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Polysaccharides from by-products of the Wonderful and Laffan pomegranate varieties: New insight into extraction and characterization

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Abstract: The main crude polysaccharides (CPS), extracted from two widely cultivated pomegranate varieties, Laffan and Wonderful, were studied and characterized. We obtained the highest CPS extraction yield (approximately 10% w/w on dried matter) by 1 h of decoction (ratio 1/40 w/v). The predominant polymers (75-80%) of the CPS samples shown a hydrodynamic volume close to 2000 kDa by size exclusion chromatography and the exocarp and mesocarp profiles were very similar. The proton spectra (¹H-NMR), according to sugar composition and gelling ability, confirmed the main polysaccharide fractions were pectin with different acylation and methylation degree. The CPS from Laffan and Wonderful mesocarp showed prebiotic properties in vitro with Lactobacillus and Bifidobacterium strains. The composition of the decoction (12 % ellagitannins and 10 % of CPS) obtained by a green extraction process of pomegranate by-products, makes it a suitable component of functional food formulations.

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1 **Polysaccharides from By-products of the Wonderful and Laffan Pomegranate Varieties: New**
2 **Insight into extraction and characterization.**

3

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24 **Abstract**

25 The main crude polysaccharides (CPS), extracted from two widely cultivated pomegranate
26 varieties, Laffan and Wonderful, were studied and characterized. We obtained the highest CPS
27 extraction yield (approximately 10% w/w on dried matter) by 1 h of decoction (ratio 1/40 w/v).
28 The predominant polymers (75-80%) of the CPS samples shown a hydrodynamic volume close to
29 2000 kDa by size exclusion chromatography and the exocarp and mesocarp profiles were very
30 similar. The proton spectra (¹H-NMR), according to sugar composition and gelling ability,
31 confirmed the main polysaccharide fractions were pectin with different acylation and methylation
32 degree. The CPS from Laffan and Wonderful mesocarp showed prebiotic properties *in vitro* with
33 *Lactobacillus* and *Bifidobacterium* strains. The composition of the decoction (12 % ellagitannins
34 and 10 % of CPS) obtained by a green extraction process of pomegranate by-products, makes it a
35 suitable component of functional food formulations.

36

37 **Keywords:** mesocarp, prebiotic activity, pectin, size exclusion chromatography, ¹H-NMR

38

39 1. Introduction

40 The *Punica granatum* L. (Punicaceae) fruit has been extensively used in the folk medicine of
41 many cultures (Viuda-Martos, Fernández-Lóaez, & Pérez-álvarez, 2010), exhibiting a wide range of
42 potential clinical applications (Viuda-Martos et al., 2010) including antitumor properties (Joseph,
43 Aravind, George, Varghese, & Sreelekha, 2013; Joseph, Aravind, Varghese, Mini, & Sreelekha,
44 2012; Li, Zhang, & Wang, 2014). Up until now, research indicated that the ellagitannins are the
45 principal bioactive constituents of the different extracts obtained from pomegranate fruit. However,
46 there are few studies regarding the extraction and characterization of the polysaccharide fractions
47 recovered from the different parts of the fruit.

48 To date, natural polysaccharides have been proven to exert antioxidant, antitumor,
49 immunomodulatory, antimicrobial, antiulcer and hypoglycemic activities (Leung, Liu, Koon, &
50 Fung, 2006; Negi, Jayaprakasha, & Jena, 2003; Schepetkin & Quinn, 2006). A polysaccharide
51 extracted from pomegranate peel has shown significant antioxidant, antiglycation and tyrosinase
52 inhibition properties (Rout & Banerjee, 2007). A more recent paper showed that a galactomannan
53 recovered from the fruit rind of *P. granatum*, exerted *in vitro* immunomodulatory and free radical
54 scavenging activities (Joseph et al., 2012), as well as anticancer activity in mice by reducing the
55 tumor either alone or in combination with doxorubicin (Joseph et al., 2013). One of these studies
56 provided evidence of the non-toxic nature of this plant-derived compound, which was also proposed
57 as an adjuvant or as a single agent for the treatment of cancer (Joseph et al., 2013). Polysaccharides
58 from pomegranate peel have also been reported as able to inhibit the proliferation of U-2 human
59 osteosarcoma cancer cells by inducing apoptosis mainly through a mitochondrial signalling
60 pathway (Li et al., 2014).

61 At the same time, it is known that polysaccharides are an important part of soluble fermentable
62 dietary fiber. They can exhibit prebiotic activity by stimulating the growth of beneficial bacteria in
63 the colon, thereby contributing to the healthy status of the gut (Di Gioia et al., 2014a; Marotti et al.,

64 2012). A balanced gut microbial composition confers benefits to the host, due to the modulation of
65 metabolic and immune functions, while microbial imbalances are associated with metabolic
66 disorders and/or diseases (Di Gioia, Aloisio, Mazzola, & Biavati 2014b; Tremaroli & Bäckhed,
67 2012). Therefore, the maintenance of a correct equilibrium between beneficial microorganisms,
68 mainly belonging to the *Bifidobacterium* and *Lactobacillus* genera, and potentially pathogenic
69 strains, is crucial for host health.

70 The interest in food processing by-products has increased recently. In particular, waste by-
71 products from pomegranate juice production are being considered for the recovery of bioactive
72 compounds, primarily ellagitannins (Akhtar, Ismail, Fraternali, & Sestili, 2015; Goula & Lazarides,
73 2015), while polysaccharides have not yet been considered. In literature, it is frequently used to
74 indicate the exocarp (the real peel) and mesocarp together, without making a real distinction
75 between these two parts of the fruit (Viuda-Martos et al., 2010). The main by-products of juice
76 production, the mesocarp (40-50 % of the whole fruit) and exocarp, have not been investigated
77 singularly as potential sources of bioactive polysaccharides, and no data are available on the
78 possible prebiotic properties of these polymers recovered from pomegranate. To the best of our
79 knowledge, none of the studies on pomegranate polysaccharides have taken into account the
80 Wonderful and Laffan varieties, the objects of our investigation.

81 The aim of this research was to study the polysaccharides from the by-products of Laffan and
82 Wonderful, generated in large amount from these two widely diffused pomegranate varieties. Water
83 extraction processes were applied to efficiently recover the polysaccharides separately from the
84 mesocarp and exocarp. Size exclusion chromatography, chemical hydrolysis and proton nuclear
85 magnetic resonance (¹H-NMR) were used to analyze the characteristics of the principal
86 polysaccharides. For the first time, the prebiotic properties of crude polysaccharides (CPS) from the
87 Wonderful mesocarp were assessed by *in vitro* by testing them on *Bifidobacterium* and
88 *Lactobacillus* strains. The dry decoction is proposed as source of polysaccharides and ellagitannins.

89

90 **2. Materials and methods**

91 *2.1 Materials*

92 The Laffan cultivar (sour-sweet) was harvested from Rif Idlib, Syria in October 2011; the
93 Wonderful cultivar was purchased from Ortofrutta Grosseto (Italy) in October 2013. About 7-10 kg
94 of fresh ripe fruits of both cultivars were used as the source of the exocarp and mesocarp for
95 extraction of polysaccharides.

