Available online at www.sciencedirect.com
ScienceDirect
Tetrahedron 64 (2008) 3794–3801
Tetrahedron
www.elsevier.com/locate/tet

Triazolopyridines. Part 26: The preparation of novel [1,2,3]triazolo[1,5-*a*]pyridine sulfoxides☆

Belén Abarca [a,*], Rafael Ballesteros [a], Rafael Ballesteros-Garrido [a,b], Françoise Colobert [b,*], Frédéric R. Leroux [b]

[a] *Departamento de Química Orgánica, Facultad de Farmacia, Universidad de Valencia, Avda. Vicente Andrés Estellés s/n, 46100 Burjassot, Valencia, Spain*
[b] *Laboratoire de stéréochimie associé au CNRS, Université Louis Pasteur (ECPM), 25 rue Becquerel, 67089 Strasbourg, France*

Received 29 November 2007; received in revised form 4 February 2008; accepted 5 February 2008
Available online 8 February 2008

Abstract

The regioselective synthesis of new triazolopyridine halides and sulfoxides with the substituent in all different ring positions of [1,2,3]triazolo[1,5-*a*]pyridines is presented. The triazolo ring opening reaction of some representative sulfoxides to obtain disubstituted pyridines is also studied.
Published by Elsevier Ltd.

Keywords: Nitrogenated heterocycles; Triazolopyridines; Sulfoxides; Palladium catalysis

1. Introduction

In the context of our study on the chemistry of [1,2,3]triazolo[1,5-*a*]pyridines we have reported their interest in coordination chemistry,[2] with applications in the field of magnetic materials,[2–4] they have also interesting optical properties, as its fluorescent behaviour,[5] that allow the obtainment of molecular chemosensors.[6]

Aryl sulfoxides are important compounds, the interest in these compounds stemmed, in part from their role as possible intermediates in homogeneous catalytic processes,[7] and in part from the fact that they are useful starting material for the synthesis of new organometallic and coordination compounds.[8] The use of aryl sulfoxides as efficient chelators of transition metals is almost unexplored. Recently we have reported the first synthesis of [1,2,3]triazolo[1,5-*a*]pyridine sulfoxides with a *p*-tolylsulfinyl substituent in 7-position by the Andersen method,[9] in low yields,[1] and in very good ones,[10] applying the Poli methodology.[11] The present article shows the preparation of new triazolopyridine sulfoxides with the sulfinyl substituent in all positions of the ring from the corresponding halotriazolopyridine, with the aim to synthesize new heterocyclic compounds for coordination.

2. Results and discussion

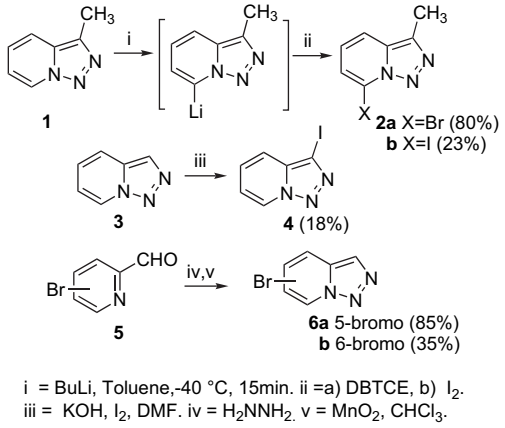
Some of us have reported the preparation of several halo-derivates from [1,2,3]triazolo[1,5-*a*]pyridines **1** and **3**. 7-Halotriazolopyridines **2** can be obtained by direct regioselective metallation of compound **1** followed by treatment with 1,2-dibromo-1,1,2,2-tetrachloroethane (DBTCE) as brominating agent or with iodine.[12–14] 3-Iodotriazolo-pyridine **4** was obtained by treating triazolopyridine **3** with iodine in DMF/KOH.[5,13] 5-Bromotriazolopyridine **6a**[14] and 6-bromotriazolopyridine **6b**[13] were prepared as they were described, and require halogenated carbaldehydes **5** as starting reagents (Scheme 1). These halotriazolopyridines are synthetic intermediates in the preparation of functionalized pyridines and bipyridines,[15] important compounds in coordination chemistry.[16]

However, the preparation of four halotriazolopyridines was not described. Using 3-bromo pyridine as starting reagent we are able now to prepare the unknown 4-bromo-3-methyl-

☆ See Ref. 1.

* Corresponding authors. Tel.: +34 963544933; fax: +34 963544939.
E-mail address: belen.abarca@uv.es (B. Abarca).

0040-4020/$ - see front matter Published by Elsevier Ltd.
doi:10.1016/j.tet.2008.02.011



Scheme 1. Preparation of known halotriazolopyridines.

[1,2,3]triazolo[1,5-*a*]pyridine **10** and 6-bromo-3-methyl-[1,2,3]triazolo[1,5-*a*]pyridine **12** using 2,5-dibromopyridine as starting material (Scheme 2).

3-Bromopyridine was protected at position 4 by direct metallation with LDA in THF trapping with TMSiCl giving **7** in good yield (70%),[17] then position 2 was functionalized with LiTMP, and after trapping with DMA, we obtained the 2-acetylpyridine **8**, that was directly transformed, without purification, by the classic method with hydrazine and MnO_2,[18] into a mixture of triazolopyridines **9** and **10**, that were isolated by chromatography.

Desilylation reaction of **9** to give **10** was performed in a heterogeneous system with Al_2O_3, KF in aqueous THF at reflux,[19] in quantitative yield. The 4-bromo-3-methyl-[1,2,3]triazolo[1,5-*a*]pyridine **10** was obtained in eight steps on gram scale with an overall yield of 52%. In order to obtain the new 6-bromo-3-methyl-[1,2,3]triazolo[1,5-*a*]pyridine **12** a regioselective halogen/metal exchange was performed on 2,5-dibromopyridine, as it is known, the bromine in position 2 reacts faster at −40 °C in toluene.[20] Trapping the 2-lithio derivative with DMA we obtained 1-(5-bromopyridin-2-yl)ethanone **11** that after reaction with hydrazine and MnO_2 gave triazolopyridine **12** almost pure with an excellent yield.

To obtain the sulfoxides we decided to apply the methodology developed by Poli,[11] that we had already used to prepare the sulfoxides **14** and **20** from triazolopyridines **2a** and **13** in good yield.[10] By this methodology we have now prepared the sulfoxides **15**, **17**–**19**. The halotriazoles **2a**, **6a** and **13**, in which the halogen is placed in a position that undergoes easily nucleophilic substitution (C7, C5 and C6′), gave in excellent yields **14**, **17** and **20** (entries 1, 4 and 7). We have observed that 6-bromo-3-methyl-[1,2,3]triazolo[1,5-*a*]pyridine **12** and 6-bromo-[1,2,3]triazolo[1,5-*a*]pyridine **6b** did not have the same reactivity (entries 2 and 3). Compound **12** gave sulfoxide **15** (32%) and 6-(*p*-tolylthio)-3-methyl-[1,2,3]triazolo[1,5-*a*]pyridine **21** (31%) (Fig. 1). Compound **6b** did not give the corresponding sulfoxide **16** and 6-(*p*-tolylthio)-[1,2,3]triazolo[1,5-*a*]pyridine **22** was the only isolated product in 36% yield. Traces of similar sulfur product **23** was also observed in the reaction with 4-bromo-3-methyl-[1,2,3]triazolo[1,5-*a*]pyridine **10**, nevertheless sulfoxide **18** was obtained in good yield (see Table 1).

