CHEMISTRY
A EUROPEAN JOURNAL

ChemPubSoc Europe

DOI: 10.1002/chem.201302999

Nickel-Catalyzed Arylation, Alkenylation, and Alkynylation of Unprotected Thioglycosides at Room Temperature

Etienne Brachet, Jean-Daniel Brion, Mouad Alami,* and Samir Messaoudi*[a]

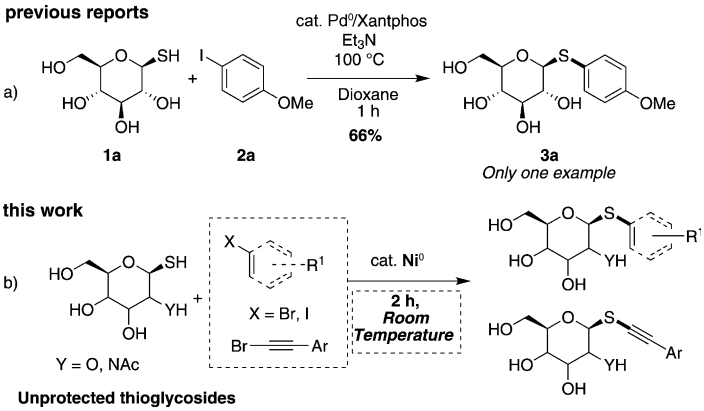
Abstract: Unprotected thioglycosides were effective nucleophiles for Ni^0-catalyzed C–S bond-forming reaction with functionalized (hetero)aryl, alkenyl, and alkynyl halides. The functional-group tolerance on the electrophilic partner was typically high and the anomeric selectivities of the thioglycosides were high in all cases. The efficiency of this general procedure was well-demonstrated by the synthesis of 4-methyl-7-thioumbelliferyl-β-D-cellobioside (MUS-CB).

Keywords: alkenylation · alkynylation · arylation · nickel · thioglycosides

Introduction

The development of transition-metal-catalyzed coupling reactions for the facile generation of unprotected polyfunctionalized compounds with useful architectures remains of great interest to academic and industrial chemists. Such processes preclude the need for prior time-consuming protection and deprotection steps, thus making the overall chemical transformations highly efficient. We are particularly interested in the development of new methods for the direct metal-catalyzed coupling of protecting-group-free thioglycosides under mild and operationally simple conditions. Catalytic reactions of this nature would be of great interest for the construction of molecules that may be sensitive to the harsh conditions that are often required for glycosidic bond-forming reactions.

Driven by the exceptional reactivity of sulfur and its importance in biology, medicine, and materials science,[1] we recently reported the synthesis of arylthioglycosides by using a protecting-group strategy that was based on the coupling of protected thioglycosides as nucleophile partners with aryl halides in the presence of a $Pd(OAc)_2$/Xantphos (Xantphos = 4,5-bis(diphenylphosphino)-9,9-dimethylxanthene) catalyst system.[2] In addition, in a single example, we demonstrated that this procedure also enabled, for the first time, the efficient coupling of unprotected thioglucose **1a** with 4-iodoanisole in an acceptable 66% yield (Scheme 1, path a). Because this preliminary result did not require any protecting-group manipulations, we set out to investigate the feasibility of this transformation for the coupling of 4-iodoanisole with various unprotected thioglycosides (e.g., 1-thio-β-D-glucopyranose, 1-thio-β-D-galactopyranose, 1-thio-β-D-ribose, 1-thio-β-D-mannopyranose, 1-thio-β-D-cellobiose, etc.). However, all of our attempts failed (Scheme 1, path a), which was not surprising because the unprotected thioglycosides showed limited stability towards high-temperature[3] and/or basic[4] environments. Conscious of these limitations, we believe that the development of a robust procedure for the coupling of unprotected thioglycosides as viable nucleophilic partners with various aglycone halides is highly desirable. To this end, a suitable coupling procedure would meet the following requirements: 1) it should not use expensive metal catalysts or sophisticated ligands; 2) it should be achievable at room temperature within a short time and allow complete stereocontrol over the coupling product; 3) it should be tolerant of many different functional groups and should be general with respect to both coupling partners; and 4) the handling, separation, and purification of the compounds should be facile.



Scheme 1. Coupling reactions of unprotected thioglycosides.