96

97 *2.2 Extraction process for recovery of CPS*

98 The exocarp and mesocarp were manually separated from fresh pomegranate fruits, then cut
99 into small pieces and freeze-dried. Both parts were powdered in a grinder and extracted with
100 distilled water as summarized in Table 1. The term dried matter in the text refers to the dry weight
101 of the mesocarp and exocarp. Each solution, recovered after centrifugation (3900 g for 12 min at
102 5°C) according to the methods listed in Table 1, was supplemented with 2 volumes of ethanol and
103 kept for 3 h at 0°C to induce the precipitation of polysaccharides, which were recovered after a new
104 centrifugation, again at 3900 g for 12 min at 5°C. The further addition of ethanol to the supernatants
105 did not induce the formation of new precipitate. The recovered polysaccharides were freeze-dried,
106 then re-dissolved in a minimum water volume and treated again with 2 volumes of ethanol. The
107 precipitate was then freeze-dried to obtain the crude polysaccharides (CPS) which were
108 successively treated to remove the proteins according to the method reported in Joseph et al.,
109 (2012). Briefly, CPS were dissolved in water and extracted with 3 volumes of chloroform. The
110 extraction was repeated several times until the water/chloroform inter-phase became clear. The
111 aqueous phase containing the purified polysaccharides was recovered and freeze-dried to obtain
112 CPSp as summarized in Table 3. CPSp were re-dissolved in water, and 500 µL of this solution were
113 transferred into an ultra-filter device with a cut-off of 10,000 Daltons (Amicon, Millipore, Billerica,

114 MA) and centrifuged at 11,000 g for 15 min. The precipitate was re-suspended in its original
115 volume by adding water; the process was repeated up to 7 times, (as indicated by the supplier), to
116 remove about 99% of possible fouling materials (polar low molecular weight molecules and salts)
117 from the sample. After these cleaning steps, the filter device was placed upside down in a clean
118 microcentrifuge tube for 2 minutes at 1,000 g; 500 μ L of distilled water were then added to dissolve
119 and recover the polysaccharides after filtration.

120

121 *2.3 1 H- NMR analysis*

122 The purified polysaccharides from the mesocarp of Wonderful (W-CPSp) and Laffan (L-CPSp)
123 were dialyzed for 48 h at 5°C in a nitrocellulose membrane with a 12-14 kDalton cut-off (Medicell
124 International Ltd, London), and then freeze-dried. The dried samples were dissolved in 1 mL of
125 D₂O and maleic acid was added as internal standard as follows: 6.1 mg W-CPSp and 1.1 mg of
126 maleic acid, 6.3 mg L-CPSp and 1.3 mg of maleic acid, purity grade 98% (Merck, Germany). The
127 1 H-NMR experiments were carried out using a 400 MHz instrument Advance 400 (Bruker, Bremen,
128 Germany). The quantitative evaluation was done according to reference guidelines (Eurolabs,
129 2014), applying the same protocol previously used for other matrices (Khatib, Pieraccini, Innocenti,
130 Melani, & Mulinacci, 2016).

131

132 *2.4 Determination of monosaccharide composition*

133 The polysaccharides in Table 2 from Laffan and Wonderful mesocarp and exocarp were
134 hydrolyzed in acidic media (Erbing, Jansson, Widmalm, & Nimmich, 1995). Briefly, 1 mL of a 2 M
135 trifluoroacetic acid water solution was added to 5 mg CPSp, maintained at 120°C for 120 min.
136 Afterwards, samples were cooled on ice, and ultrafiltered at 3500 g for 20 min using 3,000 Daltons
137 cut-off centrifuge filter devices (Amicon Ultra-4, Millipore, Billerica, MA). The supernatant was
138 then dried by a rotavapor at 37 °C, and re-suspended in 1 mL MilliQ-grade water. This

139 evaporation/re-suspension process was repeated three times, with the aim of removing the
140 trifluoroacetic acid that could introduce bias into the analysis. The samples were washed twice with
141 MilliQ-grade water, re-dissolved in 1 mL deionized water and then analyzed by ion exchange
142 chromatography using a ICS-2500 ion chromatograph with an ED₅₀ pulsed amperometric detector, a
143 gold working electrode and a Carbopac PA1 250x4mm column, all from Dionex (Sunnyvale, CA,
144 USA). The eluents used were MilliQ-grade water (solution A), 0.185 M sodium hydroxide solution
145 (solution B), and 0.488 M sodium acetate solution (solution C). A gradient elution was used
146 consisting of a first stage (injection time up to the 7th min) with the eluent constituted by 84%
147 solution A, 15% solution B, and 1% solution C; a second stage (injection time from the 7th to 13th
148 min) with the eluents constituted by 50% solution B and 50% solution C; and a final stage (injection
149 time from the 13th to the 30th min) with the eluents consisting of 84% solution A, 15% solution B,
150 and 1% solution C. The flow rate was 1 mL min⁻¹. The monosaccharides were detected according to
151 the retention time of pure monosaccharides purchased from Sigma-Aldrich (Milan, Italy) after
152 specific spike injections of the pure monosaccharides; at least three standard injections were
153 repeated in order to obtain a mean retention time of each monosaccharide, and the variance never
154 exceeded 5%.

155

156 *2.5 Size Exclusion Chromatography*

157 The apparent molecular weight of the polysaccharides of the CPS samples was determined
158 according to a previously reported method (Chen et al., 2014; Colica, Li, Rossi, De Philippis, &
159 Liu, 2015), with some modifications. The samples listed in Table 3 were weighed and dissolved in
160 distilled water, at a concentration of roughly 0.14 mg mL⁻¹. The solution was analyzed using a
161 Varian ProStar HPLC chromatograph (Varian, USA) equipped with a 355 refractive index detector
162 and a Biosep s4000 column (Phenomenex, USA). The samples were analyzed with 30 min runs by
163 HPLC-grade water as eluent at 0.6 mL min⁻¹ flow rate. Blue dextrans (Sigma-Aldrich, USA) at

164 different molecular weights (approx. 2000 kDa, 1100 kDa, 410 kDa, 150 kDa and 50 kDa) were
165 used as standards for hydrodynamic volume calculation.

166

167 2.6 *In vitro* evaluation of the prebiotic activity of CPS

168 The ability of CPS to induce the growth of beneficial bacteria (prebiotic activity) was assayed
169 using two strains previously isolated from human feces: *Bifidobacterium breve* B632 (Aloisio et al.,
170 2012) and *Lactobacillus plantarum* L12. The latter was isolated from a healthy volunteer
171 (unpublished results) and taxonomic characterization was performed via 16S rDNA amplification
172 and sequencing (Gaggia et al., 2013), this strain is available at the Bologna University, Scardovi
173 Collection of Bifidobacteria. Both strains were stored in lyophilized form. When necessary, they
174 were re-vitalized in de Man Rogosa Sharpe (MRS) medium (Oxoid, Basingstone, UK)
175 supplemented with 0.05% cysteine and incubated in anaerobic conditions at 37°C for 24 h.
176 Anaerobic conditions were created in a capped jar using an anaerobic atmosphere generation system
177 (Anaerocult A, Merck, Darmstadt, Germany).