It is known that the triazolopyridines are in equilibrium with a diazo form,[21] and that the position of the equilibrium

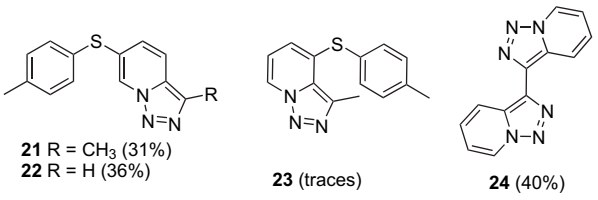
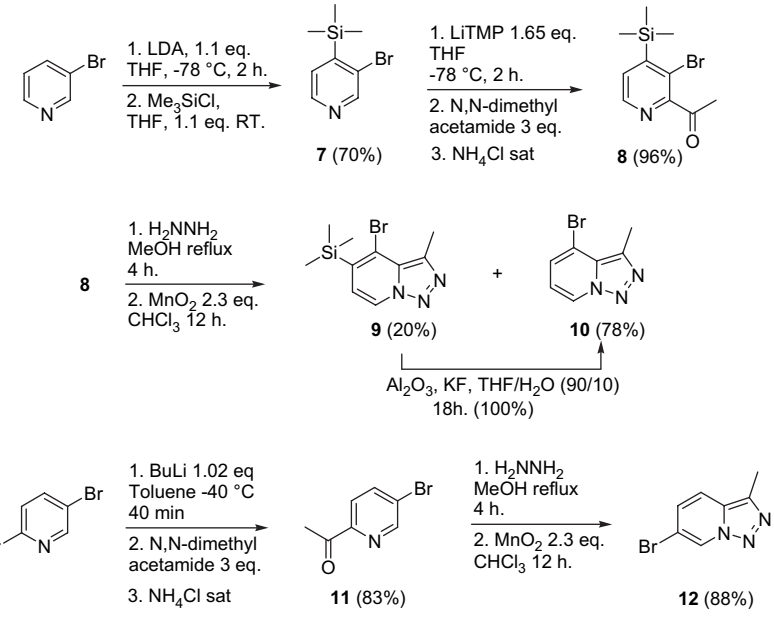
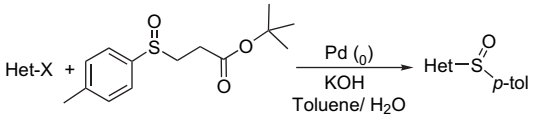


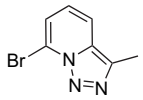
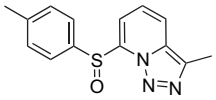
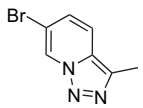
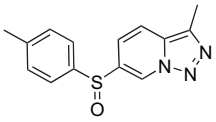
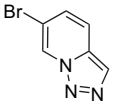
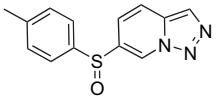
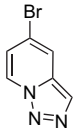
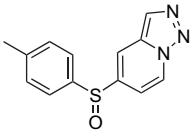
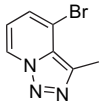
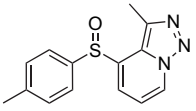
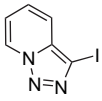
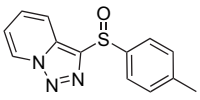
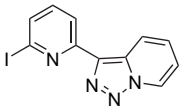
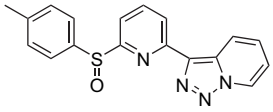
Figure 1.



Scheme 2. Preparation of new halotriazolopyridines.

Table 1
Scope of the reaction[a]



Entry	Halo-heterocycle		Product		Yield[b] (%)
1		**2a**		**14**[c]	82
2		**12**		**15**	32
3		**6b**		**16**	—
4		**6a**		**17**	84
5		**10**		**18**	80
6		**4**		**19**	20
7		**13**		**20**[c]	95

[a] Reagents and reaction conditions: aryl halide, β-sulfinylester (1.3 equiv), Pd_2dba_3 (5 mol %), xantphos (10 mol %), KOH (50% aqueous solution) in 1:1 toluene/H_2O at 109 °C.
[b] Yields are given for isolated products.
[c] Ref. 10.

depends on the substitution pattern on triazolopyridine.[22] The presence of an electron-withdrawing sulfoxide in position 6, as it is the case in **15** or **16**, shifts the equilibrium to the diazo form. The formation of thioethers **21** and **22** from the diazo form can be explained if we assume that a carbene intermediate is formed by extrusion of nitrogen,[23] and then is trapped by an oxygen transfer from the corresponding sulfoxide,[24] that on time is reduced to a thioether (Scheme 3).

3-Iodotriazolopyridine **4** provides the sulfoxide **19** in low yield, the major compound obtained in this case is the dimer **24** in 40% yield (Fig. 1). We have reported previously on a similar behaviour of compound **4**,[5] probably caused by a homocoupling Ullman reaction.[25]

3-Substituted-[1,2,3]triazolo[1,5-*a*]pyridines react with electrophiles by a triazolo ring opening reaction with loss of nitrogen yielding 2,6-disubstituted pyridines.[26] We have studied now the triazolo ring opening reaction of the most interesting sulfoxides **14**, **18** and **20** with the aim to obtain unknown, and so far by other procedures unavailable, sulfinyl-2-substituted pyridines. The reactions were performed with acetic acid or 2.5 M sulfuric acid as electrophiles. Treatment of compound **14** with aqueous sulfuric acid gave the alcohol **25** (95%) as a diastereoisomeric mixture, 5% de (determined by NMR), and with acetic acid the acetate **26** (89%, 7% de) was obtained. Small quantities of the elimination product, the vinylpyridine **27**, were also formed (Scheme 4).

Treatment of compound **18** with glacial acetic acid gave the acetate **28** also as a diastereomeric mixture (10% de).

Reaction of compound **20** with glacial acetic acid provides the acetate **29** in 56% yield (5% de). When the reaction was performed with sulfuric acid the alcohol **30** was isolated together with the oxidation product, the ketone **31**. In fact alcohol **30** is spontaneously oxidized at air to provide the ketone **31**. This compound is very interesting as a new building block in cluster chemistry[27] (Scheme 5).

In summary we have completed a new family of triazolopyridine sulfoxides, we have developed a very efficient synthesis of unknown 4-bromo-3-methyl- and 6-bromo-3-methyltriazolopyridines and we have studied the triazolo ring opening reactions of some representative triazolopyridine sulfoxides. Luminescent and coordinating properties of these triazolopyridine sulfoxides are presently in progress.