Recent notable progress in the use of naturally more-abundant and extremely cheap nickel catalysts in C–S bond-

[a] E. Brachet, Prof. J.-D. Brion, Dr. M. Alami, Dr. S. Messaoudi
Laboratoire de Chimie Thérapeutique, BioCIS-UMR 8076
LabEx LERMIT, Université Paris-Sud, CNRS
Faculté de Pharmacie, 5 rue J.-B. Clément
92296 Châtenay-Malabry (France)
Fax: (+33)146-83-58-28
E-mail: mouad.alami@u-psud.fr
samir.messaoudi@u-psud.fr

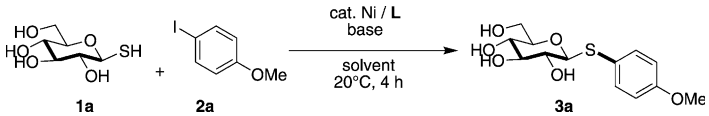
Supporting information for this article is available on the WWW under http://dx.doi.org/10.1002/chem.201302999.

forming reaction has found wide applications in organic synthesis.[5] Although the Ni-catalyzed arylation of thiophenols to form diaryl sulfides has been extensively studied, only a few examples of the use of aliphatic thiols have been reported to date.[5c,e,g] Moreover, to the best of our knowledge, there are no reports regarding the Ni-catalyzed S-arylation or heteroarylation of unprotected thiosugars. Herein, we report a general and robust coupling reaction of unprotected thioglycosides with (hetero)aryl halides, as well as alkenyl and alkynyl halides. We found that the C(sp^2)–S and C(sp)–S bonds could be stereoselectively formed under mild conditions in the presence of a catalytic amount of Ni^0 in MeOH at room temperature (Scheme 1, path b). This procedure successfully met each of the requirements described above.

Results and Discussion

Our initial efforts focused on the coupling reaction between unprotected 1-thio-β-D-glucopyranose **1a** and 4-iodoanisole (**2a**) with various nickel catalysts, ligand sources, bases, and solvents. Representative results from this study are summarized in Table 1. We found that the reaction of compound **1a** (1 equiv) with compound **2a** (2 equiv) in MeOH at room temperature in the presence of $[Ni^0(Bipy)_2(Py)]$[5c,6] (30 mol%, Bipy = bipyridine, Py = pyridine) as the catalyst, which was readily generated in situ from a mixture of $NiCl_2$ (30 mol%), bipyridine (90 mol%), and Zn^0 (1 equiv) in pyridine (300 μL) at 55 °C (see the Supporting Information), afforded the expected β-arylthioglycoside (**3a**) in 56% yield (Table 1, entry 1). Next, the screening conditions were employed with various other nickel sources. The catalytic activity of $NiCl_2$•dme (dme = dimethoxyethane) was found be superior to that of $NiCl_2$, thus leading to the formation of compound **3a** in a higher yield (78%; Table 1, entry 2). However, the use of other nickel sources, such as $NiBr_2$ or $[NiCl_2(PPh_3)_2]$, did not promote the S-arylation of compound **1a** (Table 1, entries 3 and 4). Pleasingly, we found that the bipyridine ligand was not required, because a reaction between compounds **1a** and **2a** without bipyridine under otherwise-identical conditions led to the formation of compound **3a** in quantitative yield (Table 1, entry 5). Finally, after a brief screening of other parameters (base and solvent; Table 1, entries 6–8), optimal conditions were found, that is: compound **1a** (1 equiv), compound **2a** (2 equiv), $[Ni^0(dme)(Py)]$ as the catalyst (which was generated in situ from a mixture of $NiCl_2$•dme (30 mol%), Zn^0 (1 equiv), and pyridine (300 μL) at 55 °C, according to a similar procedure for the generation of $[Ni^0(Bipy)_2(Py)]$[5c]) in MeOH at room temperature for 2 h (Table 1, entry 5). Accordingly, compound **3a** was formed in 99% yield, without the formation of any side products that would result from competitive O-arylation reactions under Ni catalysis.[7] Notably, this reaction was not limited to small-scale syntheses (0.25 mmol); it could be conveniently performed on a 1.2 g scale (5 mmol; 20-fold scale-up) with only 5 mol% Ni^0 in 76% yield, thus indicating that this procedure is practically valuable. Notably, the polyhydroxylated moieties on compounds **1a** and **3a**, which were able to coordinate to the Ni catalyst, did not have a deleterious effects on the outcome of the reactions.

