



**HAL**  
open science

## Direct Conversion of Agarose into Alkyl Mono- and Disaccharide Surfactants Based on 3,6-Anhydro L- and D-Galactose Units

Y. Wang, L. Renault, J.-P. Guégan, T. Benvegnu

► **To cite this version:**

Y. Wang, L. Renault, J.-P. Guégan, T. Benvegnu. Direct Conversion of Agarose into Alkyl Mono- and Disaccharide Surfactants Based on 3,6-Anhydro L- and D-Galactose Units. *ChemistrySelect*, 2021, 6 (3), pp.389-395. <10.1002/slct.202004542>. <hal-03130460>

**HAL Id: hal-03130460**

**<https://hal.science/hal-03130460v1>**

Submitted on 16 Sep 2021

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



HAL Authorization

# Direct Conversion of Agarose into Alkyl Mono- and Disaccharide Surfactants Based on 3,6-Anhydro L- and D-Galactose Units

Yunhui Wang,<sup>[a]</sup> Louise Renault,<sup>[a]</sup> Jean-Paul Guégan,<sup>[a]</sup> and Thierry Benvegnu\*<sup>[a]</sup>

[a] Dr. Y. Wang, Dr. L. Renault, J.-P. Guégan, Prof. Dr.T.Benvegnu  
Univ Rennes, CNRS, ISCR-UMR 6226  
Ecole Nationale Supérieure de Chimie de Rennes  
F-35000, Rennes, France  
E-mail: [thierry.benvegnu@ensc-rennes.fr](mailto:thierry.benvegnu@ensc-rennes.fr)  
Orcid.org/http://orcid.org/0000-0003-1613-9990

Supporting information for this article is given via a link at the end of the document.

**Abstract:** In this work, a new type of agarose-derived non-ionic surfactants has been prepared through the one-pot transformation of agarose into 3,6-anhydro L- and D-galactose acetal monomers and dimers possessing one or two alkyl chains according to the cyclic or open form of the L- and D-galactose units. The two steps process involves the butanolysis of agarose into butyl mono- and disaccharide 3,6-anhydro L- and D-galactose acetals promoted by the presence of Amberlyst-15Dry, followed by the transacetalization with *n*-dodecanol using the same acid catalyst. The chemical structures of the alkyl mono- and disaccharide surfactants were fully characterized by 1D and 2D NMR experiments. Surface activities of these products in a pure form or as mixtures were investigated depending on their hydrophilicity/hydrophobicity and quite low values of superficial tensions (<27 mN m<sup>-1</sup>) and sunflower seed oil/water interfacial tensions (~5 mN m<sup>-1</sup>) were obtained.

## Introduction

On the growing sector of the green chemistry, surfactants partially produced from agro-resources already occupy an important part and they may experience a strong growth potential. However, 100% biosourced surfactants composed by a hydrophilic part and a lipophilic part both of vegetable origin remain them marginally, and represent around 5 to 10% of the global volumes.<sup>[1]</sup> The development of new 100% vegetable agro-surfactants requires the use of more efficient and more eco-compatible syntheses and the development of innovative products with greater performances and new functionalities. Within this context, marine algae represent a rich source of complex polysaccharides and oligosaccharides with innovative structures and functional properties that may find applications as starting materials for the production of sugar-based surfactants and cosmetic actives. However, if lignocellulosic biomass has been intensively investigated as a renewable raw material for the synthesis of alkyl glycoside surfactants,<sup>[2]</sup> the use of algal polysaccharides to provide anionic or non-ionic carbohydrate surfactants is much less common.

To the best of our knowledge, only the preparation of surfactants derived from alginates, i.e. renewable polysaccharides extracted from brown seaweeds, has been reported in the literature.<sup>[3]</sup> Controlled chemical and/or enzymatic depolymerizations of the algal polysaccharides gave saturated and/or unsaturated functional oligomannuronates. Clean chemical processes allowed the efficient transformation of the

oligomers into neutral or anionic surface-active compounds characterized by a high biodegradability profile, the absence of aquatic ecotoxicity and attractive foaming or emulsifying properties.

More recently, long-chain alkyl-L-gulonamides and D-mannuronamides were additionally produced from alginates through the preparation of *n*-butyl uronate monosaccharide intermediates involving methanesulfonic acid-promoted hydrolysis, Fisher glycosylation and esterification reactions, followed by in situ solvent-free aminolysis reaction with fatty amines.<sup>[4]</sup> These uronamide surfactants exhibited both efficient emulsion stabilizing properties and promising antibacterial effects.