3. Experimental

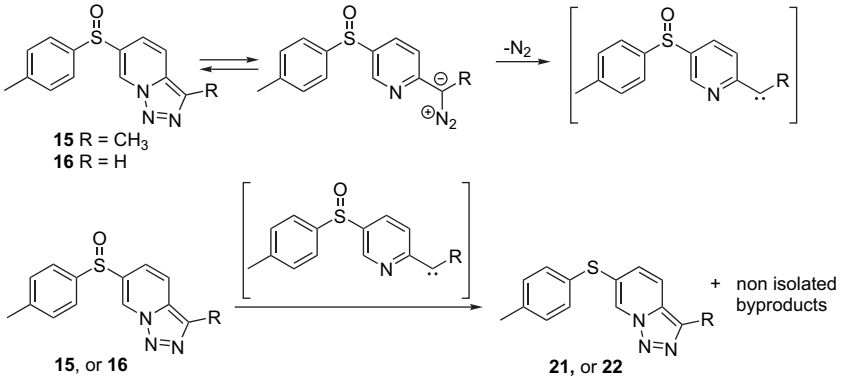
3.1. General

Melting points were determined on a Kofler heated stage and are uncorrected. NMR spectra were recorded on a Bruker AC300 MHz in $CDCl_3$ as solvent. COSY experiments were done for all compounds. HRMS (EI) determinations were made using a VG Autospec Trio 1000 (Fisons). All the lithiation reactions were done under inert atmosphere and dry solvents.[28]

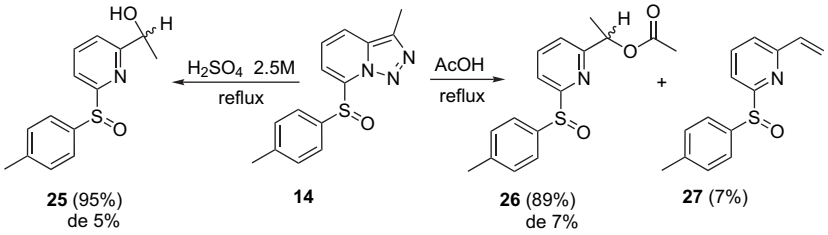
3-Bromo-4-(trimethylsilyl)pyridine (**7**),[17] 7-bromo-3-methyl-[1,2,3]triazolo[1,5-*a*]pyridine (**2a**),[29] 6′-iodo-3-(2′-pyridyl)-[1,2,3]triazolo[1,5-*a*]pyridine (**13**),[22] 3-iodo-[1,2,3]triazolo[1,5-*a*]pyridine (**4**),[5] 5-bromo-[1,2,3]triazolo[1,5-*a*]pyridine (**6a**),[14] 6-bromo-[1,2,3]triazolo[1,5-*a*]pyridine (**6b**)[14] and β-sulfinylester[11] were prepared as described elsewhere.

3.2. 1-(3-Bromo-4-(trimethylsilyl)pyridin-2-yl)ethanone (8)

At 0 °C, butyllithium (13 mL, 21 mmol, 1.65 equiv) in hexane (1.6 M) was added to a solution of tetramethylpiperidine (2.9 mL, 2.4 g, 21 mmol, 1.7 equiv) in tetrahydrofuran (15 mL). After 15 min, the mixture was cooled to −78 °C and 3-bromo-4-(trimethylsilyl)pyridine (**7**) (2.9 g, 13 mmol, 1.0 equiv) in tetrahydrofurane (8 mL) was added dropwise. The mixture was kept for 40 min at −78 °C before *N*,*N*-



Scheme 3.

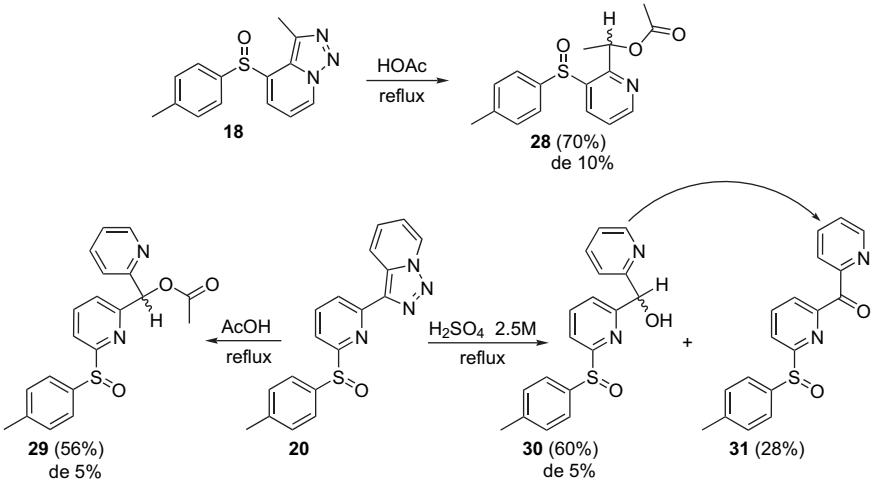


Scheme 4.

dimethylacetamide (3 mL, 2.8 g, 32 mmol, 2.5 equiv) was added and allowed to arrive to 20 °C (1 h). The reaction mixture was quenched with a saturated aqueous solution of NH_4Cl (10 mL). Then the resulting mixture was extracted with dichloromethane (3×50 mL). The organic extracts were combined, washed with brine (10 mL), dried over Na_2SO_4, filtered and concentrated providing 1-(3-bromo-4-(trimethylsilyl)pyridin-2-yl)ethanone (**8**) as brown oil, 3.4 g, 96%. HRMS found for M^+ 271.0041; $C_{10}H_{14}NOSiBr$ requires 271.0028. ^1H NMR (300 MHz, $CDCl_3$) δ=8.34 (d, J=4.6 Hz, 1H), 7.26 (d, J=4.6 Hz, 1H), 2.52 (s, 3H), 0.30 (s, 9H). ^{13}C NMR (75.5 MHz, $CDCl_3$) δ=201.0 (C), 154.1 (C), 146.1 (CH), 139.0 (C), 131.7 (CH), 123.3 (C), 28.8 (CH_3), 0.9 ($3CH_3$). EM (EI) *m/z* (%) 273 (80), 271 (85), 259 (100), 257 (96), 245 (29), 243 (30), 228 (23), 230 (33), 216 (30), 214 (37), 193 (45), 73 (45).

*3.3. 4-Bromo-3-methyl-5-trimethylsilanyl-[1,2,3]triazolo[1,5-a]-pyridine (**9**) and 4-bromo-3-methyl-[1,2,3]triazolo[1,5-a]-pyridine (**10**)*

A mixture of 1-(3-bromo-4-(trimethylsilyl)pyridin-2-yl)-ethanone (**8**) (1.4 g, 4.9 mmol, 1 equiv) and hydrazine monohydrate (5 mL, 5.2 g, 103 mmol) was heated at 50 °C for 20 min. Then methanol was added (17 mL) and the mixture was heated to reflux. The reaction was monitored by TLC upon completion



Scheme 5.

of the reaction (3 h). The reaction mixture was quenched with an aqueous solution of NaOH (20 mL, 30%), and the resulting mixture was extracted with dichloromethane (3×50 mL). The organic extracts were combined, washed with brine (20 mL), dried over Na_2SO_4, filtered and concentrated providing the corresponding hydrazone. The hydrazone was directly diluted in chloroform (13 mL) then activated manganese dioxide (1.5 g, 17 mmol) was added and the heterogeneous mixture was heated to reflux overnight. The resulting mixture was cooled to rt and filtrated with Celite and concentrated. Chromatotron (silica gel, ethyl acetate/cyclohexane gradient) provided 4-bromo-3-methyl-[1,2,3]triazolo[1,5-*a*]pyridine (**10**) that was obtained as a white solid, 820 mg, 78%. Mp 160–161 °C. HRMS found for M^+ 210.9747; $C_7H_6N_3Br$ requires 210.9745. ^1H NMR (300 MHz, $CDCl_3$) δ=8.59 (d, J=7.0 Hz, 1H), 7.33 (d, J=7.0 Hz, 1H), 6.75 (t, J=7.0, 7.08 Hz, 1H), 2.83 (s, 3H). ^{13}C NMR (75.5 MHz, $CDCl_3$) δ=138.7 (C), 130.3 (C), 127.1 (CH), 124.5 (CH), 115.1 (CH), 112.3 (C), 12.7 (CH_3). EM (EI) *m/z* (%) 213 (21), 211 (22), 185 (19), 184 (37), 183 (20), 182 (38), 159 (40), 157 (43), 104 (100), 78 (62) and 4-bromo-3-methyl-5-trimethylsilanyl-[1,2,3]triazolo[1,5-*a*]pyridine (**9**), 270 mg, 20%. Mp 111–114 °C. HRMS found for M^+ 283.0152; $C_{10}H_{14}N_3BrSi$ requires 283.0140. ^1H NMR (300 MHz, $CDCl_3$) δ=8.51 (d, J=7.0 Hz, 1H), 6.82 (d, J=7.0 Hz, 1H), 2.82 (s, 3H), 0.42 (s, 9H). ^{13}C NMR (75.5 MHz, $CDCl_3$) δ=137.2 (C), 136.0 (C), 129.9 (C), 124.5 (CH), 120.1 (C), 119.6 (CH), 13.6 (CH_3), 0.7 ($3CH_3$). EM (EI) *m/z* (%) 285 (48), 283 (46), 257 (30), 256 (42), 255 (30), 254 (38), 242 (72), 241 (35), 240 (67), 239 (27), 176 (100), 160 (91), 139 (58), 137 (55), 118 (35), 73 (20).