Table 1. Optimization of the coupling reaction between compounds **1a** with **2a**.[a]



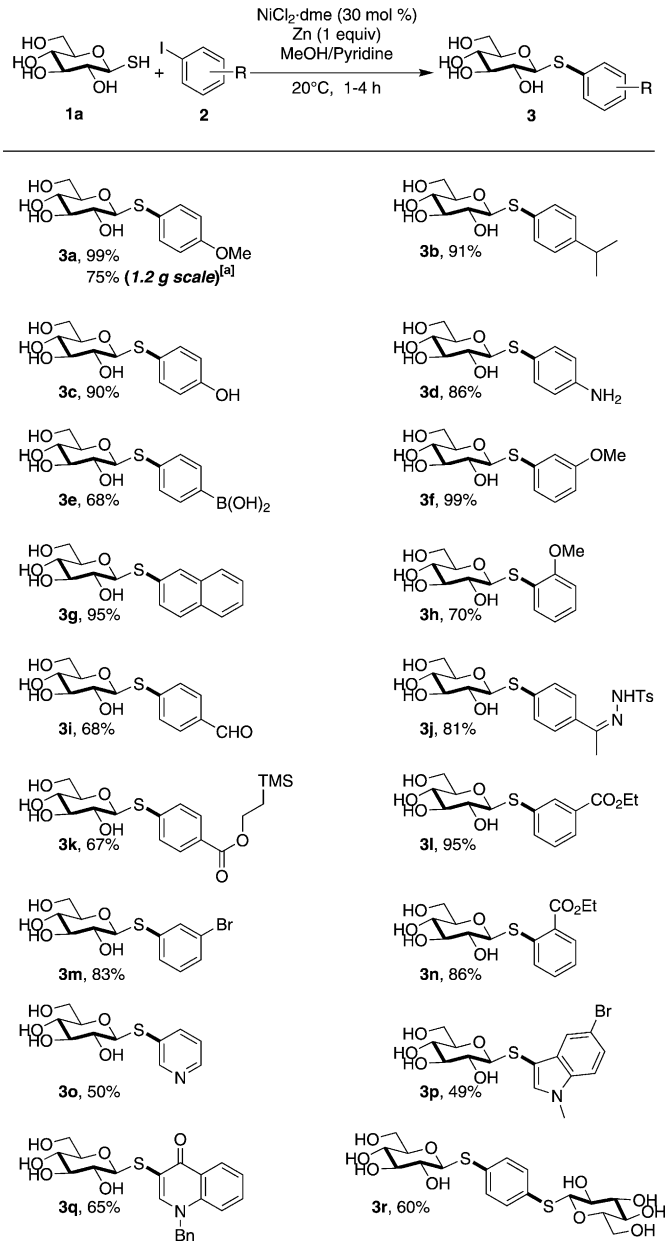
Entry	Ni catalyst	L	Base	Solvent	Conversion[b] [%]	Yield[c] [%]
1	$NiCl_2$	Bipy	Py	MeOH	95	56
2	$NiCl_2$•dme	Bipy	Py	MeOH	96	78
3	$NiBr_2$	Bipy	Py	MeOH	0	–
4	$[NiCl_2(PPh_3)_2]$	Bipy	Py	MeOH	0	–
5	$NiCl_2$•dme	–	Py	MeOH	100	99[d]
6	$NiCl_2$•dme	–	Et_3N	MeOH	0	–
7	$NiCl_2$•dme	–	Py	EtOH	71	23
8	$NiCl_2$•dme	–	Py	water	75	26

[a] A mixture of Zn (1 equiv), NiX_2 (30 mol%), bipyridine (90 mol%), and Py (300 μL) was heated at 55 °C for 15 min to generate $[Ni^0(Bipy)_2(Py)]$. A solution of compound **1a** (0.25 mmol) and compound **2a** (0.5 mmol) in solvent (1 mL) was added dropwise to the Ni^0 complex and the mixture was stirred at 20 °C for 1 h. [b] Conversion was determined by ^1H NMR spectroscopy of the crude reaction mixture and was based on the chemical shift of the signal of the anomeric proton of the sugar moiety. [c] Yield of isolated compound **3a**. [d] The reaction was stirred at 20 °C for 2 h.

