Preparation of some heterocyclic enones and ynones by isomerisation of the propargylic alcohols Ramazan Erenler^{*a,b}, Masaharu Uno^c, Thirumani Venkateshwar Goud^a and Jean-François Biellmann^a

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The propargylic alcohols were synthesised by treatment of aldehydes with substituted acetylenes. The conversion of propargylic alcohols to propynones and propenones takes place with pyridine hydrochloride in methanol at room temperature. In presence of pyridinium triflate and *p*-toluenesulfonate the propynone was the only product isolated in the isomerisation of alcohol. The silylated propenone undergoes with cyclopentadiene a Diels–Alder cycloaddition to give ketone whose skeleton is related to that of quinine.

Keywords: isomerisation, propargylic alcohol, enone; ynone, heterocyclic

The pyridine ring plays a key role in several biological processes.^{1,2} The quinoline ring system is an important target in synthetic chemistry. It is found in a large number of natural products, many of which have important biological activities.³⁻⁷ In addition, they are used as dvestuffs and photographic sensitisers.⁸

In a preliminary communication we reported the facile isomerisation of heterocyclic propargylic alcohols to propenones and propynones in the presence of pyridine hydrochloride.⁹ We had shown that this isomerisation occurs when the propargylic hydrogen is activated at C-2 and C-4 in case of pyridine and that the ethylenic protons originated from protons of the solvent. An enolic allene was postulated as an intermediate and its protonation gives a (Z) enone subsequently isomerised to the (E) form. Related isomerisation and the reported on different systems under various conditions.¹⁰⁻²⁰ We now report more examples of this isomerisation and the results obtained with two other pyridinium salts as catalysts and the Diels–Alder reaction of one of these enones whose chemistry has not been explored.

Results and discussions

We prepared in good yields the proparglic alcohols 3 from aldehydes 1 and substituted acetylenes 2. These alcohols 3 except 3a, 3m and 3n are not too stable and their isomerisation was carried out without delay. Table 1 shows the results of the preparation of the propargylic alcohols 3 and their isomerisation with pyridine hydrochloride catalyst to ynones 4 and enones 5. The structure of enone 5d was elucidated by X-ray diffraction (Fig. 1). We tried with the quinoline alcohol other pyridinium salts: trifluoromethanesulfonate, *p*-toluensulfonate, and compared the results with those obtained with pyridinium hydrochloride. (Table 2). The ynone 6 was the only product isolated in the presence of pyridinium triflate and pyridinium toluenesulfonate. Enone 7 was found only in the presence of pyridinium hydrochloride. The presence of air seemed to increase the yield of the ynone, but the ynone was also obtained under argon (Table 2). In addition to the ynone and enone, coloured and polar material was obtained.

Concerning the mechanism of the conversion of the propargylic alcohols, the protonation of the nitrogen is an essential step. So the first step is the protonation at the nitrogen to give the pyridinium or quinolinium cation. Now the hydrogen at the alpha position is activated and is abstracted by a base to give the anhydro base 8. This base 8

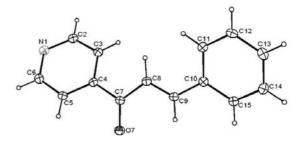


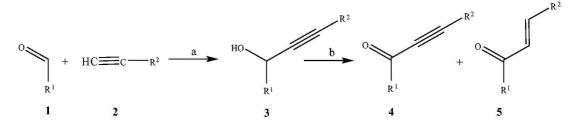
Fig. 1 ORTEP structure of 5d.

Table 1	Preparation of propargylic alcohol	s (3) and their conversion to ynones ((4) and enones (5) with pyridinium hydrochloride
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Compound		3ª	4 (ynone)	5 (enone)	
	R ¹	R ²	Yield/%	Yield/%	Yield/%
а	Phenyl	Me₃Si	100	_	-
b	4-Pyridyl	Me ₃ Si	83	26	52
C	4-Pyridyl	Me	82	15	49
d	4-Pyridyl	Phenyl	90	10	55
е	4-Pyridyl	t-Butyl	96	12	75
f	4-Quinolyl	Me ₃ Si	79	see Table 2	
g	4-Quinolyl	Me	83	30	36
ĥ	4-Quinolyl	t-Butyl	80	26	37 (E)-18(Z)
i	4-Quinolyl	Phenyl	74	24	21
k	2-Pyridyl	Me ₃ Si	88	—	42
m	3-Pyridyl ^{21,22}	Me ₃ Si	97	Stable	
n	3-Pyridyl ^{21,22}	Н		Stable	

^aExcept for **3n** prepared from **3m** by removal of the trimethylsilyl group by TBAF.

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Scheme 1 Reagents and conditions: (a) n-BuLi, THF, -78°C (b) C5H6NCI, MeOH.

	MeOH O	TMS +		TMS
3f	6	5	7	
PyH⁺ salt	Atmosphere	Additive	6	7
CF ₃ SO	Air	-	36%	-
-	Ar	-	32%	\sim
p-Me-C ₆ H ₄ -SO ₃	Air	—	67%	-
	Ar		49%	-
	Ar	Na ₂ CO ₃	33%	-
CI-	Air		40%	-
	Ar	-	40%	50%

