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Facile synthesis of unknown 6,7-dihydrofuro[3,4-*c*]pyridines and 3,4-diaryloylpyridines from *N*-homopropargylic β-enaminones†

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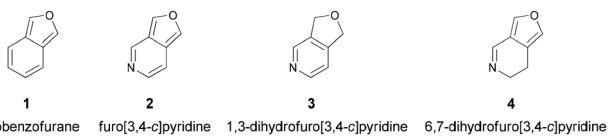
In this paper, we have uncovered a new reaction of *N*-homopropargylic β-enaminones, *i.e.* *N*-(4-phenyl-3-butynyl)-β-enaminones. When subjected to a reaction with excess molecular iodine or *N*-iodosuccinimide in the presence of cesium carbonate, *N*-homopropargylic β-enaminones afford 6,7-dihydrofuro[3,4-*c*]pyridines in low to moderate yields. The generation of two new C/O–C bonds during the reaction leads to the construction of unknown heterobicyclic 5,6-fused ring systems. In some reactions, 3,4-diaryloylpyridines are also observed in low yields. During the formation of 3,4-diaryloylpyridines, a new carbonyl (ketone) group is generated. The synthesized 6,7-dihydrofuro[3,4-*c*]pyridines and 3,4-diaryloylpyridines may be of use in pharmaceutical and medicinal chemistry as new and novel molecular entities and structural leads.

Introduction

Isobenzofurans (**1**) are recognized as an interesting class of reactive intermediates in organic synthesis since they generally behave as reactive dienes and participate in Diels–Alder reactions, leading to the formation of a variety of polycyclic ring systems including natural products of biological importance (Scheme 1).[1] On the other hand, heteroanalogues of isobenzofurans have received much less attention.[2] For instance, the parent furo[3,4-*c*]pyridine (**2**) was reported in 1977 as a white crystalline solid that is stable only at low temperature and undergoes fast polymerization around room temperature (Scheme 1).[3] Although not isolated, substituted furo[3,4-*c*]pyridines (**2**) have also been identified as reactive intermediates/dienes, similar to isobenzofurans (**1**), in the synthesis of hetero-polyaromatic compounds by tandem Hamaguchi–Ibata[4] and Diels–Alder reactions.[5] More recently, the Sarkar research group used their reactivity to prepare conformationally restricted analogues of nicotine and anabasine *via* intramolecular Diels–Alder reactions.[6] Notably, the utility of heteroisobenzofurans as potential building blocks for the construction of polycyclic heteroaromatics is critically dependent on their availability. So far, furo[3,4-*c*]pyridines have been synthesized by (i) retro-Diels–Alder reactions of 1,4-epoxides *via* flash vacuum thermolysis (FVT) (Scheme 2a),[3] (ii) lithiation and subsequent *o*-silylation of pyridine-phthalides (Scheme 2b),[7] and (iii) the Hamaguchi–Ibata reaction[4] of *o*-aminodiazocarbonyl precursors (Scheme 2c).[6,8] Sometimes, dihydro derivatives hold greater importance in terms of their biological activity and material properties as compared to their parent compounds. 1,3-Dihydrofuro[3,4-*c*]pyridines (**3**) are known (Scheme 1)[9,10] and they are commonly synthesized by the metal-catalyzed [2 + 2 + 2] cycloaddition between dipropargyl ethers and nitriles (Scheme 2d).[10] In contrast, to the best of our knowledge, 6,7-dihydrofuro[3,4-*c*]pyridines (**4**) are not known (Scheme 1). Therefore, the potential value of 6,7-dihydrofuro[3,4-*c*]pyridines, particularly in medicinal chemistry and materials science, is not known. Obviously, the development of new methodologies for the synthesis of these compounds may increase their significance in related fields.

Pyridines are one of the most studied families of heterocyclic compounds due to their widespread presence in the



Scheme 1 Structures of isobenzofuran, furo[3,4-c]pyridine, 1,3-dihydrofuro[3,4-c]pyridine and 6,7-dihydrofuro[3,4-c]pyridine.

