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Esterification of unprotected sucrose with acid chlorides in aqueous medium: kinetic reactivity versus acyl- or alkyloxycarbonyl-group migrations

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Abstract

The study of the competition between formation, migration and hydrolysis of sucrose mono-esters and -carbonates confirmed that the pre-eminent reactivity of some secondary positions persists in aqueous medium, and in particular, OH-2, even though fast subsequent migrations finally enrich the mixture in compounds substituted at the primary positions. The reaction was also shown to depend strongly on the starting sucrose concentration providing higher substituted derivatives in the case of hydrophobic acylating agents, in contrast to smaller chains. © 1999 Elsevier Science Ltd. All rights reserved.

Keywords: Sucrose; Migration; Esters; Carbonates

1. Introduction

The esterification of sucrose with octanoyl chloride or allyl and octyl chloroformates in aqueous medium [1,2] is part of our research dedicated to the understanding of the chemical reactivity of unprotected sucrose in water or various aqueous media, in connection with the utilisation of sucrose as a chemical raw material [3–6]. In particular, our goal is to define new methods for the preparation of surface-active or polymerisable derivatives from readily available carbohydrates based on simple and direct routes [7–9].

Two main points have to be investigated in the case of reactions involving sucrose as a polyol, the first one being the control of the degree of substitution. This selectivity is critical, since the degree of substitution is closely related to the nature of the industrial application of the compounds [10]. For example, different emulsion types (oil-in-water or water-in-oil) are obtained depending on the substitution distribution of sucrose fatty esters [11–15]. The regioselectivity is the second important issue. Even with similar physicochemical properties, regioisomers might differ in their toxicity, smell, taste or biodegradability. Therefore, the position of the substituent(s) has to be known, and better, to be controlled.

The difference of reactivity between the eight hydroxyl groups of sucrose is thus a key factor in its chemical exploitation. In organic

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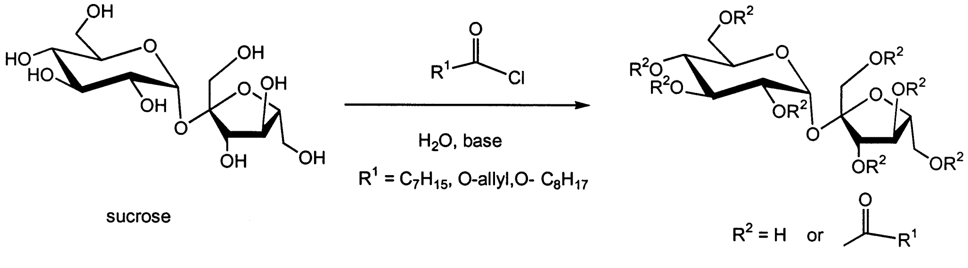
solvents (*N*,*N*′-dimethylformamide or dimethyl sulfoxide), primary positions might react faster than secondary ones if the reaction is essentially sensitive to steric interactions. This is typically the case for tritylation or Mistunobu-type reactions [3–5,16–19]. On the other hand, the reaction might be more sensitive to the acidity of the alcohol functions [20,21]. In this respect, OH-2 has been shown to be the most reactive among the eight hydroxyl groups of sucrose [22]. This is related to a strong hydrogen-bond network involving O-2 and OH-1′ or OH-3′ able to overcome the interactions with highly polar solvents. The product distribution of a reaction (for example an etherification) is then consistent with the equilibrium between two main conformations [23–25,31]. Spectroscopic investigations and theoretical studies [26–31] have provided consistent clues on the relative reactivity of the sucrose hydroxyl groups in organic media, and more recently, in water. In this latter case, it was shown that OH-2 and OH-1′ or OH-3′ are involved in a more complex hydrogen-bond network that incorporates one water molecule.

In the case of esterifications, the link between the relative reactivities of the various hydroxyl groups and the distribution of the sucrose derivatives might be disturbed by competitive backward processes, intermolecular transesterifications and intramolecular migrations, if the reaction is under thermodynamic control. Besides the enzymatic transesterifications, which are very selective [32–35], complicated mixtures of regioisomers are usually obtained in which the primary esters are the major products [36–38]. Under special conditions, secondary hydroxyl groups can be esterified [39–41].

In this paper, we describe the results of our investigations on the regiochemistry of the monoacylation of unprotected sucrose in aqueous medium with water-sensitive reactants such as acid chlorides and alkyl chloroformates (Scheme 1). The possibility of using water as an alternative solvent for the esterification of sucrose instead of organic solvents such as *N*,*N*-dimethylformamide, dimethyl sulfoxide or pyridine was studied. The main targets were the sucrose esters having a low degree of substitution, which have potential industrial applications either in the field of surface-active agents [42] or as polymerisable compounds.

2. Results and discussion

The reaction of sucrose with octanoyl chloride in alkaline aqueous medium was studied first [1], with special focus on the influence of the concentration of sucrose in water on the outcome of the reaction [43]. It was conducted at pH 10 (10 M NaOH, pH-stat) in a sucrose concentration range from 10 to 70% (0.4–2.7 M) but with a constant sucrose:acylating agent ratio. The results are reported in Tables 1 and 2. When performed at low water content, acceptable yields of sucrose esters were obtained, in a manner consistent with slower saponification (vide infra). The degree of substitution of the products was shown to be very sensitive to the starting sucrose concentration, since mostly polysubstituted derivatives (with an average degree of substitution (DS) of 4) were obtained. This can be related to the known effect of sucrose, which strengthens the water structure, thus increasing the polysubstitution pathway driven by the hydrophobic



Scheme 1.

Table 1
Effect of sucrose:water ratio on ester distribution using NaOH or DMAP as the base

Sucrose concn (w/w%)	Octanoates (%)			Global yield [b] (%)
	Mono-	Di-	Tri- and over [a]	
NaOH [c]				
40	12	11	19	42
50	10	10	30	50
60	4	8	50	62
70	1	2	65	68
DMAP [d]				
40	30	20	23	73
50	35	21	31	87
60	42	15	35	92
70	45	13	40	98

[a] Average degree of substitution determined from the integration in ^{1}H NMR spectra.

[b] Isolated yields, based on the acid chloride conversion, after silica gel chomatography and determination of the degree of substitution by proton NMR.

[c] Reactions conducted at 15 °C at pH 10 (pH-stat 10 M NaOH) with 0.25 equiv of octanoyl chloride (reaction time: 1 h).

[d] Reactions conducted at rt using 2 equiv of DMAP and 0.25 equiv of octanoyl chloride (reaction time: 10 min).

effect [44]. Alternatively, when promoted by a stoichiometric amount of 4-dimethylaminopyridine (DMAP), the polysubstitution tendency was not observed on increasing the sucrose concentration. The acylpyridinium species [45] involved in the mechanism might be less sensitive to the entropy-driven aggregation effect, and the catalysis should increase the acylation rate but not the saponification rate. As shown in Table 1, good yields of sucrose esters were then obtained, even in the case of dilute sucrose solutions (10% w/w). For higher sucrose concentrations, very high conversion of the fatty chain was obtained (polysubstituted sucrose fatty esters are also interesting derivatives as non-caloric fat substitutes [46,47]). Among other amines, dodecyldimethylamine led also mainly to mono- and di-substituted sucrose esters, although at a lower reaction rate. Other bases such as pyridine, triethylamine and diisopropylethylamine were unsuccessful, whereas diazabicyclo[5.4.0]undec-7-ene (DBU) led to extensive polysubstitution.

The behaviour of the reaction using a catalytic amount of DMAP together with NaOH (at pH 10) as the stoichiometric base was different (Table 2). The reaction was again faster and led to very good yields even in dilute solutions, but the tendency towards polysubstitution upon increasing the starting sucrose concentration is nearly as marked as without catalyst. This indicates that the natures of both the intermediate acylating agent and of the sucrate ion pair are responsible for the observed results. By decreasing the temperature, the yields were slightly improved, due to a slower competitive saponification. On the other hand, at higher temperature, saponification of the sucrose esters occurred more rapidly. In the presence of sucrose mono-octanoates (SMO), the fast emulsification of the reaction mixture led to an efficient reaction. The combination of both DMAP and monoesters yielded the sucrose esters in a nearly quantitative global yield, although the monoester proportion was not improved in comparison with either 10 mol% of DMAP or 10 mol% of monoesters. Other mixtures such as DMAP and sodium hydrogencarbonate, and DMAP and triethylamine were used in variable amounts. Under these conditions,
increasing the proportion of DMAP in the mixture of bases led to consistent increases in the global yield and the monoester content.