3.4. 4-Bromo-3-methyl-[1,2,3]triazolo[1,5-a]pyridine (*10*)

To a stirred solution of **9** (100 mg, 0.35 mmol, 1 equiv) in tetrahydrofurane (43 mL) and water (7 mL), potassium fluoride in alumina (40%) (211 mg) was added at 25 °C. The resulting mixture was heated at 66 °C and stirred for 16 h. Then it was filtrated, diluted with CH_2Cl_2 (50 mL), dried over Na_2SO_4, filtered and concentrated giving **10** as a white solid, 74 mg, 99%.

3.5. 1-(5-Bromopyridin-2-yl)ethanone (*11*)

At −40 °C, butyllithium (13 mL, 21 mmol, 1 equiv) in hexane (1.6 M) was added to a solution of 2,5-dibromopyridine (4.9 g, 21 mmol, 1.7 equiv) in toluene (210 mL). The mixture was kept for 40 min at −40 °C before *N*,*N*-dimethylacetamide (3.5 mL, 3.6 g, 37 mmol, 1.7 equiv) was added and allowed to arrive to 20 °C (1 h). The reaction mixture was quenched with a saturated aqueous solution of NH_4Cl (20 mL). Then the resulting mixture was extracted with dichloromethane (3×50 mL). The organic extracts were combined, washed with brine (20 mL), dried over Na_2SO_4, filtered and concentrated providing 1-(5-bromopyridin-2-yl)ethanone (**11**) as brown solid, 3.5 g, 83%. Mp 109–111 °C. HRMS found for M^+ 198.9634; C_7H_6NOBr requires 198.9632. ^1H NMR (300 MHz, $CDCl_3$) δ=8.71 (d, J=1.87 Hz, 1H), 7.90 (dd, J=7.0, 1.87 Hz, 1H), 7.86 (d, J=7.0 Hz, 1H), 2.67 (s, 3H). ^{13}C NMR (75.5 MHz, $CDCl_3$) δ=199.2 (C), 151.8 (C), 150.1 (CH), 139.5 (CH), 125.3 (C), 122.9 (CH), 25.7 (CH_3). EM (EI) *m/z* (%) 201 (98), 199 (100), 186 (45), 184 (45), 173 (48), 171 (50), 159 (67), 158 (75), 157 (69), 156 (73).

3.6. 6-Bromo-3-methyl-[1,2,3]triazolo[1,5-a]pyridine (*12*)

A mixture of 1-(5-bromopyridin-2-yl)ethanone (**11**) (3.5 g, 17.5 mmol, 1 equiv) and hydrazine monohydrate (10 mL, 10.4 g, 206 mmol) in methanol (50 mL) was heated to reflux. The reaction was monitored by TLC upon completion of the reaction (3 h). The reaction mixture was quenched with an aqueous solution of NaOH (20 mL, 30%), and the resulting mixture was extracted with dichloromethane (3×50 mL). The organic extracts were combined, washed with brine (20 mL), dried over Na_2SO_4, filtered and concentrated providing the corresponding hydrazone. The hydrazone was directly diluted in chloroform (13 mL) then activated manganese dioxide (3.7 g, 42 mmol) was added and the heterogeneous mixture was heated to reflux overnight. The resulting mixture was cooled to rt and filtrated with Celite. After concentration 6-bromo-3-methyl-[1,2,3]triazolo[1,5-*a*]pyridine (**12**) was obtained as a yellow solid, 3.3 g, 88%. Mp 116–119 °C. HRMS found for M^+ 210.9748; $C_7H_6N_3Br$ requires 210.9745. ^1H NMR (300 MHz, $CDCl_3$) δ=8.79 (dd, J=1.46, 0.85 Hz, 1H), 7.51 (dd, J=9.32, 0.85 Hz, 1H), 7.22 (dd, J=9.31, 1.46 Hz, 1H), 2.60 (s, 3H). ^{13}C NMR (75.5 MHz, $CDCl_3$) δ=135.2 (C), 130.2 (C), 127.4 (CH), 125.3 (CH), 117.8 (CH), 110.5 (C), 10.5 (CH_3). EM (EI) *m/z* (%) 213 (32), 211 (31), 185 (66), 184 (100), 183 (72), 182 (96), 159 (93), 157 (95), 104 (28), 78 (67).

3.7. General procedure for palladium-catalyzed arylation of sulfenate anions under biphasic conditions

To a solution of $Pd_2(dba)_3$ (5 mol %) in toluene (0.500 mL) was added xantphos (10 mol %). The solution was stirred at rt for 5 min. Then, a solution of a heteroarylbromide (0.5 mmol in 1.5 mL of toluene), β-sulfinylester (0.7 mmol in 1.5 mL of toluene), distilled water (3.5 mL) and 50% aqueous KOH solution (10 mmol) were successively added. The resulting biphasic system was stirred and heated to reflux. The reaction was monitored by TLC. Upon completion of the reaction (2–4 h) and cooling to rt, the aqueous phase was extracted with dichloromethane (3×50 mL). The combined organic layers were dried over anhydrous Na_2SO_4 and the solvent was removed under reduced pressure.

7-(*p*-Tolylsulfinyl)-3-methyl-[1,2,3]triazolo[1,5-*a*]pyridine (**14**) and 3-(6′-(*p*-tolylsulfinyl) pyridine-2′-yl)-[1,2,3]triazolo[1,5-*a*]pyridine (**20**) were prepared as described elsewhere.[10]

3.8. 3-Methyl-6-(p-tolylsulfinyl)-[1,2,3]triazolo[1,5-a]-pyridine (*15*)

Prepared from 6-bromo-3-methyl-[1,2,3]triazolo[1,5-*a*]pyridine (**12**) (0.5 g, 2.5 mmol). The crude product was purified by flash chromatography (ethyl acetate/cyclohexane, 1:5→