Agarans are another class of algal polysaccharides extracted from red seaweeds that consist of linear chains of alternating 3-linked β-D-galactose and 4-linked α-L-galactose units and present different degrees of cyclization of the α-L-galactose residues to give 3,6-anhydro-α-L-galactose.<sup>[5]</sup> The neutral, completely cyclized agarose is agarose and its content in some red algae species can go up to 65%.<sup>[6]</sup> The chemical structure gives agarose a capacity to form gels through the formation of intra- and inter-molecular hydrogen bonds at room temperature that are very resistant even at low concentrations. At higher temperatures,<sup>[7]</sup> the hydrogen bonds can be dissociated rendering agarose more susceptible to chemical transformations. As an example, the MgCl<sub>2</sub>-catalyzed production of 5-hydroxymethylfurfural (5-HMF) was achieved from agarose in aqueous phase at 200°C in satisfactory yield (~40%) and selectivity (~50%).<sup>[8]</sup> In the same way, 5-HMF or levulinic acid (LA) were selectively obtained through a simple, highly efficient and tunable microwave-assisted aqueous conversion of agarose in the absence of any catalyst (5-HMF: 51% yield) or alternatively with the addition of 1% v/v sulfuric acid (LA: 64% yield).<sup>[9]</sup> Additionally, galactose could be also generated as the main product (45-77%) by adjusting the temperature conditions and the amounts of sulfuric acid catalyst.

Another potential valuable transformation of agarose deals with its depolymerization into 3,6-anhydro-L-galactose (L-AHG) monomer as a high-valued functional food or cosmetic material. Indeed, L-AHG exhibits a large variety of physiological activities, such as skin whitening,<sup>[10]</sup> moisturizing,<sup>[10]</sup> anti-inflammation,<sup>[10]</sup> and anticariogenicity<sup>[11]</sup>. If L-AHG is not yet commercially available because of its complex and costly production process, a more efficient two-step route utilizing a single enzyme was recently proposed as a feasible solution for its commercialization and mass production.<sup>[12]</sup>

In this study, we describe the synthesis of alkyl glycosides from agarose as novel non-ionic surfactant compositions based on 3,6-anhydro L- and D-galactose units. The use of L-galactose as the polar head group of the surfactant is unprecedented and the

presence of the 3,6-anhydro form could provide both attractive surface activities and bio-activities as exhibited by L-AHG. Moreover, alkyl D-galactosides were reported as ingredients of dentifrices having strong coaggregation-inhibitory effect and antibacterial effect against dental caries and periodontal disease-causing bacteria ( $\beta$  anomer);<sup>[13]</sup> these galactosides in the D series possessing a linear alkyl chain, also showed anti-microbial ( $\beta$  anomer)<sup>[14]</sup> and anti-tumor properties ( $\alpha/\beta$  anomeric mixture)<sup>[15]</sup>.

Over the past ten years, intensive research work for the synthesis of sugar-based surfactants investigated the direct transformation of natural abundant polysaccharides into glycosyl surfactants through the one-pot depolymerization of these biopolymers into monomers through hydrolysis and/or alcoholysis and their subsequent functionalization with a lipophilic alkyl chain or through a direct transglycosylation of polysaccharides with fatty alcohols.<sup>[2,16]</sup> The main goals of these attractive synthetic routes were to enhance cost-effectiveness of the process and to provide original surfactant compositions. Generally, cellulose, starch and hemicellulose were used as raw materials for the direct production of alkyl glucosides and pentosides (D-xylose, L-arabinose) using water and/or short alcohols (methanol, ethanol or *n*-butanol) or ionic liquids as solvents at high temperatures (80-200°C) or under supercritical conditions, and homogeneous or heterogeneous acid catalysts (inorganic acids, heteropolyacids, ion-exchange resins, or modified carbon materials).

Herein, we have used a cascade process that involves the butanolysis of agarose into butyl L- and D- mono- and digalactoside intermediates without any additional solvent and using Amberlyst-15Dry as the catalyst, followed by the transacetalization with *n*-dodecanol. This strategy permits to bypass the difficulties in terms of low reactivity of the direct glycosylation with fatty alcohols. Both 3,6-anhydro L- and D-galactose acetal monomers and dimers possessing one or two alkyl chains were obtained and preliminary evaluation of interfacial properties revealed promising interfacial activities.

## Results and Discussion

### Conversion of agarose into butyl mono- and disaccharide 3,6-anhydro L- and D-galactose acetals

The objective of our work was first to transform agarose into butyl L- and D- mono- and di-galactoside products through simultaneous hydrolysis and butanolysis reactions in order to break down the polysaccharide structure into monomers and

dimers, and to graft a short alkyl chain at the anomeric positions. Amberlyst-15Dry was selected as a heterogeneous acid catalyst as reported by Villandier *et al.*<sup>[16]</sup> for the transformation of cellulose into alkyl glycosides. In our approach, the procedure did not require the use of ionic liquids as solvents, but a biphasic system composed of *n*-butanol and water was used to act as both solvent and reagent.

Agarose was solubilized in the *n*-butanol/water mixture (121.5 eq./375 eq.) in the presence of Amberlyst-15Dry (1.0 eq.) and then the reaction medium was heated at 90°C for 22 h (Scheme 1). Both the water added at the beginning of the reaction and the water formed during the reaction were gradually removed by co-evaporation with *n*-butanol and the pressure was reduced in order to maintain a reflux in the Dean-Stark apparatus. The reaction mixture was then cooled down to room temperature and the catalyst was filtrated on celite. The filtrate was neutralized with a 1N aqueous solution of NaOH and concentrated under reduced pressure. Finally, the resulting residue was chromatographed on silica gel column with gradient elution consisting of CH<sub>2</sub>Cl<sub>2</sub>/MeOH from 98:2 to 85:15.