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†Electronic supplementary information (ESI) available: Experimental procedures, spectroscopic data and copies of NMR spectra for starting materials and products (PDF). CCDC 2379026 (**10a**). For ESI and crystallographic data in CIF or other electronic format see DOI: https://doi.org/10.1039/d4ob01884b

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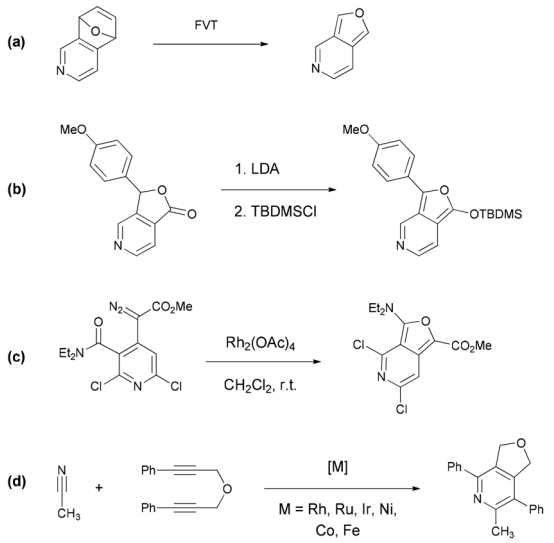
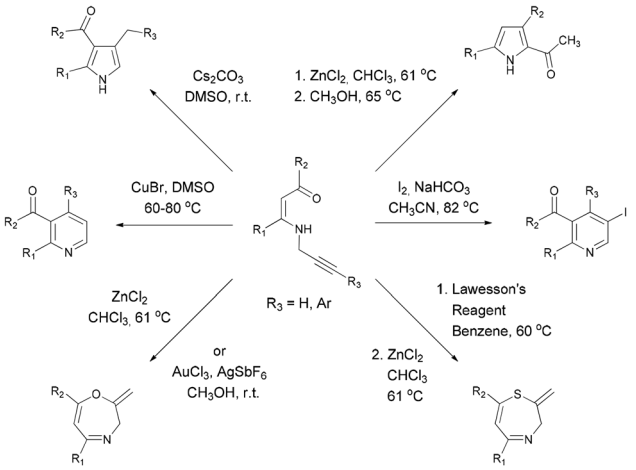


Scheme 2 Strategies for the synthesis of furo[3,4-*c*]pyridines (a–c) and 1,3-dihydrofuro[3,4-*c*]pyridines (d).

structures of medicines, vitamins, food flavorings, dyes, adhesives, insecticides and herbicides.[11] Notably, pyridines, due to their diverse physiochemical properties such as water solubility, weak basicity, chemical stability, hydrogen bond-forming ability, protein-binding capacity and cell permeability, have gained significant importance in drug design and development. In fact, there are many FDA approved pharmaceuticals that stem from a pyridine or dihydropyridine core.[12] Abiraterone acetate and crizotinib (cancer), delavirdine (HIV/AIDS), isoniazid and ethionamide (tuberculosis), nilvadipine (hypertension) and tacrine (Alzheimer's) are some examples of such pharmaceuticals.[13] An ever-growing aspect of these studies is to find novel pyridine molecules, which may provide a new mode of action for the treatment of a specific disease. To the best of our knowledge, 3,4-diaryloylpyridines (3,4-dibenzoylpyridines) are very limited and only a few examples of 3,4-diaryloyl-containing monocyclic (unfused) pyridine derivatives in particular are known.[14,15] So the value of these derivatives is underrepresented in medicinal chemistry due to limitations in existing synthetic approaches.

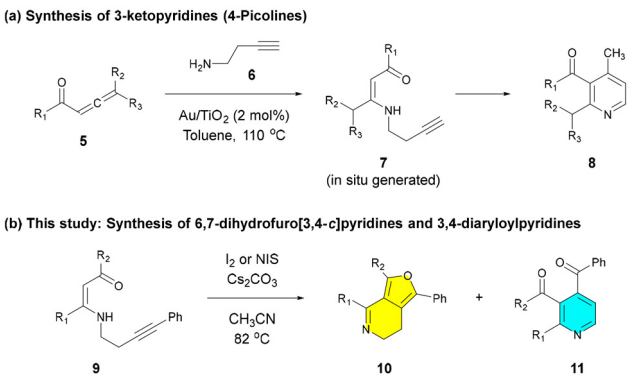
Recently, enaminones have emerged as valuable substrates in organic synthesis.[16] In particular, *N*-propargylic β-enaminones have been commonly employed as important starting precursors and/or intermediates for the synthesis of new heterocyclic ring systems (Scheme 3).[17] When treated with suitable reagents, these substances can easily produce five-, six- and seven-membered heterocyclic compounds *via* one-pot cyclization. Pyrroles,[18] 2-acetylpyrroles,[19] pyridines,[18] iodo-substituted pyridines,[20] 1,4-oxazepines[21] and 1,4-thiazepines[22] are the main products obtained from these reactions (Scheme 3).[23]

Although *N*-propargylic β-enaminones have been extensively explored, little is known about the reactions of *N*-(3-butynyl)-β-enaminones, generally called *N*-homopropargylic β-enaminones, which feature one more carbon in their



Scheme 3 Representative reactions of *N*-propargylic β-enaminones.