Table 2 Conversion of 3f using various pyridinium salts

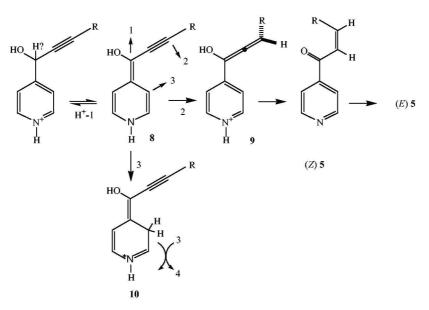
may be protonated at several positions: 1, 2 and 3. At position 1 to give back the pyridinium salt, resulting in the exchange of this hydrogen. With the protonation at position 2, the terminal carbon of the triple bond, the pyridinium allenol 9 is obtained. The deprotonation of the nitrogen and the ketonisation of the allenol gives at first the (Z) isomer of ketone later isomerised to the (E) isomer. The kinetic product of the protonation at C-3 (position 3) gives iminium salt 10 which could be involved in the oxidation of the alcohol to the ynones. We have not tried to isolate the reduced products resulting from this dismutation. If we follow the reaction by NMR using MeO²H, the exchange of the alpha hydrogen of propargylic alcohol is observed

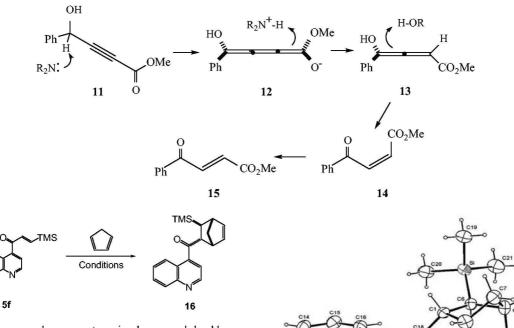
and later the appearance of the (Z) enone is observed and its transformation to the (E) enone and both hydrogens at the ethylenic positions are exchanged with a deuteron as shown by ¹H NMR and mass spectrometry. A related intramolecular dismutation reaction has been observed in the reaction of vinylmagnesium bromide with isonicotinaldehyde.²⁸

The isomerisation of γ -hydroxy- α , β -alkynoates **11** to γ -oxo- α , β -alkenoates with the organic base (DABCO) or sodium bicarbonate in DMSO-water has been studied.²⁹ The base removes the propargylic proton giving rise to a cumulene **12** which is protonated by the conjugated acid to an allenol **13** which in turn is protonated by an external proton. The protonation occurs to give first the (*Z*) isomer **14** later isomerised to the (*E*) isomer **15**. The propargylic proton is transferred to the vinylic position with little exchange and the other proton originates from solvent. In the propargylic alcohol, the ester group provides the acidity so that the proton can be removed. In the propargylic alcohols in Table 1, the protonation at the nitrogen lowers the *pKa* of the proton so that it can be removed by a base.

The easy preparation of heterocyclic enone induced us to try the Diels–Alder reaction with cyclopentadiene to prepare a cyclic system related to quinine. The Diels–Alder adduct 16 with cyclopentadiene was obtained at 120 °C (neat) in a yield of 25%.

In boron trifluoride etherate at $-78 \,^{\circ}$ C in toluene, no adduct was isolated. So, we turned to lithium chloride as a catalyst and obtained in THF at 25 $^{\circ}$ C the adduct **16** in a yield of 50%.³⁰ The *endo* cycloaddition product is obtained as expected.^{31,32} This has been ascertained by the structure determination by X-ray diffraction (Fig. 2).





These enones and ynones not previously prepared should open a new strategy for the synthesis of some complex heterocyclic systems such as alkaloids. They also could be the precursors of synthetically and pharmaceutically valuable compounds.

Experimental

General procedures

Commercial reagents were purchased from standard chemical suppliers and purified if needed. Solvents were purified and dried by passing through activated aluminum oxide under argon pressure. Flash column chromatography was carried out on Silica Gel 60 (230-400 mesh, E. Merck). TLC was performed on pre-coated glass plates of Silica Gel 60 F254 (0.25 mm, E. Merck); detection was done by spraying with a solution of Ce(NH₄)₂(NO₃)₆, (NH₄)₆Mo₇O₂₄, and H₂SO₄ in water or ninhydrin and acetic acid solution in n-butanol and subsequent heating on a hot plate. Melting points were determined with a Büchi B-540 apparatus and are uncorrected. ¹H and ¹³C NMR spectra were recorded with Bruker AV400 and 500 MHz instruments. Chemical shifts are in ppm from TMS as internal standard, generated from the CDCl₃. IR spectra were taken with a Perkin-Elmer Paragon 1000 FT-IR spectrometer. Elemental analysis was done with a Perkin-Elmer 2400CHN instrument. Mass spectra were obtained with a FAB JMS-700 double focusing mass spectrometer (JEOL, Tokyo, Japan).

1-*Phenyl-3-trimethylsilanyl-prop-2-yn-1-ol* (**3a**): Prepared according to the literature and its physical data were in agreement with those published.²¹

4-(1-Hydroxy-3-trimethylsilanyl-2-propynyl) pyridine (**3b**): To a solution of (trimethylsilyl) acetylene (1.7 mL) in THF (20 mL) at -78 °C was added a solution of n-BuLi (7 mL, 1.6 M in hexane). The reaction mixture was allowed to warm to -10 °C, then a solution of 4-pyridinecarboxaldehyde (1.0 g) in THF (3 mL) was added. After 1 h stirring, saturated NH₄Cl solution in water was added and the organic layer was washed with brine (2 × 30 mL), extracted with CH₂Cl₂ and dried over MgSO₄ and concentrated in *vacuo*. Product **3b** is a colourless solid (1.6 g, 83%), m.p. 94–95 °C. (lit. m.p. 83–85 °C).²⁴ ¹H NMR (400 MHz, CDCl₃): δ 0.17 (s, 9H), 4.60 (brs, 1H), 5.48 (s, 1H), 7.49 (d, J = 6.0 Hz 2H), 8.53 (d, J = 6.0 Hz 2H). ¹³C NMR (100 MHz, CDCl₃): δ -0.18, 63.2, 92.0, 104.2, 121.5, 149.4, 150.3, MS (EI): m/2 205 [M]⁺.