With our catalyst system in hand, we explored its versatility in the coupling reactions of unprotected 1-thio-β-D-glucopyranose (**1a**) with various (hetero)aryl iodides. As shown in Scheme 2, 1-thio-β-D-glucopyranose **1a** was readily coupled with aryl iodides that contained *para* and *meta* electron-donating or electron-withdrawing substituents to give thioglycosylated products **3a**–**3g** and **3i**–**3m** in good-to-excellent yields with complete β selectivity. In addition, the sterically demanding *ortho*-substitution pattern was tolerated in the coupling reaction with compound **1a**, thus leading to β-thioglycosylated derivatives **3h** and **3n** in good yields, regardless of the electronic nature of the substituents. As shown in Scheme 2, the presence of hydroxy, free-amino, or boronic-acid groups on the aryl-halide partner did not interfere with the outcome of the reaction (compounds **3c**–**3e**). In particular, reactive electrophilic functional groups, such as aldehyde, ester, hydrazone, and bromo substituents, were well-tolerated, which should be instrumental for the further derivatization of the thus-obtained β-arylthioglycosides (**3i**–**3n**).

Extending this method to the heteroarylation of compound **1a** was also successful. 3-Iodopyridine, 2-iodo-5-bromoindole, and 3-bromoquinolinone were good partners for the coupling reaction with compound **1a** under our optimized conditions, thereby furnishing the desired thioglycosides (**3o**–**3q**) in acceptable yields (45–65%).

In a further set of experiments, we investigated the scope of this method with respect to mono- and dithiosaccharides **1a**–**3e** (Figure 1). As shown in Scheme 3, the coupling reactions proceeded cleanly in high yields, without the presence of any side reactions, such as anomerization of the resulting



Scheme 2. Ni-catalyzed coupling reactions of unprotected 1-thio-β-D-glucopyranose (**1a**) with various (hetero)aryl halides (**2**). Reaction conditions: A mixture of Zn (1 equiv), $NiCl_2$•dme (30 mol%), and Py (300 μL) was heated at 55°C to generate [$Ni^0(dme)_2(Py)$]. A solution of compound **1a** (0.25 mmol) and compound **2** (0.5 mmol) in MeOH (1 mL) was added dropwise to the Ni^0 complex and the mixture was stirred at 20°C. [a] 5 mol% $NiCl_2$•dme was used.

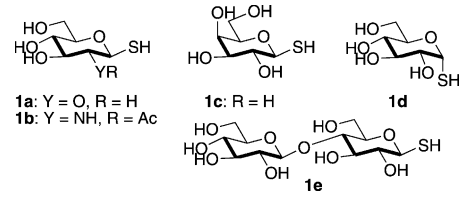
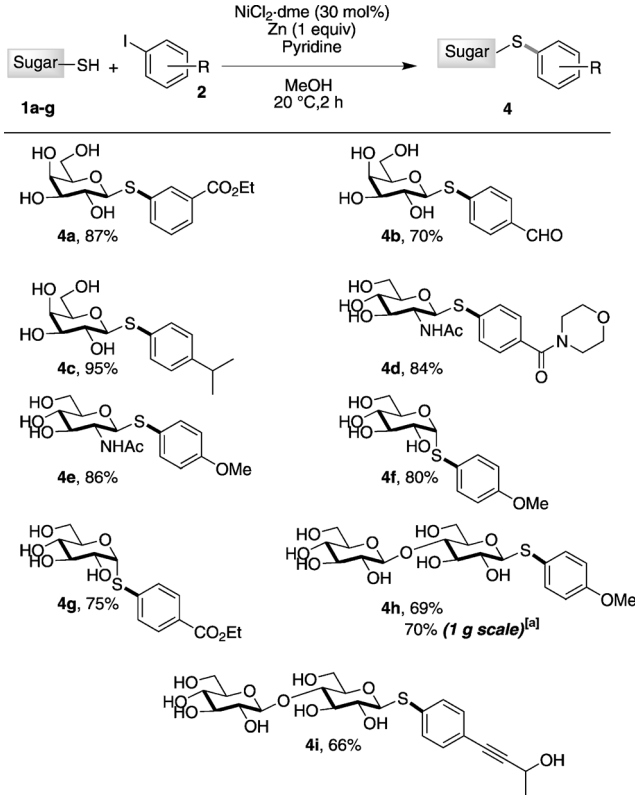