N-substitution as compared to *N*-propargylic β-enaminones. When *N*-(3-butynyl)-β-enaminones are employed in these reactions, elementary considerations suggest that their reactions should produce heterocyclic ring systems with an additional carbon atom. To the best of our knowledge, there is only one study in this regard. The Stratakis research group reported that *N*-homopropargylic β-enaminones **7**, generated *in situ* from the reaction of allenones **5** with 3-butynylamine (**6**), underwent 6-*exo-dig* cyclization, followed by dehydrogenation (aromatization), in the presence of Au nanoparticles on TiO_2 (Au/TiO_2), to yield 3-ketopyridines or 4-picolines **8** in good yields (Scheme 4a).[24] An isolated derivative of β-enaminones **7** also furnished the corresponding 4-picoline **8** under the same conditions (Au/TiO_2). However, when 4-aryl-3-butynyl amines containing an internal alkyne functionality were employed under the same reaction conditions, the *in situ* generated *N*-homopropargylic β-enaminones were entirely unreactive and did not produce any cyclization products, which was attributed to steric effects. Our previous studies prompted us to investigate the reactions of *N*-homopropargylic β-enaminones **9** with iodinating reagents in the presence of a base (Scheme 4b).[20] Unfortunately, our initial studies showed that β-enaminones **9**



Scheme 4 Reactions of *N*-homopropargylic β-enaminones.

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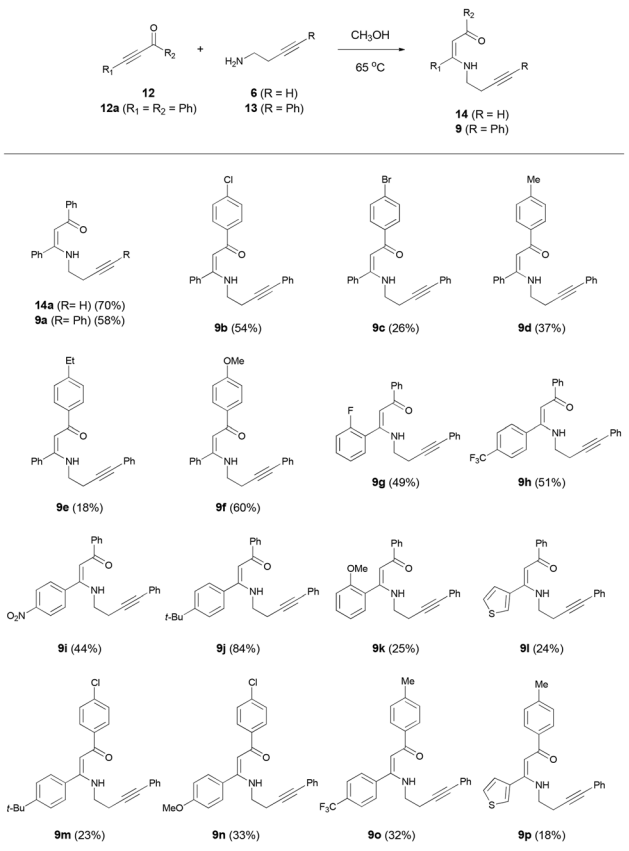
did not give the expected products, presumably due to conformational and electronic effects; instead, they afforded two new products, bicyclic 6,7-dihydrofuro[3,4-*c*]pyridines **10** and/or 3,4-diaryloylpyridines **11** (Scheme 4b). To the best of our knowledge, the formation of such heterocyclic molecules from β-enaminones is without any precedent. In this paper, we report the preliminary results of this study.

Results and discussion

After preparing homopropargylamines according to known literature procedures (see the ESI†),[24,25] we synthesized *N*-homopropargylic β-enaminones, as shown in Scheme 5. First of all, we prepared the parent *N*-homopropargylic β-enaminone **14a** in 70% yield by conjugate addition of 3-butynylamine (**6**) to α,β-alkynic ketones **12a** in refluxing methanol.[18,20] Similarly, we synthesized phenyl-substituted *N*-homopropargylic β-enaminones **9** as well. Conjugate addition of 4-phenylbut-3-yn-1-amine (**13**) to α,β-alkynic ketones **12** in refluxing methanol afforded the desired β-enaminones **9**.[18,20] We prepared 16 derivatives of β-enaminones **9**, the yields of which ranged between 18–84% (Scheme 5).



Scheme 5 Synthesis of *N*-homopropargylic β-enaminones. All the presented yields are isolated yields.