The monoester content was shown to depend strongly on the excess quantity of sucrose compared with the acid chloride (Table 3). The polysubstitution driven by the hydrophobic effect was the main behaviour in the case of a 1:1 ratio, whereas increasing the amount of sucrose (and water in order to keep the same concentration and therefore competition between water and sucrose as nucleophiles) for a given quantity of acid chloride led almost exclusively to monosubstituted esters. More solvent is also present to solubilise the poorly soluble octanoyl chloride, which might also be helpful to the global homogeneity of the mixture. On the other hand, the pH had an effect on the global yield because of its consequence on the competitive esterification and saponification rates, but no effect on the distribution of the esters in terms of DS. This effect decreases for higher concentrations since hydrolysis is already disfavoured.

However, the same conditions applied to the higher fatty acid chlorides led to extensive polysubstitution. The global yield of the acylation consistently decreased (from 58 to 30 to 15%) in a water–sucrose mixture (60% w/w) when using longer acid chlorides (0.25 equiv, C_8–C_{12}–C_{16}), whereas the average DS of the esters obtained consistently increased (from 3 to 4.5 to 4.7). The effect of chain length is consistent with stronger hydrophobic effects, similar to what we observed in the presence of lithium chloride, a structure-making agent. For such longer chain substrates, the addition of an organic co-solvent was an efficient alternative. In a 1:1 water–tetrahydrofuran mixture, laurates and palmitates having a low average DS were obtained in fair yields and rather similar distributions, showing that in such a medium, hydrophobic aggregation is dramatically less favoured (Table 4). This example illustrates the possibility of directing a chemical system towards one or other pathway by selecting the solvent with respect to its sensitivity to hydrophobic effects [48]. Good yields of sucrose esters can thus be obtained in an aqueous or hydro-organic medium, with a natural propensity towards polysubstitution in pure water, unlike in the case of methacryloyl

Table 2
Effect of sucrose:water ratio, catalyst and temperature on ester distribution [a]

Sucrose concn (w/w%)	Catalyst (equiv)	T (°C)	Octanoates [b] (%)			Global yield (%)
			Mono-	Di-	Tri- and over	
10		25	2	0	0	2
10	DMAP (0.05)	25	38	11	17	60
10	DMAP (0.10)	0	62	8	12	82
10	DMAP (0.10)	25	52	11	9	72
10	DMAP (0.10)	30	40	8	5	53
10	DMAP (0.10)	45	11			11
20	DMAP (0.10)	0	49	20	24	93
20	DMAP (0.10)	25	39	24	22	85
30	DMAP (0.10)	0	32	23	39	94
30	DMAP (0.10)	25	28	24	34	86
40	DMAP (0.10)	0	26	24	46	96
40	DMAP (0.10)	25	22	21	50	93
50	DMAP (0.10)	0	21	22	53	96
50	DMAP (0.10)	25	21	22	52	95
60	DMAP (0.10)	25	19	22	54	95
10	py (0.10)	25	7	3	2	12
10	P-py [c] (0.10)	25	39	8	4	51
10	PVPy [d] (0.1)	25	4			4
10	SMO [e] (0.1)	25	33	5	7	45
10	DMAP–SMO (0.05+0.05)	25	53	15	25	93

[a] Reactions conducted at pH 10 (pH-stat 10 M NaOH) with 0.1 equiv of octanoyl chloride.

[b] Isolated yields.

[c] Pyrrolidinopyridine.

[d] Polyvinylpyridine (in pyridine equivalents).

[e] Sucrose monooctanoates isolated by flash chromatography.

Table 3
Effect of sucrose:acid chloride ratio and pH on ester distribution [a]

Sucrose excess (per mol of acid chloride)	Catalyst (equiv) [b]	pH	Octanoates [c] (%)			Global yield (%)
			Mono-	Di-	Tri- and over	
1	0.1	10	10	14	44	68
5	0.1	10	35	8	27	70
10	0.1	10	52	11	9	72
20	0.1	10	64	5	0	69
5	0.05	8	23	7	10	40
5	0.05	9	31	12	16	59
5	0.05	10	38	11	17	66
5	0.05	11	25	10	11	46

[a] Reactions conducted at 25 °C with DMAP as catalyst, using a 10% (w/w) aqueous sucrose solutions.

[b] Based on chloroformate.

[c] Isolated yields.

chloride for which only the global yield was affected by the water content [49,50].

In the case of chloroformates, the reaction with carbohydrates is known to provide either cyclic carbonates or alkyloxycarbonyl derivatives [51–55]. Such products have also been reported by reaction from sucrose [56].

Addition of allyl chloroformate (0.25 equiv) to an aqueous sucrose solution led to good yields of allyloxycarbonyl sucrose monosubstituted derivatives. The reverse addition mode led mostly to more substituted derivatives [52]. A 40% (w/w) sucrose solution in water at pH 10 and 2 °C as reaction temperature provided the best balance between the esterification rate and the hydrolysis of the products or the starting chloroformate (Table 5). In most cases, small amounts of less polar derivatives were also obtained and were identified as dicarbonates. The concentration of sucrose in water did not affect the distribution of the carbonates. Only the reaction rate was increased and the global yield was slightly higher. Sucrose allyl carbonates could be obtained even at neutral pH, but in a sluggish reaction. Adding DMAP as catalyst but keeping the temperature as low as 2 °C led to good yields for a reaction at pH 8. At higher pH (11), the reaction was fast, but extensive carbonate saponification occurred. In this case, almost no disubstituted derivatives were detected because of the competitive hydrolysis, and the distribution of the regioisomers (mostly primary carbonates) was also distinctive of extensive carbonate cleavage and migrations (vide infra).

In the case of the reaction with octyl chloroformate, the same global outcome was observed as for the esterification of sucrose with fatty acid chlorides. The tendency towards polysubstitution was even stronger for an eight-carbon alkyl chain, preventing acceptable yields of monosubstituted esters being obtained (Table 5).

Even with stoichiometric amounts of DMAP, the polysubstitution was the major process. Moreover, the poly-*O*-octyloxycarbonyl sucrose derivatives, when formed in large quantities, tend to separate out of the reaction mixture and to cover the glassware as well as the pH-stat electrode, thus preventing an accurate measurement and control of the basic conditions.

Using a 9:1 water–THF mixture, the yield of monosubstituted derivatives was slightly improved. However, the tendency towards polysubstitution was still observed, especially when increasing the starting sucrose concentration from 5 to 60%. This series of experiments was carried out in the presence of 0.1 equivalent of monocarbonates in order to promote the reactant mixing. In 1:1 water–THF mixture and in the presence of catalytic amounts of DMAP, better yields of mono-*O*-octyloxycarbonyl sucrose derivatives were obtained when a sufficiently low sucrose concentration was used.

Regiochemichal aspects.—After isolation of the sucrose esters or carbonates by silica gel chromatography, the fraction containing the monosubstituted derivatives was submitted to semi-preparative HPLC, leading to the pure regioisomers. Identification of each octanoyl ester was based on the chemical shifts of the hydrogen atom(s), which is in the α position next to the acylated hydroxyl group (ca. + 0.5), and, in ^{13}C NMR, the carbon atom directly concerned (+1–2 ppm) and those next to it (ca. −2 ppm). In the case of carbonates, the changes in the carbon chemical shifts were +6–7 ppm for the carbon bearing the hydroxy group involved in the substitution, and ca. −3 ppm for the α carbons (see Table 6) [57,58]. For a given set of reaction conditions, the monosubstituted derivatives were isolated, and the mixture of regioisomers was analysed by HPLC, providing a chromatographic pattern in which each isomer is easily recognisable.

