



Preliminary communication / Communication

Valorisation of agricultural resources: synthesis of green tensioactives agents from carbohydrates

Mathilde Capderou^a, Patrick Pale^{b,*}

^a Laboratoire de chimie, Milupa SA, 20, rue d'Agen, 68027 Colmar, France

^b Laboratoire de synthèse et réactivité organique, Institut Le-Bel, université Louis-Pasteur, BP 296, 67000 Strasbourg, France

Received 1 August 2003; accepted after revision 2 February 2004

Abstract

Aldonolactones were selectively acylated in a one-pot process using either chemical reagents or enzymes. The so formed derivatives exhibited interesting tensioactive properties. Aldonolactones were thus converted into green tensioactives compounds. *To cite this article: M. Capderou, P. Pale, C. R. Chimie 7 (2004).*

© 2004 Académie des sciences. Published by Elsevier SAS. All rights reserved.

Résumé

Des aldonolactones ont pu être sélectivement acylées par voie chimique ou enzymatique. Ces méthodes ont permis d'obtenir en une seule étape des composés possédant des propriétés tensioactives, utilisables comme détergents « verts ». *Pour citer cet article : M. Capderou, P. Pale, C. R. Chimie 7 (2004).*

© 2004 Académie des sciences. Published by Elsevier SAS. All rights reserved.

Keywords: Carbohydrates; Enzyme; Selective acylation; Surfactant

Mots clés : Glucides ; Enzyme ; Acylation sélective ; Surfactant

Carbohydrates are the most abundant natural substances produced by living organisms, especially plants. They are therefore the main products of agriculture, however only a small part of them is really used and the major application is obviously nutrition and food. Non-food applications of carbohydrates [1] would offer tremendous opportunities to agriculture and also environmentally safe alternatives to the classical chemistry based on fossil sources [2,3].

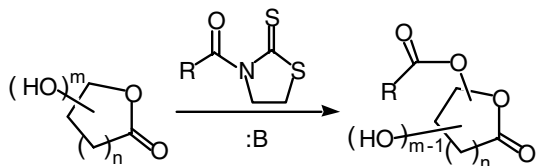
One of the main developments of carbohydrates towards non-food applications lies on the synthesis of new and green surfactants [1,4]. Indeed, carbohydrates fulfil half of the required properties for a surfactant with their hydrophilic structure. Grafting long hydrophobic chain onto them would yield a compound having tensioactive properties. Few examples have already appeared in the literature [4,5]. Surprisingly, aldonolactones have almost never been studied for this purpose [6,7], although they could lead to non-ionic as well as ionic detergents.

* Corresponding author.

E-mail address: ppale@chimie.u-strasbg.fr (P. Pale).

In this communication, we present a mild and efficient one-pot access to tensioactive compounds derived from aldonolactones using either chemical reagents or enzymes.

D-Glucono-1,5-lactone **1a** and L-galactono-1,4-lactone **2** were selected for their availability and submitted to various protocols introducing an alkyl chain on them. To get authentic samples, we first relied on a classical protection–deprotection sequence allowing to unambiguously preparing aldonolactones carrying only one chain but at different positions. Using selective and successive protections, any acylated derivatives of **1a,b** or **2** can be produced after a tedious multistep sequence [8]. However, industrial applications and developments would require a synthesis as short as possible, we thus looked for a selective and rapid method able to introduce an alkyl chain. Plusquellec type reagents are known to provide selective acylation of carbohydrates [9], we thus applied these reagents to the lactones **1a** and **2** in the presence of bases in various solvents (Scheme 1).



Scheme 1

To find the right conditions, *N*-(11-undecenoyl)-1,3-thiazolidine-2-thione **3** (R = (CH₂)₈CH=CH₂ in Scheme 1) [10] was first used as a model. In this reagent, the alkyl chain was selected with a chain length long enough to induce tensioactive properties and with a double bond that can act as a reporter group, facilitating NMR studies of the products formed. The treatment of **1a** or **2** with *N*-(11-undecenoyl)-1,3-thiazolidine-2-thione **3** in appropriate conditions indeed provided the expected monoacylated products. Typical results were reported in Table 1.

Strong bases proved to be inefficient and no acylation product could be detected under these conditions (entries 1, 3, 5). The starting lactones were recovered untouched, except for D-glucono-1,5-lactone **1a**, which was quantitatively isomerised to the corresponding 1,4-lactone **1b** (entry 1). Mild bases such as amines were however effective, especially when DMF was used as solvent (entries 2, 4, 6).

Table 1

Chemical acylation of aldonolactones with reagent **3**.

^a Yields are given for pure isolated products.

^b R = (CH₂)₈CH=CH₂.

^c Py = pyridine.

^d Various amines were experimented and NEt₃ proved to be the most convenient.