Afterward, we studied the reactions of *N*-homopropargylic β-enaminones **9** with iodinating reagents such as molecular iodine (I_2) or *N*-iodosuccinimide (NIS). In order to test the reaction and optimize the conditions, we first examined the reaction of *N*-homopropargylic β-enaminone **9a**, as shown in Table 1. In the beginning, we chose molecular iodine as the iodinating reagent since it is a low cost, mild and eco-friendly electrophile, which catalyzes or mediates a variety of organic reactions with high efficiency and selectivity.[26] In the first phase of the study, we tested the reaction of **9a** in the presence of varying amounts of molecular iodine and sodium bicarbonate in refluxing acetonitrile (Table 1, entries 1–3). These reactions produced an iodo-substituted azepine derivative with the formula $C_{25}H_{18}INO$, determined from the HRMS analysis, in 9–25% yields, the structure of which could not be fully assigned. Then we employed cesium carbonate as the base and repeated the reaction with different amounts of I_2 and Cs_2CO_3 (Table 1, entries 4–6). Surprisingly, two new products, 1,3,4-triphenyl-6,7-dihydrofuro[3,4-*c*]pyridine (**10a**) and 3,4-dibenzoyl-2-phenylpyridine (**11a**), were obtained from these reactions in 13–30% and 10–23% yields, respectively. The structure of **10a** was unambiguously identified by X-ray crystal analysis. The ORTEP view of **10a** is given in Table 1. When using 5.0 equiv. of I_2, the yield (19%) of **10a** was reduced (Table 1, entry 7). In short, the highest yield (30%) of **10a** was obtained with 4.0 equiv. of I_2 and 2.5 equiv. of Cs_2CO_3 (Table 1, entry 5). Thus we continued the reaction with these equivalencies. When the reaction time was prolonged to the maximum such as 48 h, no product was isolated, possibly due to decomposition (Table 1, entry 8). On the other hand, when the reaction was carried out under dilute conditions or in a pressure tube, only 6,7-dihydrofuro[3,4-*c*]pyridine **10a** was formed but in low yields (11 and 21%, respectively) (Table 1, entries 9 and 10). In the absence of molecular iodine or a base, no cyclized products were observed (Table 1, entries 11 and 12) but, in the first reaction, the starting β-enaminone **9a** was recovered in 97% yield. Potassium carbonate and silver carbonate were also tested in these reactions (Table 1, entries 13 and 14), but only the latter gave a product (**11a**) in 16% yield. The reaction was also conducted in *N*,*N*-dimethylformamide and ethanol (Table 1, entries 15 and 16), producing 6,7-dihydrofuro[3,4-*c*]pyridine **10a** and 3,4-dibenzoylpyridine **11a** in 6–28% and 10–15% yields, respectively. In the case of 1,2-dichloroethane, no product formation was observed (Table 1, entry 17). When the reaction was performed in dioxane, only 6,7-dihydrofuro[3,4-*c*]pyridine **10a** was formed but in a low yield (11%). Clearly, other solvents were not as efficient as acetonitrile. In general, *N*-iodosuccinimide is better than molecular iodine in terms of the iodinating property.[27] When the reactivity of I_2 is insufficient, NIS is frequently employed. Thus, we carried out the reaction with *N*-iodosuccinimide as well as in acetonitrile and *N*,*N*-dimethylformamide (Table 1, entries 19 and 20). From these reactions, 6,7-dihydrofuro[3,4-*c*]pyridine **10a** was isolated in 28–29% yields, very close to the highest yield (30%) produced by molecular iodine, while 3,4-dibenzoylpyridine **11a** was obtained in

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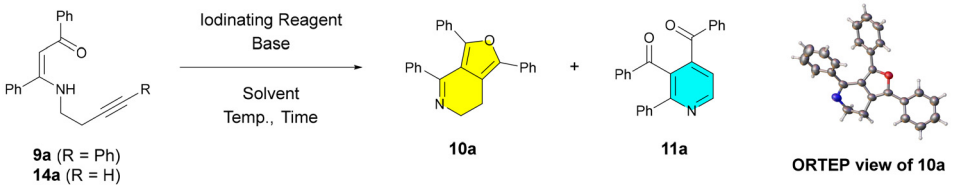
Table 1 Optimization of the reaction conditions[a]



9a (R = Ph)
14a (R = H)