The full separation, analysis and characterisation of all the regioisomers of the monosubstituted esters and carbonates allowed the estimation of their proportions as a function of the reaction conditions. In all cases, the distribution of the monosubstituted derivatives was a complex mixture of seven isomers, with the three primary derivatives as the major products, but the secondary isomers often accounted for a large proportion, sometimes nearly half of the mixture. The 4-*O*-acylated isomer was absent, probably because of a very fast migration towards OH-6. We also observed that the chromatographic pattern also depended on the reaction conditions. For example, the distribution of the mono-*O*-allyloxycarbonyl sucrose derivatives was shown to depend on the pH at which the reaction was conducted. Notably, even though some carbonate groups might have migrated during the reaction and isolation of the products, the amount of the isomer at the primary position OH-1′ and at the secondary OH-2 increases under less basic conditions. In contrast, secondary carbonates are present in much smaller amount at higher pH because of extensive saponification and migration. For octyloxycarbonylated derivatives, the proportion of secondary isomers increased consistently with the content of the organic solvent when going from pure water to hydro-organic media, with carbonates at OH-2 and OH-3 being distinctively favoured. This shows that, even though water is disturbing the hydrogen bond network through the solvation process, the intrinsic pre-eminent reactivity of some hydroxyl groups of sucrose persists in aqueous medium.

Since the relative amounts of products are the result of a complex competition between esterification, migration and saponification rates, the outcome of the hydrolysis of the

Table 4
Esterification of sucrose in aqueous medium with longer acid chlorides [a]

R	Solvent	Sucrose excess	Sucrose esters [b] (%)			Global yield (%)
			Mono-	Di-	Tri- and over	
C_7H_{15}	water	10	52	11	9	72
$C_{11}H_{23}$	water	10	2	6	12	20
$C_{11}H_{23}$	water [c]	10	4	6	12	22
$C_{11}H_{23}$	water [d]	10	2	6	12	20
$C_{11}H_{23}$	water	20	4	7	11	22
C_7H_{15}	water–THF 1:1	10	67	2	0	69
$C_{11}H_{23}$	water–THF 1:1	10	58	2	0	60
$C_{11}H_{23}$	water–THF 1:1	5	41	16	0	57
$C_{15}H_{31}$	water–THF 1:1	10	45	15	0	60

[a] Reactions conducted in a 10% (w/w) sucrose solution, at pH 10 (pH-stat 10 M NaOH), $T = 22$ °C, in the presence of 0.1 equiv of DMAP.

[b] Isolated yields after silica gel chromatography and determination of the average degree of substitution by NMR analysis.

[c] At 0 °C.

[d] With 0.2 equiv of DMAP.

Table 5
Reaction of sucrose with ROCOCl (0.25 equiv) in aqueous medium

R	Sucrose concn (w/w%)	Solvent (w/w)	pH [a]	DMAP [b] (equiv)	T (°C)	t (h) [c]	Yield (%) [d,e]
Allyl	40	water	7		23	2	55 (62)
Allyl	40	water	7	0.01	19	1.25	24 (26)
Allyl	40	water	7	0.1	2	1.25	47 (67)
Allyl	40	water	8		2	3	68 (81)
Allyl	40	water	8	0.01	2	1	62 (75)
Allyl	40	water	9		2	0.5	65 (77)
Allyl	40	water	10		2	0.3	77
Allyl	40	water	10		2	0.3 [f]	44
Allyl	40	water	11		3	0.5	46 (50)
n-Octyl	10	water	10	0.1	20	0.3	8 [g]
n-Octyl	10	water	9	0.01	0	1.5	13 [g]
n-Octyl	10	9:1 water–THF	10		0	4.5	
n-Octyl	10	9:1 water–THF	10	0.01	1	1.5	18 [g]
n-Octyl	10	1:1 water–THF	10	0.1	1	0.8	72
n-Octyl	10	1:1 water–propan-2-ol	10	0.1	1	0.8	76

[a] pH-stat, 10 M NaOH.
[b] Based on chloroformate.
[c] Chloroformate addition time 15–40 min.
[d] Isolated yields of the monosubstituted products after silica gel chromatography.
[e] The global yield in mono- and di-substituted carbonates is given in brackets.
[f] Chloroformate addition in one portion.
[g] Abundant polysubstituted carbonates detected (TLC).

monosubstituted derivatives obtained from sucrose and octanoyl chloride or octyl chloroformate has also been studied. As depicted in Fig. 1, using sodium hydrogencarbonate, the rate of saponification of the octyloxycarbonylsucroses was decreased considerably when the hydrolysis was conducted in a 50% (w/w) sucrose solution (curve A). Disubstituted sucrose derivatives were detected at the beginning of the reaction in pure water, whereas in sucrose solutions, almost none of these isomers were formed. This can be explained by the occurrence of transesterification reactions between two monosubstituted sucrose derivatives, giving sucrose and one disubstituted compound in pure water, whereas in a sucrose solution, the more probable transesterification reaction involves one monoester and one molecule of the 'external', very abundant, sucrose. The rather stable amount of monocarbonates measured in a 50% sucrose solution in the presence of sodium hydrogencarbonate in fact hides large variations in the relative amounts of each regioisomer (curves B and C).

Large variations were observed for the reaction in pure water (curve B). In this case, the amount of carbonate at OH-2 decreased very fast, to the benefit of the isomer at OH-3, which then decreased at a rate consistent with the increase of the proportion of isomer at OH-6. All the curves presented are consistent with a fast migration from the secondary positions towards the primary ones, an extensive acylation at the secondary positions, and a global stronger resistance of the primary esters or carbonates with respect to the saponification process. The overall behaviour observed in the case of the mono-octanoates was similar (Fig. 2). In the case of the $NaHCO_3$-catalysed reaction in a sucrose solution, the amount of ester at OH-2 was increasing somewhat at the very beginning of the hydrolysis (Fig. 2, curve F). This is the result of transesterification reactions between sucrose and mono-octanoates that consume the most abundant isomers in the mixture, i.e., the primary ones, and produces again the distribution corresponding to intrinsic relative reactivity in sucrose.

In Fig. 3 are shown the chromatograms corresponding to a sample of mono-*O*-octyloxycarbonyl sucrose derivatives in a mixture of water and acetonitrile (the HPLC eluent)

Table 6

^{13}C NMR chemical shifts (more affected values are in bold type) of the sucrose skeleton for monosubstituted allyloxycarbonyl (AOC), octyloxycarbonyl (OOC) and octanoyl (O) sucrose carbonates and esters [a,b]