Under these conditions, several butyl acetal derivatives were isolated with an overall yield of 61%. The main products of this transformation are butyl D-galactosides isolated as an isomeric mixture, with a 40% yield. These are  $\alpha$ -D-butyl galactopyranoside **1a** (<sup>1</sup>H-NMR (MeOD):  $\delta_{H-1}$  = 4.82 ppm, d, *J* = 3.3 Hz (Figure S1 in the Supporting Information); <sup>13</sup>C-NMR (MeOD):  $\delta_{C-1}$  = 98.9 ppm) and  $\beta$ -D-butyl galactopyranoside **1b**<sup>[17]</sup> (<sup>1</sup>H-NMR (MeOD):  $\delta_{H-1}$  = 4.22 ppm, d, *J* = 7.3 Hz (Figure S1 in the Supporting Information); <sup>13</sup>C-NMR (MeOD):  $\delta_{C-1}$  = 103.6 ppm). 2D-HMBC spectrum (Figure S2 in the Supporting Information) shows correlations between OCH<sub>2</sub> of the butyl chain and the anomeric protons H-1 $\alpha$  and H-1 $\beta$ . Additional mono- and disaccharide acetals were identified through 1D (<sup>1</sup>H) and 2D (COSY, HSQC and HMBC) NMR investigations in MeOD or D<sub>2</sub>O as the solvent. Firstly, the unexpected acyclic dibutyl acetal **2** including the 3,6-anhydro unit was isolated in a 8% yield (Scheme 1). This compound results from the opening of the L-galactose cycle at the C-1 carbon by *n*-butanol. The presence of the 3,6-anhydro unit was confirmed by 2D-HSQC spectrum in MeOD (Figure 1a) which displayed the signal of C-6 at 74.85 ppm with a correlation with the two signals (doublets of doublets) at 3.81 and 3.95 ppm corresponding to protons H-6. The doublet at 4.50 ppm with a coupling constant of 7.6 Hz, was assigned to the acetal proton H-1. The acyclic acetal structure was determined from HMBC spectrum (Figure 1b) which did not exhibit any correlation between C-1 and H-5 and C-5 and

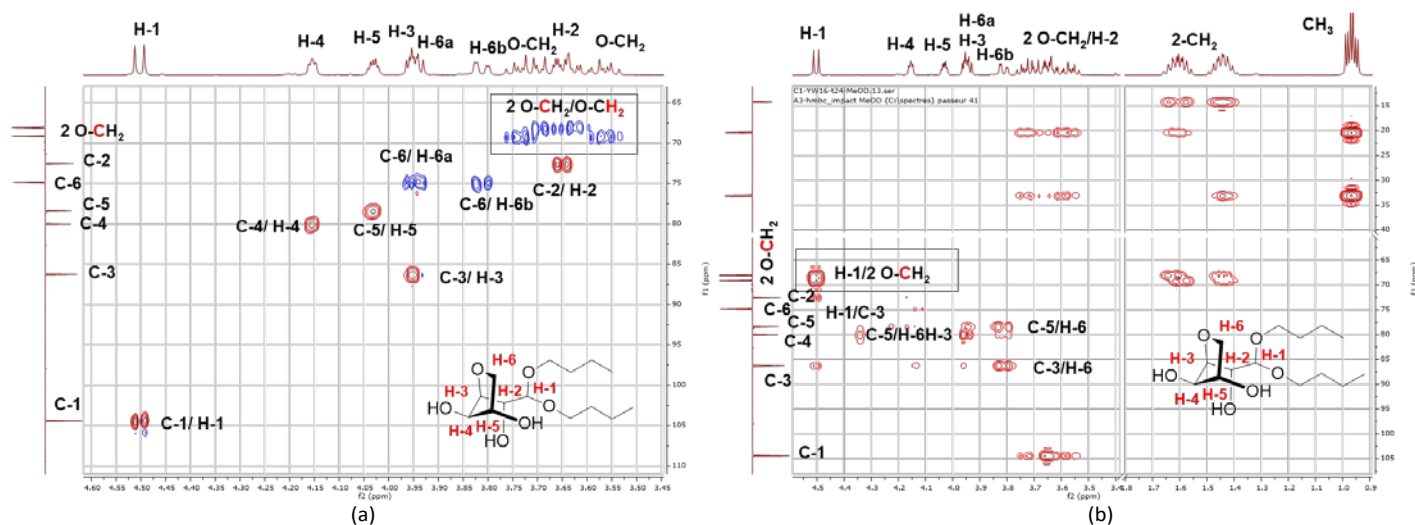
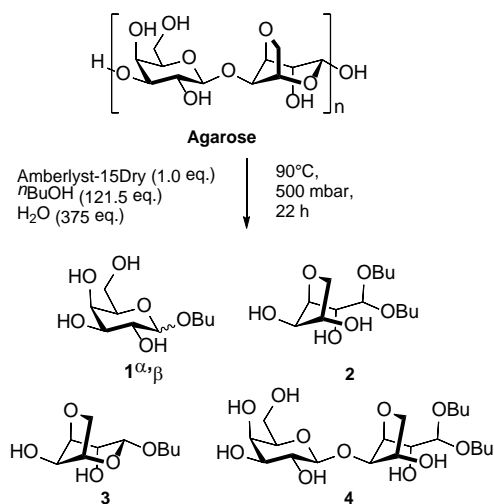


Figure 1 2D-HSQC spectrum (a) and 2D-HMBC spectrum (b) in MeOD of dibutyl acetal 2.