4-(1-Hydroxy-2-butynyl) pyridine (3c): To a solution of propyne (1.12 g) in THF (10 mL), was added a solution of n-BuLi (7.0 mL, 1.6 M in hexane) as for **3b**. A solution of 4-pyridinecarboxaldehyde (1.0 g) in THF (5 mL) was added. The product **3c** was isolated as for **3b**, and as a liquid (1.12 g, 82%). UV (CH₂Cl₂): λ_{max} (ε) 255 (3540 M⁻¹ cm⁻¹). IR (CH₂Cl₂): 1230, 1414, 1564, 1602, 1716, 2232, 2874, 2959, 3018, 3026, 3061 cm⁻¹. ¹H NMR (400 MHz, CDCl₃): δ 1.76 (s, 3H), 5.37 (d, J = 1.6 Hz, 1H), 6.30 (brs, 1H), 7.41 (d J = 5.9 Hz, 2H).

Fig. 2 ORTEP structure of 16.

8.36 (d, J = 5.9 Hz, 2H). ¹³C NMR (100 MHz, CDCl₃): δ 34.8, 62.5, 78.8, 82.8, 121.6, 149.0, 151.1. MS (FAB⁺): m/z 148 (M + H⁺). Anal. Calcd for C₉H₉NO: C, 73.45; H, 6.16; N, 9.52. Found: C, 73.40; H, 6.12; N, 9.47%.

4-(1-Hydroxy-3-phenyl-2-propynyl)pyridine (3d): Phenylacetylene (1.04 g) in THF (10 mL) was treated as for 3b with n-BuLi (7.0 mL) and 4-pyridinecarboxaldehyde (1.0 g) in THF (5 mL) was added. The product (1.75 g, 90%) was a liquid. UV (CH₂Cl₂): λ_{max} (ϵ) 242 (5100), 309 (1300). IR (CH₂Cl₂): 1042, 1243, 1376, 1461, 1733, 2869, 2926, 2960, 3583. ¹H NMR (500 MHz, CDCl₃): δ 3.95 (brs, 1H), 5.68 (s, 1H), 7.27 (m, 3H), 7.40 (m, 2H), 7.53 (d, J = 6.0 Hz, 2H), 8.55 (d, J = 6.0 Hz 2H). ¹³C NMR (125 MHz, CDCl₃): δ 63.2, 86.7, 87.9, 121.4, 121.6, 128.2, 128.6, 131.7, 146.2, 149.4. MS (FAB⁺): *m*/z 201 [M+H]⁺. Anal. Calcd for Cl₄H₁₁NO (209.2): C, 80.36; H, 5.30; N, 6.69. Found: C, 80.20; H, 5.34; N, 6.74%.

4-(1-Hydroxy-4,4-dimethyl-2-pentynyl)pyridine (3e): 3, 3-Dimethyl-1-butyne (0.46 g) in THF (10 mL) was treated as for **3b** with n-BuLi (3.5 mL, 1.6 M in hexane) and 4-pyridinecarboxaldehyde (0.50 g) in THF (3.0 mL) was added. The product **3e** (0.85 g, 96%) was a solid, m.p. 85–88°C. UV (CHCl₃): λ_{max} (i) 257 (2000). IR (CH₂Cl₂): 1068, 1404, 1599, 2232, 2333, 2363, 2970, 3060, 3596, 3685 cm⁻¹. ¹H NMR (500 MHz, CDCl₃): δ 1.20 (s, 9H), 3.50 (brs, 1H), 5.42 (s, 1H), 7.44 (d, J=4.7 Hz, 2H), 8.50 (d, J=4.7 Hz, 2H). ¹³C NMR (125 MHz, CDCl₃): δ 27.4, 30.7, 62.8, 77.6, 95.9, 121.4, 149.3, 151.0. MS (FAB⁺): *m/z* 190 [M + H]⁺. Anal. Calcd for C₁₂H₁₃NO (189.3): C, 76.16; H, 7.99; N, 7.40. Found: C, 76.11; H, 8.03; N, 7.47%.

4-(1-Hydroxy-3-trimethylsilanyl-2-propynyl)quinoline (3f):Trimethylsilylacetylene (0.39 g) in THF (10 mL) was treated as for **3b** with n-BuLi (2.5 mL, 1.6 M, in hexane) and 4-quinolinecarboxaldehyde (0.5 g) in THF (2 mL) was added. The product **3f** was a solid (0.64 g, 78%). m.p. 95–96 °C; UV (CH₂Cl₂): λ_{max} (ε) 234 (13900), 281 (4800 M⁻¹ cm⁻¹). IR (CH₂Cl₂): 1510, 1573, 1607, 1636, 1654, 1686, 1717, 1734, 1750, 1774, 1801, 1830, 1884, 1963, 2174, 2305, 2339, 2360 cm⁻¹. ¹H NMR (400 MHz, CDCl₃): & 0.15 (s, 9H), 4.80 (brs, 1H), 6.10 (s, 1H), 7.55 (dd, J = 7.6 Hz, J = 15.6 Hz, 1H), 7.65 (dd, J = 7.6 Hz, J = 15.6 Hz, 1H), 7.69 (d, J = 4.4 Hz, 1H), 8.10 (d, J = 8.4 Hz, 1H), 8.25 (d, J = 8.4 Hz, 1H), 8.72 (d, J = 4.4 Hz, 1H). ¹³C NMR (100 MHz, CDCl₃): & -0.4, 61.3, 92.4, 104.1, 118.2, 124.1, 125.6, 126.7, 129.3, 129.4, 146.1, 147.7, 149.8. MS (FAB⁺): m/e (%): 256 [M + H]⁺ (100), 180(5), 154 (6), 130 (10). Anal. Calcd for C1₃H₁₇NOSi: C, 70.54; H, 6.71; N 5.48. Found: C, 70.50; H, 6.69; N, 5.52%.

