Chemodivergent synthesis of \(N\)-(pyridin-2-yl) amides and 3-bromoimidazo[1,2-a]pyridines from \(\alpha\)-bromoketones and 2-aminopyridines†

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\(N\)-(pyridin-2-yl)amides and 3-bromoimidazo[1,2-a]pyridines were synthesized respectively from \(\alpha\)-bromoketones and 2-aminopyridine under different reaction conditions. \(N\)-(pyridin-2-yl)amides were formed in toluene via C–C bond cleavage promoted by I\(_2\) and TBHP and the reaction conditions were mild and metal-free. Whereas 3-bromoimidazopyridines were obtained in ethyl acetate via one-pot tandem cyclization/bromination when only TBHP was added, the cyclization to form imidazopyridines was promoted by the further bromination, no base was needed, and the versatile 3-bromoimidazopyridines could be further transferred to other skeletons.

Introduction

Aminopyridines serve as pharmacophores for many molecules with significant biological and therapeutic value. Particularly, \(N\)-(pyridin-2-yl)amides and imidazo[1,2-a]pyridines have received great attention in recent years due to their varied medicinal applications. Some examples of pharmaceutical molecules containing \(N\)-(pyridin-2-yl)amides and imidazo[1,2-a]pyridines are shown in Fig. 1. Owing to the attractive biological properties of \(N\)-(pyridin-2-yl)amides and imidazo[1,2-a]pyridines, developing convenient synthetic methods, especially by which we can synthesize these two kinds of structures respectively from the same starting materials, is very meaningful.

Amides are ubiquitous in organic compounds, polymers, natural products, and pharmaceuticals. Synthesis of amides is one of the most executed reactions in organic chemistry. Pre-activated acyl halides or anhydrides are used as starting materials in traditional methods for constructing amide bond. Recently, many alternative substrates, such as aldehydes, alcohols, azides, aldoximes, nitriles and halides compounds had been employed for amide synthesis. C–C bond cleavage is another developing approach to synthesize amides, but the excellent stability of C–C bond makes this subject develop slowly, exploring new methods for constructing amides directly by C–C bond cleavage is attractive. \(N\)-(pyridin-2-yl)amide was previously synthesized via a Cu-catalyzed dehydrogenative reaction between aldehyde and aminopyridine in the presence of I\(_2\) (Scheme 1a). Adimurthy’s group synthesized \(N\)-(pyridin-2-yl)amides via oxidative amidation of methylenures using TBHP in decane. Recently, two elegant works on Cu-catalyzed aerobic oxidative C–C bond cleavage for the preparation of \(N\)-(pyridin-2-yl)amide had been developed. Hwang et al. reported a visible-light-promoted aerobic oxidative C–N coupling between 2-aminopyridine and terminal alkynes through C=C triple bond cleavage (Scheme 1b). Kaliappan disclosed a biomimetic oxidation of methyl ketones for preparation of \(N\)-heterocyclic amides (Scheme 1c). However, these methodologies suffer from several drawbacks, such as harsh reaction conditions, long reaction time and the use of transition metal complexes. Recently, we reported a metal-free method for synthesizing \(N\)-(pyridine-2-yl)amides from ketones via oxidative cleavage of C–C bond.
bond in water.\textsuperscript{11} Herein, we will continue to report the selective synthesis of N-(pyridine-2-yl)amides from α-bromoketones and 2-aminopyridine via controlling reaction conditions.