3:1) affording 3-methyl-6-(*p*-tolylsulfinyl)-[1,2,3]triazolo[1,5-*a*]pyridine (**15**) as a yellow solid, 213 mg, 32%. Mp 152–154 °C. HRMS found for M^+ 271.0778; $C_{14}H_{13}N_3OS$ requires 271.0779. ^{1}H NMR (300 MHz, $CDCl_3$) δ=9.05 (d, J=1.37 Hz, 1H), 7.59 (m, 3H), 7.31 (d, J=8.3 Hz, 2H), 7.06 (dd, J=9.26, 1.37 Hz, 1H), 2.58 (s, 3H), 2.39 (s, 3H). ^{13}C NMR (75.5 MHz, $CDCl_3$) δ=142.9 (C), 140.1 (C), 137.3 (C), 133.3 (C), 132.1 (C), 130.4 (CH), 125.0 (CH), 123.4 (CH), 119.1 (CH), 118.6 (CH), 21.5 (CH_3), 10.3 (CH_3). EM (EI) *m/z* (%) 271 (26), 243 (27), 226 (30), 195 (64), 139 (100), 123 (62), 91 (40), 65 (50) and 3-methyl-6-(*p*-tolylthio)-[1,2,3]triazolo[1,5-*a*]pyridine (**21**) as a yellow solid, 198 mg, 31%. Mp 87–90 °C. HRMS found for M^+ 255.0833; $C_{14}H_{13}N_3S$ requires 255.0830. ^{1}H NMR (300 MHz, $CDCl_3$) δ=8.36 (br s, 1H), 7.44 (dd, J=9.1, 0.9 Hz, 1H), 7.32 (d, J=8.1 Hz, 2H), 7.15 (d, J=8.1 Hz, 2H), 7.00 (dd, J=9.1, 1.4 Hz, 1H), 2.54 (s, 3H), 2.33 (s, 3H). ^{13}C NMR (75.5 MHz, $CDCl_3$) δ=139.0 (C), 134.7 (C), 132.8 (CH), 130.5 (CH), 130.2 (C), 128.5 (C), 126.6 (C), 126.3 (CH), 123.7 (CH), 117.0 (CH), 21.1 (CH_3), 10.3 (CH_3). EM (EI) *m/z* (%) 255 (10), 227 (100), 226 (67), 123 (15), 91 (25), 65 (20).

3.9. 6-(p-Tolylthio)-[1,2,3]triazolo[1,5-a]pyridine (22)

Prepared from 6-bromo-[1,2,3]triazolo[1,5-*a*]pyridine (**6b**) (99 mg, 0.5 mmol). The crude product was purified by chromatotron (silica, ethyl acetate/cyclohexane gradient) affording 6-(*p*-tolylthio)-[1,2,3]triazolo[1,5-*a*]pyridine (**22**) as a yellow solid, 40 mg, 36%. Mp 80–83 °C. HRMS found for M^+ 241.0680; $C_{13}H_{11}N_3S$ requires 241.0674. ^{1}H NMR (300 MHz, $CDCl_3$) δ=8.48 (s, 1H), 8.00 (s, 1H), 7.60 (d, J=9.2 Hz, 1H), 7.38 (d, J=8.1 Hz, 2H), 7.21 (d, J=8.0 Hz, 2H), 7.12 (d, J=9.2 Hz, 1H), 2.38 (s, 3H). ^{13}C NMR (75.5 MHz, $CDCl_3$) δ=139.3 (C), 133.1 (CH), 132.2 (C), 130.7 (CH), 128.1 (C), 127.7 (CH), 127.3 (C), 125.8 (CH), 123.4 (CH), 117.4 (CH), 21.2 (CH_3). EM (EI) *m/z* (%) 243 (3), 241 (57), 213 (100), 212 (58), 198 (20), 171 (21), 123 (15), 91 (10).

3.10. 5-(p-Tolylsulfinyl)-[1,2,3]triazolo[1,5-a]pyridine (17)

Starting material 5-bromo-[1,2,3]triazolo[1,5-*a*]pyridine (**6a**) (100 mg, 0.5 mmol). The crude product was purified by chromatotron (silica, ethyl acetate/cyclohexane, 1:4→2:1) affording 5-(*p*-tolylsulfinyl)-[1,2,3]triazolo[1,5-*a*]pyridine (**17**) as a yellow solid, 108 mg, 84%. Mp 134–135 °C. HRMS found for M^+ 257.0622; $C_{13}H_{11}N_3OS$ requires 257.0623. ^{1}H NMR (300 MHz, $CDCl_3$) δ=8.67 (d, J=7.3 Hz, 1H), 8.23 (m, 1H), 8.18 (d, J=0.95 Hz, 1H), 7.56 (d, J=8.0 Hz, 2H), 7.3 (d, J=8.0 Hz, 2H), 6.88 (dd, J=7.3, 1.7 Hz, 1H), 2.38 (s, 3H). ^{13}C NMR (75.5 MHz, $CDCl_3$) δ=144.1 (C), 143.1 (C), 140.3 (C), 132.8 (C), 130.5 (CH), 127.3 (CH), 126.0 (CH), 125.2 (CH), 114.8 (CH), 110.2 (CH), 21.44 (CH_3). EM (EI) *m/z* (%) 259 (4), 257 (89), 229 (3), 181 (70), 139 (15), 123 (45), 90 (100).

3.11. 3-Methyl-4-(p-tolylsulfinyl)-[1,2,3]triazolo[1,5-a]-pyridine (18)

Starting material 4-bromo-3-methyl-[1,2,3]triazolo[1,5-*a*]-pyridine (**10**) (100 mg, 0.5 mmol). The crude product was purified by flash chromatography (silica, ethyl acetate/cyclohexane, 1:4→2:1) affording 3-methyl-4-(*p*-tolylsulfinyl)-[1,2,3]triazolo[1,5-*a*]pyridine (**18**) as a yellow solid, 107 mg, 80%. Mp 157–160 °C. HRMS found for M^+ 271.0786; $C_{14}H_{13}N_3OS$ requires 271.0779. ^{1}H NMR (300 MHz, $CDCl_3$) δ=8.70 (d, J=7.0 Hz, 1H), 7.90 (d, J=7.0 Hz, 1H), 7.50 (d, J=8.1 Hz, 2H), 7.27 (d, J=8.1 Hz, 2H), 7.10 (t, J=7.0 Hz, 1H), 2.60 (s, 3H), 2.38 (s, 3H). ^{13}C NMR (75.5 MHz, $CDCl_3$) δ=143.3 (C), 140.2 (C), 137.3 (C), 134.4 (C), 133.5 (C), 132.0 (C), 130.5 (CH), 127.3 (CH), 126.6 (CH), 122.2 (CH), 114.1 (CH), 21.5 (CH_3), 13.1 (CH_3). EM (EI) *m/z* (%) 271 (0.5), 243 (83), 228 (32), 226 (49), 200 (100), 123 (7) and 3-methyl-4-(*p*-tolylthio)-[1,2,3]triazolo[1,5-*a*]pyridine (**23**), traces. HRMS found for M^+ 255.0832; $C_{14}H_{13}N_3S$ requires 255.0830. ^{1}H NMR (300 MHz, $CDCl_3$) δ=8.39 (d, J=6.9 Hz, 1H), 7.30 (d, J=8.0 Hz, 2H), 7.18 (d, J=8.0 Hz, 2H), 6.66 (t, J=7.0 Hz, 1H), 6.55 (d, J=7.0 Hz, 1H), 2.78 (s, 3H), 2.36 (s, 3H). ^{13}C NMR (75.5 MHz, $CDCl_3$) δ=139.2 (C), 136.9 (C), 135.6 (C), 133.9 (C), 133.2 (CH), 130.6 (CH), 127.1 (C), 122.4 (CH), 118.3 (CH), 114.8 (CH), 21.1 (CH_3), 12.8 (CH_3). EM (EI) *m/z* (%) 255 (15), 227 (27), 226 (95), 212 (100), 194 (32).

