



**HAL**  
open science

## Potential valorization of polymeric substances excreted by *Chaetomorpha aerea*, a macro-algae harmful to French oyster industry

Guillaume Pierre, Valérie Sopena, Camille Juin, Amira Mastouri, Marianne Graber, Thierry Maugard

### ► To cite this version:

Guillaume Pierre, Valérie Sopena, Camille Juin, Amira Mastouri, Marianne Graber, et al.. Potential valorization of polymeric substances excreted by *Chaetomorpha aerea*, a macro-algae harmful to French oyster industry. *Biotechnology and Bioprocess Engineering*, 2011, 16, pp.937-945. hal-00652073

**HAL Id: hal-00652073**

**<https://hal.science/hal-00652073v1>**

Submitted on 15 Dec 2011

**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.

1 **Antibacterial activity of a sulfated galactan extracted from the marine alga**  
2 ***Chaetomorpha aerea* against *Staphylococcus aureus*.**

3 **Guillaume Pierre <sup>1</sup>, Valérie Sopena <sup>1</sup>, Camille Juin <sup>1</sup>, Amira Mastouri <sup>1</sup>, Marianne**  
4 **Graber <sup>1</sup>, Thierry Maugard <sup>1,\*</sup>**

5 (1) UMR 6250 CNRS - ULR LIENSs. Université de La Rochelle, UFR Sciences, Bâtiment  
6 Marie Curie, avenue Michel Crépeau, 17042 La Rochelle, France.

7 \* Tel: (33) 5 46 45 82 77 Fax: (33) 5 46 45 82 65 E-mail: thierry.maugard@univ-lr.fr

8 **Abstract**

9 The *in vitro* antimicrobial activity of the marine green algae *Chaetomorpha aerea* was  
10 investigated against gram-positive bacteria, gram-negative bacteria, and a fungus. The water-  
11 soluble extract of algae was composed of a sulfated (6.3%) galactan with a molecular weight  
12 of  $1.160 \times 10^6$  Da and a global composition close to commercial polysaccharides as dextran  
13 sulfate or fucoidan. The polysaccharide was composed of 18% arabinose, 24% glucose, 58%  
14 galactose. The re-suspended extracts (methanol, water) exhibited selective antibacterial  
15 activities against three gram-positive bacteria including *Staphylococcus aureus* (ATCC  
16 25923). Minimum inhibitory concentration and minimum bactericidal concentration tests  
17 showed that the sulfated galactan could be a bactericidal agent for this strain ( $40 \text{mg} \cdot \text{mL}^{-1}$ ).  
18 Results of the present study confirmed the potential use of the green algae *Chaetomorpha*  
19 *aerea* as a source of antibacterial compounds or active known molecules.

20 **Keywords:** Seaweed, *Chaetomorpha aerea*, sulfated galactan, antibacterial activity,  
21 *Staphylococcus aureus*

22

## 23 INTRODUCTION

24 Seaweeds are used by coastal populations for thousands of years owing to their high  
25 nutritional values [1, 2]. However, the industrialization of seaweeds does not necessarily need  
26 their consumption. Medical and pharmaceutical industries are also interested since marine  
27 plants are rich in active molecules [3, 4]. Indeed, the therapeutic potentials of certain  
28 substances are extremely promising, especially as antimicrobial and antiviral factors [5, 6].  
29 Besides, the use of fucoidans allows fighting against the formation and growth of malignant  
30 tumors [7, 8]. Numerous studies have investigated the biological activities of algae extracts  
31 [9]. Different seaweeds, e.g. *Ulva fasciata* or *Enteromorpha compressa*, have presented  
32 antimicrobial activities against *Staphylococcus aureus* or *Pseudomonas aeruginosa*, two  
33 bacteria commonly found in many human infections [10]. Nevertheless, microorganisms are  
34 able to adapt their metabolism for resisting to the action of antimicrobial drugs [11, 12]. This  
35 problem is one of the main reasons which require further research of new antimicrobial  
36 compounds, including molecules from marine algae [13]. *Chaetomorpha aerea* is a green  
37 filamentous alga which develops in many marine mediums as oyster ponds. Numerous species  
38 of *Chaetomorpha* have often been studied since these organisms behave like opportunistic  
39 macrophytes, causing evident ecological changes in the ecosystem contaminated. In French  
40 oyster ponds (Marennes-Oléron, France), the excessive proliferation of these seaweeds  
41 prevent the proper development of the phytoplanktonic portion that oysters need to grow up.  
42 More generally, different studies have attempted to positively exploit these algae. It was  
43 reported that *Chaetomorpha linum* was able to chelate heavy metals (copper and zinc) in  
44 aqueous solutions [14]. A heparin-like polysaccharide has been highlighted in the seaweed  
45 *Chaetomorpha antennina* [15]. Finally, the biological properties of sulfated arabinogalactans  
46 [16, 17] extracted from green algae like *Chaetomorpha* were investigated. In this way, an

47 interesting polysaccharide composed of arabinose (57%), galactose (38.5%), rhamnose (3.8%)  
48 and sulfates (11.9%) was purified from *Chaetomorpha linum* [18].

49 In the present study, we have developed a method to extract extracellular polysaccharides  
50 from *Chaetomorpha aerea*. These polysaccharides were studied and biochemically  
51 characterized to determine their composition and their partial structure. We have also  
52 investigated the potential antimicrobial activities of these different extracts against  
53 microorganisms, i.e. *Staphylococcus aureus* (ATCC 25923), *Salmonella enteritidis* (ATCC  
54 13076), *Pseudomonas aeruginosa* (ATCC 27853), *Enterococcus faecalis* (CIP 103214),  
55 *Bacillus subtilis* (CIP 5262), *Micrococcus luteus* (ATCC 4698) and *Candida glabrata* (DSMZ  
56 6425). This investigation could scientifically proof that the natural compounds of  
57 *Chaetomorpha aerea* could be potentially used as antibacterial agents.

## 58 MATERIALS AND METHODS

### 59 Materials

60 Ground and dried *Chaetomorpha aerea* (Fig. 1), harvested on oyster ponds (Marennes-  
61 Oléron, France) during winter (January 2009). Dowex Marathon C, BicinChonic Acid  
62 (BCA) Protein Assay Kit, Azure A, N,O-bis(trimethylsilyl)trifluoroacetamide:  
63 trimethylchlorosilane (BSTFA: TMCS) (99: 1), Zinc sulfate and Baryum hydroxide were  
64 obtained from Sigma–Aldrich. Standard carbohydrates (dextran, dextran sulfatate, blue  
65 dextran, heparin, fucoidan, glucose, galactose, rhamnose, fucose, fructose, xylose, arabinose,  
66 mannose, lactose, raffinose, myo-inositol, glucuronic and galacturonic acid) and a protein  
67 standard (Bovine Serum Albumin, BSA) were obtained from Sigma–Aldrich. Fucogel  
68 1000PP, composed of a 3)- $\alpha$ -L-Fucp-(1 $\rightarrow$ 3)- $\alpha$ -D-Galp-(1 $\rightarrow$ 3)- $\alpha$ -D-GalpA-(1 $\rightarrow$   
69 polysaccharide, was obtained from Solabia [19]. Solvents (chloroform, hexane, ethanol) were  
70 from Carlo Erba. The ICSep ORH-801 and TSK Gel G3000 PWXL-CP columns for High

71 Performance Liquid Chromatography analysis (HPLC) were obtained from Interchim. The  
72 DB-1701 J&W Scientific column (30m, 0.32mm, 1mm) for Gas Chromatography-Mass  
73 Spectrometry analysis (GC/MS) was obtained from Agilent.