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4-(1-Hydroxy-2-butynyl)quinoline (**3g**): Propyne (0.38 g) in THF (10 mL) was treated as for **3b** with n-BuLi (2.5 mL, 1.6 M in hexane), and 4-quinolinecarboxaldehyde (0.50 g) in THF (2 mL). The product **3g** was a solid (0.52 g, 83%); m.p. 130°C. UV (MeOH): λ_{max} (*b*) 210 (13400), 222 (13000), 283 (4400). IR (CH₂Cl₂): 556, 648, 698, 1035, 1049, 1109, 1379, 1414, 1432, 1453, 1475, 2808, 2878, 2900, 2978, 2992, 3056, 3092, 3184, 3432, 3567 cm⁻¹. ¹H NMR (400 MHz, DMSO-d6): & 1.75 (s, 3H), 5.95 (brs, 1H), 6.35 (d, J = 4.4 Hz, 1H), 7.60 (t, J = 5.7 Hz, J = 12.2 Hz, 1H), 7.63 (d, J = 3.4 Hz, 1H), 7.72 (t, J = 5.7 Hz, J = 12.2 Hz, 1H), 7.63 (d, J = 3.4 Hz, 1H), 7.72 (t, 14), 8.84 (d, J = 3.4 Hz, 1H). ¹³C NMR (100 MHz, DMSO-d6): δ 3.6, 60.3, 80.1, 82.9, 118.4, 124.9, 125.4, 126.9, 129.7 (2C), 147.6, 148.1, 150.8. MS (EI): m/e (%): 197 [M]⁺ (100), 182 (77), 130 (50), 129 (20). Anal. Calcd for C₁₃H₁₁NO (197.2): C, 79.16; H, 5.62; N 7.10. Found: C, 79.27; H, 5.80; N 6.99%.

4-(1-Hydrox)-4,4-dimethyl-2-pentynyl)quinoline(**3h**):3,3-Dimethyl-1-butyne (0.31 g) in THF (8 mL) was treated as for **3b** with n-BuLi (2.4 mL, 1.6 M in hexane), and 4-quinolinecarboxaldehyde (0.5 g) in THF (3 mL) was added. The product was liquid (0.61 g, 80%). UV (CH₂Cl₂): λ_{max} (ε) 283 (4900). IR (CH₂Cl₂): 3428 cm⁻¹. ¹H NMR (500 MHz, CDCl₃): δ 1.18 (s, 9H), 4.20 (brs, 1H), 6.08 (s, 1H), 7.55 (dd, J = 1.1 Hz, J = 8.2 Hz, 1H), 7.67 (m, 2H), 8.10 (d, J = 8.4 Hz, 1H), 8.26 (d, J = 8.4 Hz, 1H), 8.79 (d, J = 4.4 Hz, 1H). ¹³C NMR (125 MHz, CDCl₃): δ 27.5, 30.7, 61.3, 77.5, 96.7, 118.0, 124.1, 125.7, 126.6, 129.2, 129.6, 146.5, 148.0, 150.0 MS (FAB⁺): m/z 240[M + H]⁺. Anal. Calcd for C₁₆H₁₇NO: C, 80.30; H, 7.16; N, 5.85. Found: C, 80.19; H, 7.22; N, 5.91%.

4-(1-Hydroxy-3-phenyl-2-propynyl)quinoline (3i): Phenylacetylene (0.39 g) in THF (8 mL) was treated as for **3b** with n-BuLi (2.39 mL, 1.6 M in hexane) and 4-quinolinecarboxaldehyde (0.50 g) in THF (3 mL) was added. The product **3j** (0.610 g, 74%) was a liquid. UV (CH₂Cl₂): λ_{max} (ε) 225 (24000). IR (acetone): 3618 cm⁻¹. ¹H NMR (500 MHz, McOD): δ 4.85 (brs, 1H), 6.33 (s, 1H), 7.30 (m, 3H), 7.39 (m, 2H), 7.67 (ddd, J = 0.9 Hz, J = 8.1 Hz, 1H), 7.78 (ddd, J = 0.9 Hz, J = 8.1 Hz, 1H), 7.86 (d, J = 4.5 Hz, 1H), 8.07 (d, J = 8.4 Hz, 1H), 8.88 (d, J = 4.5 Hz, 1H). ¹³C NMR (125 MHz, McOD): δ 60.7, 86.3, 87.8, 117.9, 122.2, 124.2, 125.6, 126.6, 128.1, 128.3, 128.4, 129.4, 131.1, 147.6, 149.8. MS (FAB⁺): m/z260 [M + H]⁺. Anal. Calcd for C₁₈H₁₃NO: C, 83.37; H, 5.05; N, 5.40.Found: C, 83.41; H, 5.11; N, 5.31%.

General procedure for the reaction of propargylic alcohol (3) with pyridinium hydrochloride

To a solution of propargylic alcohol 3 (1 mmol) in MeOH (4 mL) was added pyridinium hydrochloride (0.04 mmol) at r.t. After stirring for 6 h, water (5 mL) was added, extraction with CH_2Cl_2 (2 × 10 mL) was performed. The organic layer was dried over MgSO₄ and concentrated under vacuum to yield the products **4b**-i and **5b**-i which were separated by column chromatography.

Reaction of 4-(1-hydroxy-3-trimethylsilanyl-2-propynyl) pyridine (**3b**) with pyridinium hydrochloride

4-(1-Hydroxy-3-trimethylsilanyl-2-propynyl) pyridine **3b** (0.20 g) in MeOH (4.0 mL), pyridinium hydrochloride (5.6 mg). yielded the two products separated by column chromatography (silica gel, hexane/ EtOAc, 4/1).