178 The MRS medium composition was modified to perform the growth experiment with the
179 pomegranate polysaccharides. The modified medium (m-MRS) did not contain the carbon source
180 (glucose), which was provided by the pomegranate polysaccharides, and had a halved amount of
181 potential growth substrate, such as peptone, yeast extract and meat extract compared to those
182 present in the original medium (peptone, 5 g L⁻¹; yeast extract, 2 g/L, meat extract, 5 g L⁻¹, where
183 the amounts are in m-MRS).

184 The prebiotic activity was evaluated using CPS at 0.5% (w/v) in m-MRS. A positive growth
185 control was performed using m-MRS with 0.5% glucose and a negative control in m-MRS with no
186 added carbon source. The medium containing CPS as the carbon source was prepared as follows:
187 the m-MRS ingredients were weighed in a flask, dissolved in water and the medium was autoclaved
188 at 120°C for 15 min. A 0.5% (w/v) fiber or glucose at the same concentration were added to the hot

189 medium, stirred, and sterilized again at 102°C for 10 min. This procedure allowed the fiber to
190 dissolve in the medium and, at the same time, to prevent risk of growth of **undesirable**
191 microorganisms. The *B. breve* B632 and *L. plantarum* M12 strains were grown overnight in the
192 respective media, centrifuged, washed in phosphate buffered saline (PBS) and re-suspended in PBS
193 to obtain a solution having an absorbance of 0.7 at 600 nm. This suspension was used to inoculate at
194 2% (v/v) the flasks containing the m-MRS medium plus the fiber, the m-MRS medium plus glucose
195 (positive control) and the m-MRS medium with no additional carbon source (negative control). The
196 flasks were incubated at 37°C in anaerobic conditions for 48 h and a 1 mL culture was sampled
197 from each flask for viable bacterial counts at pre-established times (0, 6, 24, 30 and 48 h of
198 incubation). The sampled amount was mixed with 9 mL of PBS, serially diluted in the same
199 solution and plated on agarized MRS supplemented with cysteine. Following incubation of the
200 plates at 37°C in anaerobic conditions for 24 h, the number of colonies, corresponding to the
201 number of viable cells, was counted. The number of cells expressed as CFU mL⁻¹ were transformed
202 into Log₁₀ value (Log CFU mL⁻¹).

203

204 *2.7 Proximate composition and dietary fiber analyses*

205 The proximate composition was determined for the decoction from mesocarp of the Wonderful
206 variety. Protein content (PC) was evaluated using the Kjeldhal method: $PC (g/100g) = N * 6.25$,
207 where N is total nitrogen. The total fat content was determined by Soxhlet extraction, and
208 gravimetrically determined according to ISS protocol (1996/34). Ash content was evaluated by
209 gravimetric assay, according to ISS protocol, (1996/34 method b). Dietary fibers (both soluble and
210 insoluble) were quantified according to AOAC method 991.43 (Determination of soluble, insoluble
211 and total dietary fiber in foods and food products, final approval 1991).

212

213 *2.8 Statistical analysis*

214 All data in Figure 1, Tables 1 and 3, are presented as mean±SD from triplicate measurements of
215 each measuring point. Statistical significance for evaluating the prebiotic properties of CPS from
216 the mesocarp of Laffan and Wonderful cultivars was calculated within each evaluation time (T6,
217 T24, T30, T48) with a t-test, using the MEANS procedure (SAS).

218

219 **3. Results and Discussion**

220 *3.1 Recovery of polysaccharides: preliminary evaluation on Laffan*

221 The decision to study the by-products from Laffan and Wonderful pomegranate varieties, was
222 mainly determined by the high amount produced because the diffusion of the two varieties. The
223 Laffan pomegranate is widely present in Syria but also in Southern Turkey and Israel, while the
224 Wonderful is one of the principal variety cultivated in the Western world. Although a valorisation of
225 the by-products derived from juice production, requires better knowledge of their composition, so
226 far little attention has been addressed to polysaccharides from pomegranates, and the fruits are
227 mainly known for their juice rich in anthocyanins and ellagitannins. Water extraction (sometimes
228 coupled with increased temperature), and subsequent precipitation by adding ethanol, is the most
229 commonly utilized method for recovering polysaccharides from different sources (Huie & Di, 2004;
230 Joseph et al., 2012; Zhu & Liu, 2013). We used a similar procedure on the mesocarp and exocarp
231 separately, to evaluate the polysaccharide content of Wonderful and Laffan. First of all, to select the
232 most efficient extractive procedure, we used the Laffan mesocarp as reference material.

233 To increase the extractive yields, (Table 1), different extraction times, extraction temperatures
234 and dried matter/water ratios, were evaluated. Firstly, 30 and 60 min were set, applying a single or
235 two successive extraction steps, and varying the extractive ratio from 1:15 w/v to 1:40 w/v. The
236 extraction was firstly performed at 25±2 °C as previously proposed for pomegranate (Rout &
237 Banerjee, 2007). A second approach was to pre-treat the dried material with a hydroalcoholic
238 solution to remove the ellagitannins, and then extract the polysaccharides by hot water.

239 To remove part of the impurities co-precipitated after the first ethanol addition, the
240 polysaccharides were re-dissolved in water and precipitated again, adding ethanol to get the CPS
241 listed in Table 1. To verify if this latter step was effective in cleaning the polysaccharides, we
242 evaluated the amount of the impurities by weighing the dried supernatant recovered after the second
243 ethanol addition. The impurities were 5.4% and 7.4% of dried mesocarp for Wonderful and Laffan,
244 respectively, and close to 3% of the dried exocarp for both varieties. These results indicate that the
245 second addition of ethanol was necessary to obtain a cleaner polysaccharide fraction (CPS).
246 As shown in Table 1, the yield in CPS increased from 5% to 8% with a longer extraction time (from
247 30 to 60 min) by applying the same extractive ratio (1:15 w/v). The yield further increased up to
248 10% by applying a single extraction of 60 min and a higher extractive ratio (1/40 w/v). A successive
249 extractive step of 60 min, as well as previous contact of the dried material with water before the
250 decoction, did not increase the recovery of CPS.

251 Overall, the best result in terms of yield and reproducibility, was obtained with a single
252 decoction of 60 min and an extractive ratio of 1/40 p/v (Table 1). Similar recoveries of
253 polysaccharides (10-13%) were reported by Zhu et al., for a pomegranate purchased from a local
254 Chinese market and extracted by hot water (Zhu and Liu, 2013). The same authors have
255 successively proposed an ultrasound-assisted hot water extraction, but obtained similar yields (Zhu,
256 Zhai, Li, Wu, & Li, 2015). In both these studies, and as frequently reported in literature, the authors
257 cited the pomegranate peel but did not specify if the raw material was comprised only of the
258 exocarp or of the mesocarp plus exocarp. Lastly, and in agreement with a previous report (Rout &
259 Banerjee, 2007), we confirmed that extraction with water at a temperature close to 25°C, even when
260 applying long extraction times, gave considerably lower CPS yields (Table 1).