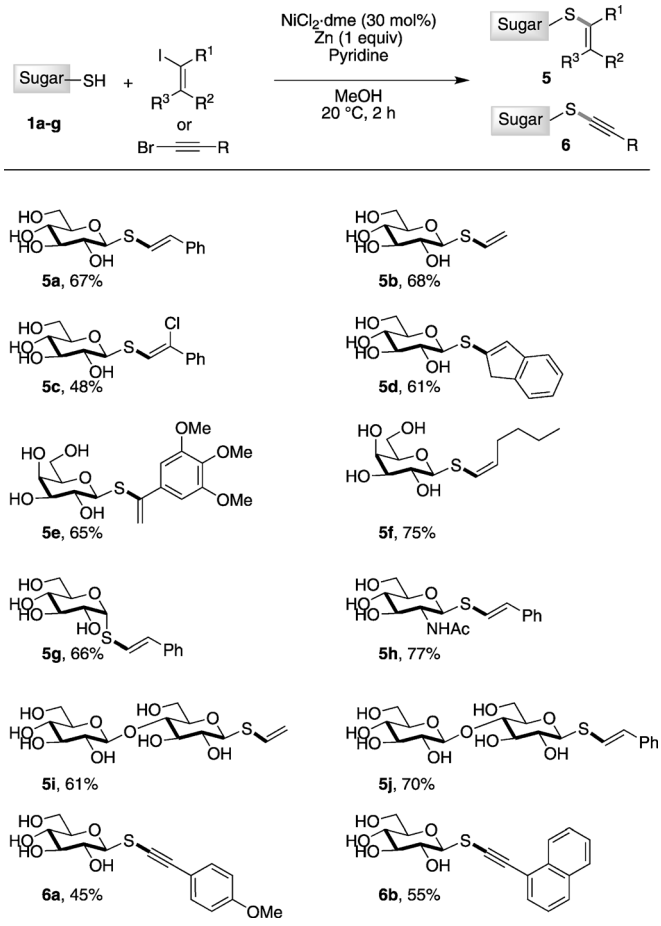
Figure 1. Thiosaccharides **1a**–**1e** that were used in this study.



Scheme 3. Nickel-catalyzed coupling reactions of unprotected thiosaccharides **1a**–**1g** with various aryl iodides (**2**). Reaction conditions: A mixture of Zn (1 equiv), $NiCl_2$•dme (30 mol%), and Py (300 μL) was heated at 55°C to generate [$Ni^0(dme)_2(Py)$]. A solution of compound **1a**–**1g** (0.25 mmol) and compound **2** (0.5 mmol) in MeOH (1 mL) was added dropwise to the Ni^0 complex and the mixture was stirred at 20°C for 2 h. [a] 10 mol% $NiCl_2$•dme was used.

arylthioglycosides. This reaction was found to be general with respect to the configuration of the sugar, because 1-thio-β-D-galactopyranose (**1c**) and *N*-acetyl-1-thio-β-D-aminoglucopyranose (**1b**) gave their corresponding products (**4a**–**4e**) in excellent yields. Our coupling procedure was not limited to thioglycosides with an anomeric β configuration; it also worked successfully with thiol **1d**, which had an anomeric α configuration. Moreover, there were no significant differences in reactivity between the α and β anomers; good yields were obtained from the coupling reactions of 4-iodoanisole with 1-thio-α-D-glucopyranose (**1d**) and 1-thio-β-D-glucopyranose (**1a**; 80% and 99% yields, respectively). In addition, the coupling procedure was not only limited to monothioglycosides; it also worked successfully with challenging 1-thiodisaccharides, such as 1-thio-β-D-cellobiose (**1e**). Exclusive 1,2-trans β-diholosides **4h** and **4i** were obtained in 69% and 66% yields, respectively, and the stereochemistry of the 1-4′-O-glycosidic bond remained intact.