7.05 (d, J=18.8 Hz, 1H), 7.25 (d, J=18.8 Hz, 1H), 7.60 (dd, J=6.0 Hz, J=2.0 Hz, 2H), 8.70 (dd, J=6.0 Hz, J=2.0 Hz, 2H), ¹³C NMR (100 MHz, CDCl₃): δ -1.8, 121.8, 137.4, 143.9, 150.7, 152.7, 189.9. MS (EI): 205 [M]⁺. Anal. Calcd for C₁₁H₁₅NOSi (205.3): C, 64.34; 7.36; N, 6.82. Found: C, 64.30; H, 7.34; N, 6.85%.

Reaction of 4-(1-hydroxy-2-butynyl) pyridine (3c) with pyridinium hydrochloride

4-(1-Hydroxy-2-butynyl) pyridine 3c (0.18 g) in MeOH (8 mL), pyridinium hydrochloride (7 mg) yielded the two products separated by column chromatography (silica gel, CHCl₃/Hexane, 2/1).

1-Pyridin-4-yl-but-2-yn-1-one (**4c**): Yellow liquid (27 mg, 15%), UV (CH₂Cl₂): λ_{max} (\$247 (9050 M⁻¹ cm⁻¹). IR (CH₂Cl₂): 1206, 1223, 1271, 1467, 1710, 2398, 2872, 2886, 2928, 2958, 3016, 3024 cm⁻¹. ¹H NMR (400 MHz, CDCl₃): δ 2.17 (s, 3H), 7.68 (d, J = 5.8 Hz, 2H), 8.81 (d, J = 5.8 Hz). ¹³C NMR (100 MHz, CDCl₃): δ 29.7, 78.6, 94.7, 122.1, 142.4, 150.8, 177.0, MS (EI): *m/z* 145 [M]⁺. HRMS Calcd for C₃H₂NO: 145.1580. Found: 145.1577.

(E)-*1-Pyridin-4-y1-but-2-en-1-one* (**5c**): Yellow liquid (88 mg, 49%), UV (CH₂Cl₂): λ_{max} (ε) 249 (9300 M⁻¹ cm⁻¹). IR (CH₂Cl₂): 1228, 1296, 1336, 1441, 1555, 1595, 1625, 1676, 3018, 3024 cm⁻¹. ¹H NMR (400 MHz, CDCl₃): δ 2.04 (dd, J = 1.6 Hz, J = 6.9 Hz, 3H), 6.81 (dq, J = 1.6 Hz, J = 3.2 Hz, J = 15.4 Hz, 1H), 7.07–7.16 (m, 1H), 7. 69 (d, J = 5.8 Hz, 2H), 8.80 (d, J = 5.8 Hz, 2H). ¹³C NMR (100 MHz, CDCl₃): δ 18.8, 121.7, 127.2, 144.3, 147.7, 150.7, 190.1. MS (EI): m/2 147 [M]⁺. HRMS Calcd for C₉H₉NO: 147.1739. Found: 147.1735.

Reaction of 4-(1-hydroxy-3-phenyl-2-propynyl) pyridine (3d) with pyridinium hydrochloride

3-Phenyl-1-(pyridine-4-yl) prop-2-yn-1-ol (**3d**) (0.20 g) in MeOH (5 mL), pyridinium hydrochloride (5.5 mg) yielded two products separated by column chromatography (silica gel, hexane/EtOAc, 1/1).

(E)-*1-Pyridin-4-yl-3-phenyl-prop-2-en-1-one* (**5d**) (0.11 g, 55%). m.p. 75–76°C. UV (CH₂Cl₂): λ_{max} (ɛ) 235 (14800), 308 (14600). IR (CH₂Cl₂): 1149, 1261, 1416, 1541, 2291, 2397, 2516, 2675, 2980, 3046, 3682, 3755 cm⁻¹. ¹H NMR (500 MHz, CDCl₃): δ 7.39 (d, J = 15.7 Hz, 1H), 7.43 (m, 3H), 7.63 (m, 2H), 7.76 (d, J = 5.4 Hz, 2H), 7.81 (d, J = 15.7 Hz, 1H), 8.82 (d, J = 5.4 Hz, 2H), 7.81 (d, J = 15.7 Hz, 1H), 8.82 (d, J = 5.4 Hz, 2H), 7.81 (d, J = 15.7 Hz, 121.5, 128.6, 129.1, 131.2, 134.3, 144.4, 146.8, 150.7, 189.8. MS (FAB⁺): m/2 210 [M + H]⁺. Anal. Calcd for C₁₄H₁₁NO (209.2): C, 80.36; H, 5.30; N, 6.69. Found: C, 80.40; H, 5.29; N, 6.72%.

Reaction of 4-(1-hydroxy-4, 4-dimethyl-2-pentynyl) pyridine (3e) *with pyridinium hydrochloride*

4-(1-Hydroxy-4, 4-dimethyl-2-pentynyl) pyridine (3e) (0.57 g) in MeOH (10 mL) pyridinium hydrochloride (17 mg) yielded after column chromatography (silica gel, hexane/EtOAc, 9/1) two products.