261 Since there are about 12% of ellagitannins in the decoction of Laffan mesocarp (Khatib, 2015),
262 a pretreatment with ethanol 70% v/v was also tested to remove these polar compounds before
263 precipitation of the CPS. Even if the CPS yields are lower than those obtained without applying this

264 treatment, this latter approach can be useful when the objective is to efficiently recover the
265 ellagitannins before precipitation of polysaccharides (Table 1).

266

267 *3.2 CPS recovered from the two cultivars*

268 After the pre-screening carried out only on the Laffan mesocarp, only the more efficient
269 methods were selected to extract the CPS from the Laffan and Wonderful exocarp and mesocarp
270 (Table 2). Overall, by applying the same extractive method, we obtained similar results from the
271 exocarp and mesocarp of the two varieties. Again, a one-step decoction gave the highest % yields,
272 and the hot water is determinant for maximizing the extractability of CPS because it increases
273 polysaccharide solubility. On the other hand, the extraction carried out at room temperature, was
274 confirmed as the worst. Despite the low yields, this latter method was tested again to verify the
275 effect of temperature on the characteristics of CPS. To this aim, we analyzed the recovered
276 polysaccharides by size exclusion chromatography and compared their profiles with those from
277 CPS obtained by the hot extraction. As shown in Table 2, CPS were mainly located in the mesocarp,
278 with lower values in the exocarp (4.5-4.7%) for both varieties. There was some variability in the
279 method with the CPS amount recovered from exocarp having higher standard deviation values,
280 from 11% to 25%. This finding is attributable to the non-homogeneous thickness of the removed
281 exocarp, still containing residual parts of mesocarp, which is hard to completely remove. Lastly, the
282 decoction of the exocarp, carried out after a previous extraction with ethanol/water (7:3v/v),
283 provided CPS amounts close to 4% and similar to those derived without using the hydroalcoholic
284 solution pre-treatment.

285 It must be emphasized that boiling is a suitable method not only for polysaccharides but also
286 for co-extraction of the ellagitannins in amounts close to 120 mg/g dried decoction (Khatib, 2015).
287 Furthermore, the drying process of the decoction did not require the addition of excipients such as
288 the maltodextrins, commonly used to reduce the final hygroscopicity of the dried herbal extract.

289 This advantage, not frequently observed during the management of herbal products, can be
290 attributable to the presence of CPS in a relatively high amounts.

291 Due to the difficulty of procuring enough fresh Laffan pomegranate during the civil war in
292 Syria, we only determined the nutritional composition of the Wonderful mesocarp decoction. In
293 summary, the total dietary fiber determined by the AOAC.993.41 method was 9.66 % comparable to
294 the CPS content. Moreover, the main fraction was soluble fiber, (6.67 %) fermentable by human
295 microbiota. There was 2.3 % of total proteins and 5.6 % ash, indicating an appreciable amount of
296 minerals.

297

298 *3.3 Sugar composition by hydrolysis*

299 To verify the purity grade of polysaccharides in terms of the co-presence of oligosaccharides
300 and inorganic salts, the efficiency of the ultrafiltration devices was tested on CPSp from the
301 mesocarp of the two varieties (Table 2). The hydrolysis of CPSp samples before and after the cut-
302 off filtration provided the same results in terms of molar percentage of monosaccharides suggesting
303 that the samples listed in Table 2 did not need further purification by this filter device.

304 The CPSp samples listed in Table 3 were treated with TFA acid to hydrolyze the polysaccharide
305 strands and subsequently determine sugar composition by ionic exchange chromatography,
306 according to a previous method (Erbing et al., 1995). The CPSp samples from both the mesocarp
307 and exocarp showed a very similar composition for both the varieties (Table 3). Hexoses galactose
308 and glucose, deoxysugar rhamnose, and galacturonic acid, were the most abundant monomers,
309 while the main aldopentoses were xylose and arabinose. From our findings it emerges that these two
310 varieties, Laffan from Syria and Wonderful widely diffused throughout the western world, have a
311 very similar compositional profile in terms of polysaccharides. This result is not completely
312 unexpected, and in agreement with a previous work in which it was hypothesized that the
313 Wonderful is derived from the more antique Laffan variety (Goor, 1967).

314 Overall, other reports on pomegranate by-products did not include the varieties selected in this
315 study. In regard to polysaccharides, the literature indicates there is a wide variability in terms of
316 sugar composition depending on the variety, growth site and purity grade of the polysaccharide
317 itself (Normakhtov, Rakhmanberdyeva, & Rakhimov, 1999; Jahfar, Vijayan, & Azadi, 2003) .

318 *3.4 Characterization of the polysaccharide fractions*

319 The CPSs from the mesocarp and exocarp of the two cultivars were analyzed by size exclusion
320 chromatography to determine their apparent molecular weight. Since these polymers may be
321 characterized by a branched structure, often related to the presence of arabinose, galactose and
322 xylose, their size was calculated in terms of hydrodynamic volume, and not in terms of actual
323 molecular weight. The CPS samples were compared to dextrans standards, considering that a 2000
324 kDa fraction has the same hydrodynamic volume as dextran at 2000 kDa molecular weight. The
325 analyzed fractions throughout the text are identified as molecular weight, although with
326 approximation.

327 The data in Figure 1 highlighted that CPS of Laffan and Wonderful mesocarp and exocarp,
328 were of similar molecular weight, since no significant differences were found; all the CPS were
329 characterized by a predominant fraction of about 2000 kDa, accounting for 75.4% of the total. The
330 remaining 24.6% was represented by five minor fractions, the most common being: i) a fraction
331 having a molecular weight between 410 kDa, and 150 kDa (7.4% of total CPS); ii) a fraction having
332 a molecular weight lower than 50 kDa, accounting for 8.9% of total CPS. As expected, more
333 variability was observed for the fractions having small molecular weights (much lower than 50
334 kDa).

335 Few reports are available to date on polysaccharide structure from pomegranate fruit. A first
336 report described a glucofructan extracted from the peel, having 31 kDa molecular weight, that was
337 separated using Sephadex G100 column (Jahfar, et. al., 2003). Sun described a polysaccharide
338 extracted from the rind of a non-specified variety, having a molecular weight of 110 kDa

339 determined by gel filtration on a Sephadex G200 column and dextrans at different molecular
340 weights as reference standards (Sun, Li, Yan, & Liu, 2010). More recently, a glucomannan was
341 extracted from the rind of a ripe pomegranate fruit and the authors indicated a molecular weight of
342 110 kDa (Joseph et al., 2012). None of these studies specified which cultivar or variety was
343 investigated.

344 The present work shows the molecular weight distribution of pomegranate polysaccharides
345 obtained from the Laffan and Wonderful cultivars by using size exclusion chromatography for the
346 first time. We demonstrated that the CPS samples have similar apparent molecular weight
347 distribution with overlapping profiles of the two cultivars and the two parts of the fruit. We also
348 verified that hot extraction (100°C, 1 h) did not modify the CPS composition as demonstrated by
349 the complete overlap of size exclusion chromatography profiles obtained after extraction with cold
350 water and boiling water (Table 2).