10a **11a** ORTEP view of **10a**

Entry	Enaminone	Iodinating reagent (equiv.)[b]	Base (equiv.)[b]	Solvent	Temp. (°C)	Time (h)	Yield of **10a** (%)	Yield of **11a** (%)
1[c,d]	**9a**	I_2 (1.5)	$NaHCO_3$ (1.5)	MeCN	82	4.0	—	—
2[e,f]	**9a**	I_2 (2.5)	$NaHCO_3$ (2.5)	MeCN	82	4.0	—	—
3[g]	**9a**	I_2 (4.0)	$NaHCO_3$ (4.0)	MeCN	82	4.0	—	—
4	**9a**	I_2 (2.5)	Cs_2CO_3 (2.5)	MeCN	82	4.0	13	23
5	**9a**	I_2 (4.0)	Cs_2CO_3 (2.5)	MeCN	82	4.0	30	10
6	**9a**	I_2 (4.0)	Cs_2CO_3 (4.0)	MeCN	82	3.5	15	16
7	**9a**	I_2 (5.0)	Cs_2CO_3 (2.5)	MeCN	82	3.0	19	—
8	**9a**	I_2 (4.0)	Cs_2CO_3 (2.5)	MeCN	25	48.0	—	—
9[h]	**9a**	I_2 (4.0)	Cs_2CO_3 (2.5)	MeCN	82	3.0	—	11
10[i]	**9a**	I_2 (4.0)	Cs_2CO_3 (2.5)	MeCN	82	2.5	—	21
11[j]	**9a**	—	Cs_2CO_3 (2.5)	MeCN	82	4.0	—	—
12	**9a**	I_2 (4.0)	—	MeCN	82	1.5	—	—
13	**9a**	I_2 (4.0)	K_2CO_3 (2.5)	MeCN	82	3.0	—	—
14	**9a**	I_2 (4.0)	Ag_2CO_3 (2.5)	MeCN	82	4.0	—	16
15	**9a**	I_2 (4.0)	Cs_2CO_3 (2.5)	DMF	110	3.5	28	15
16	**9a**	I_2 (4.0)	Cs_2CO_3 (2.5)	EtOH	78	9.0	6	10
17	**9a**	I_2 (4.0)	Cs_2CO_3 (2.5)	DCE	84	3.5	—	—
18	**9a**	I_2 (4.0)	Cs_2CO_3 (2.5)	Dioxane	101	3.0	11	—
19	**9a**	NIS (4.0)	Cs_2CO_3 (2.5)	MeCN	82	6.0	29	13
20	**9a**	NIS (4.0)	Cs_2CO_3 (2.5)	DMF	110	6.0	28	29
21	**14a**	I_2 (4.0)	Cs_2CO_3 (2.5)	MeCN	82	4.0	—	—

[a] Isolated yields. [b] Equivalency is given according to that of the starting β-enaminone **9a** or **14a**. [c] The starting β-enaminone **9a** was recovered in 25% yield. [d] An iodo-substituted azepine derivative with the formula $C_{25}H_{18}INO$ was isolated in 9% yield, the structure of which could not be fully elucidated. [e] The starting β-enaminone **9a** was recovered in 10% yield. [f] An iodo-substituted azepine derivative with the formula $C_{25}H_{18}INO$ was isolated in 25% yield, the structure of which could not be fully elucidated. [g] An iodo-substituted azepine derivative with the formula $C_{25}H_{18}INO$ was isolated in 18% yield, the structure of which could not be fully elucidated. [h] This reaction was performed under dilute conditions by using 30 mL of solvent at the scale of 0.1 mmol of **9a**. [i] This reaction was performed in a pressure tube by using 2 mL of solvent at the scale of 0.1 mmol of **9a**. [j] The starting β-enaminone **9a** was recovered in 97% yield.

10–29% yields, slightly higher than that (23%) with molecular iodine. In short, the results obtained by using both reagents (I_2 and NIS) were quite similar, and no dramatic change in yields was observed with NIS, especially with regard to **10a**. Finally, we tested the reaction of β-enaminone **14a**, *i.e.* the terminal alkyne analog of **9a** (Table 1, entry 21). Unfortunately, the reaction of **14a** with molecular iodine in refluxing acetonitrile ended up with no product formation. It should be mentioned that the optimization reactions were generally not so clean, resulting in some unidentifiable products, but in low amounts, which made purification difficult. In summary, the highest yields of 1,3,4-triphenyl-6,7-dihydrofuro[3,4-*c*]pyridine (**10a**) were obtained with 4.0 equiv. of I_2 or NIS and 2.5 equiv. of Cs_2CO_3 in refluxing acetonitrile, as shown in entries 5 and 19 in Table 1. So the generality of the reaction and the scope of the substrates were explored under these conditions.