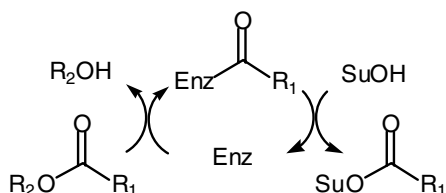
Entry	Aldonolactones	Solvent	Base	Time (h)	Yields ^a (%)	Products ^b
1		Py ^c	NaH	24	100	1b
2		DMF	NR ₃ ^d	24	20	4b =
D-Glucono-1,5-lactone 1a						
3		Py ^c	NaH	24	0	1b
4		DMF	NR ₃ ^d	5	20	4b =
D-Glucono-1,4-lactone 1b						
5		Py ^c	NaH	24	0	2
6		DMF	NR ₃ ^d	16	22	5 =
L-Galactono-1,4-lactone 2						

The acylation position proved to be highly dependent on the starting lactone structure. D-Gluconolactone as a 1,5-lactone **1a** or as a 1,4-lactone **1b** gave only the 6-undecenoyl ester as expected due to the primary position of the 6-hydroxyl group (entries 2, 4), but the L-galactono-1,4-lactone **2** gave a product where the acyl chain is located at the 2 position (entry 6). Control experiments have shown that this selectivity was not the result of acyl migration. Conformational analysis revealed that the hydroxyl group in the 2-position of **1a,b** and **2** has different environment. Further work is in progress to elucidate this reactivity difference.

Although highly selective, this direct acylation method is not really practical, since the yield of acylated product remained around 20% whatever the solvent and the base used. The yields could be increased using other acylating reagents, the selectivity however decreased depending on both aldonolactone and reagent structures. It is nevertheless worth to point out that these reactions provide in a one-pot process *only one* acylated compound, which can easily be recovered by chromatography from the remaining starting materials, which itself could be recycled.

Enzymes can also realize the selective acylation of various hydroxylated compounds, including carbohydrates, providing water is excluded from the reaction medium [11]. The enzymes used are hydrolytic en-

zymes, which are first acylated by an appropriate reagent. In the absence of water, the so-formed acyl enzyme intermediate can be attacked by a hydroxyl group of the substrate. The enzyme is thus regenerated and the hydroxyl group acylated (Scheme 2).



Scheme 2

The application of this process to aldonolactones could however raise several problems. Indeed, the lactone group in these carbohydrates could act as an acylating agent and thus polymerisation could occur as shown in Scheme 3.

An industrial group already reported an enzymatic acylation of gluconolactone, but they indeed obtained mixture of compounds [6]. Nevertheless, we submitted **1** and **2** to an enzyme screening from which the crude extract of pig pancreas (PPL) and *Candida antarctica* lipase (CAL) emerged. All other enzymes leaved the starting aldonolactones untouched, no oligo- or polymerisation product have been detected. Since PPL and CAL were able to catalyse the acylation of D-glucono-1,5-lactone, conditions' optimisation was then conducted with each enzyme, but the most interesting results were obtained with CAL and they are collected in Table 2.

In sharp contrast with the chemical route, only the 6-acylated compounds were isolated whatever the structure of the starting lactones and moreover, the reaction could give excellent yields. Yields do not seem to be correlated to the chain length (entries 2 vs 3 and 6 vs 7) but rather to the acylating power of the reagent used. Indeed, the more electron-withdrawing the ester, the more efficient the acylation (entries 4 vs 3 and 8 vs

7). Although acids have been reported as acylating agents in enzymatic reactions [12], they proved to be unreactive here (entries 1, 5). Ethyl esters were not reactive enough (entries 2, 3, 6, 7), they probably cannot efficiently form the acyl enzyme intermediates (see Scheme 2, $R_2 = \text{Et}$), even after prolonged reaction time. With the 2,2,2-trifluoroethyl ester, the acyl enzyme is probably easily formed by displacement of the labile 2,2,2-trifluoroethanol (see Scheme 2, $R_2 = \text{CF}_3\text{CH}_2$), the reaction is thus more rapid and much more efficient (entries 4, 8).

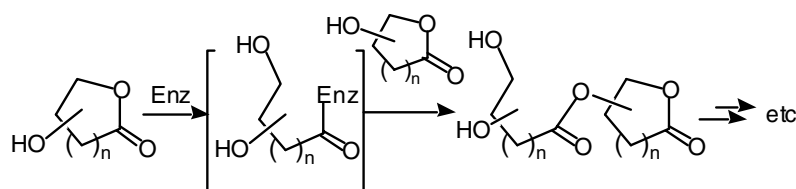
The mechanism of this enzymatic reaction implies that the carbohydrate must react with the acyl enzyme intermediate. The carbohydrate must thus enter the enzyme up to its active site and one of carbohydrate hydroxyl groups should displaced the acyl group linked to the enzyme active site. This complex mechanism could explain the very high selectivity observed for acylation of the primary hydroxyl group, independently of the lactone structure.

The tensioactives properties (CMC, emulsifying properties and foam formation) of the compounds obtained either from the chemical route or from the enzymatic step have been investigated. These physicochemical studies will be described later. Some of the compounds exhibited interesting properties, which could lead to industrial applications as mild detergents or emulsifiers.

