## ChemComm





View Article Online View Journal | View Issue



Cite this: Chem. Commun., 2016, 52, 6549

Received 8th March 2016, Accepted 12th April 2016

DOI: 10.1039/c6cc02063a

www.rsc.org/chemcomm

Catalytic transformation of esters of 1,2-azido alcohols into  $\alpha$ -amido ketones<sup>†</sup>

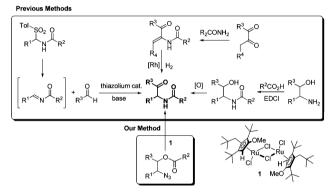
Yongjin Kim, Han Kyu Pak, Young Ho Rhee\* and Jaiwook Park\*

The esters of 1,2-azido alcohols were transformed into  $\alpha$ -amido ketones without external oxidants through the Ru-catalyzed formation of N-H imines with the liberation of N<sub>2</sub> followed by intramolecular migration of the acyl moiety. A wide range of  $\alpha$ -amido ketones were obtained, and one-pot transformation into the corresponding oxazoles (or a thiazole) was demonstrated.

 $\alpha$ -Amido ketones are biologically relevant molecules and useful building blocks for valuable compounds in organic synthesis.<sup>1</sup> In addition, they are useful substrates in various organic transformations such as the Robinson–Gabriel reaction to oxazoles<sup>2</sup> and thiazoles,<sup>2e</sup> the Norrish–Yang photocyclization to 2-aminocyclobutanols,<sup>3</sup> the epoxy-annulation reaction to epoxide-fused heterocycles<sup>4</sup> and the reaction with ammonium acetate (or primary amines) to imidazoles.<sup>5</sup>

For the versatile transformations,  $\alpha$ -amido ketones have been synthesized by various methods, including Pd-catalyzed coupling reaction of methylene aziridines with carboxylic acids,<sup>6</sup> Rh-catalyzed denitrogenative hydration of *N*-sulfonyl-1,2,3-triazoles,<sup>7</sup> the Dakin–West reaction of  $\alpha$ -amino acids with acid anhydrides,<sup>8</sup> the Neber rearrangement of ketoxime sulfonates<sup>9</sup> and a radical cascade reaction of alkynes with *N*-fluoroarylsulfonimides and alcohols.<sup>10</sup> However these methods suffer from the difficulty in preparing substrates, harsh reaction conditions, and/or limitations of the substrate scope.

Additional and noticeable methods are compared with our new finding in Scheme 1. The aza-benzoin condensation reaction of aldehydes with *N*-acyl imines is an interesting method using thiazolium organocatalysts.<sup>5c,11</sup> However, the synthesis of tosylamides from tosylsulfinic acid, amides, and aldehydes is required to generate the intermediate *N*-acyl imines, and is not effective for enolizable aldehydes.<sup>12</sup> The asymmetric hydrogenation of  $\alpha$ -dehydroamido ketones can provide optically active  $\alpha$ -amido ketones,<sup>13</sup> but the scope is limited by the intrinsic

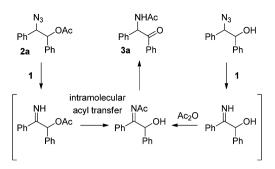


Scheme 1 Synthetic methods for  $\alpha$ -amido ketones.

regioselectivity problem in the condensation reaction of 1,2-diketones and primary amides. An old method employing 1,2-amino alcohols as the starting substrates looks simple but suffers practically from inefficiency in the *N*-acylation and the subsequent oxidation.<sup>5c,14</sup> A carboxyl-activating agent and an oxidant are required in a stoichiometric amount in the acylation and the oxidation, respectively. Meanwhile, 1,2-amino alcohols are frequently prepared from 1,2-azido alcohols by the Staudinger reaction using triphenylphosphine as a reductant. Herein we wish to report an efficient synthesis of  $\alpha$ -amido ketones from 1,2-azido alcohols without oxidation and reduction steps through a novel one-step catalytic transformation of 1,2-azido esters under neutral and mild conditions.

Recently we found an interesting Ru-catalyzed transformation of alkyl azides to N–H imines.<sup>15</sup> As an application of the catalytic transformation, we have developed an efficient method for the synthesis of enamides from alkyl azides and acyl donors utilizing the *N*-acylation of intermediate N–H imines.<sup>16</sup> In a related study on the *N*-acylation of N–H imines containing a hydroxyl group, we observed the unexpected formation of  $\alpha$ -amido ketones in the catalytic reactions of 1,2-azido alcohols. For example, *N*-(2-oxo-1,2-diphenylethyl)acetamide (**3a**) was obtained in 55% yield by the reaction of 2-azido-1,2-diphenylethanol with acetic anhydride in the presence of the ruthenium catalyst **1** (Scheme 2). Then we envisioned

Department of Chemistry, POSTECH (Pohang University of Science and Technology), Pohang 790-784, Korea. E-mail: pjw@postech.ac.kr; Web: http://oml.postech.ac.kr † Electronic supplementary information (ESI) available. See DOI: 10.1039/c6cc02063a