We next investigated the generality and substrate scope of the reaction of *N*-homopropargylic β-enaminones **9**, as illustrated in Scheme 6. As an iodinating reagent, we mostly preferred to use molecular iodine for the reasons mentioned above. However, in some cases, *N*-iodosuccinimide was also used in addition to molecular iodine. A large variety of *N*-homopropargylic β-enaminones **9** bearing aromatic and heteroaromatic groups with electron-donating and electron-withdrawing substituents were utilized in these reactions, which afforded 6,7-dihydrofuro[3,4-*c*]pyridines **10** and/or 3,4-diaryloylpyridines **11**. In fact, all reactions afforded the expected 6,7-dihydrofuro[3,4-*c*]pyridine derivatives **10** in 11–55% yields. Apparently, the use of NIS, instead of I_2, increased the yields of four products (**10g**, **i**, **m** and **o**) to some extent (Scheme 6). The highest yields were observed for 6,7-dihydrofuro[3,4-*c*]pyridines **10g** (50%) and **10k** [55%]. Six derivatives of 3,4-diaryloylpyridines **11** were also obtained from these reactions, as shown in Scheme 6, the yields of which ranged between 9–29%. Notably, in some reactions, 3,4-diaryloylpyridines **11** did not form or were formed in very low yields, as a result of which they could not be isolated. The highest yields for 3,4-diaryloylpyridines were obtained for **11a** [29%]. Thiophenes are highly important precursors and intermediates for the synthesis of a diverse range of pharmaceuticals and agrochemicals and in materials science.[28] Thus, we synthesized two derivatives (**10l** and **p**) of 4-(thiophen-3-yl)-substituted 6,7-dihydrofuro[3,4-*c*]pyridines and one derivative (**11l**) of 2-(thiophen-3-yl)-substituted 3,4-dibenzoylpyridines, as shown in

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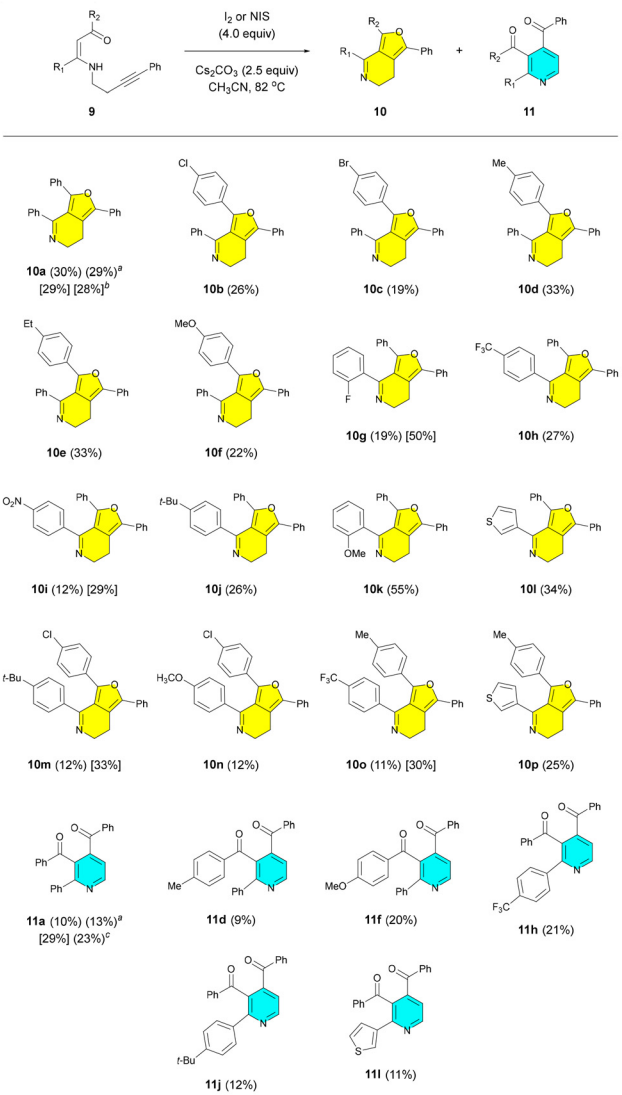
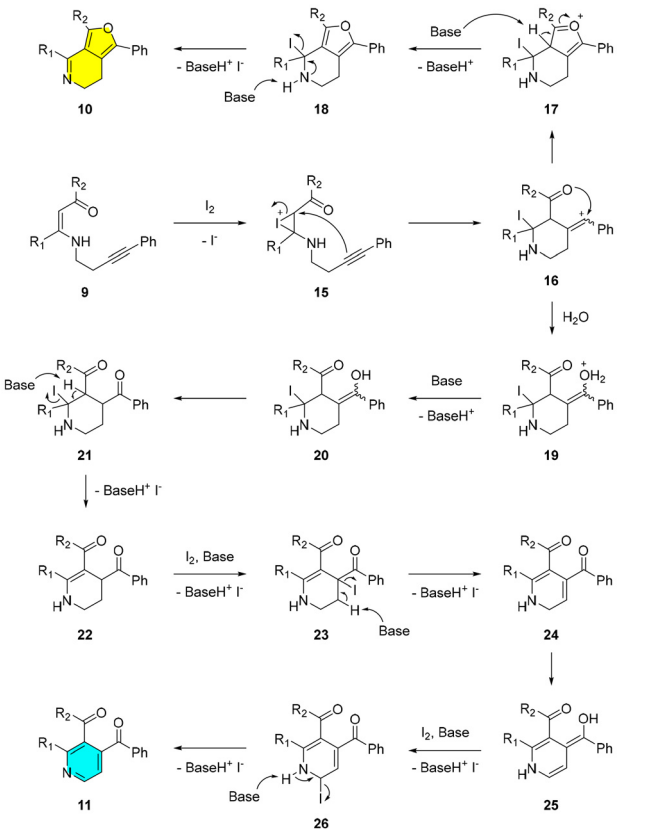


