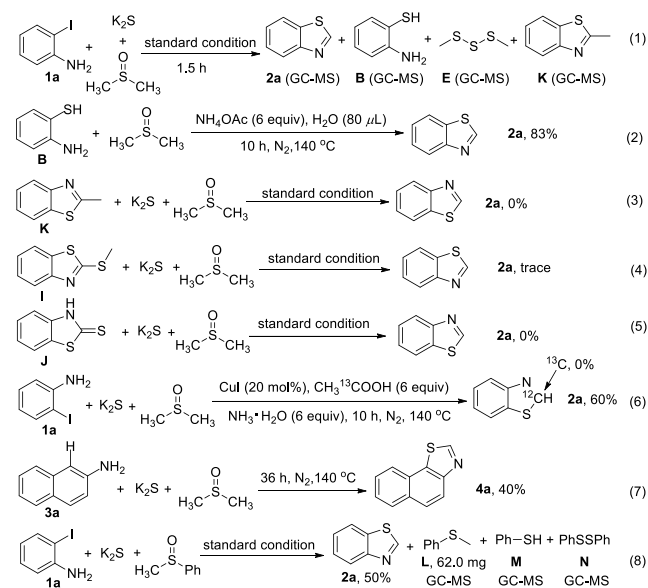


^aReaction conditions: **5** (0.2 mmol), NH_4OAc (6 equiv), H_2O (80 μL), and DMSO (2 mL) in a sealed Schlenk tube at $140\text{ }^\circ\text{C}$ for 10 h under N_2 atmosphere.

treated with NH_4OAc (6 equiv), H_2O (80 μL), and DMSO (2 mL). Fortunately, an array of substituents such as $-\text{CH}_3$, $-\text{OCH}_3$, $-\text{F}$, $-\text{Cl}$, $-\text{Br}$, $-\text{COOCH}_3$, $-\text{CN}$, $-\text{NO}_2$, and $-\text{COPh}$ on the phenyl ring at *o*-phenylenediamine were well tolerated, and the corresponding products were afforded in moderate to good yields (**6b–6k**). In addition, the disubstituted *o*-phenylenediamines could smoothly transform into the target products in moderate yields (**6l** and **6m**). Importantly, the *N*-substituted-benzene-1,2-diamines, such as *N*-methylbenzene-1,2-diamine, *N*-benzylbenzene-1,2-diamine, and *N*-phenylbenzene-1,2-diamine, were also competent substrates; the corresponding *N*-substituted-2-unsubstituted benzimidazoles were obtained in moderate to good yields (**6n–6p**).

Some control experiments were performed to investigate the possible reaction mechanism (Scheme 5). The benzothiazole (**2a**), *o*-aminobenzenethiol (**B**), dimethyl trisulfide (**E**), and a small amount of 2-methylbenzothiazole (**K**) could be detected from the reaction mixture by GC–MS analysis when *o*-iodoaniline (**1a**) was reacted with K_2S and DMSO for 1.5 h (eq 1, see the SI). Subsequently, the benzothiazole (**2a**) could be synthesized from *o*-aminobenzenethiol (**B**) in the absence of CuI and K_2S (eq 2), but the 2-(methylthio)benzo[*d*]thiazole (**k**) could not be reacted with K_2S and DMSO under standard conditions (eq 3). The results showed that *o*-aminobenzenethiol (**B**) may be the intermediate of the reaction and CuI only worked in the early stages of the reaction. The 2-mercaptobenzothiazole (**J**) could be obtained in 29% and 25% yields in the absence of NH_4OAc (Table 1, entries 3 and 8)—here, 2-(methylthio)benzo[*d*]thiazole (**I**)

Scheme 5. Controlled Experiments

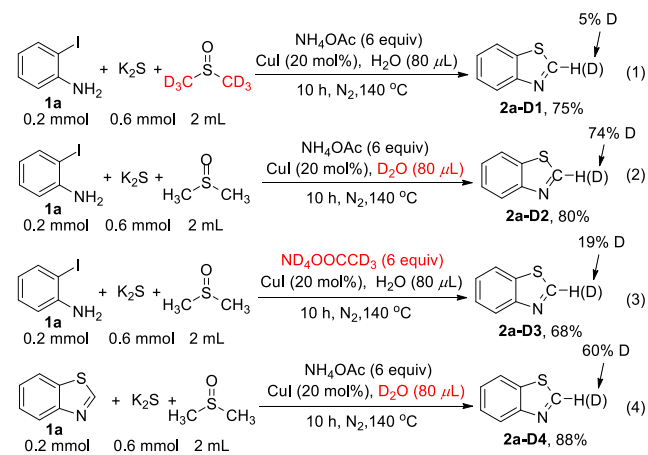


(eq 4) and 2-mercaptobenzothiazole (**J**) (eq 5) are possible intermediates, respectively. Product **2a** was not obtained. These results indicated that the reaction underwent different mechanisms from our previous report^{7b} perhaps because of the acid–base effect of NH_4OAc .