Intensive researches have been conducted to develop new and efficient strategies for constructing imidazo[1,2-a]pyridines.\textsuperscript{12} Halo-substituted imidazo[1,2-a]pyridines are important building blocks and versatile synthons for preparing more complex imidazopyridines.\textsuperscript{13} Classically, halo-substituted imidazo[1,2-a]pyridines are synthesized by the halogenation of imidazo[1,2-a]pyridines, such as Adimurthy’s report.\textsuperscript{14} For the synthesis of the intermediate imidazo[1,2-a]pyridines, base is generally needed.\textsuperscript{15} While methods for direct synthesis of halo-substituted imidazo[1,2-a]pyridines in one-pot reaction without base were rarely reported. Jiang and co-workers reported a copper-catalyzed method for the synthesis of 2-halo-substituted imidazopyridines from haloalkynes and aminopyridines (Scheme 1d). 3-Iodoimidazopyridines were synthesized by Zhao and co-workers in the presence of copper supported on manganese oxide-based octahedral molecular sieves OMS-2 (CuOx/OMS-2) via tandem cyclization/iodination (Scheme 1e).\textsuperscript{17} Yan and Huang’s group reported copper bromide-mediated aerobic oxidative synthesis of 3-bromoimidazo[1,2-a]pyridines with pyridines and enamides (Scheme 1f).\textsuperscript{18} Besides, metal-free tandem chlorocyclization of 2-aminopyridines with carboxylic acids to synthesize chloro-substituted imidazopyridines was also described by Zeng’s group.\textsuperscript{19} However, these transformations over-relied on metal catalysts or stoichiometric excess of halogen sources. From the viewpoint of green chemistry, developing an atom-economical and metal-free approach to construct halo-substituted imidazo[1,2-a]pyridine is highly desirable.

Given the importance of N-(pyridin-2-yl)amides and imidazo[1,2-a]pyridines, chemodivergent synthesis of these two skeletons from same starting materials is very appealing. Herein, we developed a method to synthesize N-(pyridin-2-yl)amides and imidazo[1,2-a]pyridines respectively from α-bromoketones and 2-aminopyridine by controlling reaction conditions (Scheme 1).

**Results and discussion**

Traditionally, C–C bonds cleavage has been accomplished in the presence of transition-metal catalyst.\textsuperscript{20} Initially, various metal catalysts were screened for the preparation of amide 3aa from α-bromoacetophenone 1a and 2-aminopyridine 2a using 70% aqueous tert-butyl hydroperoxide (TBHP) as oxidant in toluene, but the yield of 3aa was not pleasurable and the highest yield was only 17% in the presence of CuI (Table 1, entry 1).

Surprisingly, after extensive screening, the desired amide 3aa was obtained solely with yields of 83% and 79% respectively when I2 or KI were used as the catalyst (Table 1, entries 4, 5). This transformation was sensitive to the types of the solvents and oxidants (Table 1, entries 6–8). Finally, the optimized reaction conditions for the synthesis of amides were obtained as follows: TBHP (4 equivalents) and iodine (20 mol%) in toluene at 100 °C for 2 hours (protocol A, Table 1, entry 9).

Surprisingly, the 3-bromoimidazopyridine 4aa was isolated with good yield when just using TBHP as oxidant in toluene (Table 1, entry 12). To further improve the yield of 4aa, several solvents were screened, and the results showed that ethyl acetate was the most effective solvent for the preparation of 4aa (Table 1, entry 14). Other oxidants such as H2O2 and oxygen (balloon) were also evaluated, however, the results were not pleasurable (entries 15–16). After extensive screening, 4aa was successfully obtained in yield of 93% using 2 equivalents of TBHP as oxidant in ethyl acetate at 90 °C for 3 hours (protocol B, Table 1, entry 17).

With the optimized reaction conditions in hand, first, the scope of the oxidative amidation approach was examined with a range of α-bromoketones and aminopyridines. As shown in
Table 1  Optimization of the reaction conditions