#### 74 **Extraction and purification methodology**

75 From 5g of ground and dried *Chaetomorpha aerea*, a first step of delipidation and  
76 depigmentation was performed by using mixtures of chloroform/hexane (2/1 v/v) (Fig. 2, Step  
77 1). The second step consisted to extract the extracellular polymers through an aqueous  
78 extraction procedure, during 24h at 40°C (Fig. 2, Step 2). A filtration stage was then applied  
79 to clear out unwanted residues. After freeze-drying, the combination of aqueous solutions of  
80 zinc sulfate (5%) and barium hydroxide (0.3N) on the sample allowed realizing the defecation  
81 step (Fig. 2, Step 3). The supernatant was recovered after centrifugation then freeze-dried.  
82 Finally, a purification step was applied to the sample through dialysis, to further purify the  
83 carbohydrate fraction (Fig. 2, Step 4). This fraction was named *Chaetomorpha aerea*  
84 carbohydrates-rich (CACR) fraction. A simple extraction was done (only the step 2) to  
85 compare the composition of the CACR fraction with this water-extracted fraction. This  
86 fraction was named control fraction (CF).

#### 87 **Biochemical characterization**

88 Total sugar content was determined using the phenol-sulfuric acid assay, developed by  
89 Dubois, using glucose as a standard [20]. Protein content was determined using the  
90 bicinchoninic acid (BCA) assay, using bovine serum albumin (BSA) as a standard [21]. The  
91 sulfate content was measured by the Azure A [22] and the barium chloride gelation method  
92 [23], using dextran sulfate as a standard. Fourier Transform Infrared Spectroscopy (FTIR)  
93 analyses were performed on the CACR fraction and commercial controls (dextran, dextran  
94 sulfate, fucoidan, bovine serum albumin, Fucogel 1000PP) by using a Spectrum 100 FTIR

95 equipped with an Attenuated Total Reflectance (ATR) module and a crystal diamond.  
96 Principal Component Analyses (PCA) were realized (XLStats) to characterize and classify the  
97 IR spectrum of the CACR fraction among IR spectra of standards.

#### 98 **Molecular weight determination**

99 Analysis of the carbohydrate fractions was carried out by HPLC using a Hewlett Packard  
100 series 1100. The following conditions were used to determine the molecular weight  $M_x$  of the  
101 polysaccharide by differential refractometry: 20 $\mu$ L of an aqueous solution of the purified  
102 polysaccharides (10 to 50 g/L) were injected into a TSK Gel G3000 PWXL-CP column at  
103 40°C, using water as elution solvent at a flow rate of 0.7mL/min. Dextran, dextran sulfate,  
104 blue dextran, heparin, fucoidan, glucose, lactose, raffinose were used as standards.

#### 105 **Carbohydrates monomers characterization**

106 Acidic hydrolysis conditions, i.e. 4h at 90°C in 2M HCl, were performed on purified fractions  
107 to obtain samples containing mostly carbohydrates monomers. Preparations were then freeze-  
108 dried and stored at 20°C. Prior to carbohydrates characterization by HPLC (Hewlett Packard  
109 series 1100), 20 $\mu$ L of an aqueous solution of the fractions rich in monomers were injected  
110 into a ICSep ORH-801 at room temperature, using an aqueous solution of H<sub>2</sub>SO<sub>4</sub> 0.01M as  
111 elution solvent at a flow rate of 0.6mL/min. Analysis of the hydrolyzed carbohydrate fractions  
112 was also carried out by GC/MS using a Varian CP-3800 GC/Varian Saturn 2000. 400 mL of  
113 pyridine and 400 mL of BSTFA: TMCS (99:1) was added to 2 mg of purified  
114 polysaccharides. The solution was mixed for 2 h at room temperature, then injected into a  
115 DB-1701 J&W Scientific column (30 m, 0.32 mm, 1 mm) at a flow of 1 mL/min. The helium  
116 pressure was 8.8 psi. The temperature of the injector was set at 250°C. The rise in temperature  
117 in the oven was programmed for a first step at 150°C for 0 min, then an increment of  
118 10°C/min up to 200°C with a final step at 200°C for 35 min. The ionization was performed by

119 Electronic Impact (EI, 70 eV), the trap temperature was set at 150°C and the target ion was  
120 fixed at 40–650 m/z.

### 121 **Microbiological material and microorganism sources**

122 Growth media were from Biokar Diagnostics and antibiotic solutions (ampicillin and  
123 cycloheximid) were from Sigma-Aldrich. The microorganisms used in this study, i.e.  
124 *Staphylococcus aureus* (ATCC 25923), *Salmonella enteritidis* (ATCC 13076), *Pseudomonas*  
125 *aeruginosa* (ATCC 27853), *Enterococcus faecalis* (CIP 103214), *Bacillus subtilis* (CIP 5262),  
126 *Micrococcus luteus* (ATCC 4698) and *Candida glabrata* (DSMZ 6425), were obtained from  
127 American Type Culture Collection (ATCC), Collection of Institute Pasteur (CIP) and German  
128 Collection of Microorganisms and Cell Cultures (DSMZ). All of the microorganisms were  
129 provided in the form of pure bacterial stock culture.

### 130 **Antibiotic susceptibility testing**

131 Antimicrobial susceptibility testing was determined by the disc diffusion method (Sanofi,  
132 Dianostics Pasteur). However, the method was adapted for the use of microwells, instead of  
133 employing discs, which allowed working with larger volumes and concentrations. The  
134 photometric calibration method was used to adjust the inoculum of the microbial suspensions:  
135 microbial suspensions were prepared in a phosphate buffer (0.1M pH 7.2) adjusting the cell  
136 density to  $1-3 \cdot 10^8$  microbial cells/mL, corresponding to an optical density between 0.10 and  
137 0.12 at 550nm. Microbial suspensions were then diluted in Mueller Hinton media (MH) to 1:  
138 100. MH or Yeast Peptone Dextrose (YPD) agar plates (for *Candida glabrata*) were flooded  
139 by these suspensions (2mL). After 15min at 37°C, sterile microwells (in glass, internal  
140 diameter: 4mm, external diameter: 6mm, height: 7mm) were put onto the microbial field and  
141 inoculated by 30µL of the CACR fraction. It is noteworthy that these samples were previously  
142 re-solubilized at 20 and 50mg.mL<sup>-1</sup> in different solvents: methanol, acetone,

143 dimethylsulfoxide (DMSO) and ethanol. Ampicillin and cycloheximid (10mg/ml) were used  
144 as positive controls. The plates were incubated at 30°C (for *Candida glabrata*) or 37°C and  
145 the zones of inhibition were observed after 24h.