(E)-1-Pyridin-4-yl-4,-4-dimethyl-pent-2-en-1-one (**5e**): (0.43 g, 75%), UV (CHCl₃): λ_{max} (z) 235 (11300), IR (CH₂Cl₂); 1220, 1300, 1334, 1610, 1652, 1671, 2206, 2297, 2859, 2959, 3044 cm⁻¹. ¹H NMR (400 MHz, CDCl₃): à 1.05 (s, 9H), 6.59 (d, J = 15.8 Hz, 1H), 7.01 (d, J = 15.8 Hz, 1H), 7.57 (d, J = 5.7 Hz, 2H), 8.68 (d, J = 5.7 Hz, 2H), ¹³C NMR (100 MHz, CDCl₃): à 28.5, 34.3, 120.4, 121.5, 114.5, 150.5, 161.7, 190.6. MS (FAB⁺): m/z 190 [M + H]⁺, Anal. Calcd for C₁₂H₁₅NO (189.3): C, 76.16; H, 7.99; N, 7.40. Found: C, 76.13; H, 8.66; N, 7.35%.

(E)-1-Quinolin-4-yl-3-trimethylsilanyl-prop-2-en-1-one (**5f**): 4-(1-Hydroxy-3-trimethylsilanyl-2-propynyl) quinoline (**3f**) (0.42 g) in MeOH (8 mL) pyridinium hydrochloride (9.5 mg, For the p-toluenesulfonate and the triflate pyridinium salts the same molar amount was used), yielded after column chromatography (hexane/ EtOAc 4/1) one product **5f** (0.231 g, 55%), as a yellow liquid. UV (CH₂Cl₂): λ_{max} (a) 232 (11200), 317 (2450 M⁻¹ cm⁻¹), IR (CH₂Cl₂): 1463, 1509, 1579, 1603, 1658, 1726, 2332, 2862, 2932, 3374, 3610 cm⁻¹. ¹H NMR (400 MHz, CDCl₃): à 0.14 (s, 9H), 6.95 (d, J = 15.3 Hz, 1H), 7.09 (d, J = 15.3 Hz, 1H), 7.39 (d, J = 3.4 Hz, 1H), 7.58 (t, J = 5.6 Hz, J = 12.2 Hz, 1H), 7.74 (t, J = 5.6 Hz, J = 12.2 Hz, 1H), 8.15 (d, J = 7.0 Hz, 1H), 8.98 (d, J = 3.4 Hz, 1H), 1³C NMR (100 MHz, CDCl₃): à -1.9, 119.4, 125.3, 127.7, 129.9 (2C), 141.7, 143.9, 148.7, 149.5, 154.0, 155.4, 194.6, MS (EI): m/e (%): 255 [M]⁺(50), 240 (100), 183 (10), 156 (15), 128 (20). Anal. Calcd for C₁₅H₁₇NOSi (255.4): C, 70.54; H, 6.71; N, 5.48. Found: C, 70.51; H, 6.74; N, 5.50%.

Reaction of 4-(1-hydroxy-2-butynyl) quinoline $(\mathbf{3g})$ with pyridinum hydrochloride

4(1-Hydroxy-2-butynyl) quinoline (**3g**) (0.22 g) in MeOH (10 mL), pyridinium hydrochloride (6.4 mg) yielded after column chromatography (silica gel, hexane/EtOAc, 4/1) two products.

(E)-*1-Quinolin-4-yl-but-2-en-1-one* (5g): Orange liquid (79 mg, 36%). UV (CHCl₃): λ_{max} (ϵ) 243 (9700), 306 (2800), 317(2900). IR (CH₂Cl₂): 1264, 1282, 1456, 1503, 1539, 1621, 1653, 1683, 1716, 1732, 1771, 1843, 2401, 2851, 2925 cm⁻¹. ¹H NMR (400 MHz, CDCl₃): δ 2.0 (dd, J = 1.1 Hz, J = 6.8 Hz, 3H), 6.62 (dd, J = 1.1 Hz, J = 15.7 Hz, 1H), 6.82 (septet, 1H), 7.41 (d, J = 3.6 Hz, 1H), 7.59 (t, J = 7.3 Hz, J = 15.3 Hz, 1H), 8.18 (d, J = 8.5 Hz, 1H), 9.0 (d, J = 3.6 Hz, 1H), 8.02 (d, J = 8.5 Hz, 1H), 8.18 (d, J = 8.5 Hz, 1H), 9.0 (d, J = 3.6 Hz, 1H), ¹³C NMR (100 MHz, CDCl₃): δ 30.2, 119.2, 124.7, 125.4 (2C), 127.8, 129.9, 130.1, 132.4, 144.8, 148.8, 149.6, 195.0 MS (EI): *m/z* 197 [M]⁺. Anal. Calcd for C₁₃H₁₁NO (197.2): C, 79.16; H, 5.62; N, 7.10. Found: C, 79.18; H, 5.59; N, 7.7%.

Reaction of 4-(1-hydroxy-4, 4-dimethyl-2-pentynyl) quinoline (3h) with pyridinium hydrochloride

4-(1-Hydroxy-4, 4-dimethyl-2-pentynyl) quinoline (**3h**) (0.40 g) in MeOH (10 mL), pyridiniym hydrochloride (9.6 mg) yielded after column chromatography (silica, hexane/EtOAc, 9/1) three products.

1-Quinolin-4-yl-4, *4-dimethyl-pent-2-yn-1-one* (**4h**): (0.103 g, 26%). UV (CH₂Cl₂): λ_{max} (c) 250 (12100), 328 (6400). IR (CH₂Cl₂): 1508, 1652, 2204, 2974 cm⁻¹. ¹H NMR (500 MHz, CDCl₃): δ 1.37 (s, 9H), 7.64 (ddd, J = 1.2 Hz, J = 6.8 Hz, 1H), 7.74 (ddd, J = 1.2 Hz, J = 6.8 Hz, 1H), 8.15 (d, J = 8.1 Hz, 1H), 8.07 (d, J = 4.4 Hz, 1H), 8.15 (d, J = 8.1 Hz, 1H), 8.08 (d, J = 4.4 Hz, 1H), 8.15 (d, J = 8.1 Hz, 1H), 8.88 (d, J = 8.1 Hz, 1H), 9.08 (d, J = 4.4 Hz 1H). ¹³C NMR (125 MHz, CDCl₃): δ 28.1, 29.9, 79.5, 104.5, 123.9, 124.0, 125.5, 128.8, 129.8 (2C), 139.8, 149.2, 149.8, 179.3. MS (FAB⁺): *m/z* 238 [M + H]⁺. Anal. Calcd for C₁₆H₁₅NO: C, 80.98; H, 6.37; N, 5.90. Found: C, 80.85; H, 6.45; N, 6.01%.