Scheme 2 Formation of  $\alpha$ -amido ketone **3a** from 1,2-azido acetate **2a** or from the corresponding 1,2-azido alcohol.

that its intramolecular version would improve the efficiency of the transformation. We examined the transformation of 2-azido-1,2-diphenylethyl acetate (2a) under various conditions (Table 1). The transformation was more efficient in polar solvents than in non-polar ones such as THF and toluene (entries 1 and 2). In dimethylformamide (DMF), 3a was formed in 89% yield (entry 3). Noticeably, the transformation was effective in ionic liquids,<sup>17</sup> which have some advantages such as being experimentally safe and recycled. In particular 3a was formed in almost quantitative vield in 1-butyl-3-methylimidazolium chloride ([bmim]Cl) (entry 4). A gram-scale reaction was also effective to give 3a in 91% isolated yield (entry 5), and recycling of [bmim]Cl was possible simply by removing water from the aqueous phase by heating after the workup procedure (entry 6).<sup>18</sup> Decreasing the reaction temperature to 50 °C significantly lowered the yield of 3a (entry 7), while increasing it to 100 °C was not beneficial (entry 8). As in the synthesis of enamides involving N-acylation of N-H imines,<sup>16</sup> a catalytic amount of triethylamine was helpful for the formation of 3a (entry 9).17

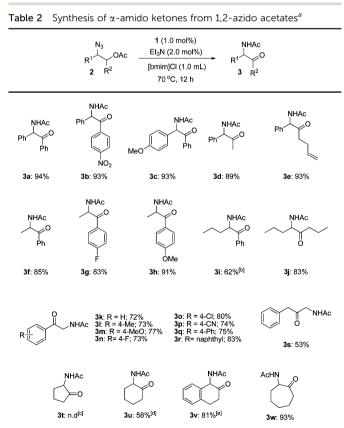
The transformation to  $\alpha$ -amido ketones was applicable for a broad range of acetates of 1,2-azido alcohols (Table 2). The electronic effect of the substituents of aromatic rings was not so

Table 1	Transformation of <b>2a</b> to <b>3a</b> under various conditions <sup>a</sup>			
	N₃ Ph → OAc - Ph <b>2a</b>	<b>1</b> (1.0 mol solvent Additive (2.0 Temperate	mol%) Ph	
Entry	Solvent	Additive	Temp. (°C)	Yield <sup>b</sup> (%)
1	THF	Et <sub>3</sub> N	70	15
2	Toluene	$Et_3N$	70	28
3	DMF	$Et_3N$	70	89
4	[bmim]Cl	Et <sub>3</sub> N	70	96 $(94)^c$
5	[bmim]Cl	Et <sub>3</sub> N	70	91 <sup>c,d</sup>
6	[bmim]Cl	Et <sub>3</sub> N	70	90 <sup>e</sup>
7	[bmim]Cl	Et <sub>3</sub> N	50	15
8	[bmim]Cl	Et <sub>3</sub> N	100	91
9	[bmim]Cl	None	70	85

<sup>*a*</sup> Typical reaction conditions: a solution of an azide (0.25 mmol), **1** (1.0 mol%) and Et<sub>3</sub>N (2.0 mol%) in a solvent (1.0 mL) was stirred for 12 h. <sup>*b*</sup> Estimated by <sup>1</sup>H NMR using nitromethane as an internal standard. <sup>*c*</sup> Isolated yield. <sup>*d*</sup> A large scale reaction employing 1.06 g (3.6 mmol) of **2a** and 15 mg (0.5 mol%) of **1** in 6.0 mL of [bmim]Cl at 70 °C for 36 h. <sup>*e*</sup> The yield of the reaction using [bmim]Cl recovered from the 5th recycling reaction.

significant (3a-3c and 3g-3h). The yields of  $\alpha$ -amido ketones were high in the transformation of the derivatives having alkyl groups (3d-3j). The low yield of 3i was due to the formation of unidentified side-products, and the use of DMF as a solvent gave 3i in 62% yield. The transformation of esters of primary  $\beta$ -hydroxy azides to  $\alpha$ -amido ketones (3k-3r) was also successful despite the fact that the intermediates are unstable N-H aldimines. The transformation was effective for various derivatives containing functional groups on aromatic rings such as methyl, methoxy, halides and nitrile substituents. The yield of the  $\alpha$ -amido ketone (3s), which has a benzyl moiety, was moderate with the formation of unidentified side products. The transformation of cyclic substrates (3t-3w) was less efficient than that of linear ones, probably due to the rigidity of ring structures. A six-membered cyclic  $\alpha$ -amido ketone (3u) was obtained in moderate yield, while a five-membered one (3t) was not formed. However, interestingly, a seven-membered cyclic one (3w) was obtained in high yield, and a benzofused six-membered bicyclic one (3v) was formed in a much higher yield than the monocyclic one (3u).