Scheme 6 Scope of the cyclization of *N*-homopropargylic β-enaminones **9**. All the presented yields are isolated yields. Yields obtained with I_2 are given in parentheses while those obtained with NIS are shown in square brackets. [a] Yield obtained from the reaction performed at the 1.99 mmol scale of **9a**. [b] Yield obtained from the reaction performed in DMF at 110 °C. [c] Yield obtained from the reaction carried out by using 2.5 equiv. of I_2.

Scheme 6. Many drugs and drug candidates in clinical trials are halogenated compounds because halogen bonds improve the drug-target binding affinity.[29] In particular, fluorinated drugs occupy a special place in the pharmaceutical industry since fluorination has a positive effect on absorption, distribution, metabolism and excretion.[30] Overall, we synthesized seven derivatives (**10b**, **c**, **g**, **h** and **m**–**o**) of halogen-containing 6,7-dihydrofuro[3,4-*c*]pyridines and one derivative (**11h**) of halogen-bearing 3,4-aryloylpyridines (Scheme 6). The reaction of β-enaminone **9a** with I_2 was carried out on a relatively larger scale (by using 1.99 mmol of **9a**) as well. This reaction afforded the expected products **10a** and **11a** in 29 and 13% yields, respectively (Scheme 6).

It is noteworthy that all the isolated 3,4-diaryloylpyridine derivatives in this study are new compounds although 3,4-diaryloylpyridines are known. The synthesis of pyridines from *N*-propargylic and *N*-homopropargylic β-enaminones is well known,[18,20,23,24] but, to the best of our knowledge, the formation of 3,4-diaryloylpyridine derivatives from such β-enaminones is not known. Since our focus in this study has been mainly on the synthesis of the unknown bicyclic 6,7-dihydrofuro[3,4-*c*]pyridine ring systems, we plan to investigate the synthesis of 3,4-diaryloylpyridines in detail from *N*-homopropargylic β-enaminones in a separate study.

The proposed mechanism for the synthesis of 6,7-dihydrofuro[3,4-*c*]pyridines **10** and 3,4-diaryloylpyridines **11** is shown in Scheme 7. First, the reaction of molecular iodine with enaminone **9** produces the iodonium ion **15**, which initiates the nucleophilic addition of the alkyne moiety to give vinyl cation **16**. Then this vinyl cation is trapped by the ketone functionality, resulting in the formation of the cyclized intermediate **17**. The abstraction of α-hydrogen by the base furnishes tetrahydrofuro[3,4-*c*]pyridine **18**. Finally, the elimination of iodine generates the 6,7-dihydrofuro[3,4-*c*]pyridine derivative **10** (Scheme 7). Possibly, the vinyl cation intermediate **16** could also be trapped by trace amounts of water present in the reaction, forming intermediate **19**. Removal of one hydrogen from the water moiety yields enol **20**, the tautomerization of which



Scheme 7 Proposed mechanism for the formation of 6,7-dihydrofuro[3,4-*c*]pyridines and 3,4-diaryloylpyridines.