With the aim of further pushing the limit of this nickel-catalyzed S-(hetero)arylation reaction of thiosugars, we examined the coupling reactions of unprotected α- or β-thioglycosides **1a**–**1e** with alkenyl iodides and alkynyl bromides as aglycone partners (Scheme 4). Delightfully, if *E*- or *Z*-al-



Scheme 4. Nickel-catalyzed coupling reactions of thiosaccharides **1a–1g** with alkenyl and alkynyl halides. Reaction conditions: A mixture of Zn (1 equiv), $NiCl_2$·dme (30 mol%), and Py (300 μL) was heated at 55 °C to generate $[Ni^0(dme)_2(Py)]$. A solution of compound **1a–1g** (0.25 mmol) and compound **2** (0.5 mmol) in MeOH (1 mL) was added dropwise to the Ni^0 complex and the mixture was stirred at 20 °C for 2 h.

kenyl iodides were employed, the coupling reactions with compounds stereoselectively **1a–1e** afforded the desired alkenylthioglycoside derivatives (**5a–5j**) in good yields without any thermal isomerization, thereby clearly demonstrating the mild nature of this selective coupling reaction. In addition to the alkenyl halides that were evaluated above, substituted alkynyl bromides were examined as aglycon coupling partners. Alkynylated thioglycoside products **6a** and **6b** were obtained diastereoselectively in acceptable yields. The synthesis of compounds **5** and **6** that feature alkenyl or alkynyl substituents on the sulfur atom of the sugar moiety have not previously been reported, perhaps owing to the difficulty in their preparation by using standard procedures.[8]

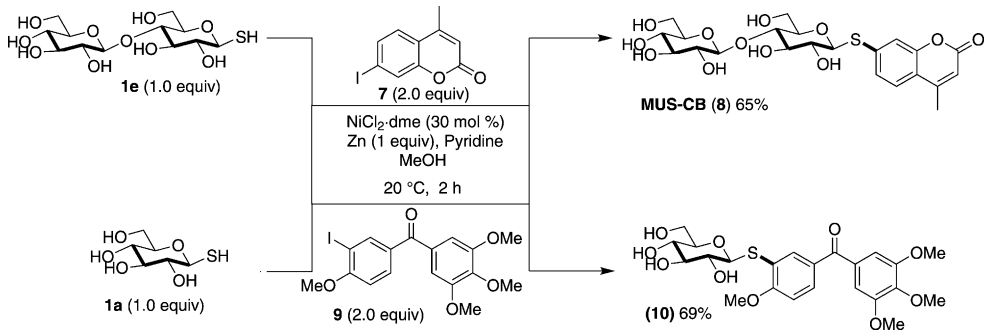
Finally, the synthetic potential of this procedure was well-illustrated by the preparation of 4-methyl-7-thioumbelliferyl-β-D-cellobioside (MUS-CB),[9] a fluorescent non-hydrolyzable analogue of cellulases. The key step in this synthesis was the coupling reaction between 7-iodocoumarin (**7**)[10] and fully deprotected β-D-disaccharide **1e** under our optimized conditions to give MUS-CB (**8**) in an excellent 65% yield, with exclusive β selectivity (Scheme 5). In addition, subjecting iodophenstatin **9** to the coupling reaction with compound **1a** under our reaction conditions similarly resulted in the rapid preparation of thioglycoside **10**, an analogue of phenstatin[11] and *iso*combretastatin A-4 (*iso*CA-4),[12] two highly promising cytotoxic and antitubulin agents.

Conclusion

In conclusion, we have demonstrated that unprotected thioglycosides could be used as viable nucleophilic partners with aglycone halides. A catalyst system based on Ni^0 allowed the efficient S-arylation, alkenylation, and alkynylation of unprotected thioglycosides at room temperature. This reaction was highly diastereoselective, functional-group tolerant, step-economical, and proceeded stereoselectively in good-to-excellent yields. The value of this transformation has been highlighted in the synthesis of biologically interesting thioglycosylated compounds **8** and **10**. We expect that this simple and general procedure will be of broad utility for the synthesis and development of new medicinal agents.

Experimental Section

General procedure for the nickel-catalyzed coupling of unprotected thioglycosides with (hetero)aryl, alkenyl, and alkynyl halides: $NiCl_2$·dme (16.5 mg,0.075 mmol) was added to a stirring slurry of Zn (16.5 mg,



Scheme 5. Synthesis of (MUS-CB) and phenstatin analogue **10**.

0.25 mmol) in pyridine (0.3 mL) at RT. Then, the temperature was increased to 55 °C and vigorous stirring was continued for 15 min. The resulting [Ni^0(dme)(Py)] complex was cooled to RT and a solution of the aryl (or alkenyl/alkynyl) halide (0.5 mmol) and the thioglycoside (0.25 mmol) in MeOH (1 mL) was added. After stirring for 2 h at RT, the mixture was filtered through a short plug of silica (CH_2Cl_2/MeOH) and concentrated in vacuo. The crude product was purified by flash chromatography on silica gel to afford the desired product.