#### 146 **Minimal inhibitory concentration (MIC) and minimal bactericidal concentration (MBC)** 147 **tests**

148 The sensitivity of microorganism to CACR fractions was measured by using a tube dilution  
149 technique, which allows the determination of the MIC and MBC of the seaweed used in this  
150 study. These tests were done to determine the lowest concentration of the different extracts,  
151 where the bactericidal and bacteriostatic effect can be shown. The test was performed in  
152 tubes and allowed replicating each sample (triplicate). Microbial suspensions were prepared  
153 in the same way than previously. Microbial suspensions, diluted in MH at 1: 100, were added  
154 into increasing concentrations of CACR fractions, i.e. 2 to 50mg.mL<sup>-1</sup>. The tubes were  
155 incubated at 30°C or 37°C during 24h. The first clear tube before turbid samples allowed the  
156 determination of the MIC. All clear tubes were placed out onto MH agar plates, and plates  
157 were incubated at 30°C or 37°C for 24h. Finally, the number of microorganism colonies  
158 developed on each agar plates was counted to determine the MBC, i.e. the plate where the  
159 concentration of the CACR fraction was sufficient to destroy 99.99% of the microorganism  
160 population. Ampicillin (10mg/ml) was used as positive control.

## 161 **RESULTS AND DISCUSSION**

### 162 **Biochemical characterization**

163 Many studies have highlighted that molecules from algae showed original biochemical  
164 compositions, behind nutritional [24], medical and antibacterial properties [25]. Seaweeds  
165 contain various compounds as polysaccharides, proteins, lipids, amino-acids, sterols or  
166 phenolic molecules which show bioactivity against microorganisms [26, 27] or virus [28]. On



167 the other hand, sulfated polysaccharides extracted from marine algae can be used for their  
168 anticoagulant and antithrombotic properties [29]. The main goal of this study was in a first  
169 time to find a valorization path of the macroalga *Chaetomorpha aerea*, which is an ecological  
170 problem for French west coast and especially oyster ponds. The extracellular polysaccharides  
171 of this green alga were firstly extracted and their compositions were characterized. Indeed,  
172 certain authors have highlighted that green algae as *Chaetomorpha* were composed of  
173 interesting polysaccharides (arabinogalactans), sometimes sulfated [16, 18]. The biochemical  
174 compositions (% w/w) of the control and the CACR fractions were determined (Table 1). The  
175 control fraction (CF) was composed of carbohydrates (3.82%), proteins (2.30%) and other  
176 compounds (93.9%) which were probably lipids, pigments and impurities. Owing to the  
177 extraction procedure, the CACR fraction obtained was composed of 76.6% carbohydrates,  
178 17.3% proteins and the unknown part was reduced to 5.8%. From 5g of *Chaetomorpha aerea*,  
179 the method allowed the extraction of 233mg of the CACR fraction (extraction yield of  
180 4.67%), whether approximately 178mg of carbohydrates and 40mg of proteins. The fraction  
181 was rich in carbohydrates and proteins (17.3%) (Table 1), which was coherent with previous  
182 works on a similar alga, *Chaetomorpha linum* [16]. It was noteworthy that the CACR fraction  
183 contained a large part of sulfated carbohydrates (6.3%) (Table 1). Besides, carbohydrates  
184 were sulfated (6.3%). In this way, Percival (1979) showed the important sulfatation degree of  
185 polysaccharides extracted from *Chaetomorpha* and a sulfated polysaccharide (11.9%) has  
186 been already purified from *Chaetomorpha antennina* [18].

187 FTIR analyses coupled to PCA allowed classifying the IR profile of the CACR fraction with  
188 various IR profiles of commercial polymers (Fig. 3). The general composition of this fraction  
189 was close to the composition of neutral and sulfated polysaccharides, as the dextran sulfate  
190 (17% sulfur). Owing to its composition, the dextran sulfate is known for its anticoagulant  
191 properties or its inhibitory effects against enzymes, cells or virus [30]. The general

192 composition and the sulfatation degree of the CACR fraction suggest that this extract could  
193 present similar biological activities.

#### 194 **Molecular weight determination and carbohydrates monomers characterization**

195 Gel permeation chromatography analyses allowed the determination of the molecular weight  
196 of the CACR fraction. One peak was visible, at a retention time of 7.3min, by using the TSK  
197 Gel G3000 PWXL-CP column (Fig. 4, A). Comparing this retention time to the logarithmic  
198 standard curve, we concluded that the CACR fraction was composed of a main  
199 polysaccharide of  $1.160 \times 10^6 \pm 0.150 \times 10^6$  Da. Other HPLC analyses, realized by using the  
200 ICSep ORH-801 fraction, showed that the CACR fraction was composed of three main  
201 monosaccharides: glucose, galactose and arabinose (Fig. 4, B). CPG/MS analyses confirmed  
202 the presence of glucose (24%), galactose (58%), arabinose (18%) and the traces of xylose  
203 (Table 2). The homology of MS spectra was verified (>91%), by comparing the MS spectra of  
204 standards and the MS spectra of the monosaccharides identified in the CACR fraction.  
205 According to previous studies [16, 18], the identification of a xyloarabinogalactan from the  
206 extracellular polysaccharides of a green alga was coherent and interesting.  
207 Xyloarabinogalactans, water-solubles and extracted from *Chlorophyceae*, are branched and  
208 sulfated heteropolysaccharides, presenting various composition, without repeating unit, except  
209 residues of (1,4)-L-arabinose separated by D-galactose units [16]. Although it is difficult to  
210 characterize the complete structure of this type of sulfated heteroglycans, numerous studies  
211 have highlighted the anti-herpetic, anti-coagulant activities or antioxidant capacity of sulfated  
212 galactans extracted from seaweeds [31].