3.12. 3-(p-Tolylsulfinyl)-[1,2,3]triazolo[1,5-a]pyridine (19)

3-Iodo-[1,2,3]triazolo[1,5-*a*]pyridine (**4**) (0.43 mmol) was used. The crude product was purified by chromatotron (silica, ethyl acetate/cyclohexane) affording 5-(*p*-tolylsulfinyl)-[1,2,3]triazolo[1,5-*a*]pyridine (**19**) as a yellow solid, 25 mg, 20%. Mp 119–123 °C. HRMS found for M^+ 257.0622; $C_{13}H_{11}N_3OS$ requires 257.0623. ^{1}H NMR (300 MHz, $CDCl_3$) δ=8.77 (d, J=7.0 Hz, 1H), 7.80 (d, J=8.9 Hz, 1H), 7.69 (d, J=8.1 Hz, 2H), 7.33 (m, 3H), 7.09 (dt, J=7.0, 1.1 Hz, 1H), 2.39 (s, 3H). ^{13}C NMR (75.5 MHz, $CDCl_3$) δ=141.6 (C), 139.9 (C), 133.3 (C), 132.4 (C), 130.0 (CH), 127.8 (CH), 125.9 (CH), 124.5 (CH), 118.2 (CH), 116.5 (CH), 21.4 (CH_3). EM (EI) *m/z* (%) 257 (2), 229 (13), 213 (21), 212 (100), 181 (83), 180 (51), 91 (12), 78 (21).

3.13. 1-[6-(p-Tolylsulfinyl)pyridin-2-yl]ethanol (25)

7-(*p*-Tolylsulfinyl)-3-methyl-[1,2,3]triazolo[1,5-*a*]pyridine (**14**) (0.1 g, 0.4 mmol, 1.0 equiv) was diluted in an aqueous solution of sulfuric acid (10 mL, 2.5 M) and heated to 100 °C. The reaction was monitored by TLC. Upon completion of the reaction (6 h) the reaction mixture was quenched with saturated aqueous solution of $NaHCO_3$ (11 mL) until pH=8. Then the resulting mixture was extracted with dichloromethane (3×50 mL). The organic extracts were combined, washed with brine (20 mL), dried over Na_2SO_4, filtered and concentrated. Column chromatography (silica gel, ethyl acetate/cyclohexane gradient) provided 1-(6-(*p*-tolylsulfinyl)pyridin-2-yl)ethanol

(**25**) as a yellow oil, 91 mg, 95%. HRMS found for M^+ 261.0820; $C_{14}H_{15}NO_2S$ requires 261.0823. ^1H NMR (300 MHz, $CDCl_3$) δ=7.84 (m, 2H), 7.63/7.62 (d, J=8.2 Hz, 2H), 7.32/7.31 (d, J=7.5 Hz, 1H), 7.21/7.20 (d, J=8.0 Hz, 2H), 4.85 (m, 1H), 3.79/3.77 (s, 1OH), 2.32 (s, 3H), 1.43/1.42 (d, J=6.6 Hz, 3H). ^{13}C NMR (75.5 MHz, $CDCl_3$) δ=164.5/164.4 (C), 164.3/164.2 (C), 141.6/141.5 (C), 140.6 (C), 138.8 (CH), 129.8 (CH), 124.8 (CH), 120.9/120.8 (CH), 116.9/116.8 (CH), 69.2/69.1 (CH), 24.0/23.9 (CH_3), 21.4/21.3 (CH_3). EM (EI) *m/z* (%) 261 (100), 228 (30), 123 (40), 91 (15).

*3.14. 1-[6-(p-Tolylsulfinyl)pyridin-2-y]ethyl acetate (**26**) and 2-(p-tolylsulfinyl)-6-vinyl-pyridine (**27**)*

7-(*p*-Tolylsulfinyl)-3-methyl-[1,2,3]triazolo[1,5-*a*]pyridine (**14**) (0.1 g, 0.4 mmol, 1.0 equiv) was diluted in acetic acid (10 mL) and heated to 100 °C. The reaction was monitored by TLC. Upon completion of the reaction (4 h), acetic acid was separated by distillation and the reaction mixture was quenched with saturated aqueous solution of $NaHCO_3$ (5.0 mL) until pH=8. Then the resulting mixture was extracted with dichloromethane (3×50 mL). The organic extracts were combined, washed with brine (20 mL), dried over Na_2SO_4, filtered and concentrated. Column chromatography (silica gel, ethyl acetate/cyclohexane, 1:5→2:1) provided 1-(6-(*p*-tolylsulfinyl)pyridin-2-yl)ethyl acetate (**26**) as a yellow-brown oil, 100 mg (89%) (7% de). HRMS found for M^+ 303.0927; $C_{16}H_{17}NO_3S$ requires 303.0929. ^1H NMR (300 MHz, $CDCl_3$) δ=7.91/7.89 (d, J=7.8 Hz, 1H), 7.81/7.80 (t, J=7.8 Hz, 1H), 7.65 (d, J=8.1 Hz, 2H), 7.32/7.29 (d, J=8.0 Hz, 1H), 7.21 (d, J=7.1 Hz, 2H), 5.86/5.85 (m, 1H), 2.32 (s, 3H), 2.08/2.06 (s, 3H), 1.53/1.46 (d, J=6.6 Hz, 3H). ^{13}C NMR (75.5 MHz, $CDCl_3$) δ=170.0/169.9 (C), 164.5/164.4 (C), 160.7/160.5 (C), 141.3/141.2 (C), 140.9/140.8 (C), 138.6/138.5 (CH), 129.6/129.5 (CH), 124.6/124.5 (CH), 121.3/120.8 (CH), 117.1/116.9 (CH), 72.2 (CH), 21.2 (CH_3), 21.1/20.9 (CH_3), 20.4/20.1 (CH_3). EM (EI) *m/z* (%) 303 (50), 243 (100), 226 (40), 123 (50), 91 (23) and 2-(*p*-tolylsulfinyl)-6-vinylpyridine (**27**) (6.2 mg, 7%). HRMS found for M^+ 243.0720; $C_{14}H_{13}NOS$ requires 243.0717. ^1H NMR (300 MHz, $CDCl_3$) δ=7.89 (dd, J=7.8, 1.0 Hz, 1H), 7.80 (t, J=7.8 Hz, 1H), 7.70 (d, J=8.2 Hz, 2H), 7.26 (m, 3H), 6.75 (dd, J=17.4, 10.7 Hz, 1H), 6.24 (dd, J=17.4, 1.3 Hz, 1H), 5.52 (dd, J=10.7, 1.3 Hz, 1H), 2.35 (s, 3H). ^{13}C NMR (75.5 MHz, $CDCl_3$) δ=155.9 (C), 141.4 (C), 141.0 (C), 138.4 (CH), 135.6 (CH), 129.7 (CH), 124.8 (CH), 124.7 (C), 122.0 (CH), 119.9 (CH_2), 116.7 (CH), 21.3 (CH_3). EM (EI) *m/z* (%) 243 (66), 242 (30), 228 (65), 210 (33), 123 (100), 104 (35), 91 (30).