Derivative	C-1	C-2	C-3	C-4	C-5	C-6	C-1′	C-2′	C-3′	C-4′	C-5′	C-6′
Sucrose [c]	92.0	71.9	73.4	70.2	73.1	60.8	62.4	104.3	77.4	74.6	82.8	62.4
3-*O*-AOC [c]	91.7	**69.7**	**80.5**	**67.5**	72.7	60.1	62.3	104.3	77.0	74.4	82.9	63.0
4′-*O*-AOC [c]	92.5	71.9	73.0	69.9	73.0	60.5	61.6	104.7	**75.1**	**81.6**	**80.2**	62.6
Mixture of 6-, 1′- and 6′-*O*-AOC [c,d]	91.9	71.6	72.9	69.9	72.9	60.7	61.8	104.2	76.5	73.5	83.0	62.7
	92.0	71.7	to	70.0	to 73.1	61.0	62.3	104.5	76.6	74.7	83.1	63.0
	91.9	71.8	73.1	70.3	69.6 (6)	65.9 (6)	69.2 (1′)	102.0 (1′)	77.2	74.9	79.2 (6′)	67.1 (6′)
Sucrose [e]	92.6	71.5	73.0	69.7	72.8	60.5	61.8	104.1	76.8	74.4	81.8	62.8
2-*O*-OOC [e]	**89.9**	**76.3**	**70.8**	69.9	72.9	60.8	61.9	104.5	76.5	74.4	82.0	62.8
3-*O*-OOC [e]	92.6	**70.8**	**79.7**	**68.2**	72.9	60.7	62.0	104.3	77.0	74.5	81.9	62.9
6-*O*-OOC [e]	92.6	70.8	73.0	70.0	**71.5**	**69.1**	62.1	104.2	77.3	74.5	82.0	62.9
1′-*O*-OOC [e]	93.1	71.4	73.1	69.6	73.1	60.6	**65.8**	**102.6**	77.0	73.4	82.2	62.0
3′-*O*-OOC [e]	92.3	71.6	73.0	69.4	72.6	60.5	62.0	**104.0**	**81.1**	**73.5**	82.4	63.7
4′-*O*-OOC [e]	92.9	71.6	73.1	69.5	73.1	60.5	62.0	104.9	**75.9**	**80.4**	**80.6**	62.7
6′-*O*-OOC [e]	92.5	71.7	73.2	70.1	73.1	61.3	62.5	104.2	77.6	75.2	**79.2**	**69.7**
2-*O*-O [e]	**90.1**	**73.0**	**70.8**	69.7	72.8	60.5	61.5	104.4	75.9	74.3	81.9	62.8
3-*O*-O [e]	92.6	**69.9**	**75.4**	**68.0**	72.8	60.5	61.8	104.3	76.9	74.5	81.9	62.8
6-*O*-O [e]	92.3	71.4	72.7	70.0	**70.5**	**61.8**	63.0	104.1	76.7	74.5	81.9	63.6
1′-*O*-O [e]	93.0	71.4	72.9	69.5	72.9	60.5	**62.8**	**102.8**	77.0	73.7	82.0	62.4
3′-*O*-O [e]	92.0	71.4	72.8	69.5	72.6	60.5	62.2	**103.7**	**77.5**	**73.4**	82.3	63.3
4′-*O*-O [e]	92.7	71.5	73.0	69.5	72.9	60.4	61.6	104.6	**75.1**	**76.4**	**80.1**	62.7
6′-*O*-O [e]	92.5	71.6	73.1	69.8	72.9	60.8	61.8	104.4	76.8	75.1	**79.0**	**66.1**
Sucrose [f]	93.9	73.8	75.4	72.2	75.3	62.8	63.2	106.2	80.2	75.9	84.8	65.2
6-*O*-O [f]	93.7	72.2	75.3	72.0	**73.7**	**64.8**	63.9	106.1	80.1	76.2	84.9	65.1
1′-*O*-O [f]	94.3	73.5	75.4	72.2	74.8	62.7	**64.4**	**104.4**	79.2	75.4	84.6	63.0
6′-*O*-O [f]	93.7	73.9	75.5	72.5	75.1	63.1	64.8	106.4	79.8	77.0	**81.2**	**67.0**

[a] In some cases for which chemical shifts are very close, C-2 and C-5 or C-1′ and C-6′ might be interchanged.

[b] NMR data for some of these compounds in other solvents are reported [59,60].

[c] In Me_2SO-d_6.

[d] Precise group position is given in brackets for the peaks assigned to one precise isomer among the three primary carbonates.

[e] In D_2O.

[f] In pyridine-d_5.

which was analysed over a longer period, but in absence of base. Again, a slow migration was observed from OH-2 to OH-3, and finally to OH-6. Esters at OH-6 and OH-6′ increased in a similar manner, whereas the isomer at OH-1′ was almost unchanged because of the absence of a vicinal hydroxy group that could participate in acyl migration.

These results show that the acyl migration mostly occurs in one direction, i.e., from the secondary positions towards the primary ones. The extent of secondary esters or carbonates in the reaction mixture is a sign of the competitive reactivity of the secondary positions, and among them, OH-2 and OH-3′. Therefore, the overall selectivity towards the primary substituted sucrose derivatives does not express the relative reactivity of all the hydroxy groups in aqueous medium, but the intricate competition between the esterification, the migrations, the transesterifications and the hydrolyses.

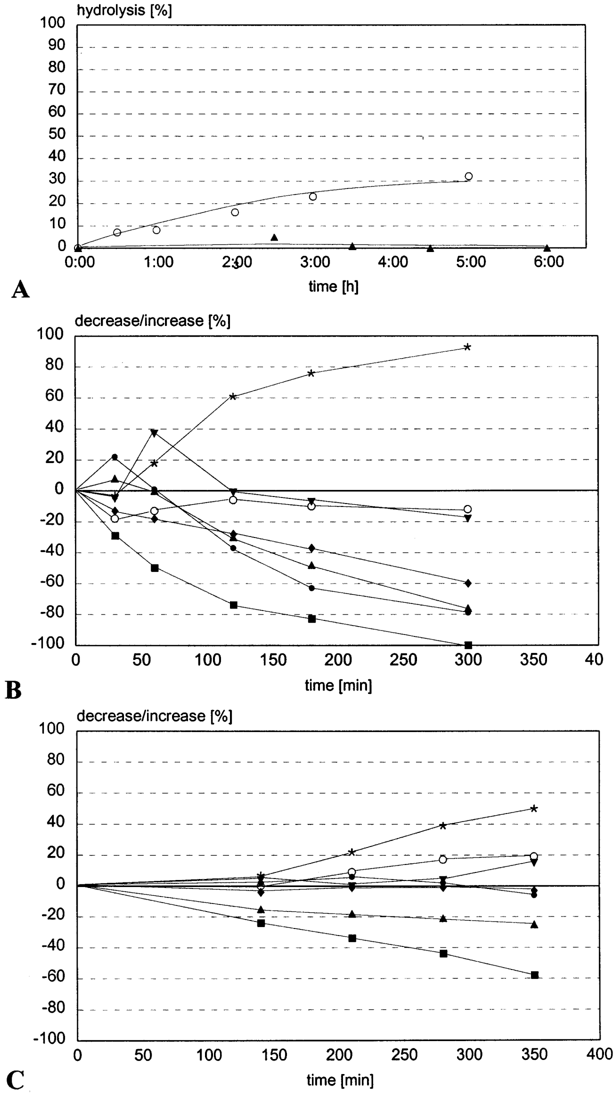


Fig. 1. Hydrolysis of mono-*O*-octyloxycarbonyl-sucrose derivatives using 1 equiv of $NaHCO_3$ in water (○) or 50% aq sucrose (▲) soln at rt (A) and distribution of the various isomers of mono-*O*-octyloxycarbonyl-sucroses in alkaline aq media as a function of time ((B) $NaHCO_3$, water; (C) $NaHCO_3$, 50% aq sucrose; ●: OH-3; ▲: OH-3′; ■: OH-2; ◆: OH-4′; ✱: OH-6; ▼: OH-1′; ○: OH-6′).