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affords 3,4-diaryloylpiperidine **21**. Elimination of hydrogen iodide with a base gives the tetrahydropyridine derivative **22**. In the presence of molecular iodine and a base, α-iodination takes place to yield intermediate **23**, which, upon hydrogen iodide elimination, produces dihydropyridine **24**. Keto–enol tautomerization of **24** first generates *in situ* enol **25**; then its reaction with molecular iodine furnishes iodo-substituted dihydropyridine **26**. Finally, elimination of hydrogen iodide with a base affords the 3,4-diaryloylpyridine derivative **11** (Scheme 7). It is noteworthy that the reaction does not stop with the formation of tetrahydropyridine **22**, presumably due to the presence of a carbonyl group at the 4-position of the molecule. In the presence of excess molecular iodine, this carbonyl group triggers iodination, setting the stage for hydrogen iodide elimination from the molecule by the base. So, this oxidative aromatization continues until a pyridine ring forms. Notably, iodine-catalyzed or mediated oxidative aromatization is well known in the literature.[31]

Conclusions

In summary, we have disclosed a new reaction of *N*-homopropargylic β-enaminones with molecular iodine and *N*-iodosuccinimide, leading to the formation of 6,7-dihydrofuro[3,4-*c*]pyridines and/or 3,4-diaryloylpyridines. When treated with excess molecular iodine in the presence of cesium carbonate, *N*-homopropargylic β-enaminones produced bicyclic 6,7-dihydrofuro[3,4-*c*]pyridines in low to moderate yields. During the course of the reaction, two new C/O–C bonds formed, giving rise to the formation of new five- and six-membered fused heterobicyclic molecules. Importantly, the skeletal diversity of the synthesized heterobicyclic frame may provide many new nitrogen- and oxygen-based heterobicyclic hybrid systems for drug discovery and development. Some reactions afforded 3,4-diaryloylpyridines in low yields as well. During the formation of 3,4-diaryloylpyridine derivatives, a new carbonyl (ketone) group formed. Notably, the presence of a dibenzoyl group in the pyridine unit offers the potential for further functionalization of these molecules, given that this functionality can be converted into pyrroles, furans, thiophenes and pyridazines. In fact, the reaction could be a potentially powerful method for the synthesis of 6,7-dihydrofuro[3,4-*c*]pyridines and 3,4-diaryloylpyridines; however, at present, the scope and limitations exhibited by these systems are less than optimal, which need to be improved. Further investigation of the mechanism, scope and limitations of this methodology is currently underway and will be reported in due course.

Experimental

General procedure for the synthesis of *N*-homopropargylic β-enaminones 9 and 14 (Scheme 5)

To a stirred solution of the appropriate α,β-alkynic ketone **12** (1.94 mmol) in MeOH (10 mL) was added 3-butynylamine (**6**) (1.94 mmol) or 4-phenylbut-3-yn-1-amine (**13**) (1.94 mmol), and the resulting mixture was then refluxed until α,β-alkynic ketone **12** was completely consumed, as monitored by routine TLC. After the reaction was over, the solvent was removed using a rotary evaporator, and ethyl acetate (50 mL) and a saturated NH_4Cl solution (50 mL) were added. After the layers were separated, the aqueous layer was extracted with ethyl acetate (3 × 50 mL). The combined organic layers were dried over $MgSO_4$ and evaporated using a rotary evaporator to give the crude product, which was purified by flash chromatography on silica gel using hexane/ethyl acetate (9 : 1 followed by 4 : 1) as the eluent to afford the corresponding *N*-homopropargylic β-enaminone **9** or **14**.

General procedure for the cyclization of *N*-homopropargylic β-enaminones 9 leading to 6,7-dihydrofuro[3,4-*c*]pyridines 10 and/or 3,4-diaryloylpyridines 11 (Scheme 6)

The appropriate *N*-homopropargylic β-enaminone **9** (0.28 mmol) in acetonitrile (4.0 mL) was stirred at room temperature under argon and then molecular iodine (1.12 mmol) and Cs_2CO_3 (0.70 mmol) were added to the reaction mixture. The resulting mixture was then refluxed until *N*-homopropargylic β-enaminone **9** was completely consumed, as monitored by routine TLC. After the reaction was over, the solvent was removed using a rotary evaporator, and ethyl acetate (40 mL) and a saturated aqueous solution of $Na_2S_2O_3$ (15 mL) were added. After the layers were separated, the aqueous layer was extracted with ethyl acetate (2 × 30 mL). The combined organic layers were dried over $MgSO_4$ and evaporated using a rotary evaporator to give the crude product, which was purified by flash chromatography on silica gel using 4 : 1 hexane/ethyl acetate as the eluent to afford the corresponding 6,7-dihydrofuro[3,4-*c*]pyridine **10** and/or 3,4-diaryloylpyridine **11**.

Data availability

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

Crystallographic data for **10a** have been deposited at the CCDC under 2379026.†

Conflicts of interest

There are no conflicts to declare.

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