351 Recently, some authors (Moorthy, Maran, Surya, Naganyashree, & Shivamathi, 2015; Pereira et
352 al., 2016) observed the presence of pectin in pomegranate fruit but no spectral data, particularly ¹H-
353 NMR spectra, are reported or discussed. Taking into account these data, we searched for the
354 presence of pectin by analysing of the proton spectra of CPSp from Laffan and Wonderful mesocarp
355 (Figure 2). According to the literature (Bédouet, Courtois, & Courtois, 2003), specific signals
356 indicate the presence of O-methyl and O-acetyl groups typical of pectin and their intensity can be
357 associated with the degree of methylation and acetylation. As shown in Figure 2, the two spectra
358 obtained dissolving comparable amounts of CPSp from the two varieties, clearly revealed signals
359 attributable to O-acetyl groups in the region (of δ 1.98-2.15) and an intense signal ascribable to a
360 singlet of O-methyl groups close to δ 3.7. Both these data and the high percentage of galacturonic
361 acid after the acidic hydrolysis (Table 3), confirm the presence of pectin in Laffan and Wonderful.
362 The singlet at δ 6.31 is due to maleic acid, that added as internal standard permits a preliminary
363 comparison of the degree of methylation and acylation in CPSp from the two varieties. In other

364 words, the addition of an accurately weighed internal standard can be usefully applied for
365 quantitative purposes. Particularly, the higher intensity observed for the signal at δ 2.15 in the
366 Wonderful spectrum, indicates a higher degree of acylation compared to that of Laffan. The
367 opposite behavior is observed for the signal at δ 1.98 ppm that was more intense in Laffan sample.
368 Analogously, a different degree of methylation is indicated by the signal at δ 3.73, ascribable to a
369 singlet of O-methyl groups (Cui, 2005) at higher intensity in the Laffan sample. Finally, the
370 presence of less intense signals close to δ 1.1 is in agreement with the presence of low amounts of
371 rhamnose units according to hydrolysis results (Table 3). Overall, this rapid measurement, obtained
372 without the need of high magnetic field spectrometer, was able to point out structural differences
373 between W-CPSp and L-CPSp, not highlighted by the size exclusion chromatography technique,
374 showing the same profile for these samples.

375 Although further studies are needed to elucidate the structure of these polysaccharides, the ^1H -
376 NMR spectra and the sugar composition derived by acidic hydrolysis suggest that the main
377 polysaccharides of pomegranate mesocarp are pectin with different degree of methylation and
378 acetylation. This applied hydrolysis method was recently confirmed as being suitable to guarantee a
379 complete hydrolysis of pectin (Wikiera, Mika, Starzyńska-Janiszewska, & Stodolak, 2015).

380 We also carried out preliminary tests to evaluate the water-absorption ability of some dried
381 polysaccharide fractions: LM-CPS, WM-CPS and WE-CPS. The adsorbed water ranged from 98.6
382 to 99.1% of the dried material. Adsorption was rapid and the final samples appeared as clumps with
383 a gel consistency, exhibiting the well-known pectin behaviour.

384

385 *3.5 In vitro evaluation of prebiotic properties*

386 The decoction from mesocarp, was used to recover the CPS for *in vitro* tests of prebiotic
387 properties. **We investigated the** ability of *B. breve* B632 and *L. plantarum* L12 strains to use crude
388 polysaccharides from pomegranate exocarp and mesocarp as their carbon source and compared this

389 to their growth on glucose, *i.e.* an easily fermentable carbon source. Bifidobacteria and Lactobacilli
390 are able to compete for nutrients with enteric pathogens, to adhere strongly to the intestinal mucosa,
391 thus preventing pathogen adhesion, and to stimulate the development of the mucosal immune
392 system. Moreover, they are known to provide some protection against incoming enteric pathogens
393 in man (Jankowska, Laubitz, Antushevich, Zabielski, & Grzesiuk, 2008; Symonds et al., 2012).

394 Figure 3 shows that both strains grow well on CPS from Laffan and Wonderful mesocarp, being
395 significantly higher ($p < 0.01$) than the negative controls (*i.e.* with no added carbon source) and
396 comparable to that of an easily fermentable carbon source such as glucose added at the same
397 concentration. Growth on the Laffan variety at 24 h was only 0.6 and 0.1 Log CFU/mL lower than
398 that on glucose for *L. plantarum* L12 and *B. breve* B632, respectively. Growth on the Wonderful
399 variety at 24 h was 1.0 and 0.2 Log CFU/ml lower, respectively, than that on glucose for the same
400 strains. After the 24th h of incubation, both strains grown on glucose entered the steady phase,
401 whereas a small decrease in cell survival was observed with CPS as the carbon source. The results
402 shown in Figure 3 clearly indicate that CPS and/or the products of their degradation are not toxic
403 for the assayed strains and, on the contrary, are good growth substrates for them. Growth on the
404 medium with no added carbon source reached only a 1 Log CFU/mL increase at the 24th h
405 compared to the beginning of incubation, thus showing that the m-MRS medium used in the
406 experiments is a valid choice for performing prebiotic activity tests. Furthermore, if we might
407 propose the whole dried decoction for human consumption, due to its easy and rapid preparation,
408 the same is not true for the sub-fractions in Figure 1, whose preparation was longer and more
409 complex. Evaluation of the prebiotic activity of a single fraction from CPS was outside of the scope
410 of our research, but could be object of future investigations.

411 In agreement with our results, a high ability to ferment pectin by human gut microbiota
412 associated with an increase of almost 25 % of *Bifidobacterium* has been demonstrated *in vitro*
413 (Yang, Martinez, Walter, Keshavarzian, & Rose, 2013). Moreover, several studies in the literature
414 (as reviewed by Koropatkin, Cameron, & Martens, 2012) show that the degradation of complex

415 carbohydrates (glycans and polysaccharides) is a major symbiotic function carried out by
416 microorganisms that inhabit the human distal gut, which increases host nutrition by digesting
417 glycans that the host cannot degrade, providing the host with usable metabolic products such as
418 short-chain fatty acids. Therefore, glycans shape the composition of the gut microbiota. Members of
419 the Firmicutes and Actinobacteria phyla, to which *Lactobacillus* and *Bifidobacteria* spp. belong,
420 possess different glycan acquisition strategies that also involve glycan-degrading enzymes
421 (Mahowald et al., 2009).