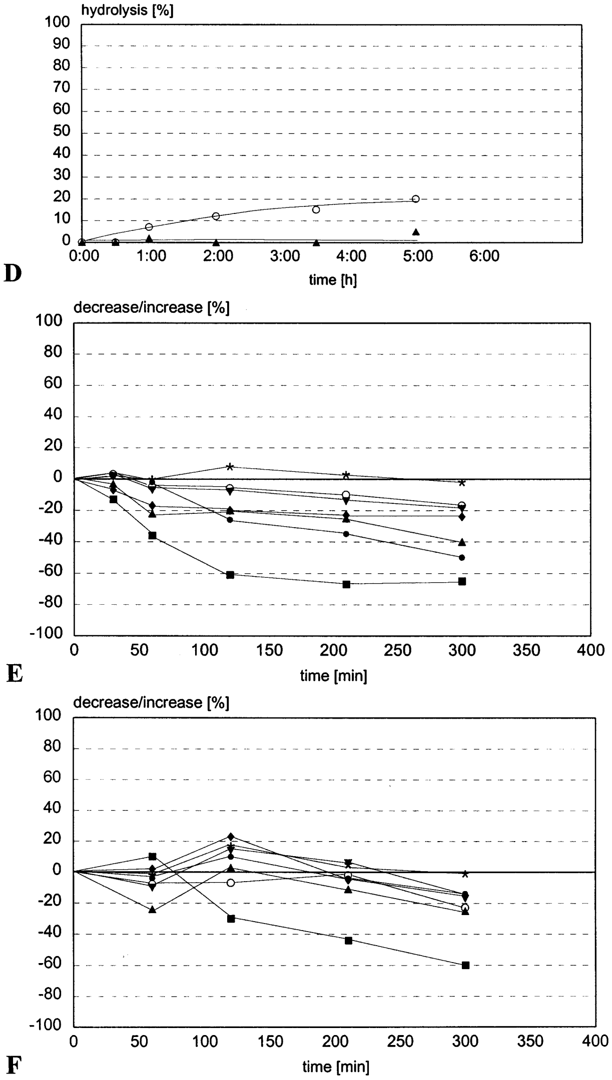


Fig. 2. Hydrolysis of mono-*O*-octanoylcarbonyl-sucroses using 1 equiv of $NaHCO_3$ in water (○) or 50% aq sucrose (▲) soln at rt (D) and distribution of the various isomers of mono-*O*-octanoyl-sucroses in alkaline aq media as a function of time ((E) $NaHCO_3$, water; (F) $NaHCO_3$, 50% aq sucrose; ●: OH-3; ▲: OH-3′; ■: OH-2; ◆: OH-4′; ✱: OH-6; ▼: OH-1′; ○: OH-6′).

3. Conclusions

The regioisomeric distribution of the monosubstituted sucrose derivatives obtained by reaction with acid chlorides or alkyl chloroformates in aqueous medium could be measured as a function of the reaction conditions, and the hydrolysis and group migration rates could be visualised. The hydroxyl group at OH-2 was shown to be very reactive in water just as it is in organic solvents. Because of extensive group migration, primary esters are the final mixture components. These results provide new chemical evidence for the intrinsic pre-eminent reactivity of some of the hydroxyl groups of sucrose, and in particular OH-2, in spite of the solvation by water.

4. Experimental

General methods.—NMR spectra were recorded on Bruker AC spectrometers at 50.32 or 75.47 MHz for ^{13}C NMR and 200 or 300 MHz for ^{1}H NMR. Reactions were monitored by TLC using aluminium silica gel plates ($60F_{254}$). Flash-chromatography separations were performed using Silica Gel 60H (40–63 μm) under 1 bar of pressure. Analytical and semi-preparative high performance liquid chromatography analyses were performed using NH_2- or C_{18}-bound columns (Nucleosil or Spherisorb) with refractive-index detection (RI). Mass spectrometry analysis (FAB) was performed at the 'Centre de Recherche sur les Macromolécules Végétales (CERMAV)' in Grenoble. High-resolution mass spectra were recorded at the 'Centre de Spectrométrie de Masse' de l'UFR de Chimie Biochimie de l'Université Claude Bernard Lyon 1. Elemental analyses were performed by the 'Service Central d'Analyse du CNRS', Vernaison. Molecular rotations were measured using a Perkin–Elmer 141 polarimeter in a 10 cm cell. Adjustment of the pH was carried out with a Metrohm 736 GP Titrino pH-stat apparatus. Sucrose was provided by Béghin-Say Co. All other chemicals were purchased from Aldrich Chemical Co. Solvents (HPLC grade) were purchased from Adrich, Carlo Erba or SDS. An Elga apparatus was used to produce ultrapure water.

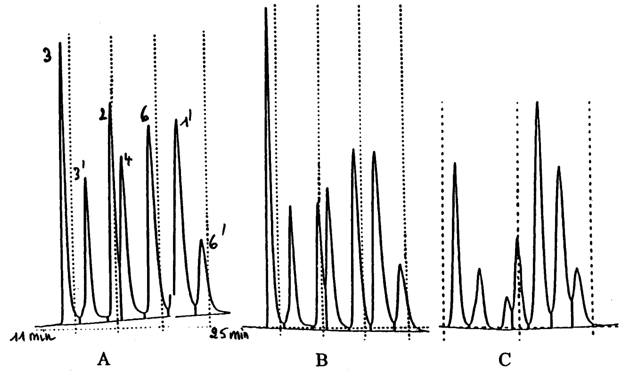


Fig. 3. Chromatographic patterns for mono-*O*-octyloxycarbonyl-sucroses in an 9:1 MeCN–water mixture at rt ((A) $t=0$; (B) after 2 weeks; (C) after 5 weeks).

General procedure for the reaction of sucrose with acid chlorides.—A typical experiment consisted in adding neat octanoyl chloride (8.78 mmol, 1.5 mL) using an automatic syringe (0.1 mL/min flow rate) to a stirred 60% w/w aq sucrose soln (sucrose: 88 mmol, 30 g, water: 20 g) adjusted to pH 10 with 10 M NaOH (pH-stat or manually). Reactions were monitored by TLC using a 14:5:5:1 mixture of CH_2Cl_2, EtOH, acetone and water as the eluent. After neutralisation by adding 0.5 M HCl, water was added in order to get a less viscous solution, and the crude sucrose esters could be extracted with 1-butanol (2 or 3 × 30 mL). After evaporation of the solvent, flash chromatography (same solvent as for TLC) allowed isolation first of the more substituted octanoates ($R_f = 0.70$–0.90), then the dioctanoates ($R_f = 0.55$–0.65), and finally the monooctanoates ($R_f = 0.32$–0.40). The average DS was determined by comparing integration for the alkyl chain and sugar regions in ^{1}H NMR spectra (Me_2SO-d_6). Monoesters could be further purified by semi-preparative HPLC (nucleosil NH_2, 10 × 250 mm, 93:7 MeCN–water, 5.3 mL/min, RI detection Shimazu LC-6A) and identified by ^{1}H and ^{13}C NMR spectroscopy. Analytical HPLC was performed using a Nucleosil NH_2 column (4.6 × 250 mm) eluted with a 9:1 MeCN–water mixture at an 0.7 mL/min flow rate.

The hydrolysis of the octanoyl chloride or the saponification of the sucrose esters could be followed by measuring the octanoic acid formation rate using a C_{18} analytical column eluted with a 4:1 MeOH–water mixture at an 0.6 mL/min flow rate.

Reactions with longer acid chlorides (lauryl and palmitoyl) were performed following the same procedure as for octanoyl chloride, and the variously substituted sucrose esters were isolated using the same eluents, with somewhat faster migration. In some cases, the strong emulsifying properties of the products led to very viscous phases, in which the control of the pH was disturbed, with a slower response of the pH-stat.

General methods for the preparation of sucrose carbonates.—To a stirred aq soln of sucrose (28 mmol, 9.6 g in different solvents) adjusted with a pH-stat (NaOH) and cooled to about 0 °C (ice–salt bath) was added allyl or octyl chloroformate (7 mmol) within 15–40 min (automatic syringe). The reaction was considered finished when the pH value (addition of base) was measured to be constant over 10 min. The solution was neutralised with 5% (w/w) aq AcOH. The crude mixture was either extracted with butan-2-ol and analysed by analytical HPLC or evaporated to dryness and submitted to silica gel chromatography (as a solid mixture adsorbed on silica gel). Two fractions were isolated: polysubstituted products ($R_f = 0.60$–0.80 for allyl and 0.90–1.00 for octyl) and monosubstituted products ($R_f = 0.40$–0.50 for allyl and 0.60–0.75 for octyl). Eluent for the TLC and flash-chromatography: $CHCl_3$:EtOH:acetone:water (14:5:5:1). Sucrose did not elute in this solvent. HPLC: Nucleosil NH_2 column with 9:1 MeCN–water, flow: 0.8 mL/min, RI detection. Mono-*O*-octanoyl sucrose derivatives were further purified by semi-preparative HPLC using an NH_2 Nucleosil column 20 × 250 mm, 5 µm, eluted with a 22:3 MeCN–water mixture at a 20 mL/min flow rate. Isolated regioisomers were then analysed by NMR spectroscopy.