#### 213 **Antibiotic susceptibility testing**

214 The second part of this work was dedicated to a preliminary screening of the potential  
215 antibacterial activities of these natural extracted polysaccharides against various strains of

216 microorganisms, including pathogenic or resistant bacteria (*Pseudomonas aeruginosa*,  
217 *Staphylococcus aureus*), which contaminate many biological or inert surfaces. Inhibition  
218 zones were measured for each re-suspended CACR fractions ( $50\text{mg}\cdot\text{mL}^{-1}$ ). Positive controls  
219 confirmed that the strain correctly grew up and was affected by ampicillin. Negative controls  
220 showed that the solvents used did not affect the growth of the different microorganisms. First,  
221 no inhibition area was observed for the strains *Salmonella enteritidis* (ATCC 13076),  
222 *Pseudomonas aeruginosa* (ATCC 27853), *Enterococcus faecalis* (CIP 103214) or *Candida*  
223 *glabrata* (DSMZ 6425) (Table 3). Only the strains *Bacillus subtilis* (CIP 5262), *Micrococcus*  
224 *luteus* (ATCC 4698) and *Staphylococcus aureus* (ATCC 25923) were affected by the presence  
225 of the CACR fraction resuspended in water (Table 3). Moreover, the strain of *Staphylococcus*  
226 *aureus* (ATCC 25923) was affected by different CACR fractions, re-suspended in different  
227 solvents (Fig. 5). *Staphylococcus aureus* (ATCC 25923) showed an important sensibility to  
228 the CACR fractions during the contact periods (Fig. 5). The methanol CACR extract showed  
229 the greatest diameter of inhibition, i.e.  $13\text{mm} \pm 1$  (Fig. 5, D; Table 4), probably due to a better  
230 solubility of the molecules composing the CACR fraction (Table 4). It is important to note  
231 that the CACR fractions had an inhibitory activity only against three gram-positive  
232 microorganisms. Antimicrobial activities from seaweeds are mostly higher recurrent against  
233 gram positive bacteria as *Staphylococcus aureus* [32]. However, no inhibitory activity of the  
234 CACR fraction was found against *Enterococcus faecalis* (CIP 103214). Several authors  
235 clarified there is several reasons to explain why biological extracts could be active or not  
236 against different microbial strains, e.g. (i) the absence of target structure in the bacteria, (ii)  
237 the cell wall of the bacteria or (iii) the ability of the bacteria to modify the structure of the  
238 molecules composing the tested fraction [33].

239 **MIC and MBC tests for the pathogenic strain *Staphylococcus aureus* (ATCC 25923)**

240 Bacterial turbidities of *Staphylococcus aureus* (ATCC 25923) in contact with increasing  
241 concentrations of the CACR fraction (re-suspended in water or methanol) allowed the  
242 determination of the MIC and MBC. No bacterial turbidity, corresponding to the MIC values,  
243 was found at 40 and 42 mg.mL<sup>-1</sup> for the methanol and water CACR fractions respectively  
244 (Table 4). This result indicated that the CACR fraction could block the cell wall formation of  
245 this bacterium, inducing its lysis and death. However, it is noteworthy that the concentration  
246 of the antibacterial agent can greatly influence its classification as bacteriostatic or  
247 bactericidal agent. The protocol used to determine the MBC of the methanol and water CACR  
248 fractions highlighted a MBC value of 45 mg.mL<sup>-1</sup> for both. The MBC/MIC ratio indicated  
249 that the two CACR fractions presented a bactericidal activity against *Staphylococcus aureus*  
250 (ATCC 25923). However, a high dose of a bacteriostatic antibacterial molecule (as 45  
251 mg.mL<sup>-1</sup>) will be bactericidal [12]. Finally, several significant findings were found whereby  
252 the CACR fraction, composed of a sulfated xyloarabinogalactan, which exhibited a selective  
253 inhibitory activity against the Gram-positive bacterium *Staphylococcus aureus* (ATCC  
254 25923). *Staphylococcus aureus* is a common pathogen spread by ingestion of contaminated  
255 food or water. Seafood is one of the sources of staphylococcal infection for humans [34].  
256 Moreover, marine animals, as oysters, may be reservoirs or carriers of infectious agents and  
257 biological toxins [35]. In this way, studies have highlighted that oysters could be  
258 contaminated by *Staphylococcus aureus*, indirectly from contaminated water [36, 37]. The use  
259 of *Chaetomorpha aerea* in oyster ponds could be allowed to biologically purify water. The  
260 “secretion” of its extracellular sulfated galactan could avoid the microbial contamination of  
261 oysters against this pathogen bacterium, and finally could minimize the number of human  
262 food poisoning.

## 263 **CONCLUSION**

264 Therefore, this study allowed the extraction and partially characterization of an extracellular  
265 polysaccharide from the green alga *Chaetomorpha aerea*. The CACR fraction was mainly  
266 composed of one type of polysaccharide of  $1.160 \times 10^6$  Da. This fraction contained 76.6%  
267 carbohydrates and 6.3% of them were sulfated. Chromatographic and GC/MS analyses  
268 highlighted that the polysaccharide is a xyloarabinogalactan, composed of 17.9% arabinose,  
269 23.8% glucose, 58.3% galactose and some traces of xylose. Microbiological tests showed that  
270 the CACR fraction selectively inhibited the growth of *Staphylococcus aureus* (ATCC 25923)  
271 and could be potentially a bactericidal agent ( $40 \text{mg} \cdot \text{mL}^{-1}$ ). It could be interesting to better  
272 purify the CACR fraction by using ion exchange resins to eliminate the presence of proteins.  
273 On the other hand, the fact that the CACR fraction was composed of a sulfated  
274 xyloarabinogalactan is of primary interest since these kinds of algal sulfated heteroglycans are  
275 known for their biological activities as antimicrobial and especially anti-coagulant properties.  
276 The presence of this kind of polysaccharide could be a potential path to valorize the  
277 deleterious alga *Chaetomorpha aerea*.

278 **Acknowledgements** This study was financially supported by the Conseil Général of  
279 Charente-Maritime and the Centre National de la Recherche Scientifique.

## 280 REFERENCES

- 281 [1] Zemke-White, W. L., and M. Ohno (1999) World seaweed utilization: an end-of-century  
282 summary. *J. Appl. Phycol.* 11: 369-376.
- 283 [2] MacArtain, P., C. I. R. Gill, M. Brooks, R. Campbell, and I. R. Rowland (2007)  
284 Nutritional value of edible seaweeds. *Nutr. Rev.* 65: 535-543.
- 285 [3] Pérez, R. (1997) Ces algues qui nous entourent. pp. 65-178. In: S. Arbault, O. Barbaroux,  
286 P. Phliponeau, C. Rouxel (eds.). *Aquaculture*. Editions IFREMER, Plouzané, France.