## FULL PAPER

H-1. On the contrary, strong correlation was observed between H-1 at 4.50 ppm and the carbons at 68.03 and 69.14 ppm corresponding to OCH<sub>2</sub> of the two butyl chains. In addition, the integrated intensity of the signals in the 0.9-3.8 ppm region revealed the presence of two butyl chains (Figure S3 in the Supporting Information).



**Scheme 1** Transformation of agarose into monomeric and dimeric butyl acetal derivatives 1-4.

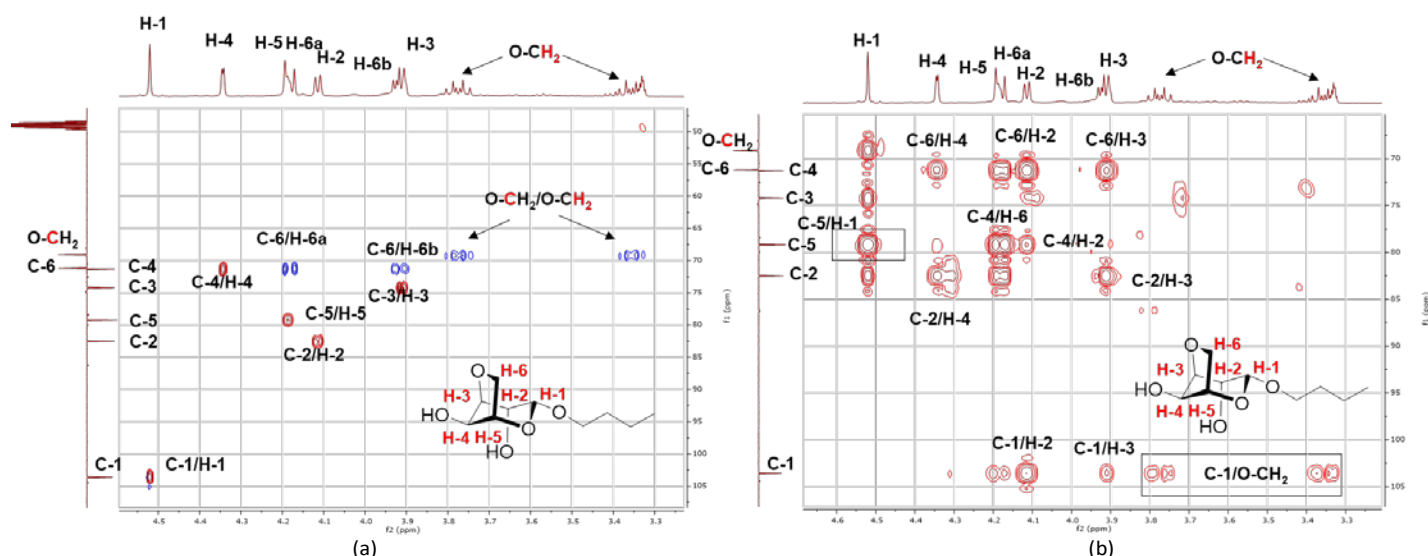
Another monomeric L-galactoside was isolated in a 4% yield. This is *n*-butyl-3,6-anhydro-L-galactopyranoside **3** possessing a single butyl chain at the anomeric position as shown by integrating the signals in the 0.9-3.8 ppm region. The signal relative to proton H-1 appeared as a singlet at 4.52 ppm in MeOD, a value very close to that obtained with compound **2** (Figure 2a). In HMBC spectroscopy, a significant correlation at 4.52/79.18 ppm (H-1/C-5) was found, which indicated a pyranose structure with the positions 1 and 5 connected (Figure 2b). Finally, disaccharide **4** characterized by an acyclic structure of the acetal unit as in monomer **2**, was isolated in a 9% yield (Scheme 1). For this product, a relatively low methanol solubility was observed since a turbid suspension was formed instead of a clear solution. On the contrary, it was found to be highly water soluble. As a result, the NMR sample of **4** was prepared in D<sub>2</sub>O. The <sup>1</sup>H-NMR spectrum of acetal **4** exhibited a doublet at 4.47 ppm ( $J = 7.8$  Hz) that was assigned to H-1' of the reducing 3,6-anhydro-L-galactose unit and

a doublet at 4.45 ppm ( $J = 7.8$  Hz) corresponding to H-1 of the non-reducing D-galactose unit. A series of additional 2D-HSQC and 2D-HMBC NMR experiments (Figures S7-S8 in the Supporting Information) was achieved that provided confirmation of the presence of the 3,6-anhydro unit, the acetal moiety based of two butoxy groups and the hydroxymethyl function of the D-galactoside unit. Moreover, 2D-HMBC spectrum (Figure S8 in the Supporting Information) gave evidence of the dimeric structure of **4** through the correlation between C-1 at 102.62 ppm (D-galactose unit) and proton H-4' at 4.27 ppm (3,6-anhydro-L-galactose unit).