General method for the sucrose monoester or monocarbonate hydrolysis rate studies.—The sucrose monosubstituted esters or carbonates (as a mixture of isomers, 70–100 mg) were treated in water or 50% water–sucrose mixture (2 g) containing $NaHCO_3$ or Na_2CO_3 (1 equiv compared to monooctanoate) at room temperature (rt), with vigorous stirring. Samples (100 µL) were regularly taken over 5 h and analysed by analytical HPLC. For octyloxycarbonyl derivatives, 100 mg of the mixture was treated in a 2 mL soln of $NaHCO_3$ (17 mg, 1 equiv) or Na_2CO_3 (22 mg, 1 equiv), and 100 µL samples were taken.

*Data for the mono-*O*-octanoylsucroses.*—Mixture of isomers: Anal. Calcd for $C_{20}H_{36}O_{12}$: C, 51.3; H, 7.7. Found: C, 51.2; H, 7.7. HRMS (FAB$^+$) m/z requires 491.2104 $[M + Na]^+$, found 491.2104. NMR data (in order of elution from the semi-preparative HPLC):

*3-*O*-Octanoylsucrose.* $[\alpha]_D^{21}$ +66.6° (c 1.5, MeOH); ^{1}H NMR (200 MHz D_2O,): δ 0.7–1.0, 1.2–1.4, 1.5–1.7, 2.4–2.6 (4 m, 3, 8, 2, 3 H, alkyl), 3.62 (t, 1 H, $J_{3,4}$ 9, H-4), 3.65 (s, 2 H, H-1′ab), 3.7 (dd, 1 H, $J_{2,3}$ 10, H-2), 3.8–4.0 (m, 6 H, H-5, H-5′, H-6ab, H-6′ab), 4.09 (t, 1 H, $J_{4',5'}$ 8, H-4′), 4.25 (d, 1 H, $J_{3',4'}$ 8.4, H-3′), 5.2 (t, 1 H, $J_{3,4}$ 9, H-3), 5.46 (d, 1 H, $J_{1,2}$ 3.6, H-1); ^{13}C NMR (50 MHz, D_2O): δ 14.0, 22.6, 25.0, 28.8, 28.9, 31.7, 34.6 (alkyl), 60.5 (C-6), 61.8 (C-1′), 62.8 (C-6′), 68.0 (C-4), 69.9 (C-2), 72.8 (C-5), 74.5 (C-4′), 75.4 (C-3), 76.9 (C-3′), 81.9 (C-5′), 92.6 (C-1), 104.3 (C-2′), 176.8 (C=O).

*3′-*O*-Octanoylsucrose.* $[\alpha]_D^{21}$ +20.0° (c 0.5, MeOH); ^{1}H NMR (200 MHz, D_2O): δ 0.7–1.0, 1.2–1.4, 1.5–1.7, 2.4–2.6 (4 m, 3, 8, 2, 3 H, alkyl), 3.5 (t, 1 H, $J_{3,4}$ 9, H-4), 3.55 (dd, 1 H, $J_{2,3}$ 10, H-2), 3.65 (s, 2 H, 1ab′-H), 3.7 (t, 1 H, $J_{3,4}$ 9, H-3), 3.8–4 (m, 6 H, H-5, H-5′, H-6ab, H-6′ab), 4.37 (t, 1 H, $J_{4',5'}$ 8, H-4′), 5.45 (d, 1 H, $J_{1,2}$ 3.6, H-1), 5.47 (d, 1 H, $J_{3',4'}$ 8.4, H-3′); ^{13}C NMR (50 MHz, D_2O): δ 13.9, 22.4, 24.8, 28.5, 28.6, 31.4, 34.2 (alkyl), 60.5 (C-6), 62.2 (C-1′), 63.3 (C-6′), 69.5 (C-4), 71.4 (C-2), 72.6 (C-5), 72.8 (C-3), 73.4 (C-4′), 77.5 (C-3′), 82.3 (C-5′), 92.1 (C-1), 103.7 (C-2′), 176.4 (C=O).

*2-*O*-Octanoylsucrose.* $[\alpha]_D^{21}$ +69.3° (c 1.4, MeOH); ^{1}H NMR (200 MHz, D_2O): δ 0.7–1.0, 1.2–1.4, 1.5–1.7, 2.4–2.6 (4 m, 3, 8, 2, 3 H, alkyl), 3.55 (t, 1 H, $J_{3,4}$ 9, H-4), 3.65 (s, 2 H, H-1′ab), 3.8–4.0 (m, 6 H, H-5, H-5′, H-6ab, H-6′ab), 3.95 (t, 1 H, $J_{3,4}$ 9, H-3), 4.05 (t, 1 H, $J_{4',5'}$ 8, H-4′), 4.25 (d, 1 H, $J_{3',4'}$ 8.4, H-3′), 4.75 (dd, 1 H, $J_{2,3}$ 10, H-2), 5.53 (d, 1 H, $J_{1,2}$ 3.7, H-1); ^{13}C NMR (50 MHz, D_2O): δ 13.9, 22.5, 24.6, 28.6, 28.8, 31.5, 34.3 (alkyl), 60.6

(C-6), 61.5 (C-1′), 62.9 (C-6′), 69.7 (C-4), 70.8 (C-3), 72.8 (C-5), 73.0 (C-2), 74.3 (C-4′), 75.9 (C-3′), 82.0 (C-5′), 90.1 (C-1), 104.4 (C-2′), 176.5 (C=O).

*4′-*O*-Octanoylsucrose.* $[\alpha]_D^{21}$ +35.7° (*c* 0.2, MeOH); ^{1}H NMR (200 MHz, D_2O): δ 0.7–1.0, 1.2–1.4, 1.5–1.7, 2.4–2.6 (4 m, 3, 8, 2, 3 H, alkyl), 3.5 (t, 1 H, $J_{3,4}$ 9, H-4), 3.6 (dd, 1 H, $J_{2,3}$ 10, H-2), 3.8 (t, 1 H, $J_{3,4}$ 9, H-3), 3.7–4.1 (m, 8 H, H-1′ab, H-5, H-5′, H-6ab, H-6′ab), 4.5 (d, 1 H, $J_{3',4'}$ 8.7, H-3′), 5.25 (t, 1 H, $J_{4',5'}$ 8.25, H-4′), 5.45 (d, 1 H, $J_{1,2}$ 3.75 Hz, H-1); ^{13}C NMR (50 MHz, D_2O): δ 13.8, 22.4, 24.7, 28.4, 28.5, 31.3, 34.2 (alkyl), 60.4 (C-6), 61.6 (C-1′), 62.7 (C-6′), 69.5 (C-4), 71.5 (C-2), 72.9 (C-5), 73.0 (C-3), 75.1 (C-3′), 76.4 (C-4′), 80.1 (C-5′), 92.7 (C-1), 104.6 (C-2′), 175.8 (C=O).