In conclusion, we have been able to selectively acylate aldonolactones in a one-pot process using either chemical reagents or enzymes. The so formed derivatives exhibited interesting tensioactive properties. Aldonolactones were thus converted to green tensioactives compounds.

Acknowledgements

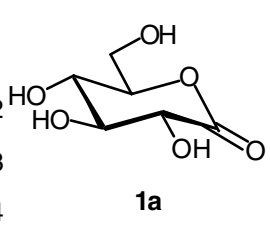
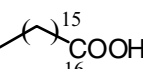
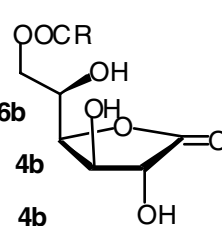
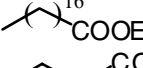

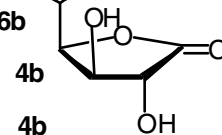
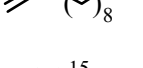
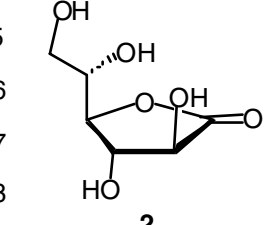
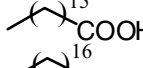
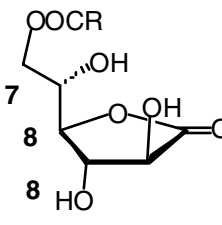
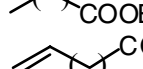
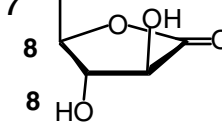
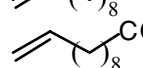
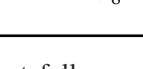
This paper is dedicated to the memory of Prof. J. Chucho, 'Université de Reims-Champagne-



Scheme 3

Table 2

Enzymatic acylation of aldonolactones.^a^a The reactions were performed in *t*BuOH at 45 °C in the presence of molecular sieves to remove water and/or alcohol.^b 8 equiv of the acylating reagent were used TFE = –CH₂CF₃.^c Yields are given for pure isolated products; **6b**, **7**, R = –(CH₂)₁₆CH₃; **4b**, **8**, R = –(CH₂)₈CH=CH₂.

Entry	Aldonolactones	Reagent ^b	Time (h)	Yields ^c (%)	Products	
1	 1a	 (CH ₂) ₁₅ COOH	24	0	 6b	
2		 (CH ₂) ₁₆ COOEt	52	20		
3		 (CH ₂) ₈ COOEt	52	20		 4b
4		 (CH ₂) ₈ COOTFE	18	76		
5	 2	 (CH ₂) ₁₅ COOH	24	0	 7	
6		 (CH ₂) ₁₆ COOEt	24	30		 8
7		 (CH ₂) ₈ COOEt	42	31		
8		 (CH ₂) ₈ COOTFE	24	85		

Ardenne'. The company ARD (Pomacle) is gratefully acknowledged for generous gifts of aldonolactones and for performing the tensioactive evaluation of our products. The authors thank the 'Région Champagne-Ardenne' for financial supports.

References

- [1] F.N. Lichtenthaler (Ed.), Carbohydrates as Organic Raw Materials, VCH, Weinheim, Germany, 1991.
- [2] M. Lancaster, Green Chemistry, RSC, Cambridge, 2002.
- [3] M. Dohy, B. Sillion (Eds.), La chimie des substances renouvelables, L'Actualité chimique (2002).
- [4] J.H. Clarke, Green Chem. 1 (1999) 1; see also: Green Chem. 1 (1999) G6–G9.
- [5] W. Von Rybinski, K. Hill, Angew. Chem. Int. Ed. Engl. 37 (1998) 1329.
- [6] (a) D.J. Pocalyko, A.J. Carchi, B. Harirchian, J. Carbohydr. Chem. 14 (1995) 265; (b) D. Kwoh, D.J. Pocalyko, A.J. Carchi, B. Harirchian, L.O. Hargiss, T.C. Wong, Carbohydr. Res. 274 (1995) 111.
- [7] F. Garésio, N. Kardos, C. Bonnevie, S. Petit, J.-L. Luche, Green Chem. 2 (2000) 33.
- [8] M. Caperou, PhD Thesis, université de Reims–Champagne-Ardenne, Reims, France, 1995.
- [9] D. Plusquellec, F. Roulleau, J.-N. Bertho, M. Lefevre, Tetrahedron 42 (1986) 2457.
- [10] I. Toshio, T. Mukaiyama, Bull. Chem. Soc. Jpn 52 (1979) 555.
- [11] A.M. Klivanov, Acc. Chem. Res. 23 (1999) 114.
- [12] F. Börkling, S.E. Godtfredsen, O.J. Kirk, J. Chem. Soc. Chem. Commun 934 (1989); D. Colombo, F. Ronchetti, A. Scala, I.M. Taino, Tetrahedron: Asymm. 5 (1994) 1377.