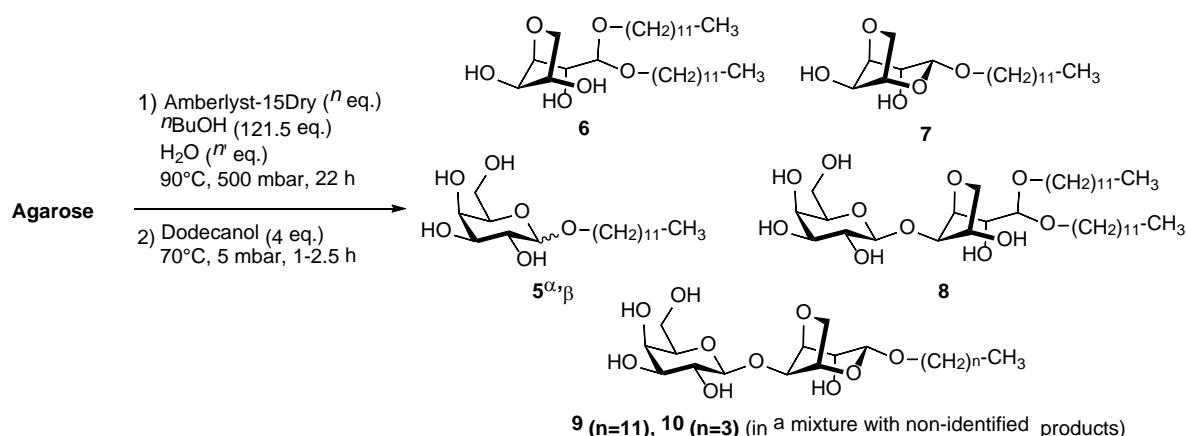
### One-pot process to produce dodecyl mono- and disaccharide acetal surfactants from agarose

We next investigated the synthesis of acetal surfactants possessing one or two fatty chains directly from agarose. A one-pot, two-steps method based on agarose hydrolysis/butanolysis reactions, and transacetalization with the fatty alcohol was performed in a cascade mode. Dodecyl alcohol was selected as the fatty alcohol since it will bring a suitable lipophilic character to the glycosides for applications as detergents or emulsifiers. The transformation of agarose into dodecyl monosaccharide and disaccharide surfactants has been carried out first by reacting agarose (500 mg, 3.26 mmol) with water (*n* equiv.) and *n*-butanol (36 mL, 396.72 mmol, 121.5 eq.), in the presence of Amberlyst-15Dry (*n* equiv.) as the catalyst (Scheme 2). The reaction mixture was heated to 90°C and left at this temperature for 22 h. Following the first step of the process that led to the formation of butyl acetal intermediates **1-4**, the reaction temperature was decreased to room temperature before adding dodecanol (4 eq.). Then, the unreacted *n*-butanol initially added in the reaction mixture and formed during the transacetalization step was removed by continuous distillation at 70°C and under reduced pressure (6 mbar) using a Dean-Stark system. A series of three different conditions in terms of water and Amberlyst-15Dry quantities used, reaction time for the transacetalization step were envisaged (Table 1). At this end of the reaction, CH<sub>2</sub>Cl<sub>2</sub> was added in the reaction mixture at room temperature and ambient pressure, and the resulting solution was filtered over celite bed, washed the bed with a mixture of CH<sub>2</sub>Cl<sub>2</sub>/MeOH (80/20; v/v), filtrate was neutralized with a 1N aqueous solution of NaOH and concentrated under reduced pressure. Finally, the resulting residue was chromatographed on silica gel column with gradient elution consisting of CH<sub>2</sub>Cl<sub>2</sub>/MeOH from 98:2 to 85:15, in order to separate the monomer and dimer products.

Four compounds **5-8** were isolated and identified by LCMS and NMR experiments after work-up and purification (ESI, Fig 9-14).



**Figure 2** 2D-HSQC spectrum (a) and 2D-HMBC spectrum (b) in MeOD of *n*-butyl-3,6-anhydro-L-galactopyranoside **3**.



**Scheme 2** One-pot conversion of agarose into monomeric and dimeric dodecyl or butyl acetal derivatives **5-10**.

These structures **5-8** are similar to acetal derivatives **1-4** except from the alkyl chains which are derived from  $n$ -dodecanol instead of  $n$ -butanol (Scheme 2). In addition, the presence of dodecyl or butyl 4- $O$ -( $\beta$ - $D$ -galactopyranosyl)-3,6-anhydro- $\alpha$ - $L$ -galactopyranosides **9,10** was revealed via a high-resolution mass spectrometry (HMRS) study. Indeed, electrospray (ESI+) mass spectra recorded on MS/MS TOF, afforded the peaks at  $m/z$  403.1580 and  $m/z$  515.2830 corresponding to the sodium adduct ions  $[M+Na]^+$  (Figures S15-S16 in the Supporting Information). However, 1D and 2D NMR experiments did not allow a clear assignment of the signals of these disaccharides due to the presence of non-identified by-products which makes the NMR analysis difficult.