| Entry | Solvent | Oxidant (4 eq.) | Catalyst (20 mol%) | Temp (°C) | t (h) | 3aa | 4aa |
|-------|---------|----------------|-------------------|-----------|------|-----|-----|
| 1     | Toluene | TBHP           | CuI               | 120       | 36   | 17  | 11  |
| 2     | Toluene | TBHP           | CuBr              | 120       | 36   | 3   | 73  |
| 3     | Toluene | TBHP           | ZnBr₂             | 120       | 36   | —   | 5%  |
| 4     | Toluene | TBHP           | I₂                | 120       | 2    | 83  | Trace |
| 5     | Toluene | TBHP           | KI                | 120       | 2    | 79  | Trace |
| 6     | DMF     | TBHP           | I₂                | 120       | 2    | Trace | 41  |
| 7     | H₂O     | TBHP           | I₂                | 100       | 12   | 49  | 3   |
| 8     | Toluene | H₂O₂           | I₂                | 120       | 2    | —   | 28  |
| 9     | Toluene | TBHP           | I₂                | 100       | 2    | 84  | Trace |
| 10    | Toluene | —              | I₂                | 120       | 2    | —   | —   |
| 11    | Toluene | —              | I₂                | 120       | 2    | —   | —   |
| 12    | Toluene | TBHP           | —                 | 120       | 3    | 2   | 83  |
| 13    | H₂O     | TBHP           | —                 | 100       | 8    | 11  | —   |
| 14    | Ethyl acetate | TBHP | — | 80 | 3 | Trace | 83 |
| 15    | Ethyl acetate | H₂O₂ | — | 80 | 5 | — | 36 |
| 16    | Ethyl acetate | O₂ (balloon) | — | 80 | 3 | — | — |
| 17    | Ethyl acetate | TBHP (2 eq.) | — | 90 | 3 | Trace | 93 |

* Reaction conditions: 1a (0.3 mmol), 2a (0.45 mmol), oxidant (1.2 mmol), catalyst (0.06 mmol), solvent (2 mL). b 70% TBHP in water and 30% H₂O₂ in water were used. c Isolated yields.

Scheme 2, both the electron-rich (–Me, –OMe) and electron-withdrawing (–CF₃) groups on α-haloketones were well tolerated and produced the corresponding amides in good yields. Halo-substituted α-bromoketones can also afford desired amides in moderate to good yields (3ca, 3da, 3ka, 3la). The steric factor has a slight effect on this transformation, as the meta-substituted α-bromoketones gave their corresponding products in moderate yields (3ga, 3ha). Besides, heterocycle- and alkyl-substituted α-haloketones were also tested and gave corresponding amides in 70–87% yields (3ma, 3na). Subsequently, the substrate scope of various 2-aminopyridines was investigated and the results showed that most of the substituted 2-aminopyridines could be transferred to their corresponding products in moderate to good yields.

Then, we evaluated various α-bromoketones 1 to examine the generality and limitations of the reaction for the synthesis of 3-homboimidazopyridines, and the results were summarized in Scheme 3. Substrates with electron-withdrawing groups (–CF₃), electron-donating groups (–Me, –OMe) or halogen groups (–F, –Cl, –Br) on the para position of aromatic ring could be transferred to the corresponding products in good to excellent yields (4ba–4ga). Furthermore, substituents at the meta or ortho positions could also provide the corresponding products with good yields (4ha–4na). Disubstituted or trisubstituted α-bromoacetophenones were all tolerated well (4ha, 4oa). The product 4pa bearing heteroaryl moiety was also obtained in 97% yield. Some alkyl-substituted α-bromoketones, like bromoacetone and ethyl bromopyruvate, could afford the desired products in good (4qa) or moderate (4ra) yield respectively. Next, we investigated the suitability of 2-aminopyridines and their heteroaromatic analogues. The results showed that 2-aminopyridines with substituents at the C-3, C-4, C-5 position reacted smoothly to give their products in moderate yields (4ab–4af, 4ag). This reaction is highly sensitive to the presence of a substituent at the C-6 position of pyridine ring attributed to steric hindrance (4ae). Besides, other ortho-amine-nitrogen-containing heteroaromatic derivatives were also investigated, and the results demonstrated that isoquinolin-1-amine was tolerated in this cascade transformation and could be transferred to products with good to excellent yields, while pyrimidin-2-amine (4ai) and 2-aminothiazole (4aj) were not well suited for this reaction.