422

423 4. Conclusions

424 This work improves the knowledge of the chemical and physical properties of polysaccharides
425 recovered from the typical wastes of the pomegranate fruit, and reveals future perspectives for
426 adding value to these food by-products, produced in large amount but currently discarded. The use
427 of hot water maximized solubility and extractability of the crude polysaccharides from the Laffan
428 and Wonderful varieties. The maximum recovery of polysaccharides was obtained from mesocarp,
429 by a single-step water decoction. At the same time, the boiling process did not modify the molecular
430 size distribution of the polysaccharides as demonstrated by their profiles in size exclusion
431 chromatography, comparable with those obtained by a cold-water extraction. For the first time, the
432 size exclusion chromatography was applied to evaluate the polysaccharides from mesocarp and
433 exocarp of Laffan and Wonderful. A very similar distribution of the apparent molecular weights of
434 the main polysaccharides was highlighted for the two varieties, with chromatographic profiles
435 characterized by a predominant polymer with a hydrodynamic volume close to 2000 kDa, and five
436 other minor fractions. The ¹H-NMR spectra, the sugar composition and the high gelling capacity of
437 some purified polysaccharide fractions of mesocarp, confirmed the presence of pectin as primary
438 component. The use of maleic acid as internal standard was proposed to evaluate the acylation and
439 methylation degree of the main purified polysaccharide fractions. Finally, the crude polysaccharides

440 from Laffan and Wonderful pomegranate mesocarp **showed** prebiotic properties *in vitro* by serving
441 as an excellent substrate for the growth of potentially probiotic bacteria such as *Lactobacillus* and
442 *Bifidobacterium* strains.

443 **We showed** that, after a simple decoction of these **pomegranate fruit** by-products, it **was**
444 possible to obtain a dry extract rich in polysaccharides with prebiotic activity, associated with a
445 pool of bioactive ellagitannins. This combination of natural compounds can help to **valorize these**
446 **by-products and to** enhance the use of pomegranate **dry** decoction in functional food formulations.

447

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565

566 **Figure Captions**

567 **Figure 1.** Apparent molecular weight distribution by size exclusion chromatography (abscissa) of
568 the CPSp samples from mesocarp and exocarp, data expressed as peak area % of total areas, as
569 mean from triplicate measurements. *W*, *Wonderful*; *L* *Laffan*.

570

571 **Figure 2.** ¹H-NMR spectra in 1mL of D₂O, at room temperature (23±2 °C) for: Laffan mesocarp -
572 CPSp (6.2 mg + 1.3 mg maleic) and Wonderful mesocarp-CPSp (6.05 mg + 1.12 mg maleic acid).
573 *O*-Acetyl, singlet of the acetyl groups; Gal A-OCH₃, singlet of the methoxyl group of galacturonic
574 acid units

575

576 **Figure 3.** Evaluation of prebiotic properties of CPS (5 % in m-MRS medium) from the mesocarp of
577 Laffan and Wonderful cultivars on (a) *L. planctarum* L12 and (b) *Bifidobacterium breve* B632.
578 *C*-: growth on m-MRS with no added carbon source; *C*+: growth on m-MRS with 0.5% glucose;
579 CFU, colony forming units

580

581 **Table 1.** Applied methods to recover CPS from Laffan mesocarp and corresponding extraction
582 yields (*mean values* as weight/dried matter); all the determinations were carried out in triplicate
583 except for of **1a** and **1b** methods that were in single.

584 § 24 hrs pretreatment with water before decoction; * 24 hrs pretreatment with 70% ethanol at 25°C.

585

586 **Table 2.** Polysaccharide content in the mesocarp and exocarp of Wonderful and Laffan varieties; the
587 values are a mean of triplicates. * 24 hrs pretreatment with 70% ethanol at 25°C

588

589 **Table 3:** Sugar composition by acidic hydrolysis , *W*, *Wonderful*; *L*, *Laffan*.

590

591

| Methods | DM (g)/ solvent (mL) | T (°C) | Time (min) | Yield (%) |
|-------------------------|-------------------------|--------|------------|-----------|
| 1a | 1/15 | 100 | 30 | 5 |
| 1b | 1/15 | 100 | 30+30 | 8 |
| *2a | 1/40 | 100 | 60 | 10 |
| *2b | 1/40 | 100 | 60+ 60 | 9.8 |
| *2c | 1/40 | 100 | 60+ 60 | 9.1 |
| *3a | 1/40 | 25 | 720 | 2.0 |
| *3b | 1/40 | 25 | 1440 | 3.3 |
| *4a | 1/25 | 100 | 60 | 7.8 |
| *^{\$}4b | 1/25 | 100 | 60 | 7.2 |

Table 1. Applied methods to recover CPS from Laffan mesocarp and corresponding extractive yields (*mean values* as w/w DM); *tests carried out in triplicate. \$, *pretreatment with ethanol 70% at 25 °C for 12 h before boiling.*

| Extractive methods | Samples | Yield (%) | Yield (%) |
|--------------------|-----------|-----------------|----------------|
| | | <i>mesocarp</i> | <i>exocarp</i> |
| 2a | Laffan | 9.80±0.28 | 4.47±0.50 |
| | Wonderful | 8.0±0.10 | 4.7±1.15 |
| 3b | Laffan | 3.7±0.42 | 1.93±0.23 |
| | Wonderful | 3.33±1.15 | 1.99±0.02 |
| 4a | Laffan | 7.80±0.28 | 4.20±0.20 |
| | Wonderful | 5.67±0.58 | 4.13±0.31 |
| 4b | Laffan | 7.15±0.21 | 3.93±0.12 |
| | Wonderful | 6.70±0.66 | 4.07±0.31 |

Table 2. Crude polysaccharides (CPs) content in mesocarp and exocarp of Wonderful and Laffan.

The values are a mean of triplicates and expressed as % on DM.

| Sugars | Molar % | | | |
|-------------------|---------|---------|---------|---------|
| | WM-CPSp | LM-CPSp | WE-CPSp | LE-CPSp |
| Rhamnose | 10.4 | 7.2 | 10.8 | 10.1 |
| Arabinose | 4.52 | 4.04 | 4.88 | 4.08 |
| Galactose | 5.91 | 7.31 | 7.34 | 7.05 |
| Glucose | 14 | 10.3 | 11.5 | 10.9 |
| Xylose | 11.2 | 7.87 | 9.36 | 9.3 |
| Fructose | 0.41 | 0.29 | 0.17 | 0.2 |
| Galacturonic acid | 53.8 | 63.1 | 56 | 58.4 |

Table 3: Sugar composition of different CPSp samples obtained by acidic hydrolysis