Synthesis of (2*R*,3*S*,4*S*,5*R*,6*S*)-2-(hydroxymethyl)-6-((4-methoxyphenyl)thio)tetrahydro-2*H*-pyran-3,4,5-triol (3a): Following the general procedure for the Ni^0-catalyzed cross-coupling reaction, a mixture of β-thioglucose **1a** (58.5 mg, 0.25 mmol) and 4-iodoanisole (0.5 mmol) was stirred for 2 h. The residue was purified by flash chromatography on silica gel (CH_2Cl_2/MeOH, 85:15) to afford the desired product (**3a**, 75 mg, 0.25 mmol, 99%) as a colorless oil, R_f = 0.38 (CH_2Cl_2/MeOH, 85:15); $[\alpha]_D^{24} = -41.0$ (c = 1.0 in MeOH); ^{1}H NMR (300 MHz, [D6]acetone, 25 °C, TMS): δ = 7.52 (d, J = 8.8 Hz, 2H), 6.88 (d, J = 8.8 Hz, 2H), 4.46 (d, J = 9.6 Hz, 1H), 4.41 (brs, 2H), 3.83 (d, J = 10.2 Hz, 1H), 3.78 (s, 3H), 3.66 (d, J = 12.3 Hz, 1H), 3.50–3.40 (m, 1H), 3.32 (d, J = 5.4 Hz, 2H), 3.16 (t, J = 9.1 Hz, 1H), 3.03 ppm (s, 2H); ^{13}C NMR (75 MHz, [D6]acetone): δ = 160.61 (C), 135.89 (2×CH), 124.15 (C), 115.05 (2×CH), 89.02 (CH), 81.38 (CH), 79.38 (CH), 73.19 (CH), 71.26 (CH), 62.90 (CH_2), 55.59 ppm (CH_3); IR (neat): $\tilde{\nu}$ = 3331, 3240, 3155, 2533, 2202, 2119, 2020, 2002, 1756, 1592, 1494, 1460, 1287, 1218, 1177, 1106 cm^{-1}; HRMS (ESI): m/z calcd for $C_{13}H_{18}NaO_6S$: 325.0716; found: 325.0708.

Acknowledgements

The CNRS is gratefully acknowledged for financial support of this research and the French Ministry of Education, Research, and Technology (MENRT) is acknowledged for a doctoral fellowship to E.B. Our laboratory, BioCIS-UMR 8076, is a member of the Laboratory of Excellence, LERMIT, which is supported by a grant from the ANR (ANR-10-LABX-33).

[1] a) L. A. Paquette, *Sulfur-Containing Reagents*, Wiley, Chichester, **2009**; b) R. Masella, *Glutathione and Sulfur Amino Acids in Human Health and Disease*, Wiley, Hoboken, **2009**; c) C. E. Hoyle, A. B. Lowe, C. N. Bowman, *Chem. Soc. Rev.* **2010**, *39*, 1355–1387; < lit d > H. Driguez, *Top. Curr. Chem.* **1997**, *187*, 85–116; e) Z. J. Witczak, *Curr. Med. Chem.* **1999**, *6*, 165–178; f) K. Pachamuthu, R. R. Schmidt, *Chem. Rev.* **2006**, *106*, 160–187; g) B. P. Zambrowicz, A. T. Sands, *Nat. Rev. Drug Discovery* **2003**, *2*, 38–51.

[2] E. Brachet, J.-B. Brion, S. Messaoudi, M. Alami, *Adv. Synth. Catal.* **2013**, *355*, 477–490.

[3] β-D-thioglucose **1a** is a sensitive substrate in basic media at elevated temperatures. Heating compound **1a** in the presence of Et_3N (1 equiv) in 1,4-dioxane at 100 °C resulted in the total disappearance of compound **1a** within 30 min. In addition, if $Pd(OAc)_2$ (5 mmol%) was added, compound **1a** disappeared within only 15 min.

[4] For the pH-dependent mutarotation of 1-thioaldoses, see: R. Caraballo, L. Deng, L. Amorium, T. Brink, O. Ramström, *J. Org. Chem.* **2010**, *75*, 6115–6121.