Under the conditions tested (entries 1-3, Table 1), the major product is a galactopyranoside **5** as an anomeric mixture, described in the literature to have an anti-decay effect in toothpaste formulations as well as anti-microbial<sup>14</sup> and anti-cancer properties<sup>15</sup>. As for the first stage, higher quantities of open acetals **6** and **8** than cyclic acetal **7** are isolated due to the more fragile character of the bicyclic structure. The best yield is obtained when using 1 equivalent of Amberlyst-Dry15 with a  $n$ -butanol/water ratio of approximately 1.6/1 (entry 1). If the same synthetic pathway is performed with 0.5 equivalent of acidic resin and a lower water content (entry 2), the overall yield clearly decreases. A reduced reaction time for the transacetalization step (entry 3) resulted in a decrease in yield for the formation of  $L$ -galactose-containing products **6-8**. In all these attempts, the presence of polar alkyl glycosides based on single-tailed disaccharides **9,10** was observed with a yield lower than 10% (Table 1).

### Evaluation of the interfacial properties

In order to study the surface activity of these sugar-based surfactants at oil/water and water/air interfaces, we measured the interfacial tension and/or surface tension of original pure compounds **6, 8** and **9,10**-based mixture. In addition, a surfactant composition made of all alkyl glycosides **5-10** obtained under the

reaction conditions of entry 1 (Table 1) and isolated after removal of dodecanol by silica gel column chromatography, was evaluated as a potential candidate for an industrial development. Interfacial tension and surface tension measurements were performed at  $25^\circ\text{C}$  with a Du Noüy ring tensiometer (K100-Krüss, Germany). The ring tear-off method used for this study is a variant of the Du Noüy ring method for measuring surface tension or interfacial tension. Instead of detecting the force maximum when the lamella is stretched, as usual with modern tensiometers, the lamella is overstretched until it detaches. The value measured in this way deviates slightly from the actual value of the surface tension.<sup>[18]</sup>

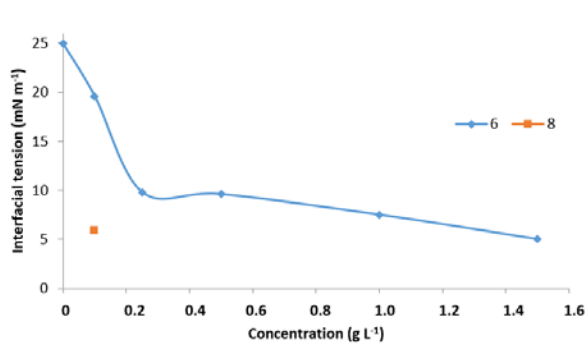
Firstly, pure acyclic didodecyl acetal **6** including the 3,6-anhydro unit was evaluated as a potential emulsifier by measuring its ability to reduce the interfacial tension between sunflower oil and water ( $24.99 \text{ mN m}^{-1}$ ). Due to its water-insolubility, this monosaccharide surfactant was dissolved in sunflower oil at various concentrations (0.1, 0.25, 0.5, 1.0 and  $1.5 \text{ g L}^{-1}$ ). Interfacial tensions measured for each concentration were plotted on a graph as illustrated in Fig. 3. It is noteworthy that a relatively low concentration, of the order of  $0.25 \text{ g L}^{-1}$ , was sufficient to significantly reduce the interfacial tension, namely less than  $10 \text{ mN m}^{-1}$ . At a higher concentration of  $1.5 \text{ g L}^{-1}$ , acyclic acetal **6** exhibited attractive interfacial properties since a low value of  $5 \text{ mN m}^{-1}$  was reached. More interestingly, disaccharide **8** possessing the same acyclic didodecyl acetal structure linked to the  $D$ -galactose unit, reduced the interfacial tension to a value of  $5.9 \text{ mN m}^{-1}$  at a low concentration of  $0.1 \text{ g L}^{-1}$ . Measurements at higher concentrations were not carried out because of the insufficient solubility of dimer **8** in oil, even after exposure of the solution to ultrasound.

The surface tension ( $\gamma$ ) at the water/air interface was measured at different concentrations by adding a subsequent volume of ultrapure water to a concentrated solution of pure compound **8** ( $\sim 1 \text{ g L}^{-1}$ ), **9,10**-based mixture ( $\sim 10 \text{ g L}^{-1}$ ) or composition made of all alkyl glycosides **5-10** ( $\sim 2 \text{ g L}^{-1}$ ) with a 765 Dosimat (Metrohm) which was connected with system programmed by LabDesktop-Software. The concentration and the surface tension were

**Table 1.** Yield of the production of dodecyl mono- and disaccharide surfactants based on 3,6-anhydro  $L$ - and  $D$ -galactose units depending on various conditions, water and Amberlyst-15Dry quantities used, transacetalization time.<sup>[a]</sup>

Entry	Amberlyst-15Dry ( $n$ eq.)	$H_2O$ ( $n$ eq./mL)	Time 2 <sup>nd</sup> step (h)	Yield (%)				Overall yield <sup>[b]</sup> (%)
				5	6	7	8	
1	1	375/22	2.5	20	11	6	8	45
2	0.5	170/10	2.5	13	7	3	6	29
2	0.5	170/10	1	14	4	0	2	20

[a] All reactions were carried out with agarose (500 mg),  $n$ BuOH (121.5 eq.),  $90^\circ\text{C}$ , 500 mbar, 22 h; then dodecanol (4 eq.),  $70^\circ\text{C}$ , 5 mbar; [b] The overall yield does not take into account the formation of polar dodecyl/butyl glycosides based on disaccharides **9,10** (yields: entry 1 ~ 6%; entry 2 ~ 9%; entry 3 ~ 8%).