We subsequently performed a ^{13}C labeling experiment with $\text{CH}_3^{13}\text{COOH}$, and **2a** was not marked by ^{13}C (eq 6). In addition, the naphtho[2,1-*d*]thiazole **4a** could be isolated in 40% yield in the absence of NH_4OAc (eq 7). This result showed that the carbon source was derived from DMSO. Furthermore, we used methyl phenyl sulfoxide instead of DMSO, and benzothiazole (**2a**) and methyl(phenyl)sulfide (**L**) could be isolated in 50% yield and 62.0 mg weight along with benzenethiol (**M**) and diphenyl disulfide (**N**) by GC–MS (eq 8, see the SI). These results indicated that DMSO is concurrently the carbon source and oxidant.

To our surprise, when DMSO was replaced by DMSO-*d*₆ in the standard reaction, only 5% of deuterium labeling product **2a-D1** was obtained (Scheme 6, eq 1). To further verify the reaction process and the hydrogen source of **2a**, we performed several deuterium-labeling experiments (Scheme 6, eqs 2–4). When D_2O or $\text{ND}_4\text{OOCDC}_3$ was used, 74% and 19% of the

Scheme 6. Deuterium Labeling Experiments



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REFERENCES

- (1) (a) Mortimer, C. G.; Wells, G.; Crochard, J.-P.; Stone, E. L.; Bradshaw, T. D.; Stevens, M. F. G.; Westwell, A. D. *J. Med. Chem.* **2006**, *49*, 179. (b) Serdons, K.; Terwinghe, C.; Vermaelen, P.; Laere, K. V.; Kung, H.; Mortelmans, L.; Bormans, G.; Verbruggen, A. *J. Med. Chem.* **2009**, *52*, 1428. (c) Hrobáriková, V.; Hrobárik, P.; Gajdoš, P.; Fitolis, I.; Fakis, M.; Persephonis, P.; Zahradník, P. *J. Org. Chem.* **2010**, *75*, 3053. (d) Chakraborty, M.; Jin, K. J.; Glover, S. A.; Novak, M. *J. Org. Chem.* **2010**, *75*, 5296. (e) Sun, Q.; Wu, R.; Cai, S.; Lin, Y.; Sellers, L.; Sakamoto, K.; He, B.; Peterson, B. R. *J. Med. Chem.* **2011**, *54*, 1126. (f) Facchinetti, V.; Reis, R. R.; Gomes, C. R. B.; Vasconcelos, T. R. A. *Mini-Rev. Org. Chem.* **2012**, *9*, 44. (g) Noël, S.; Cadet, S.; Gras, E.; Hureau, C. *Chem. Soc. Rev.* **2013**, *42*, 7747.
- (2) For reviews, see: (a) Dai, X.; Zhu, Y.; Wang, Z.; Weng, J. *Youji Huaxue* **2017**, *37*, 1924. (b) Hassan, J.; Sévignon, M.; Gozzi, C.; Schulz, E.; Lemaire, M. *Chem. Rev.* **2002**, *102*, 1359. For selected examples, see: (c) Luo, K.; Chen, Y.-Z.; Yang, W.-C.; Zhu, J.; Wu, L. *Org. Lett.* **2016**, *18*, 452. (d) Zhu, F.; Tao, J.-L.; Wang, Z.-X. *Org. Lett.* **2015**, *17*, 4926. (e) Chen, X.; Cui, X.; Yang, F.; Wu, Y. *Org. Lett.* **2015**, *17*, 1445. (f) Feng, C.-G.; Ye, M.; Xiao, K.-J.; Li, S.; Yu, J.-Q. *J. Am. Chem. Soc.* **2013**, *135*, 9322. (g) Wang, G.-W.; Zhou, A.-X.; Wang, J.-J.; Hu, R.-B.; Yang, S.-D. *Org. Lett.* **2013**, *15*, 5270. (h) Xie, Z.; Cai, Y.; Hu, H.; Lin, C.; Jiang, J.; Chen, Z.; Wang, L.; Pan, Y. *Org. Lett.* **2013**, *15*, 4600. (i) Wang, Z.; Li, K.; Zhao, D.; Lan, J.; You, J. *Angew. Chem., Int. Ed.* **2011**, *50*, 5365. (j) Hachiya, H.; Hirano, K.; Satoh, T.; Miura, M. *Org. Lett.* **2009**, *11*, 1737.