- 287 [4] Madhusudan, C., S. Manoj, K. Rahul, and C. M. Rishi (2011) Seaweeds: a diet with  
288 nutritional, medicinal and industrial value. *Res. J. Med. Plant.* 5: 153-157.
- 289 [5] Val, A. G. D., G. Platas, A. Basilio, A. Cabello, J. Gorrochategui, I. Suay, F. Vicente, E.  
290 Portillo, M. J. D. Río, G. G. Reina, and F. Peláez (2001) Screening of antimicrobial activities  
291 in red, green and brown macroalgae from Gran Canaria (Canary Islands, Spain). *Int.*
- 292 [6] Nakajima, K., A. Yokoyama, and Y. Nakajima (2009) Anticancer effects of a tertiary  
293 sulfonium compound, dimethylsulfoniopropionate, in green sea algae on Ehrlich ascites  
294 carcinoma-bearing mice. *J. Nutr. Sci. Vitaminol.* 55: 434-438.
- 295 [7] Boisson-Vidal, C., F. Zemani, G. Calliguirri, I. Galy-Fauroux, S. Collic-Jouault, D.  
296 Helley, and A. M. Fisher (2007) Neoangiogenesis induced by progenitor endothelial cells:  
297 effect of fucoidan from marine algae. *Cardiovasc. Hematol. Agents Med. Chem.* 5: 67-77.
- 298 [8] Synytsya, A., W. –J. Kim, S. –M. Kim, R. Pohl, A. Synytsya, F. Kvasnička, J. Čopíková,  
299 and Y. Il Park (2010) Structure and antitumour activity of fucoidan isolated from sporophyll  
300 of Korean brown seaweed *Undaria pinnatifida*. *Carbohydr. Polym.* 81: 41-48.
- 301 [9] Tringali, C. (1997) Bioactive metabolites from marine algae: recent results. *Curr. Org.*  
302 *Chem.* 1: 375-394.
- 303 [10] Selvin, J., and A. P. Lipton (2004) Biopotentials of *Ulva fasciata* and *Hypnea*  
304 *musciformis* collected from the Peninsular Coast of India. *J. Mar. Sci. Technol.* 12: 1-6.
- 305 [11] European Antimicrobial Resistance Surveillance System (EARSS) (2004) *Annual Report*  
306 *EARSS-2003*. Pp. 90-91. NBilthoven, The Netherland.

- 307 [12] Al-Haj, N. A., N. I. Mashan, M. N. Shamsudin, H. Mohamad, C. S. Vairappan, and Z.  
308 Sekawi (2009) Antibacterial activity in marine algae *Eucheuma denticulatum* against  
309 *Staphylococcus aureus* and *Streptococcus pyogenes*. *Res. J. Biol. Sci.* 4: 519-524.
- 310 [13] Kim, I. H., S. H. Lee, J. -M. Ha, B. -J. Ha, S. -K. Kim, and J. -H. Lee (2007)  
311 Antibacterial activity of *Ulva lactuta* against Methicillin-Resistant *Staphylococcus aureus*  
312 (MRSA). *Biotechnol. Bioprocess Eng.* 12: 579-582.
- 313 [14] Chebil Ajjabia, L., and L. Choubab (2009). Biosorption of  $\text{Cu}^{2+}$  and  $\text{Zn}^{2+}$  from aqueous  
314 solutions by dried marine green macroalga *Chaetomorpha linum*. *J. Environ. Manage.* 90:  
315 3485-3489.
- 316 [15] Anand Ganesh, E., S. Das, G. Arun, S. Balamurugan, R. Ruban Raj (2009) Heparin like  
317 compound from green alga *Chaetomorpha antennina* - as potential anticoagulant agent. *Asian*  
318 *J. Med. Sci.* 1: 114-116.
- 319 [16] Percival, E. (1979) The polysaccharides of green, red and brown seaweeds: their basic  
320 structure, biosynthesis and function. *Br. Phycol. J.* 14: 103-117.
- 321 [17] Genestie, B. (2006) *Optimisation de la production d'arabinoxyloligosaccharides*  
322 *d'intérêt biologique à partir de sons de céréales : approches méthodologiques*. Ph.D. Thesis.  
323 University of Limoges, Limoges, France.
- 324 [18] Venkata Rao, E., and K. Sri Ramana (1991) Structural studies of a polysaccharide  
325 isolated from the green seaweed *Chaetomorpha antennina*. *Carbohydr. Res.* 217: 163-170.
- 326 [19] Guetta, O., K. Mazeau, R. Auzely, M. Milas, and M. Rinaudo (2003) Structure and  
327 properties of a bacterial polysaccharide named Fucogel. *Biomacromol.* 4: 1362-1371.

- 328 [20] Dubois, M., K. A. Gilles, J. K. Hamilton, P. A. Rebers, and F. Smith (1956) Colorimetric  
329 method for determination of sugars and related substances. *Anal. Chem.* 28, 350-356.
- 330 [21] Smith, P. K., R. I. Krohn, G. T. Hermanson, A. K. Mallia, F. H. Gartner, M. D.  
331 Provenzano, E. K. Fujimoto, N. M. Goetze, B. J. Olson, and D. C. Klenk (1985) Measurement  
332 of protein using bicinchoninic acid. *Anal. Biochem.* 150: 76-85.
- 333 [22] Jaques, L. B., R. E. Ballieux, C. P. Dietrich, and L. W. Kavanagh (1968) A  
334 microelectrophoresis method for heparin. *Can. J. Physiol. Pharmacol.* 46: 351-360.
- 335 [23] Craigie, J. S., Z. C. Wen, and J. P. van der Meer (1984) Interspecific, intraspecific and  
336 nutritionally-determined variations in the composition of agars from *Gracilaria spp.* *Bot.*  
337 *Mar.* 27: 55-61.
- 338 [24] Fleurence, J. (1999) Seaweed proteins: biochemical, nutritional aspects and potential  
339 uses. *Trends Food Sci. Technol.* 10: 25-28.
- 340 [25] Chakraborty, K., A. P. Lipton, R. Paul Raj, K. K. Vijayan (2010) Antibacterial labdane  
341 diterpénoïdes of *Ulva fasciata Delile* from southwestern coast of the India Peninsula. *Food*  
342 *Chem.* 119:1399-1408.
- 343 [26] Wong, W. H., S. H. Goh and S. M. Phang (1994) Antibacterial properties of Malaysian  
344 seaweeds. pp. 75-81. In: S. M. Phang, Y. K. Lee, M. A. Borowitzka, and B. A. Whitton (eds.).  
345 Algal biotechnology in the Asia-Pacific region. University of Malaya, Kuala Lumpur,  
346 Malaysia.
- 347 [27] Nirmal Kumar, J. I., R. N. Kumar, M. K. Amb, A. Bora, and S. Kraborty (2010)  
348 Variation of biochemical composition of eighteen marine macroalgae collected from Okha  
349 Coast, Gulf of Kutch, India. *Electron. J. Environ. Agric. Food Chem.* 9: 404-410.