**Figure 3.** Interfacial tensions (sunflower oil/water) measured at different concentrations (0.1–1.5 g L<sup>-1</sup>) for didodecyl monosaccharide acetal **6** and at 0.1 g L<sup>-1</sup> for didodecyl disaccharide acetal **8**.

automatically determined by the software. For each concentration, the solution was stirred for 60 s and equilibrated for 60 s, and the average of five readings was taken. In the case of **5-10**-based surfactant composition, the initial concentrated solution was exposed to ultrasound for 15 min at 30°C, then cooled down to room temperature to facilitate the dispersion of the mixture in water. The critical micelle concentration (CMC) was obtained from the break point of the plot of  $\gamma$  versus  $\log C$  (Figures S17–S18 in the Supporting Information). The CMC and  $\gamma_{\text{CMC}}$  data shown in table 2 also include values reported in the literature concerning galactopyranoside **5**<sup>[19]</sup> which represents the major product resulting from this one-pot transformation of agarose and commercial alkylpolyglucoside, APG (Glucopon 650, C<sub>12</sub>-C<sub>14</sub>, BASF)<sup>[20]</sup>. Similar low CMC values were obtained for all products, especially the surfactant mixture based on dodecyl/butyl glycosides **9,10** and the composition including all monomer and dimer acetals **5-10**. Conversely, different surface tension values were observed depending on the structure of the alkyl glycosides. Remarkably, the double-tailed backbone of disaccharide **8** decreases the tension at the CMC to a value of 23.9 mN.m<sup>-1</sup>. This result could be related to the presence of two acetal-linked dodecyl chains, allowing the amphiphilic molecule to occupy more space at the interface and therefore to increase the surface activity. It is also important to point out that the presence of

**Table 2.** CMC and  $\gamma_{\text{CMC}}$  values of pure compounds **5** and **8**, **9,10**-based mixture and composition made of all alkyl glycosides **5-10**.

Products	CMC (g L <sup>-1</sup> )	$\gamma_{\text{CMC}}$ (mN m <sup>-1</sup> )
<b>5</b>	0.14 <sup>[a]</sup>	31.5 <sup>[a]</sup>
<b>8</b>	0.12	23.9
<b>9,10</b> -based mixture	0.085	27.0
<b>5-10</b> -based surfactant composition	0.087	26.9
<b>Glucopon® 650</b>	0.073 <sup>[a]</sup>	n.d.

[a] Values reported in the literature: **5**<sup>[19]</sup>, Glucopon® 650<sup>[20]</sup>. n.d.: not determined.

original 3,6-anhydro L- and D-galactose acetal monomers and dimers **6-10** in addition to conventional alkyl galactoside **5**, reduces dramatically the surface tension which makes this surfactant composition very promising for cosmetic or personal care applications.

## Conclusions

This study is the first report describing the eco-friendly conversion of agarose onto novel 3,6-anhydro L-galactoside-based surfactant compositions. Direct acid hydrolysis of the polysaccharide coupled with acetalization reactions of 3,6-anhydro L- and D-galactose units with *n*-butanol proceeded efficiently in the presence of Amberlyst-15Dry promoter to provide butyl D-galactosides and original 3,6-anhydro L-galactose-derived mono- and dibutyl acetals. Subsequent transformation of these monomeric and dimeric acetals into long-chain alkyl mono- and disaccharide surfactant mixtures has been carried out without any isolation and purification step of the intermediates through a one-pot solvent-free transacetalization reactions with dodecanol. These original sugar-based surfactants in a pure form or as mixtures exhibited attractive surface-active properties that compared favorably to conventional alkylpolyglycosides. Studies that are now in progress are aimed at modulating the alkyl chain length in order to optimize their efficiency and/or to extend their field of applications as foaming or emulsifying agents. Moreover, physiological activities such as skin whitening and moisturizing will be investigated to evaluate their potentiality as bioactive cosmetics as shown with 3,6-anhydro-L-galactose (L-AHG).

## Supporting Information Summary

General procedures for the synthesis of compounds **1-10**, <sup>1</sup>H NMR and <sup>13</sup>C NMR spectra of **1-4** and **6-8**, mass spectra of disaccharides **9** and **10**, curves of surface tensions of **8**, **9,10**-based mixture and **5-10**-based surfactant composition, are available in supporting information.

## Acknowledgements

This work was financially supported (grant to YW) by National Research Agency of France, in the framework of project IDEALG (ANR-10-BTBR-04).

## Conflict of Interest

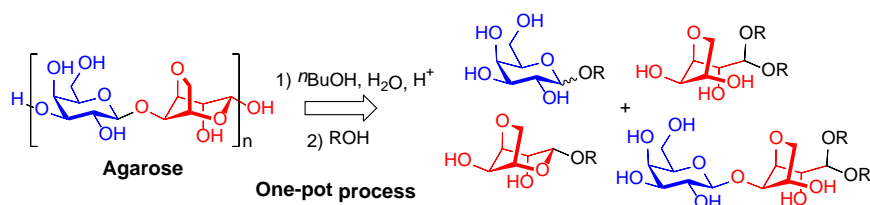
The authors declare no conflict of interest.