- (3) (a) Davis, C. S.; Knevel, A. M.; Jenkins, G. L. *J. Org. Chem.* **1962**, *27*, 1919. (b) Nale, D. B.; Bhanage, B. M. *Synlett* **2015**, *26*, 2835. (c) Liu, Z.; Gao, X.; Yu, B.; Mei, Q.; Yang, Z.; Zhao, Y.; Zhang, H.; Hao, L. *New J. Chem.* **2016**, *40*, 8282. (d) Mohammadpoor-Baltork, I.; Khosropour, A. R.; Hojati, S. F. *Catal. Commun.* **2007**, *8*, 1865. (e) Liu, J.; Liu, Q.; Xu, W.; Wang, W. *Chin. J. Chem.* **2011**, *29*, 1739. (f) Haghighat, M.; Golshekan, M.; Shirini, F. *ChemistrySelect* **2019**, *4*, 7968. (g) Gao, X.; Yu, B.; Yang, Z.; Zhao, Y.; Zhang, H.; Hao, L.; Han, B.; Liu, Z. *ACS Catal.* **2015**, *5*, 6648. (h) Song, J.; Zhou, B.; Liu, H.; Xie, C.; Meng, Q.; Zhang, Z.; Han, B. *Green Chem.* **2016**, *18*, 3956. (i) Ke, Z.; Yu, B.; Wang, H.; Xiang, J.; Han, J.; Wu, Y.; Liu, Z.; Yang, P.; Liu, Z. *Green Chem.* **2019**, *21*, 1695. (j) Ojeda-Porras, A.; Hernández-Santana, A.; Gamba-Sánchez, D. *Green Chem.* **2015**, *17*, 3157. (k) Sharma, S.; Bhattacharjee, D.; Das, P. *Org. Biomol. Chem.* **2018**, *16*, 1337. (l) Samanta, S.; Das, S.; Biswas, P. *J. Org. Chem.* **2013**, *78*, 11184. (m) Wade, A. R.; Pawar, H. R.; Biware, M. V.; Chikate, R. C. *Green Chem.* **2015**, *17*, 3879.
- (4) (a) Grundmann, C.; Kreutzberger, A. *J. Am. Chem. Soc.* **1955**, *77*, 6559. (b) Röder, L.; Nicholls, A. J.; Baxendale, I. R. *Molecules* **2019**, *24*, 1996. (c) Felipe-Blanco, D.; Alonso, F.; Gonzalez-Gomez, J. C. *Adv. Synth. Catal.* **2017**, *359*, 2857.
- (5) For reviews, see: (a) Liu, H.; Jiang, H. *Chem. - Asian J.* **2013**, *8*, 2546. (b) Zhu, N.; Zhang, Z.; Gao, M.; Han, L.; Suo, Q. *Youji Huaxue* **2013**, *33*, 1423. (c) Prajapati, N. P.; Vekariya, R. H.; Borad, M. A.; Patel, H. D. *RSC Adv.* **2014**, *4*, 60176. (d) Nguyen, T. B. *Adv. Synth. Catal.* **2017**, *359*, 1066.
- (6) (a) Pham, P. H.; Nguyen, K. X.; Pham, H. T. B.; Nguyen, T. T.; Phan, N. T. S. *Org. Lett.* **2019**, *21*, 8795. (b) Dey, A.; Hajra, A. *Org. Lett.* **2019**, *21*, 1686. (c) Jiang, J.; Li, G.; Zhang, F.; Xie, H.; Deng, G.-J. *Adv. Synth. Catal.* **2018**, *360*, 1622. (d) Tan, W.; Wang, C.; Jiang, X. *Org. Chem. Front.* **2018**, *5*, 2390. (e) Huang, H.; Xu, Z.; Ji, X.; Li, B.; Deng, G.-J. *Org. Lett.* **2018**, *20*, 4917. (f) Che, X.; Jiang, J.; Xiao, F.; Huang, H.; Deng, G.-J. *Org. Lett.* **2017**, *19*, 4576. (g) Xue, W.-J.; Guo, Y.-Q.; Gao, F.-F.; Li, H.-Z.; Wu, A.-X. *Org. Lett.* **2013**, *15*, 890. (h) Nguyen, T. B.; Ermolenko, L.; Al-Mourabit, A. *Org. Lett.* **2013**, *15*, 4218. (i) Ma, D.; Lu, X.; Shi, L.; Zhang, H.; Jiang, Y.; Liu, X. *Angew. Chem., Int. Ed.* **2011**, *50*, 1118. (j) Zhu, J.; Chen, Z.; Xie, H.; Li, S.; Wu, Y. *Org. Lett.* **2010**, *12*, 2434. (k) Ma, D.; Xie, S.; Xue, P.; Zhang, X.; Dong, J.; Jiang, Y. *Angew. Chem.* **2009**, *121*, 4286.