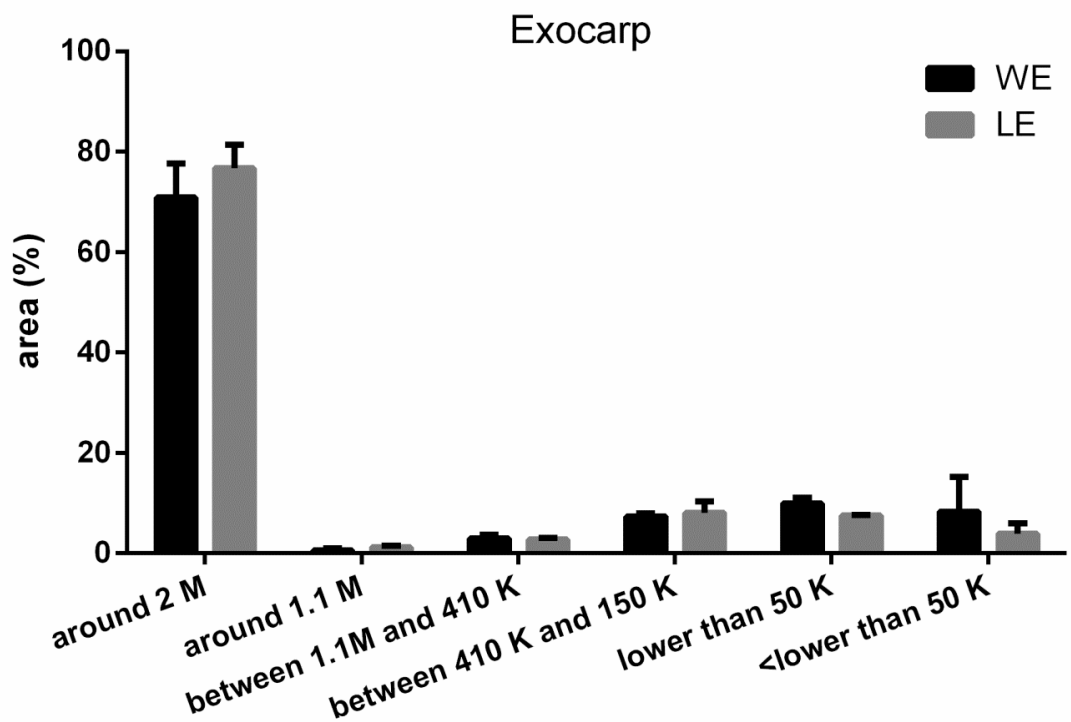
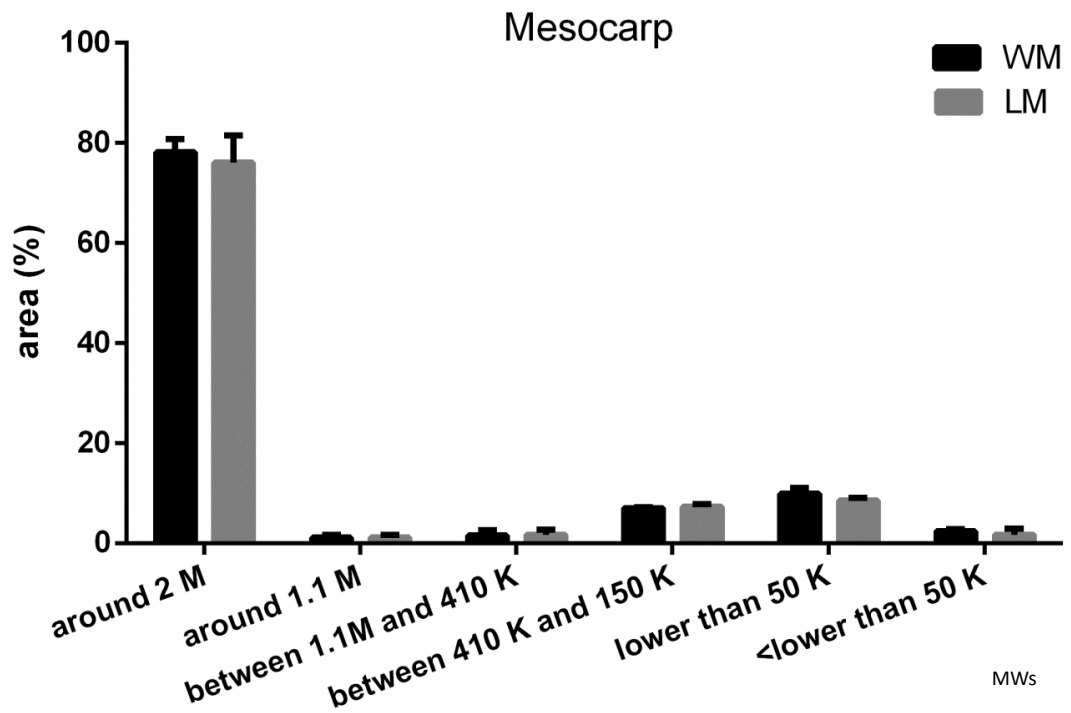


Figure 1.