**Keywords:** agarose • amphiphile • 3,6-anhydro-L-galactoside • one-pot procedure • surfactants

- [1] L. Renault, F. Pessel and T. Benvegnu, in *Carbohydrate Chemistry, Chemical and Biological Approaches*, Vol. 43 (Eds.: A. Pilar Rauter, T. K. Lindhorst, Y. Queneau), Royal Society of Chemistry, Cambridge, **2018**, 196–244.
- [2] F. Jérôme, S. Marinkovic and B. Estrine, *ChemSusChem* **2018**, *11*, 1395–1409.
- [3] M. Roussel, T. Benvegnu, V. Lognoné, H. Le Deit, I. Soutrel, I. Laurent and D. Plusquellec, *Eur. J. Org. Chem.* **2005**, 2085–3094.
- [4] N. Sari-Chmaysem, F. Pessel, J. P. Guégan, S. Taha, H. Mawlawi and T. Benvegnu, *Green Chem.* **2016**, *18*, 6573–6585.
- [5] F. Van de Velde, S. H. Knutsen, A. I. Usov, H. S. Rollema and A. S. Cerezo, *Trends Food Sci.* **2002**, *13*, 73–92.
- [6] B. Kim, J. Jeong, S. Shin, D. Lee, S. Kim, H. J. Yoon and J. K. Cho, *ChemSusChem* **2010**, *3*, 1273–1275.
- [7] K. T. Nijenhuis, *Adv. Polym. Sci.* **1997**, *130*, 194–202.
- [8] L. Yan, D. D. Laskar, S. J. Lee and B. Yang, *RSC Adv.* **2013**, *3*, 24090–24098.
- [9] M. Francavilla, S. Intini, L. Luchetti and R. Luque, *Green Chem.* **2016**, *18*, 5971–5977.

- [10] E. L. Yun, S. Lee, J. H. KIM, B. B. Kim, H. T. Kim, S. H. Lee, J. G. Pelton, N. J. Kang, I. G. Choi and K. H. Kim, *Appl. Microbiol. Biotechnol.* **2013**, *97*, 2961-2970.
- [11] E. J. Yun, A. R. Lee, J. H. Kim, K. M. Cho and S. H. Kim, *Food Chem.* **2017**, *221*, 976-983.
- [12] D. H. Kim, E. J. Yun, S. H. Lee and K. H. Kim, *J. Agric. Food Chem.* **2018**, *66*, 12249-12256.
- [13] (a) K. Ueno and M. Tamura, *JP 2009078982, A*, **2009**; (b) K. Ueno; M. Itano, *JP 2012140370*, **2012**.
- [14] S. Matsumura, K. Imai, S. Yoshikawa, K. Kawada and T. Uchibori, *J. Am. Oil Chem. Soc.* **1990**, *67*, 996-1001.
- [15] S. X. Song, M. L. Wu, X. P. He, Y. B. Zhou, L. Sheng, J. Li and G. R. Chen, *Bioorg. Med. Chem. Lett.* **2012**, *22*, 2030-2032.
- [16] (a) N. Villandier and A. Corma, *ChemSusChem* **2011**, *4*, 508-513; (b) M. J. Climent, A. Corma, S. Iborra and S. Martínez-Silvestre *ChemSusChem*, **2016**, *9*, 3492-3502; (c) A. Karam, K. De Oliveira Vigier, S. Marinkovic, B. Estrine, C. Oldani and F. Jérôme, *ChemSusChem* **2017**, *10*, 1-8; (d) I.A. Ignatyev, P. G. Mertens, C. Van Doorslaer, K. Binnemans, D. E. De Vos, *Green Chem.* **2010**, *12*, 1790-1795.
- [17] D. Ahumada, F. Arenas, F. Martínez-Gómez, C. Guerrero, A. Illanes and C. Vera, *Front. Bioeng. Biotechnol.* **2020**, *8*, 859.
- [18] K. Lunkenheimer and K. D. Wantke, *J. Colloid Interface Sci.* **1978**, *66*, 579-581.
- [19] S. Matsumura, K. Imai, S. Yoshikawa, K. Kawada and T. Uchibori, *J. Am. Oil Chem. Soc.* **1990**, *67*, 996-1001.
- [20] V. B. Rodríguez, E. J. Alameda, J. F. Martínez Gallegos, A. Reyes Requena, A. I. García López, J. M. Sampaio Cabral and P. Fernandes, *Electron. J. Biotechnol.* **2006**, *9*, 566-571.

## Entry for the Table of Contents



Direct transformation of agarose into alkyl mono- and disaccharide surfactants based on 3,6-anhydro L- and D-galactose units proceeded efficiently through butanolysis/hydrolysis and transacetalization with a fatty alcohol (ROH) in the presence of Amberlyst-15Dry to provide highly efficient surface-active agents. In particular, original open and cyclic acetals resulting from the reaction of the alcohol at the anomeric position of the 3,6-anhydro- $\alpha$ -L-galactose were produced as surface activity boosters of standard alkyl D-galactosides.