3-Iodimidazo[1,2-a]pyridine could also be prepared using this methodology in moderate yield (Scheme 4a). Moreover, the synthetic utility of 3-bromoimidazo[1,2-a]pyridines were explored, C3-arylation and alkylation reactions processed smoothly through a classical Pd-catalyzed cross-coupling strategy (Schemes 4b and c). Overall, this simple, metal-free protocol could be extended as an efficient and practical method to construct more complex C-3-substituted imidazopyridines.

To understand the mechanism of this tandem reaction, control experiments were carried out (Scheme 5). 5aa was isolated in both reactions (Scheme 5, 1). In protocol A, the reaction was suppressed remarkably when 2 equivalents of TEMPO, a radical...
trapping reagent, was added into the reaction system, indicating
that the reaction might proceed via a free radical process
(Scheme 5, 1). We speculated that 5aa was the key intermediate
for these two reactions. Thus, some control experiments based on
5aa were conducted. 4aa was obtained in 42% yield when 5aa
was subjected to HBr (1 equivalent) and TBHP (2 equivalents)
(Scheme 5, 4) and 5aa reacted with Br2 could also form 4aa in
88% yield (Scheme 5, 5), these results showed that the bromine
was formed during the synthesis of 3-bromoimidazo[1,2-a]pyridines.
Furthermore, when 1-cyclohexen-1-ylbenzene was added
to consume the in situ generated bromine, no desired 3-bromo-2-
phenylimidazo[1,2-a]pyridine was observed (Scheme 5, 6). On the
other hand, the amide product 3aa could be obtained from 5aa in
I2/TBHP system (Scheme 5, 2) or only TBHP for longer time
(Scheme 5, 3). Besides, no amide product (3aa) was obtained
from 3-bromo-imidazopyridine (4aa) or 3-iodimidazopyridine
(4sa), which illustrated that 4aa could not be further transferred
to 3aa. These results collectively indicated that there was a fierce
competition between amidation and bromination, the iodine
played an extremely important role in this C–C bond cleavage
reaction.22 As shown in Scheme 6, the reaction proceeded via
the initial displacement of the halogen atom by the pyridine
ring nitrogen to afford pyridinium salt (8), which subjected
a facile closure and provided the shared intermediate 5aa. In
protocol A, t-BuO’, which was generated in I2/TBHP system,23
attacked the double bond of 5aa to afford 9, 9 subsequently
transferred to 11. Then, oxygen radical 12 was formed under t-

Based on the above results and previous knowledge, we
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BuO’, 12 further transformed to 13 by C–C bond cleavage.10,20ae,22e Next, a tert-butyl formate was released from 13 leading to the formation of amide 14,25 which proceed an isomerization to afford the desired amide 3aa. In protocol B, the released hydrogen bromide was converted into bromine by oxidation of TBHP. The bromination of 5aa yielded the target molecule 4aa and the released hydrogen bromide could be oxidized to bromine and used for bromination again.

**Conclusions**

In conclusion, we have developed a divergent synthesis of pyridyl-amides and imidazopyridines from simple α-bromoketones and 2-aminopyridine. Various N-(pyridin-2-yl) amides or 3-bromo-imidazopyridines were obtained in moderate to good yields with high selectivity by tuning the catalyst. The one-pot tandem cyclization/bromination of α-bromoketones with 2-aminopyridine in the presence of TBHP provided versatile 3-bromo-imidazopyridines with excellent functional group tolerance and scalability. The α-haloalkette acted as both the substrate and the bromo source, and the avoidance of transition-metal, fewer synthetic steps and high atom-economy make this protocol attractive. Whereas, the addition of I₂ promote the oxidative C–C bond cleavage amiation afforded N-(pyridin-2-yl)amides in a metal-free condition. Less activity demonstrated by other metal catalysts suggested that I₂ played a vital role in this reaction. C–C bond cleavage amiation is still a difficult and significant subject especially in modification and semisynthesis of natural medicine, which can simplify the synthetic procedure and make the semisynthesis more available. Iodine as a catalyst in C–C bond cleavage amiation is rarely reported. We believe our work will be useful for completing the C–C bond cleavage amiation field.

**Conflicts of interest**

There are no conflicts to declare.

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