- 350 [28] Abrantes, J. L., J. Barbosa, D. Cavalcanti, R. C. Pereira, C. L. Frederico Fontes, V. L.  
351 Teixeira, T. L. Moreno Souza, and I. C. P. Paixão (2010) The effects of the diterpenes isolated  
352 from the Brazilian brown algae *Dictyota pfaflii* and *Dictyota menstrualis* against the herpes  
353 simplex type-1 replicative cycle. *Planta Med.* 76: 339-344.
- 354 [29] Mao, W., X. Zang, Y. Li, and H. Zhang (2005) Sulfated polysaccharides from marine  
355 green algae *Ulva conglobata* and their anticoagulant activity. *J. Appl. Phycol.* 18 :9-14.
- 356 [30] Baba, M., R. Snoeck, R. Pauwels, and E. de Clerq (1988) Sulfated polysaccharides are  
357 potent and selective inhibitors of various enveloped viruses, including herpes simplex virus,  
358 cytomegalovirus, vesicular stomatitis virus, and human immunodeficiency virus. *Antimicrob*  
359 *Agents Chemother.* 32: 1742-1745.
- 360 [31] Barahona, T., N. P. Chandía, M. V. Encinas, B. Matsuhira, and E. A. Zúñiga (2011)  
361 Antioxidant capacity of sulfated polysaccharides from seaweeds. A kinetic approach. *Food*  
362 *Hydrocolloids.* 25: 529-535.
- 363 [32] Reichelt, J. L., and M. A. Borowitzka (1984) Antimicrobial activity from marine algae:  
364 results of a large scale screening program. *Hydrobiologia.* 116-117: 158-168.
- 365 [33] Michael, T. M., M. M. John, and P. Jack (2002) Brock microbiology of microorganism.  
366 10<sup>th</sup> ed. Prentice Hall, New Jersey, US.
- 367 [34] Liston, J. (1990) Microbial hazards of seafood consumption toxins, bacteria and viruses  
368 are the principal causes of sea foodborne diseases. *Food Technol.* 44: 58-62.
- 369 [35] Jeyasekaran, G., I. Karunasagar, and I. Karunasagar (1996) Incidence of *Listeria spp.* in  
370 tropical fish. *Int. J. Food Microbiol.* 1-3 : 333-340.

371 [36] Beleneva, I. A. (2010) Incidence and characteristics of *Staphylococcus aureus* and  
372 *Listeria monocytogenes* from the Japan and South China seas. Mar. Pollut. Bull. doi:  
373 10.1016/j.marpolbul.2010.09.024.

374 [37] Oliveira, J., A. Cunha, F. Castilho, J. L. Romalde, and M. J. Pereira (2011) Microbial  
375 contamination and purification of bivalve shellfish: crucial aspects in monitoring and future  
376 perspectives – a mini-review. Food Control. 22: 805-816.

377

378 Table 1. Biochemical composition (% w/w) of the native sample and the CACR fraction  
 379 extracted from *Chaetomorpha aerea*.

<b>Composition (% w/w)</b>	<b>Carbohydrates</b>	<b>Uronic acids</b>	<b>Proteins</b>	<b>Sulfated carbohydrates</b>	<b>Others</b>
<b>Control fraction</b>	3.82 ± 0.12	nd	2.30 ± 0.11	0.33 ± 0.14	93.9
<b>Partially purified fraction</b>	28.1 ± 2.31	nd	6.53 ± 1.08	2.21 ± 0.92	71.9
<b>CACR fraction</b>	76.6 ± 0.62	nd	17.3 ± 2.85	6.3 ± 1.2	5.8

380 *nd: non determined by colorimetric assays*

381  $\pm$ : Standard deviation  $\sigma_x$  on 10 runs.

382

383 Table 2. Identification and quantification by GC/MS of the monosaccharides composing the  
 384 CACR fraction extracted from *Chaetomorpha aerea*.

<b>Monosaccharides</b>	<b>Retention time of standards</b>	<b>Retention time of peaks in the CA fraction</b>	<b>Homology MS spectra (%)</b>	<b>Concentration (% w/w)</b>
<b>Rhamnose</b>	6.49	-	-	-
<b>Arabinose</b>	6.61	6.59	93.45	18
<b>Fucose</b>	7.65	-	-	-
<b>Xylose</b>	8.59	9.11	91.87	trace
<b>Mannose</b>	10.72	-	-	-
<b>Galactose</b>	11.73	11.72	98.12	58
<b>Glucose</b>	12.67	12.59	98.89	24
<b>Inositol</b>	23.89	-	-	-

385

386

387 Table 3. Antibacterial activities against the different gram-positive/gram-negative bacteria of  
388 the CACR extract, previously re-solubilized in water.

<b>Microorganisms</b>	<b><i>Diameters of inhibition (mm)</i></b>
<b><i>Bacillus subtilis</i> (CIP 5262)</b>	14 ± 2
<b><i>Micrococcus luteus</i> (ATCC 4698)</b>	13 ± 2
<b><i>Staphylococcus aureus</i> (ATCC 25923)</b>	11 ± 0.5
<b><i>Enterococcus faecalis</i> (CIP 103214)</b>	0
<b><i>Pseudomonas aeruginosa</i> (ATCC 27853)</b>	0
<b><i>Salmonella enteritidis</i> (ATCC 13076)</b>	0
<b><i>Candida glabrata</i> (DSMZ 6425)</b>	0
<b>Ampicillin (positive control)</b>	41 ± 1.5

389 ±: Standard deviation  $\sigma_x$  on 10 runs.

390

391

392 Table 4. Antibacterial activities of the CACR extract against *Staphylococcus aureus* (ATCC  
393 25923), previously re-solubilized in different solvents.

<b>Solvents used to solubilize extracts</b>	<b><i>Diameters of inhibition (mm)</i></b>
<b>Water (50mg.mL<sup>-1</sup>)</b>	11 ± 0.5
<b>Ethanol (50mg.mL<sup>-1</sup>)</b>	11 ± 1
<b>Acetone (50mg.mL<sup>-1</sup>)</b>	12 ± 0.5
<b>Methanol (50mg.mL<sup>-1</sup>)</b>	13 ± 1
<b>Dimethylsulfoxyde (50mg.mL<sup>-1</sup>)</b>	10 ± 0.5
<b>Ampicillin (10mg.mL<sup>-1</sup>)</b>	41 ± 1.5

394 ±: Standard deviation  $\sigma_x$  on 10 runs.

395

396

397 Table 5. Bacterial turbidity of *Staphylococcus aureus* (ATCC 25923) after 24h at 37°C in  
 398 contact with different concentrations of the CACR extract, previously re-suspended in water  
 399 or methanol. Ampicillin was used as positive control.

Concentrations (mg.mL <sup>-1</sup> )	Ampicillin	CACR water-fractions	CACR methanol-fractions
2	-	+++	+++
4	-	+++	+++
8	-	+++	+++
10	-	+++	+++
15	-	+++	+++
20	-	+++	+++
30	-	++	++
35	-	+	+
40	-	+	-
42	-	-	-
45	-	-	-
50	-	-	-

+++ : very turbid microbial suspension

++: turbid microbial suspension

+: low turbid microbial suspension

-: no turbidity

400

401

402 Figure 1. *Chaetomorpha aerea*, the type of green alga which was used in this study.

403 Figure 2. Extraction and purification procedure which was developed to obtain the CACR  
404 fraction from the mucilage of *Chaetomorpha aerea*.

405 Figure 3. Principal Component Analysis (PCA) (XLStat) of the FTIR spectra obtained for the  
406 CACR fraction and different commercial polysaccharides and proteins. The spectral region  
407 selected for the PCA analysis was comprised between 650 and 4000cm<sup>-1</sup>.