*6-*O*-Octanoylsucrose.* $[\alpha]_D^{21}$ +40.3° (*c* 0.8, MeOH); ^{1}H NMR (300 MHz, D_2O): δ 0.7–1.0, 1.2–1.4, 1.5–1.7, 2.4–2.6 (4 m, 3, 8, 2, 2 H, alkyl), 3.38 (t, 1 H, $J_{3,4}$ 9.8, H-4), 3.49 (dd, 1 H, J_{23} 9.8 and $J_{1,2}$ 3.7 Hz, H-2), 3.57–3.63 (m, 2 H, H-1′ab), 3.71 (t, 1 H, H-3), 3.72–3.79 (m, 2 H, H-6′ab), 3.79–3.88 (m, 1 H, H-5′), 3.97 (t, 1 H, $J_{3',4'}$ 8.8, H-4′), 3.95–4.04 (m, 1 H, H-5), 4.16 (d, 1 H, H-3′), 4.20 (dd, 1 H, $J_{5,6a}$ 5.2 and $J_{6'a,6'b}$ 12.1, H-6a), 4.37 (dd, 1 H, $J_{5,6b}$ 1.8, H-6b), 5.34 (d, 1 H, H-1); ^{13}C NMR (75 MHz, D_2O): δ 13.7, 22.4, 24.7, 28.4, 28.6, 31.4, 34.1 (alkyl), 61.8 (C-6), 63.1 (C-1′), 63.6 (C-6′), 70.0 (C-4), 70.7 (C-5), 71.4 (C-2), 72.7 (C-3), 74.5 (C-4′), 76.7 (C-3′), 81.9 (C-5′), 92.3 (C-1), 104.1 (C-2′), 177.1 (C=O); ^{13}C NMR (50 MHz, C_5D_5N): δ 14.5, 23.1, 25.5, 29.5, 29.6, 32.1, 34.6 (alkyl), 63.9 (C-1′), 64.8 (C-6), 65.1 (C-6′), 72.0 (C-4), 72.2 (C-2), 73.7 (C-5), 75.3 (C-3), 76.2 (C-4′), 80.1 (C-3′), 84.9 (C-5′), 93.7 (C-1), 106.1 (C-2′), 174.1 (C=O); ^{13}C NMR (50 MHz, Me_2SO-d_6): δ 14.1, 22.2, 24.6, 28.5, 28.6, 31.3, 33.5 (alkyl), 62.4 (C-1′), 62.8 (C-6′), 63.8 (C-6), 70.2 (C-5), 70.2 (C-4), 71.8 (C-2), 72.9 (C-3), 74.7 (C-4′), 77.1 (C-3′), 82.9 (C-5′), 91.7 (C-1), 104.1 (C-2′), 173.2 (C=O).

*1′-*O*-Octanoylsucrose.* $[\alpha]_D^{21}$ +53.6° (*c* 0.6, MeOH); ^{1}H NMR (300 MHz, D_2O): δ 0.7–1.0, 1.2–1.4, 1.5–1.7, 2.4–2.6 (4 m, 3, 8, 2, 2 H, alkyl), 3.47 (t, 1 H, $J_{3,4}$ 9.6, H-4), 3.55 (dd, 1 H, $J_{2,3}$ 9.9 and $J_{1,2}$ 3.7, H-2), 3.74 (t, 1 H, H-3), 3.77–3.90 (m, 6 H, H-5, H-5″, H-6ab, H-6′ab), 4.07 (t, 1 H, $J_{3',4'}$ 8.8, H-4′), 4.16 (d, 1 H, H-3′), 4.18 (d, 1 H, $J_{1'a,1'b}$ 12.1, H-1′a), 4.36 (d, 1 H, H-1′b), 5.43 (d, 1 H, H-1); ^{13}C NMR (75 MHz, D_2O): δ 13.9, 22.5, 24.8, 28.6, 28.8, 31.5, 34.2 (alkyl), 60.5 (C-6), 62.4 (C-6′), 62.7 (C-1′), 69.6 (C-4), 71.4 (C-2), 72.9 (C-3,5), 73.7 (C-4′), 77.0 (C-3′), 82.0 (C-5′), 93.0 (C-1), 102.8 (C-2′), 176.4 (C=O); δ_C (50 MHz, C_5D_5N): 14.5, 23.1, 25.5, 29.5 (2), 32.1, 34.6 (alkyl), 62.7 (C-6), 63.0 (C-6′), 64.4 (C-1′), 72.2 (C-4), 73.5 (C-2), 74.8 (C-5), 75.4 (C-3), 76.4 (C-4′), 79.2 (C-3′), 84.6 (C-5′), 94.3 (C-1), 104.4 (C-2′), 173.5 (C=O).

*6′-*O*-Octanoylsucrose.* $[\alpha]_D^{21}$ +53.1° (*c* 0.7, MeOH); ^{1}H NMR (300 MHz, D_2O): δ 0.7–1.0, 1.2–1.4, 1.5–1.7, 2.4–2.6 (4 m, 3, 8, 2, 2 H, alkyl), 3.38 (t, 1 H, $J_{3,4}$ 9.2, H-4), 3.47 (dd, 1 H, $J_{2,3}$ 10.0 and $J_{1,2}$ 3.7, H-2), 3.62 (s, 2 H, H-1′ab), 3.69 (t, 1 H, H-3), 3.72–3.83 (m, 3 H, H-5′, H-6′ab), 3.92–4.03 (m, 1 H, H-5), 4.04 (t, 1 H, $J_{3',4'}$ 8.2, H-4′), 4.14 (d, 1 H, H-3′), 4.26–4.36 (m, 2 H, H-6ab), 5.32 (d, 1 H, H-1); ^{13}C NMR (75 MHz, D_2O): δ 13.8, 22.4, 24.7, 28.6, 28.7, 31.4, 34.1 (alkyl), 60.8 (C-6), 61.7 (C-1′), 66.1 (C-6′), 69.8 (C-4), 71.6 (C-2), 72.9 (C-5), 73.1 (C-3), 75.1 (C-4′), 76.8 (C-3′), 79.0 (C-5′), 92.5 (C-1), 104.4 (C-2′), 176.9 (C=O); ^{13}C NMR (50 MHz, C_5D_5N): δ 14.5, 23.1, 25.5, 29.5, 29.6, 32.1, 34.6 (alkyl), 63.1 (C-6), 64.8 (C-1′), 67.1 (C-6′), 72.5 (C-4), 73.9 (C-2), 75.1 (C-5), 75.5 (C-3), 77.0 (C-4′), 79.8 (C-3′), 81.2 (C-5′), 93.7 (C-1), 106.3 (C-2′), 174.0 (C=O); ^{13}C NMR (50 MHz, Me_2SO-d_6): δ 14.1, 22.2, 24.6, 28.6 (2), 31.3, 33.5 (alkyl), 60.9 (C-6), 61.9 (C-1′), 65.8 (C-6′), 70.2 (C-4), 71.8 (C-2), 73.0 (C-3), 73.1 (C-5), 75.0 (C-4′), 76.6 (C-3′), 79.3 (C-5′), 92.0 (C-1), 104.5 (C-2′), 173.1 (C=O).

*Data for the mono-*O*-allyloxycarbonylsucrose.*—Mixture of isomers: Anal. Calcd for ($C_{16}H_{26}O_{13}\cdot 0.7H_2O$): C, 43.8; H, 6.3. Found: C, 43.8; H, 6.1. HRMS (FAB$^+$) requires *m*/*z* 433.1534 $[M+Li]^+$, found 433.1532. ^{1}H NMR (300 MHz, Me_2SO-d_6): 3.37 (s, 2 H, CH_2), 4.60, 4.85 (2 m, 2 H, =CH_2), 5.85–6.0 (m, 1 H, =CH), 3.45 (s, 2 H, O–CH_2), 3.05–5.40 (m, 14 H, sucrose). Because of migrations leading rapidly to mixtures of products, the molecular rotations were not measured. ^{13}C NMR data for some regioisomers are listed in the following sections.

3-O-*Allyloxycarbonylsucrose.* ^{13}C NMR (50 MHz, Me_2SO-d_6): δ 60.1, 62.3, 63.0 (C-6, 1′, 6′), 67.5 (C-4), 67.7 (CH_2-allyl), 69.7 (C-2), 72.7 (C-5), 74.4 (C-4′), 77.0 (C-3′), 80.5 (C-3), 82.9 (C-5′), 91.7 (C-1), 104.3 (C-2′), 118.3, 132.6 (C=C), 154.7 (C=O).

4′-O-*Allyloxycarbonylsucrose.* ^{13}C NMR (50 MHz, Me_2SO-d_6): δ 60.5, 61.6, 62.6 (C-6, 1′, 6′), 68.4 (CH_2-allyl), 69.9 (C-4), 71.9 (C-2), 73.0 (C-3,5), 75.1 (C-3′), 80.2 (C-5′), 81.6 (C-4′), 92.5 (C-1), 104.7 (C-2′), 118.8, 132.3 (C=C), 154.2 (C=O).