(E)-*1-Quinolin-4-yl-4*, *4-dimethyl-pent-2-en-1-one* (**5h**): (0.149 g, 37%). UV (CH₂Cl₂): λ_{max} (ɛ) 230 (13400), 307 (2940), 317 (2940). IR (CH₂Cl₂): 1651, 2303, 2955, 3060 cm⁻¹. ¹H NMR (400 MHz, CDCl₃): δ 1.06 (s, 9H), 6.48 (d, *J* = 16.1 Hz, 1H), 6.77 (d, *J* = 16.1 Hz, 1H), 7.71 (ddd, *J* = 4.3 Hz, 1H) 7.55 (ddd, *J* = 1.1 Hz, *J* = 7.0 Hz, 1H), 7.71 (ddd, *J* = 1.1 Hz, *J* = 7.0 Hz, 1H), 8.01 (d, *J* = 8.5 Hz, 1H), 8.96 (d, *J* = 4.3 Hz, 1H). ¹³C NMR (100 MHz, CDCl₃): δ 28.6, 34.5, 119.4, 124.7, 125.5, 125.9, 127.7, 129.9, 130.0, 144.7, 148.9, 149.7, 163.5, 195.6. MS (FAB⁺): *m/z* 240 [M + H]⁺. Anal. Calcd for C₁₆H₁₇NO: C, 80.30; H, 7.16; N, 5.85. Found: C, 80.41; H, 7.01; N, 6.05%.

(Z)-1-Quinolin-4-yl-4, 4-dimethyl-pent-2-en-1-one (**5h**): (18% evaluated from NMR spectrum) ¹H NMR (400 MHz, CDCl₃): δ 1.16 (s, 9H), 6.08 (d, J = 13.1 Hz, 1H), 6.27 (d, J = 13.1 Hz, 1H), 7.56–7.60 (m, 2H), 7.68 (ddd, J = 1.3 Hz, J = 6.9 Hz, 1H), 8.10 (d, J = 8.4 Hz, 1H), 8.95 (d, J = 4.3 Hz, 1H).

Reaction of 4-(1-hydroxy-3-phenyl-2-propynyl) quinoline (3i) *with pyridinium hydrochloride*

4-(1-Hydroxy-3-phenyl-2-propynyl) quinoline (**3i**) (0.70 g) in MeOH (10 mL), pyridinium hydrochloride (16 mg) yielded after column chromatography (silica gel, hexane/EtOAc, 9/1) two products.

1-Quinolin-4-yl-3-phenyl-prop-2yn-1-one (**4i**): (0.17 g, 24%). UV (CH₂Cl₂): λ_{max} (ɛ) 230 (25200), 309 (13200). IR (CH₂Cl₂): 1605, 2354, 3679 cm⁻¹. ¹H NMR (400 MHz, CDCl₃): δ 7.43–7.47 (m, 2H), 7.50 (m, 1H), 7.69–7.74 (m, 3H), 7.78–7.83 (m, 1H), 8.21 (d, J = 8.5 Hz, 1H), 8.25 (d, J = 4.4 Hz, 1H), 8.98 (d, J = 8.5 Hz, 1H), 9.15 (d, J = 4.4 Hz, 1H). ¹³C NMR (100 MHz, CDCl₃): δ 88.2, 93.8, 119.7, 124.1, 125.7, 128.9, 129.2, 130.2, 131.4, 133.3, 139.7, 149.4, 150.1, 179.1. MS (FAB⁺). *m*/2 258 [M + H]⁺. Anal. Calcd for Cl₈H₁₁NO: C, 84.03; H, 4.31; N, 5.44. Found: C, 84.11; H, 4.23; N, 5.49%.

(E)-*1-Quinolin-4-yl-3-phenyl-prop-2-en-1-one* (**5i**): (0.15 g, 21%). UV (CH₂Cl₂): λ_{max} (ɛ) 230 (21300), 305 (17200). IR (CH₂Cl₂): 1599, 2156, 2191 cm⁻¹. ¹H NMR (500 MHz, CDCl₃): ö 7.18 (d, *J* = 16.1 Hz, 1H), 7.35–7.40 (m, 3H), 7.47–7.53 (m, 4H), 7.57 (t, *J* = 7.8 Hz, *J* = 15.2 Hz, 1H), 7.74 (t, *J* = 7.8 Hz, *J* = 15.2 Hz, 1H), 8.07 (d, *J* = 8.4 Hz, 1H), 8.17 (d, *J* = 8.4 Hz, 1H), 9.01 (d, *J* = 4.1 Hz, 1H). ¹³C NMR (125 MHz, CDCl₃): ô 119.2, 124.5, 126.2, 127.8, 129.1, 129.5, 129.9, 130.0, 131.3, 133.9, 144.6, 148.0, 148.7, 149.6, 194.7. MS (FAB⁺): *m/z* 260 [M + H]⁺. Anal. Calcd for C₁₈H₁₃NO: C, 83.37; H, 5.05; N, 5.40. Found: C, 83.31; H, 5.07; N, 5.49%.