- (7) (a) Dang, P.; Zeng, W.; Liang, Y. *Org. Lett.* **2015**, *17*, 34. (b) Zhu, X.; Li, W.; Luo, X.; Deng, G.; Liang, Y.; Liu, J. *Green Chem.* **2018**, *20*, 1970.
- (8) (a) Chen, L.; Min, H.; Zeng, W.; Zhu, X.; Liang, Y.; Deng, G.; Yang, Y. *Org. Lett.* **2018**, *20*, 7392. (b) Zhu, X.; Yang, Y.; Xiao, G.; Song, J.; Liang, Y.; Deng, G. *Chem. Commun.* **2017**, *53*, 11917. (c) Dang, P.; Zheng, Z.; Liang, Y. *J. Org. Chem.* **2017**, *82*, 2263. (d) Liu, W.; Min, H.; Zhu, X.; Deng, G.; Liang, Y. *Org. Biomol. Chem.* **2017**, *15*, 9804. (e) Zhang, X.; Zeng, W.; Yang, Y.; Huang, H.; Liang, Y. *Org. Lett.* **2014**, *16*, 876.
- (9) For reviews of DMSO providing carbon source: (a) Tashrfi, Z.; Khanaposhtani, M. M.; Larijanic, B.; Mahdavic, M. *Adv. Synth. Catal.* **2020**, *362*, 65. (b) Wu, X.-F.; Natte, K. *Adv. Synth. Catal.* **2016**, *358*, 336. (c) Jones-Mensah, E.; Karki, M.; Magolan, J. *Synthesis* **2016**, *48*, 1421.
- (10) (a) van Dijk, T.; Bakker, M. S.; Holtrop, F.; Nieger, M.; Slootweg, J. C.; Lammertsma, K. *Org. Lett.* **2015**, *17*, 1461. (b) Lewis, J. C.; Berman, A. M.; Bergman, R. G.; Ellman, J. A. *J. Am. Chem. Soc.* **2008**, *130*, 2493. (c) Shao, X.; Zheng, Y.; Tian, L.; Martín-Torres, I.; Echavarren, A. M.; Wang, Y. *Org. Lett.* **2019**, *21*, 9262. (d) Diness, F.; Fairlie, D. P. *Angew. Chem., Int. Ed.* **2012**, *51*, 8012.
- (11) For reviews, see: (a) Horton, D. A.; Bourne, G. T.; Smythe, M. L. *Chem. Rev.* **2003**, *103*, 893. (b) Wexler, R. R.; Greenlee, W. J.; Irvin, J. D.; Goldberg, M. R.; Prendergast, K.; Smith, R. D.; Timmermans, P. B. M. W. M. *J. Med. Chem.* **1996**, *39*, 625.
- (12) (a) Fei, H.; Yu, J.; Jiang, Y.; Guo, H.; Cheng, J. *Org. Biomol. Chem.* **2013**, *11*, 7092. (b) Jiang, X.; Wang, C.; Wei, Y.; Xue, D.; Liu, Z.; Xiao, J. *Chem. - Eur. J.* **2014**, *20*, 58. (c) Kumari, S.; Abdul Shakoor, S. M.; Markad, D.; Mandal, S. K.; Sakhuja, R. *Eur. J. Org. Chem.* **2019**, *2019*, 705. (d) Wu, X.; Zhang, J.; Liu, S.; Gao, Q.; Wu, A. *Adv. Synth. Catal.* **2016**, *358*, 218. (e) Wang, J.; Rochon, F. D.; Yang, Y.; Hua, L.; Kayser, M. M. *Tetrahedron: Asymmetry* **2007**, *18*, 1115. (f) Liu, Y.-F.; Ji, P.-Y.; Xu, J.-W.; Hu, Y.-Q.; Liu, Q.; Luo, W.-P.; Guo, C.-C. *J. Org. Chem.* **2017**, *82*, 7159. (g) Mashkina, A. V.; Khairulina, L. N. *Russ. J. Org. Chem.* **2018**, *54*, 1794. (h) Traynelis, V. J.; Hergenrother, W. L. *J. Org. Chem.* **1964**, *29*, 221. (i) Pan, X.; Liu, Q.; Chang, L.; Yuan, G. *RSC Adv.* **2015**, *5*, 51183.