Mixture of 6,1′- and 6′-O-*allyloxycarbonylsucrose.* ^{13}C NMR (50 MHz, Me_2SO-d_6): δ 63.0, 62.7, 62.3, 61.8, 61.0, 60.7 (non carbonated C-6, 1′, 6′), 69.6, 68.2, 68.1, 67.1, 65.9 (carbonated primary carbons of sucrose and CH_2-allyl), 70.3, 70.0, 69.9 (C-4), 71.8, 71.7, 71.6 (C-2), 72.9–73.1 (C-3,5), 74.9, 74.7, 73.5 (C-4′), 77.2, 76.6, 76.5 (C-3′), 83.1, 83.0, 79.2 (C-5′), 92.3, 92.0, 91.9 (C-1), 104.5, 104.2, 102.0 (C-2′), 118.8, 118.6, 132.4, 132.3 (C=C), 154.6, 154.5, 154.3 (C=O).

Data for the mono-O-*octyloxycarbonylsucrose.*—Mixture of isomers: Anal. Calcd for ($C_{21}H_{38}O_{13}\cdot 1.2H_2O$): C: 48.5; H: 7.8. Found: C: 48.3; H: 7.9. HRMS (FAB$^+$) requires m/z 521.2210 $[M+Na]^+$, found 521.2214. ^{1}H NMR (300 MHz, Me_2SO-d_6): δ 0.95 (t, 3 H, Me), 1.25 (m, 10 H, CH_2), 1.70 (m, 2 H, CH_2), 3.45 (s, 2 H, O–CH_2), 3.10–5.65 (m, 21 H, sucrose). IR (KBr, cm^{-1}): 999.9, 1047.8, 1266.8, 1401.9, 1748.8, 2855.0, 2926.7, 3341.1. MS $[M^+ + NH_3]$ m/z 516; FAB $[M+Na]$ m/z 521, $[M-H]$ 497. NMR data (in order of elution from the semi-preparative HPLC):

3-O-*Octyloxycarbonylsucrose.* ^{1}H NMR (300 MHz, D_2O): δ 0.7–1.6 (3 m, 3, 10, 2 H, alkyl), 3.23–4.34 (m, 14 H, sucrose + OCH_2), 4.83 (t, 1 H, $J_{2,3,\ 3,4}$ 9.6, H-3), 5.31 (d, 1 H, $J_{1,2}$ 3.7, H-1); ^{13}C NMR (75 MHz, D_2O): δ 14.3, 23.0, 26.1, 28.9, 29.7 (2), 32.3 (alkyl), 60.7 (C-6), 62.0 (C-1′), 62.9 (C-6′), 68.2 (C-4), 69.3 (OCH_2), 70.8 (C-2), 72.9 (C5), 74.5 (C-4′), 77.0 (C-3′), 79.7 (C-3), 81.9 (C-5′), 92.7 (C-1), 104.3 (C-2′), 156.5 (C=O).

3′-O-*Octyloxycarbonylsucrose.* ^{1}H NMR (300 MHz, D_2O): δ 0.7–1.6 (3 m, 3, 10, 2 H, alkyl), 3.32–4.15 (m, 13 H, sucrose + OCH_2), 4.19 (t, 1 H, $J_{3',4'}$ 7.7, H-4′), 5.08 (d, 1 H, H-3′), 5.33 (d, 1 H, $J_{1,2}$ 3.7, H-1); ^{13}C NMR (75 MHz, D_2O): δ 14.0, 22.9, 25.8, 28.7, 29.4 (2), 32.1 (alkyl), 60.5 (C-6), 62.0 (C-1′), 63.7 (C-6′), 69.9 (OCH_2), 69.4 (C-4), 71.6 (C-2), 72.6 (C-5), 73.0 (C-3), 73.5 (C-4′), 81.1 (C-3′), 82.4 (C-5′), 92.3 (C-1), 104.0 (C-2′), 155.5 (C=O).

2-O-*Octyloxycarbonylsucrose.* ^{1}H NMR (300 MHz, D_2O): δ 0.7–1.6 (3 m, 3, 10, 2 H, alkyl), 3.25–4.13 (m, 14 H, sucrose + OCH_2), 4.41 (d, 1 H, $J_{2,3}$ 10.3, H-2), 5.45 (d, 1 H, $J_{1,2}$ 3.3, H-1); ^{13}C NMR (75 MHz, D_2O): δ 14.3, 23.0, 25.9, 28.8, 29.6 (2), 32.3 (alkyl), 60.8 (C-6), 61.9 (C-1′), 62.8 (C-6′), 69.6 (OCH_2), 69.9 (C-4), 70.8 (C-3), 72.9 (C-5), 74.4 (C-4′), 76.3, 76.5 (C-2,3′), 82.0 (C-5′), 89.9 (C-1), 104.5 (C-2′), 155.6 (C=O).

4′-O-*Octyloxycarbonylsucrose.* ^{1}H NMR (300 MHz, D_2O): δ 0.7–1.6 (3 m, 3, 10, 2 H, alkyl), 3.25–4.10 (m, 13 H, sucrose + OCH_2), 4.31 (d, 1 H, $J_{3',4'}$ 7.7, H-3′), 4.90 (brdd, 1 H, $J_{4',5'}$ 7.0, H-4′), 5.32 (d, 1 H, $J_{1,2}$ 3.7, H-1); ^{1}H ^{13}C NMR (75 MHz, D_2O): δ 14.3, 23.1, 26.2, 28.9, 29.7, 29.8, 32.3 (alkyl), 60.5 (C-6), 62.0 (C-1′), 62.7 (C-6′), 69.3 (OCH_2), 69.5 (C-4), 71.6 (C-2), 73.1 (C-3,5), 75.9 (C-3′), 80.4, 80.6 (C-4′,5′), 93.0 (C-1), 104.9 (C-2′), 155.7 (C=O).

6-O-*Octyloxycarbonylsucrose.* ^{1}H NMR (300 MHz, D_2O): δ 0.7–1.6 (3 m, 3, 10, 2 H, alkyl), 3.22–4.35 (m, 15 H, sucrose + OCH_2), 5.23 (d, 1 H, $J_{1,2}$ 3.7, H-1); ^{13}C NMR (75 MHz, D_2O): δ 14.3, 23.0, 26.0, 28.9, 29.6 (2), 32.2 (alkyl), 62.1 (C-1′), 62.9 (C-6′), 67.0 (OCH_2), 69.1 (C-6), 70.0 (C-4), 70.8 (C-2), 71.5 (C-5), 73.0 (C-3), 74.5 (C-4′), 77.3 (C-3′), 82.0 (C-5′), 92.6 (C-1), 104.2 (C-2′), 156.1 (C=O).

1′-O-*Octyloxycarbonylsucrose.* ^{1}H NMR (300 MHz, D_2O): δ 0.7–1.6 (3 m, 3, 10, 2 H, alkyl), 3.29–4.27 (m, 15 H, sucrose + OCH_2), 5.29 (d, 1 H, $J_{1,2}$ 3.7, H-1); ^{13}C NMR (750 MHz, D_2O): δ 14.3, 23.1, 26.1, 28.9, 29.7, 29.8, 32.3 (alkyl), 60.6 (C-6), 62.0 (C-6′), 65.8 (C-1′), 69.3 (OCH_2), 69.6 (C-4), 71.4 (C-2), 73.1 (C-3,5), 73.4 (C-4′), 77.0 (C-3′), 82.2 (C-5′), 93.1 (C-1), 102.6 (C-2′), 155.9 (C=O).

6′-O-*Octyloxycarbonylsucrose.* ^{1}H NMR (300 MHz, D_2O): δ 0.7–1.6 (3 m, 3, 10, 2 H, alkyl), 3.22–4.40 (m, 15 H, sucrose + OCH_2), 5.22 (d, 1 H, $J_{1,2}$ 4.1, H-1); ^{13}C NMR (750 MHz, D_2O): δ 14.3, 23.0, 26.1, 28.9, 29.6 (2), 32.3 (alkyl), 61.3 (C-6), 62.5 (C-1′), 69.1

(OCH$_2$), 69.7 (C-6′), 70.1 (C-4), 71.7 (C-2), 73.1, 73.2 (C-3,5), 75.2 (C-4′), 77.6 (C-3′), 79.2 (C-5′), 92.5 (C-1), 104.2 (C-2′), 156.1 (C=O).

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