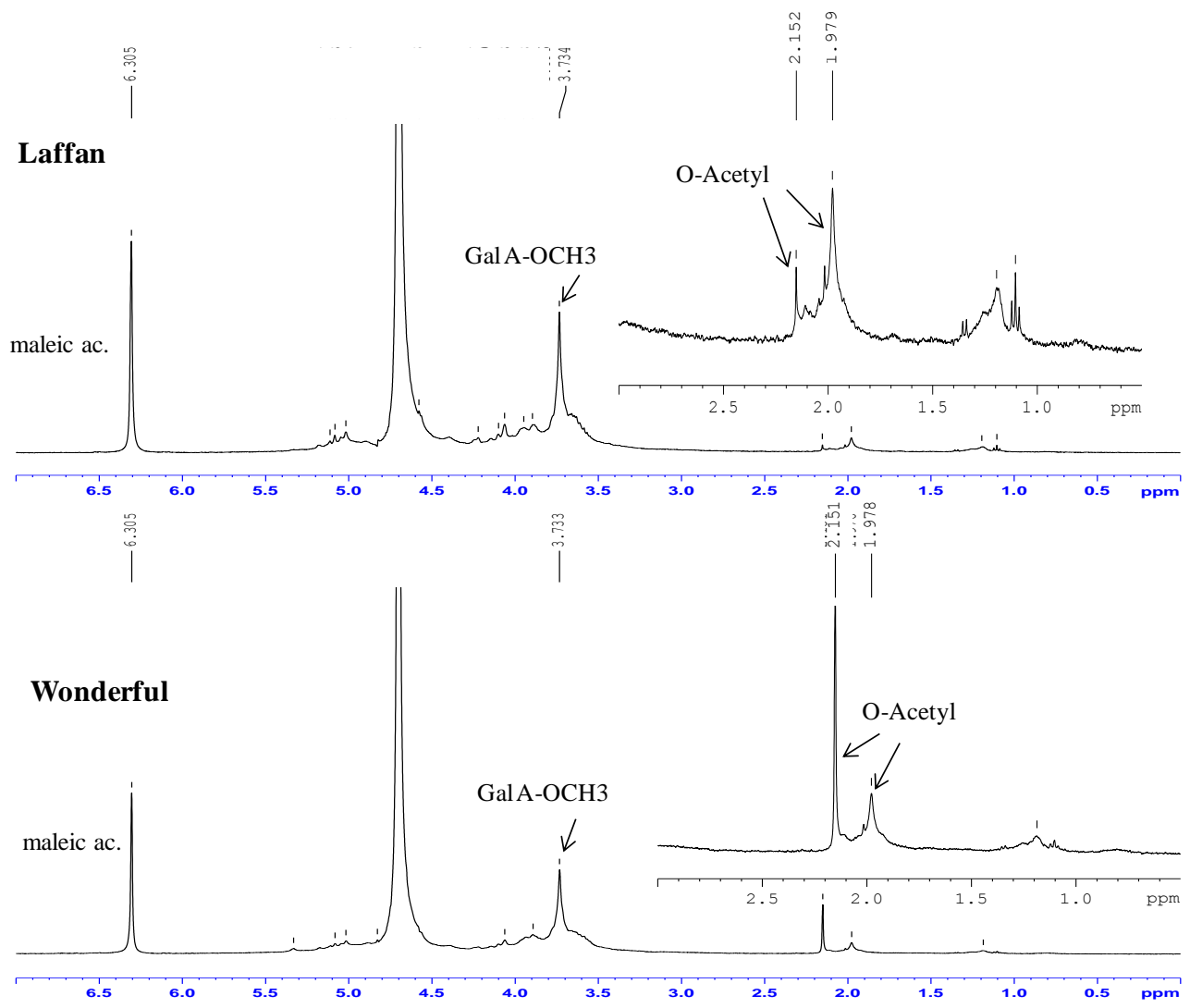


Figure 2

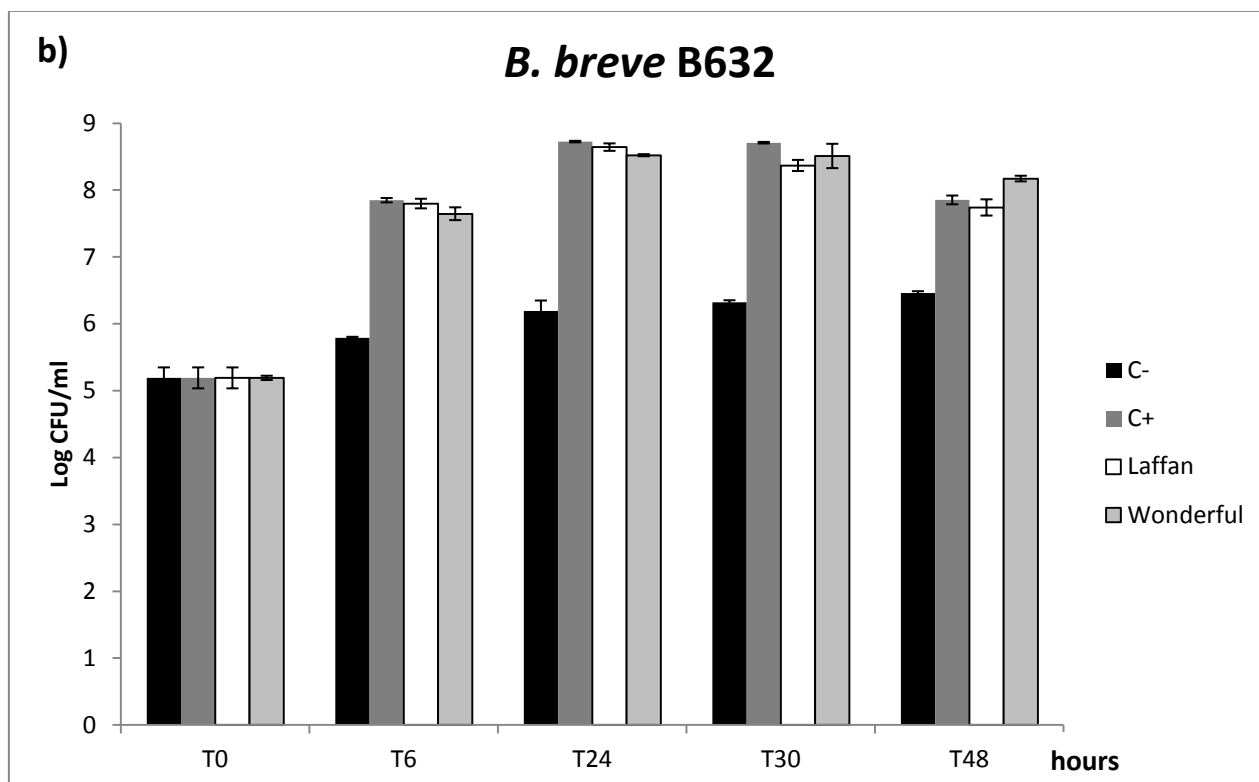
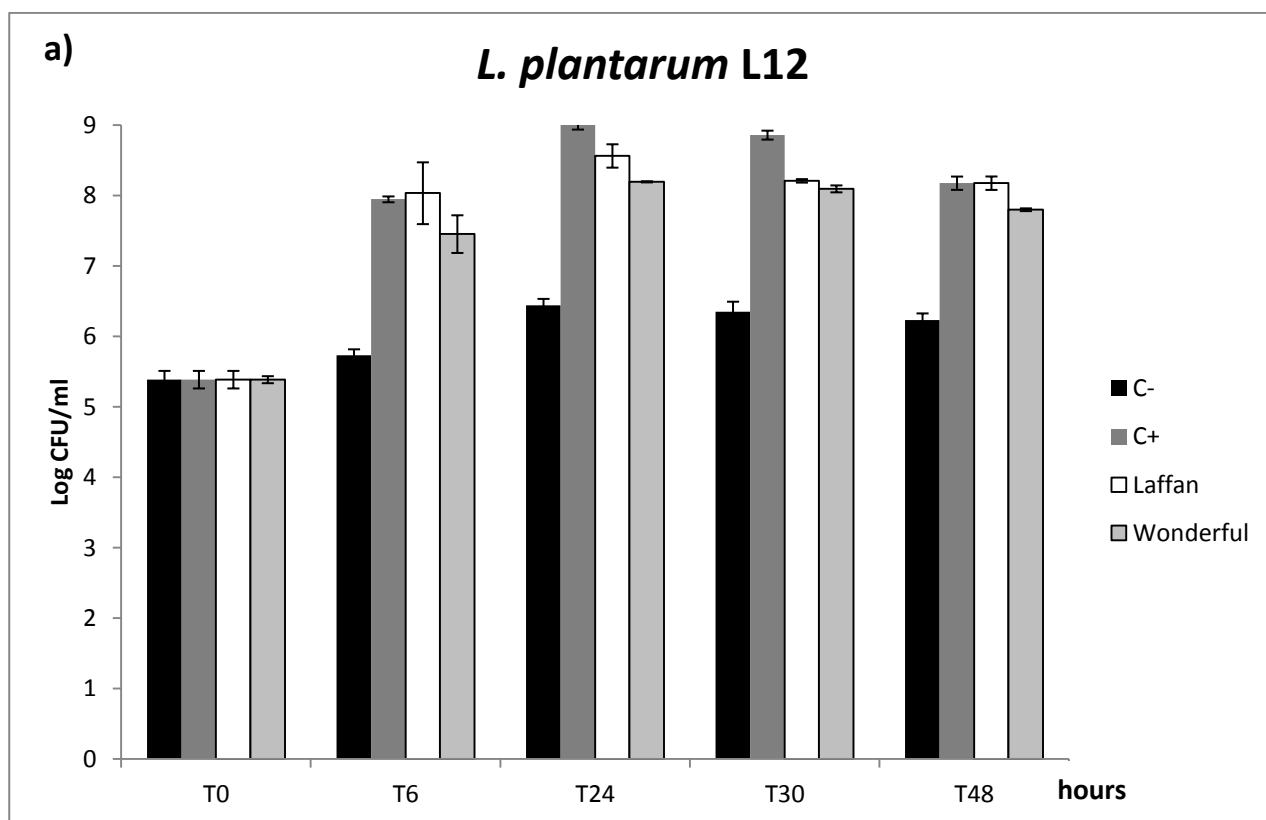


Figure 3