(E)-*1-Pyridin-2-yl-3-trimethylsilanyl-prop-2-en-1-one* (**5k**): Obtained from 2-(1-hydroxy-3-trimethylsilanyl-2-propynyl)pyridine **3k** with pyridinium hydrochloride as above in a yield of 42%. ¹H NMR (400 MHz, CDCl₃): δ 0.12 (s, 9H), 7.37 (ddd, J = 1.0 Hz, J = 4.7 Hz, 1H), 7.44 (d, J = 18.9 Hz, 1H), 7.83 (ddd, J = 2.0 Hz, J = 4.7 Hz, 1H), 8.01 (d, J = 18.9 Hz, 1H), 8.10 (d, J = 7.8 Hz, 1H), 8.70 (d, J = 4.7 Hz, 1H). ¹³C NMR (100 MHz, CDCl₃): $\delta -1.76$, 123.2, 126.7, 136.4, 136.9, 148.8, 150.2, 154.0, 188.4. IR (CH₂Cl₂): 1316, 1600, 1666, 2326, 2359, 2355, 3479 cm⁻¹. UV (CH₂Cl₂): λ_{max} (ϵ) 257 (11850). MS (FAB⁺): m/z 206 [M + H]⁺. Anal. Calcd for C₁₁H₁₅NOSi (205.3): C, 64.34; H, 7.36; N, 6.82. Found: C, 64.37; H, 7.31; N, 6.90%.

Reaction of 4-(1-hydroxy-3-trimethylsilanyl-2-propynyl) pyridine (3b) with pyridinium hydrochloride in MeO^2H

To a solution of 4-(1-hydroxy-3-trimethylsilanyl-2-propynyl) pyridine (3b) (0.15 g) in d-MeO²H (4.0 mL) was added pyridine hydrochloride (4.2 mg) at rt. After stirring for 6 h, water (5 mL) was added, extracted with CH₂Cl₂ (2 × 10 mL), dried over MgSO₄ and concentrated under vacuum to yield the product purified by column chromatography (silica gel, hexane/EtOAc, 4/1). (E)-1-pyridin-4-yl-3-trimethylsilanyl-prop-2-en-1-one **5b** was obtained in a yield of 51%. ¹H NMR (500 MHz, CDCl₃): $\delta 0.17(s, 9H)$, 7.64 (dd, J=4.5 Hz, J=1.6 Hz, 2H), 8.76 (dd, J=4.5 Hz J=1.6 Hz, 2L), 8.76 (dd, J=4.5 Hz, J=1.6 Hz, 2L), ¹³C NMR (125 MHz, CDCl₃): $\delta -1.9$, 121.7, 137.2, 143.7, 150.6, 152.4, 189.9. MS (FAB⁺): 208 [M + H]⁺. Anal. Calcd for C11H13D2NOSi (207.3): C, 63.72; H, 8.26; N, 6.76. Found: C, 63.69; H, 8.24; N, 6.79%.

Endo-2-(quinolin-4-yl-carbonyl)-exo-3-trimethylsilanylbicyclo[2.2.1]hepte-5-ene (16): A solution of the silylated enone **5f** (50 mg) and of cyclopentadiene (1 mL) in 0.1 M LiCl THF (1 mL) was left at 25 °C for 12 h. The reaction medium was chromatographed on a silica gel column (hexane–EtOAc, 9:1). The product 16 was isolated in a yield of 50%. Crystallised in MeOH:acetone (7:3) as a white solid, m.p. 87.4 °C. UV (MeOH) λ_{max} : 205 nm (0.7758), 232 (0.2188). IR (MeOH): 1679, 2974 cm⁻¹. ¹H NMR (CDCl₃, 400 MHz): δ 0.06 (s, 9H), 1.28–1.34 (m, 3H), 2.88 (s, 1H), 3.07 (s, 1H), 3.63 (q, J = 3.6 Hz, 1H), 5.63 (q, J = 3.2, 2.8 Hz, 1H), 6.41 (q, J = 3.2, 2.8 Hz, 1H), 7.54 (d, J = 4.4 Hz, 1H), 7.57 (m, 1H), 7.59 (t, J = 6.8 Hz, 1H), 7.75 (d, J = 8.4 Hz, 1H), 8.15 (d, J = 8.4 Hz, 1H), 9.0 (d, J = 4.4 Hz, 1H). ¹³C NMR (CDCl₃, 100 MHz): δ –1.85, 27.88, 44.5, 48.2, 48.9, 54.2, 118.1, 125.1, 127.9, 128.6, 129.7, 130.0, 139.5, 141.1, 145.4, 148.4, 149.3, 204.2. MS (FABMS): m/z 322 [M + H]⁺; Exact mass Calcd for C₂₀H₂₄ONS: 322.1627. Found: 322.1627.

Crystal structure determination

Diffraction measurements were made on an Enraf-Nonius CAD-4 diffratometer by use of graphite-monochromatised MoK α radiation ($\lambda = 0.7107$ Å). Unit cell parameters were obtained by least squares fit to the automatically centred settings for 25 reflections. Intensity data were collected by use of α -20 scan mode. All intensity data were collected for Lorentz polarisation and absorption (empirical ψ corrections). Crystallographic data (excluding structure factors) for the structures of enone (5d) and of the Diels–Alder adduct (16) have been deposited with the Cambridge Crystallographic Data Centre as supplementary publication no CCDC 658185 for enone (5d) and CCDC 658184 for D7A adduct (16). These data can be obtained free of charge via www.ccdc.cam.ac.uk/data_request/cif or by emailing data request@ccdc.cam.ac.uk or by contacting The Cambridge CB2 1EZ, UK; fax: + 44 1223 336033.

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