408 Figure 4. Analyses by HPLC: determination of the molecular weight by gel permeation  
409 chromatography (A) and characterization of the monosaccharides distribution (B) of the  
410 polymer composing the CACR fraction.

411 Figure 5. Sensibility of *Staphylococcus aureus* (ATCC 25923), after 24h at 37°C, against  
412 different re-suspended CACR fraction (50mg.mL<sup>-1</sup>): water (A), ethanol (B), acetone (C) and  
413 methanol (D) CACR fractions. T+ corresponded to the sensibility of the strain against  
414 ampicillin. T- showed the non-effect of the solvent used on the strain growth.

415



416

417

418



419

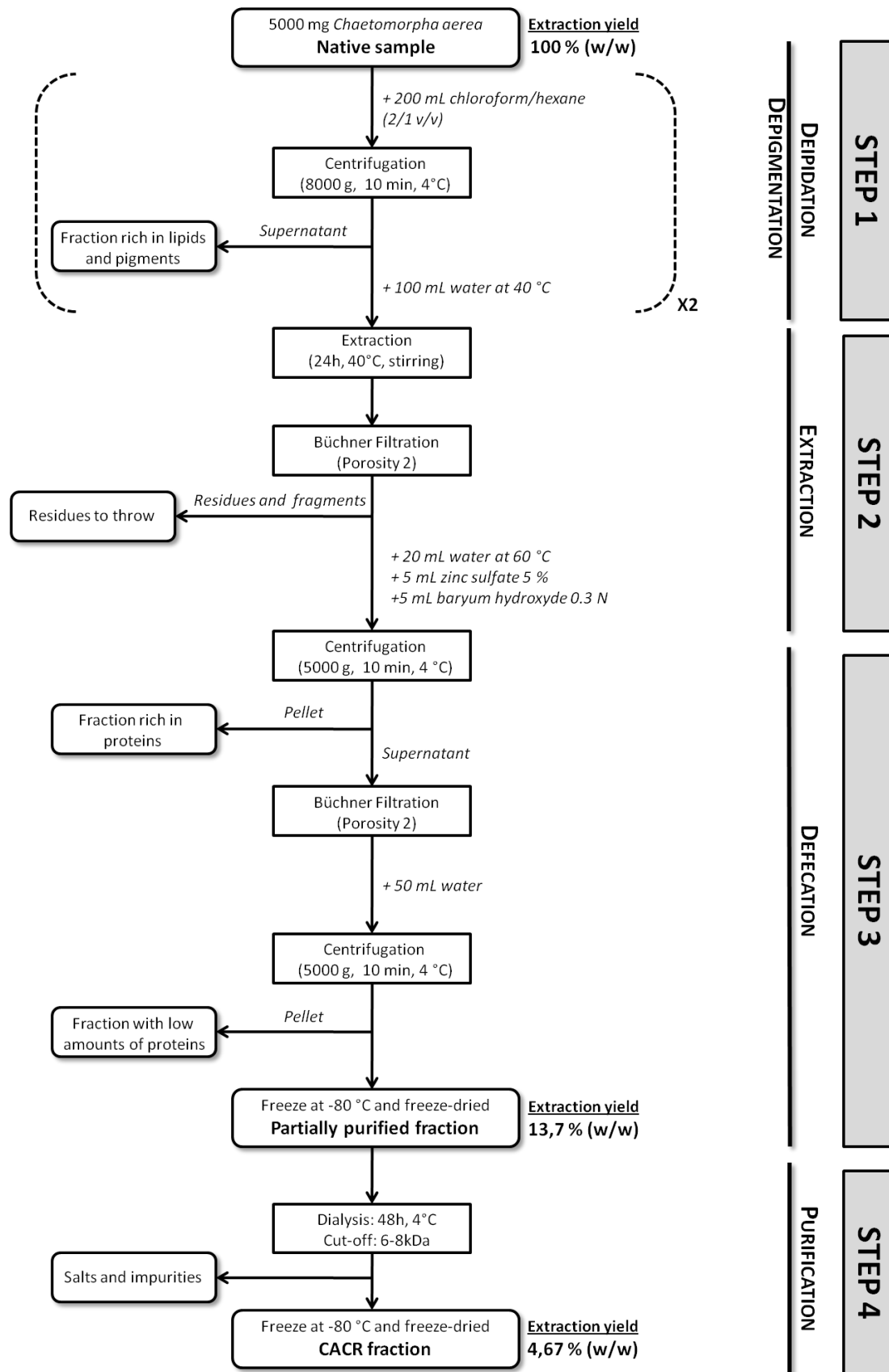
420

421

**FIGURE 1**

422

423

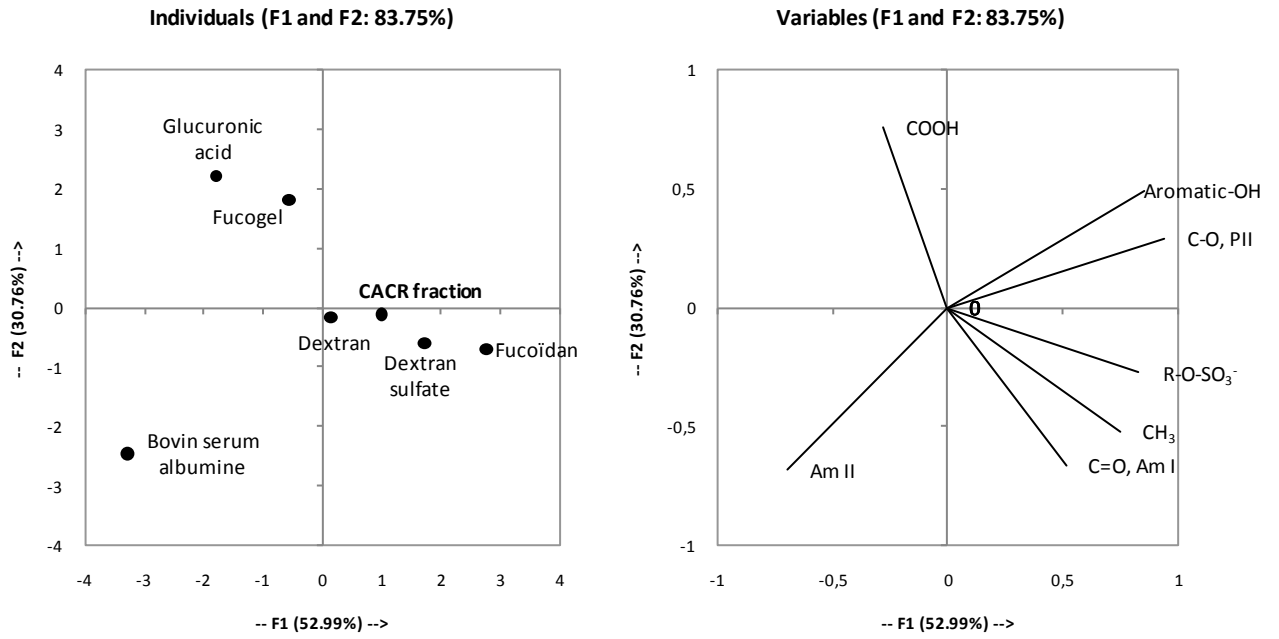


424

425

426

FIGURE 2



427

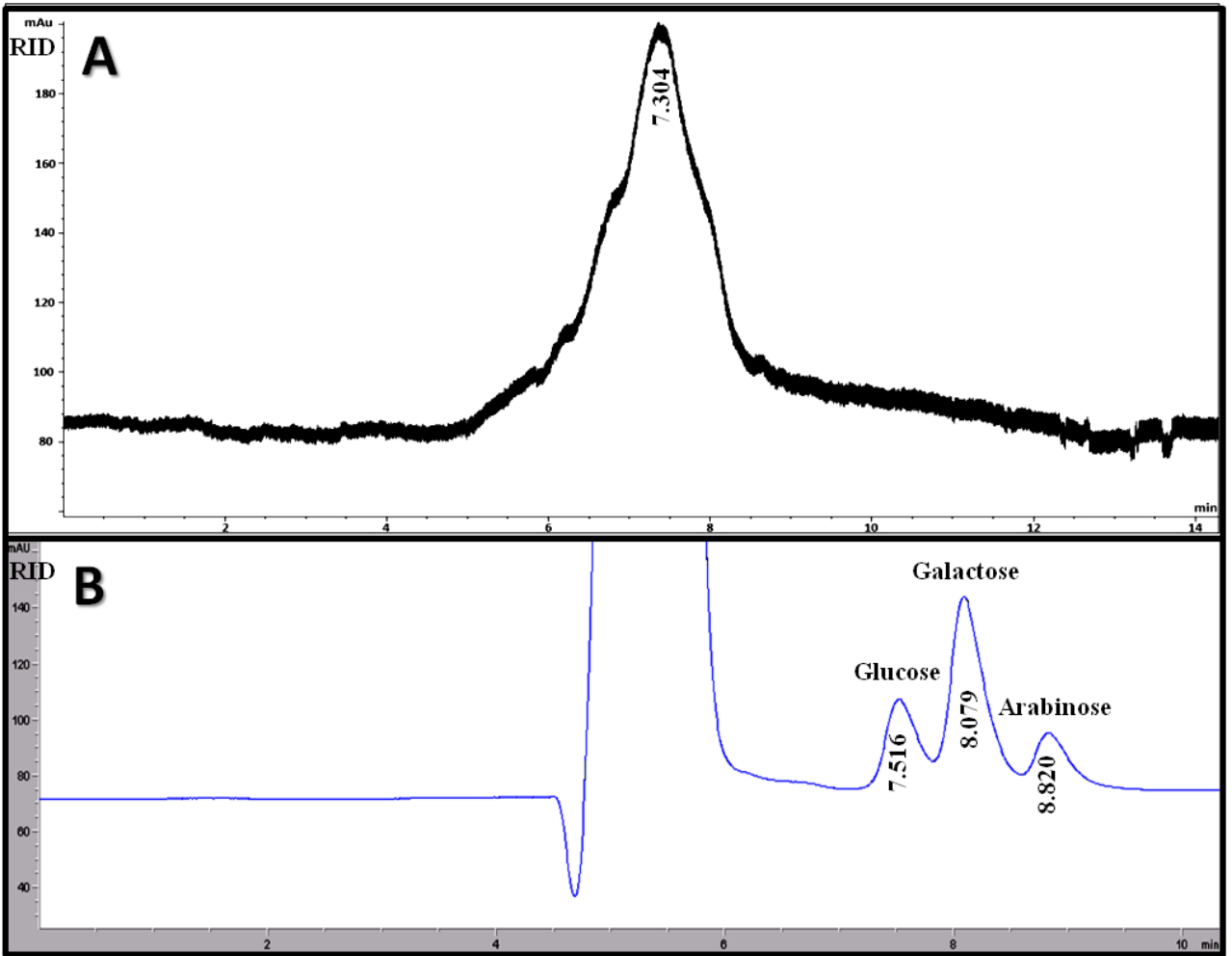
428

429

430

431

**FIGURE 3**



432

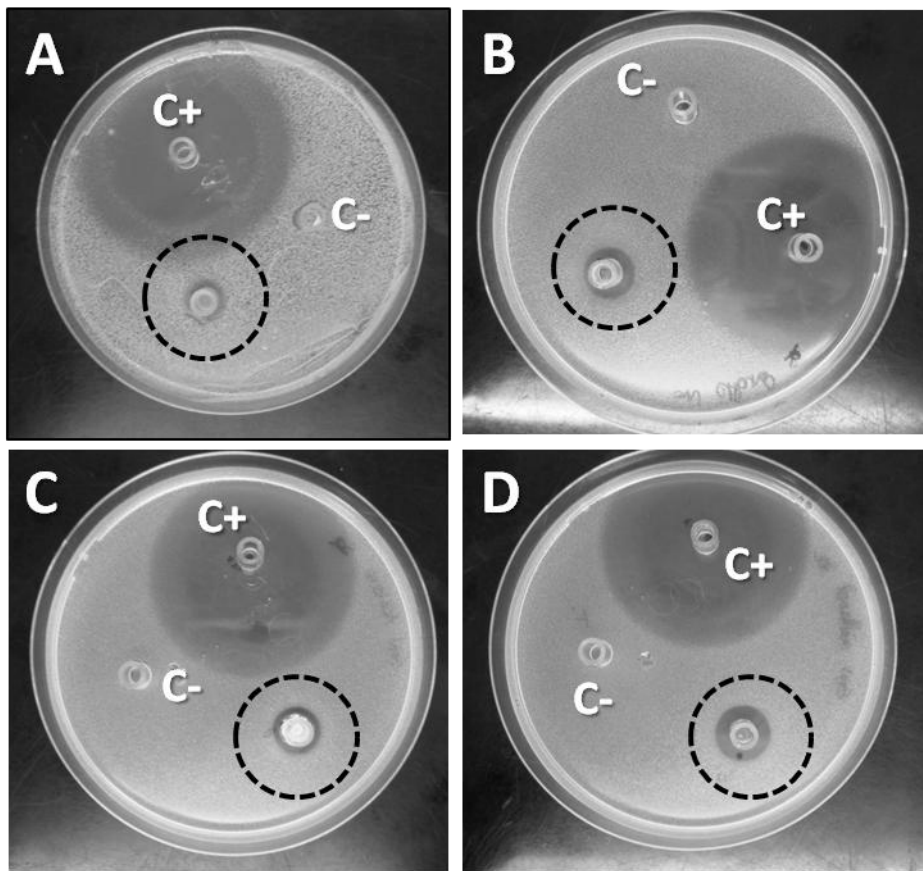
433

434

435

436

FIGURE 4



438

439

440

441

442

FIGURE 5