[5] For reviews on aryl–sulfur bond-forming reactions, see: a) I. P. Beletskaya, V. P. Ananikov, *Chem. Rev.* **2011**, *111*, 1596–1636; b) T. Kondo, T. Mitsudo, *Chem. Rev.* **2000**, *100*, 3205–3220. For selected references, see: c) X.-B. Xu, J. Liu, J.-J. Zhang, Y.-W. Wang, Y. Peng, *Org. Lett.* **2013**, *15*, 550–553; d) M. Shahjahan Kabir, M. Lorenz, M. L. Van Linn, O. A. Namjoshi, S. Ara, J. M. Cook, *J. Org. Chem.* **2010**, *75*, 3626–3643; e) S. Jammi, P. Barua, L. Rout, P. Saha, T. Punniyamurthy, *Tetrahedron Lett.* **2008**, *49*, 1484–1487; f) C. C. Silveira, P. C. S. Santos, S. R. Mendes, A. L. Braga, *J. Organomet. Chem.* **2008**, *693*, 3787–3790; g) Y. Zhang, K. C. Ngeow, J. Y. Ying, *Org. Lett.* **2007**, *9*, 3495–3498; h) Y. Yatsumonji, O. Okada, A. Tsubouchi, T. Takeda, *Tetrahedron* **2006**, *62*, 9981–9987; i) F. Y. Kwong, S. B. Buchwald, *Org. Lett.* **2002**, *4*, 3517–3520; j) H. J. Cristau, B. Chabaud, A. Chene, H. Christol, *Synthesis* **1981**, 892–894; k) C. Millois, P. Diaz, *Org. Lett.* **2000**, *2*, 1705–1708; l) V. Percec, J.-Y. Bae, D. H. Hill, *J. Org. Chem.* **1995**, *60*, 6895–6903; m) K. Takagi, *Chem. Lett.* **1987**, 2221–2224; n) J. She, Z. Jiang, Y. Wang, *Tetrahedron Lett.* **2009**, *50*, 593–596.

[6] a) R. Sustmann, P. Hopp, R. Boese, *J. Organomet. Chem.* **1989**, *375*, 259–264; b) C.-S. Yan, Y. Peng, X.-B. Xu, Y.-W. Wang, *Chem. Eur. J.* **2012**, *18*, 6039.

[7] a) C. Liu, D.-M. Shen, Q.-Y. Chen, *J. Org. Chem.* **2007**, *72*, 2732–2736; b) L.-W. Xu, C.-G. Xia, J.-W. Li, X.-X. Hu, *Synlett* **2003**, 2071–2073.

[8] E. Kato, H. Nagano, S. Yamamura, M. Ueda, *Tetrahedron* **2003**, *59*, 5909–5917.

[9] B. K. Barr, R. J. Holewinski, *Biochemistry* **2002**, *41*, 4447–4452.

[10] C. Bao, G. Fan, Q. Lin, B. Li, S. Cheng, Q. Huang, L. Zhu, *Org. Lett.* **2012**, *14*, 572–575.

[11] a) G. R. Pettit, B. Toki, D. L. Herald, P. Verdier-Pinard, M. R. Boyd, E. Hamel, R. K. Pettit, *J. Med. Chem.* **1998**, *41*, 1688–1695; b) J.-P. Liou, J.-Y. Chang, C.-W. Chang, C.-Y. Chang, N. Mahindroo, F.-M. Kuo, H.-P. Hsieh, *J. Med. Chem.* **2004**, *47*, 2897–2905.

[12] a) S. Messaoudi, B. Tréguier, A. Hamze, O. Provot, J.-F. Peyrat, J. R. Rodrigo De Losada, J.-M. Liu, J. Bignon, J. Wdzieczak-Bakala, S. Thoret, J. Dubois, J.-D. Brion, M. Alami, *J. Med. Chem.* **2009**, *52*, 4538–4542; b) A. Hamze, A. Giraud, S. Messaoudi, O. Provot, J.-F. Peyrat, J. Bignon, J.-M. Liu, J. Wdzieczak-Bakala, S. Thoret, J. Dubois, J.-D. Brion, M. Alami, *ChemMedChem* **2009**, *4*, 1912–1924; c) S. Messaoudi, A. Hamze, O. Provot, B. Tréguier, J. R. De Losada, J. Bignon, J.-M. Liu, J. Wdzieczak-Bakala, S. Thoret, J. Dubois, J.-D. Brion, Alami, *ChemMedChem* **2011**, *6*, 488–497.

Received: July 30, 2013
Published online: September 24, 2013