Then, the scope of  $\alpha$ -amido ketones was explored for the derivatives having various *N*-acyl groups (Table 3). R<sup>3</sup> in the  $\alpha$ -amido ketones 5 could be varied not only to an ethyl (5a), isopropyl (5b), or a *tert*-butyl (5c) group but also to a conjugated alkenyl (5d), chloromethyl (5e), or an ester (5f) group. The derivatives containing phenyl (5g), furyl (5h), and thiofuryl (5i)



<sup>*a*</sup> Standard reaction conditions: a solution of an azide 2 (0.25 mmol), 1 (1.0 mol%) and Et<sub>3</sub>N (2.0 mol%) in [bmim]Cl (1.0 mL) was stirred for 12 h. <sup>*b*</sup> Reaction was carried out in DMF. <sup>*c*</sup> Not detected. <sup>*d*</sup> Reaction was carried out for 24 h. <sup>*e*</sup> Reaction was carried out for 36 h.

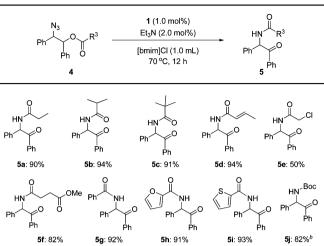


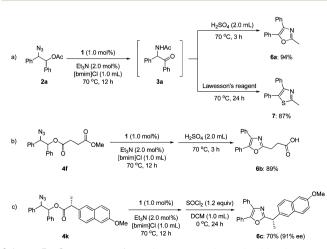
Table 3 Synthesis of  $\alpha\text{-amido}$  ketones from various esters of 1,2-azido alcohols^a

<sup>*a*</sup> Standard reaction conditions: a solution of an azide 4 (0.25 mmol), 1 (1.0 mol%) and  $Et_3N$  (2.0 mol%) in [bmim]Cl (1.0 mL) was stirred for 12 h. <sup>*b*</sup> Reaction was carried out in DMF for 36 h at 100 °C.

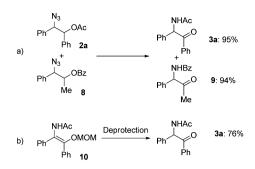
groups were also obtained in high yields. The migration of the butyloxycarbonyl (Boc) group was possible, although heating at a higher temperature for a longer reaction time was required to give an *N*-Boc protected derivative (**5j**) in good yield.

To demonstrate the utility of our synthesis of  $\alpha$ -amido ketones, we carried out one-pot transformations to oxazoles (**6a–c**) and a thiazole (7) (Scheme 3). Treatment of **3a** *in situ* generated from **2a** with sulfuric acid afforded oxazole **6a** in 94% yield. The corresponding thiazole (7) was obtained by the treatment with Lawesson's reagent in 87% yield. Noticeably, oxaprozin (**6b**), which is a well-known non-steroidal anti-inflammatory drug,<sup>19</sup> was obtained directly from **4f** in 89% yield. The stereo-chemistry of **4k** at the  $\alpha$ -position was practically maintained during the one-pot transformation to **6c**,<sup>20</sup> although the intermediate  $\alpha$ -amido ketone was formed as a 1:1 diastereomeric mixture.

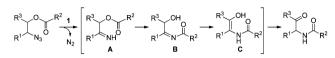
To obtain mechanistic insights into the transformation of 1,2-azido esters to  $\alpha$ -amido ketones, a crossover experiment and the generation of an enol amide were examined: only non-crossover



Scheme 3 One-pot transformations to oxazoles and a thiazole.



Scheme 4 Mechanistic investigation.



Scheme 5 Plausible pathway for the formation of α-amido ketones.

products (**3a** and **9**) were formed in high yields in the transformation of a mixture of the 1,2-azido acetate **2a** and another azide (**8**) containing a benzoyl group (Scheme 4a), and the  $\alpha$ -amido ketone **3a** was obtained in 76% yield in the deprotection reaction of a MOM-protected enol amide (**10**) (Scheme 4b).<sup>21</sup>

Now we can propose a plausible pathway for the transformation of the esters of 1,2-azido alcohols into  $\alpha$ -amido ketones (Scheme 5). On the basis of our previous reports on the formation of enamides from *N*-acyl imines,<sup>16</sup> the results of the crossover experiment support intramolecular migration of the acyl group in the intermediate N–H imine **A** to give the  $\alpha$ -hydroxyl *N*-acylimine **B**. And the result of the deprotection reaction of **10** is indicative of the intermediacy of the enol amide **C**, which is tautomerized to the final  $\alpha$ -amido ketone product.

In summary, we developed a new and simple method for the synthesis of  $\alpha$ -amido ketones from the esters of 1,2-azido alcohols just by the liberation of molecular nitrogen under mild conditions. Our method is effective for the synthesis of a wide range of multi-substituted  $\alpha$ -amido ketones, and efficient for gram scale synthesis in recyclable ionic liquids. In addition, we demonstrated the one-pot synthesis of oxazoles and a thiazole using  $\alpha$ -amido ketones as intermediates.

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP) (2015R1A2A2A01008130).

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