*3.15. 1-[3-(p-Tolylsulfinyl)pyridin-2-yl]ethyl acetate (**28**)*

4-(*p*-Tolylsulfinyl)-3-methyl-[1,2,3]triazolo[1,5-*a*]pyridine (**18**) (0.1 g, 0.4 mmol, 1.0 equiv) was diluted in acetic acid (10 mL) and heated to 100 °C. The reaction was monitored by TLC. Upon completion of the reaction (6 h) acetic acid was separated by distillation and the reaction mixture was quenched with a saturated aqueous solution of $NaHCO_3$ (5.0 mL) until pH=8. Then the resulting mixture was extracted with dichloromethane (3×50 mL). The organic extracts were combined, washed with brine (20 mL), dried over Na_2SO_4, filtered and concentrated. Chromatotron (silica gel, ethyl acetate/cyclohexane, 1:9→2:1) provided 1-(3-(*p*-tolylsulfinyl)pyridin-2-yl)ethyl acetate (**28**) as a yellow oil, 79 mg (70%) (10% de). HRMS found for M^+ 303.0922; $C_{16}H_{17}NO_3S$ requires 303.0929. ^1H NMR (300 MHz, $CDCl_3$) δ=8.70/8.68 (m, 1H), 8.42/8.14 (dd, J=8.0, 1.6 Hz, 1H), 8.26 (d, J=7.9 Hz, 1H), 7.55/7.48 (d, J=8.2 Hz, 2H), 7.45/7.38 (dd, J=8.0, 4.6 Hz, 1H), 7.28–7.24 (m, 2H), 6.26/5.95 (q, J=6.6 Hz, 1H), 2.34 (s, 3H), 2.02/1.99 (s, 3H), 1.59/1.21 (d, J=6.6 Hz, 3H). ^{13}C NMR (75.5 MHz, $CDCl_3$) δ=170 (C), 156.5/155.5 (C), 151.7/151.2 (CH), 142.6/142.4 (C), 142.1/141.3 (C), 140.7/139.9 (C), 134.0/132.7 (CH), 130.3/130.0 (CH), 126.4/125.7 (CH), 124.2/124.1 (CH), 69.8/69.7 (CH), 21.4/21.3 (CH_3), 21.1/20.9 (CH_3), 19.9/18.6 (CH_3). EM (EI) *m/z* (%) 303 (3), 286 (10), 260 (70), 244 (100), 243 (17), 226 (25), 136 (25), 84 (45).

*3.16. 1-[6′-(p-Tolylsulfinyl)pyridin-2′-yl]-1-(pyridin-2-yl)methyl acetate (**29**)*

3-[6′-(*p*-Tolylsulfinyl)pyridin-2′-yl]-[1,2,3]triazolo[1,5-*a*]-pyridine (**20**) (0.1 g, 0.3 mmol, 1.0 equiv) was diluted in acetic acid (10 mL) and heated to 100 °C. The reaction was monitored by TLC. Upon completion of the reaction (4 h) acetic acid was separated by distillation and the reaction mixture was quenched with a saturated aqueous solution of $NaHCO_3$ (5.0 mL) until pH=8. Then the resulting mixture was extracted with dichloromethane (3×50 mL). The organic extracts were combined, washed with brine (20 mL), dried over Na_2SO_4, filtered and concentrated. Column chromatography (silica gel, ethyl acetate/cyclohexane, 1:5→2:1) provided **29** as a yellow oil, 61 mg (56%) (5% de). HRMS found for M^+ 366.1032; $C_{20}H_{11}N_3O_3S$ requires 366.1038. ^1H NMR (300 MHz, $CDCl_3$) δ=8.51 (m, 1H), 7.89 (m, 2H), 7.68 (m, 1H), 7.48 (m, 4H), 7.21 (m, 1H), 7.16/7.12 (d, J=8.1 Hz, 2H), 6.85/6.84 (s, 1H), 2.33/2.32 (s, 3H), 2.20/2.18 (s, 3H). ^{13}C NMR (75.5 MHz, $CDCl_3$) δ=169.7/169.6 (C), 165.8/165.6 (C), 158.3/158.2 (C), 157.3 (C), 149.4/149.3 (CH), 141.2/141.1 (C), 140.9/140.8 (C), 138.8/138.7 (CH), 136.7/136.6 (CH), 129.6/129.5 (CH), 124.7/124.6 (CH), 123.3/123.0 (CH), 122.9/122.7 (CH), 122.4/122.2 (CH), 117.5/117.3 (CH), 78.0/77.9 (CH), 21.4/21.3 (CH_3), 21.0/20.9 (CH_3). EM (EI) *m/z* (%) 366 (100), 323 (10), 291 (15), 201 (25), 167 (23), 123 (10), 78 (10).

*3.17. 1[-6′-(p-Tolylsulfinyl)pyridin-2′-yl]-1-(pyridin-2-yl)methanol (**30**) and 1-[6′-(p-tolylsulfinyl)pyridin-2′-yl]-1-(pyridin-2-yl)methanone (**31**)*

3-[6′-(*p*-Tolylsulfinyl)pyridin-2′-yl]-[1,2,3]triazolo[1,5-*a*]-pyridine (**20**) (0.1 g, 0.3 mmol, 1.0 equiv) was diluted in an aqueous solution of sulfuric acid (10 mL, 2.5 M) and heated to 100 °C. The reaction was monitored by TLC. Upon completion of the reaction (6 h) the reaction mixture was quenched

with a saturated aqueous solution of $NaHCO_3$ (11 mL) until pH=8. Then the resulting mixture was extracted with dichloromethane (3×50 mL). The organic extracts were combined, washed with brine (20 mL), dried over Na_2SO_4, filtered and concentrated. Two chromatography columns (silica gel, ethyl acetate/cyclohexane gradient) provided 1-[6′-(*p*-tolylsulfinyl)-pyridin-2′-yl]-1-(pyridin-2-yl)methanol (**30**) as a brown oil, 59 mg, 60%. ^{1}H NMR (300 MHz, $CDCl_3$) δ=8.53/8.48 (d, J=4.9 Hz, 1H), 7.88 (m, 2H), 7.62 (m, 3H), 7.53 (m, 1H), 7.44 (m, 1H), 7.22 (m, 3H), 5.83 (s, 1H), 5.49 (br s, 1H), 2.38/2.37 (s, 3H). ^{13}C NMR (75.5 MHz, $CDCl_3$) δ=169.7/169.6 (C), 1640.8/164.7 (C), 158.3/158.2 (C), 157.3 (C), 149.4/149.3 (CH), 141.2/141.1 (C), 141.6/141.5 (C), 138.8/138.7 (CH), 136.9/136.6 (CH), 129.7/129.6 (CH), 124.8/124.7 (CH), 122.8/122.7 (CH), 121.8/121.5 (CH), 121.3/120.7 (CH), 117.3/117.1 (CH), 74.6/74.5 (CH), 21.4/21.3 (CH_3) and 1-[6′-(*p*-tolylsulfinyl)pyridin-2′-yl]-1-(pyridin-2-yl)methanone (**31**) as a colourless oil, 27 mg, 28%. HRMS found for M^+ 322.0764; $C_{18}H_{14}N_2O_2S$ requires 322.0776. ^{1}H NMR (300 MHz, $CDCl_3$) δ=8.71 (d, J=4.7 Hz, 1H), 8.24 (m, 1H), 8.06 (m, 2H), 7.96 (d, J=7.8 Hz, 1H), 7.87 (dt, J=7.7, 1.6 Hz, 1H), 7.63 (d, J=8.2 Hz, 2H), 7.52 (m, 1H), 7.23 (d, J=8.3 Hz, 2H), 2.39 (s, 3H). ^{13}C NMR (75.5 MHz, $CDCl_3$) δ=191.6 (C), 166.0 (C), 154.1 (C), 153.7 (C), 149.1 (CH), 141.6 (C), 140.5 (C), 138.8 (CH), 136.6 (CH), 129.8 (CH), 126.5 (CH), 125.7 (CH), 125.3 (CH), 124.8 (CH), 122.4/122.2 (CH), 120.8 (CH), 21.4 (CH_3). EM (EI) *m*/*z* (%), 322 (100), 305 (15), 261 (20), 216 (20), 199 (25), 149 (25), 123 (40), 106 (25), 78 (80). Compound **30** decomposed in air to give compound **31**.

Acknowledgements

We are much grateful to the Ministerio de Educación y Ciencia (Spain) (Project CTQ2006-15672-C05-03) for its financial support, and to the SCSIE for the realization of the HRMS spectra. R.B.-G. wants to thank Ministère de l'Éducation Nationale, de la Recherche et de la Technologie (France) for a predoctoral fellowship.

References and notes

1. Last part in the series: Abarca, B.; Ballesteros, R.; Ballesteros-Garrido, R.; Colobert, F.; Leroux, F. R. *Tetrahedron* **2007**, *63*, 10479–10485.
2. (a) Niel, V.; Gaspar, A. B.; Muñoz, M. C.; Abarca, B.; Ballesteros, R.; Real, J. A. *Inorg. Chem.* **2003**, *42*, 4782–4788; (b) Abarca, B.; Ballesteros, R.; Chadlaoui, M.; Ramirez de Arellano, C.; Real, J. A. *Eur. J. Inorg. Chem.* **2007**, 4574–4578.
3. Boudalis, A. K.; Raptpoulo, C. P.; Abarca, B.; Ballesteros, R.; Chadlaoui, M.; Tuchagues, J. P.; Terzis, A. *Angew. Chem., Int. Ed.* **2006**, *45*, 432–435.
4. Boudalis, A. K.; Raptopoulou, C. P.; Psycharis, V.; Sanakis, Y.; Abarca, B.; Ballesteros, R.; Chadlaoui, M. *J. Chem. Soc., Dalton Trans.* **2007**, 3582–3589.
5. Abarca, B.; Aucejo, R.; Ballesteros, R.; Blanco, F.; García-España, E. *Tetrahedron Lett.* **2006**, *47*, 8101–8103.
6. Chadlaoui, M.; Abarca, B.; Ballesteros, R.; Ramírez de Arellano, C.; Aguilar, J.; Aucejo, R.; García-España, E. *J. Org. Chem.* **2006**, *71*, 9030–9034.
7. (a) Hanquet, G.; Colobert, F.; Lanners, S.; Solladié, G. *Arkivoc* **2003**, *7*, 328–401; (b) Pellissier, H. *Tetrahedron* **2007**, *63*, 1297–1330.
8. Calligaris, M.; Carugo, O. *Coord. Chem. Rev.* **1996**, *153*, 83–154.
9. Andersen, K. K.; Gaffiels, W.; Papanikolaou, N. E.; Foley, J. W.; Perkins, R. I. *J. Am. Chem. Soc.* **1964**, *86*, 5637–5646.
10. Colobert, F.; Ballesteros-Garrido, R.; Leroux, F. R.; Ballesteros, R.; Abarca, B. *Tetrahedron Lett.* **2007**, *48*, 6896–6899.
11. Maitro, G.; Vogel, S.; Prestat, G.; Madec, D.; Poli, G. *Org. Lett.* **2006**, *8*, 5951–5954.
12. Abarca, B.; Ballesteros, R.; Mojarrad, F.; Jones, G.; Mouat, D. *J. Chem. Soc., Perkin Trans. 1* **1987**, 1865–1868.
13. Blanco, F. Ph.D. Thesis, University of Valencia, Spain, 2006.
14. Jones, G.; Pitman, M. A.; Lunt, E.; Lythgoe, D. J.; Abarca, B.; Ballesteros, R.; Elmasnaouy, M. *Tetrahedron* **1997**, *53*, 8257–8268.
15. (a) Jones, G.; Mouat, D. J.; Tonkinson, D. *J. Chem. Soc., Perkin Trans. 1* **1985**, 2719–2723; (b) Abarca, B.; Mojarrad, F.; Jones, G.; Phillips, C. *Tetrahedron* **1988**, *44*, 3005–3014.
16. Lehn, J.-M. *Supramolecular Chemistry, Concepts and Perspectives*; VCH: Weinheim, 1995.
17. Le Notre, J.; Firet, J. J.; Sliedregt Leo, A. J. M.; Van Oteen, B. J.; Van Koten, G.; Klein Gebbink Robertus, J. M. *Org. Lett.* **2005**, *7*, 363–366 and references cited therein.
18. Abarca, B.; Ballesteros, R.; Elmasnaouy, M. *Tetrahedron* **1998**, *54*, 15287–15292.
19. Kabalka, G. W.; Wang, L.; Pagni, R. M. *Arkivoc* **2001**, *iv*, 5–11.
20. Wang, X.; Rabbat, P.; O'Shea, P.; Tillyer, R.; Grabowski, E. J. J.; Reider, P. J. *Tetrahedron Lett.* **2000**, *41*, 4335–4338.
21. Boyer, J. H.; Borgers, R.; Wolford, L. T. *J. Am. Chem. Soc.* **1957**, *79*, 678–680.
22. Abarca, B.; Alkorta, I.; Ballesteros, R.; Blanco, F.; Chadlaoui, M.; Elguero, J.; Mojarrad, F. *Org. Biomol. Chem.* **2005**, *3*, 3905–3910.
23. (a) Crow, W. D.; Wentrup, C. *Tetrahedron Lett.* **1968**, *59*, 6149–6152; (b) Abarca, B.; Ballesteros, R.; Blanco, F. *Arkivoc* **2007**, *iv*, 297–303.
24. Oda, R.; Mieno, M.; Hayashi, Y. *Tetrahedron Lett.* **1967**, 2363–2365.
25. Hassan, J.; Sévignon, M.; Gozzi, V.; Schulz, E.; Lemaire, M. *Chem. Rev.* **2002**, *102*, 1359–1469.
26. Abarca, B. *J. Enzyme Inhib. Med. Chem.* **2002**, *17*, 359–367 and references cited therein.
27. (a) Papaefstathiou, G. S.; Perlepes, S. P. *Comments Inorg. Chem.* **2002**, *23*, 249–274; (b) Boudalis, A. K.; Donnadieu, B.; Nastopoulos, V.; Clemente-Juan, J. M.; Mari, A.; Sanakis, Y.; Tuchagues, J.-P.; Perlepes, S. P. *Angew. Chem.* **2004**, *116*, 2316–2320; *Angew. Chem., Int. Ed.* **2004**, *43*, 2266–2270; (c) Tsohos, A.; Dionyssopoulou, S.; Raptopoulou, C. P.; Terzis, A.; Bakalbassis, E. G.; Perlepes, S. P. *Angew. Chem.* **1999**, *111*, 1036–1038; *Angew. Chem., Int. Ed.* **1999**, *38*, 983–985; (d) Papaefstathiou, G. S.; Perlepes, S. P.; Escuer, A.; Vicente, R.; Font-Bardia, M.; Solans, X. *Angew. Chem.* **2001**, *113*, 908–910; *Angew. Chem., Int. Ed.* **2001**, *40*, 884–886; (e) Papaefstathiou, G. S.; Escuer, A.; Vicente, R.; Font-Bardia, M.; Solans, X.; Perlepes, S. P. *Chem. Commun.* **2001**, 2414–2415.
28. Perrin, D.; Armarego, L. F. *Purification of Laboratory Chemicals*, 3rd ed.; Pergamon: Oxford, 1988.
29. Abarca, B.; Ballesteros, R.; Gurnos, J.; Fatemeh, M. *Tetrahedron Lett.* **1986**, *27*, 3543–3546.