



Comparison of molecularly imprinted polymers (MIP) and sol-gel molecularly imprinted silica (MIS) for fungicide in a hydro alcoholic solution

Céline Lafarge, Manal Bitar, Leina El Hosry, Philippe Cayot, Elias Bou-Maroun

► To cite this version:

Céline Lafarge, Manal Bitar, Leina El Hosry, Philippe Cayot, Elias Bou-Maroun. Comparison of molecularly imprinted polymers (MIP) and sol-gel molecularly imprinted silica (MIS) for fungicide in a hydro alcoholic solution. *Materials Today Communications*, 2020, 24, pp.101157. 10.1016/j.mtcomm.2020.101157 . hal-02613429

HAL Id: hal-02613429

<https://institut-agro-dijon.hal.science/hal-02613429>

Submitted on 22 Aug 2022

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.



Distributed under a Creative Commons Attribution - NonCommercial 4.0 International License

1 **Comparison of molecularly imprinted polymers (MIP) and sol-gel**
2 **molecularly imprinted silica (MIS) for fungicide in a hydro alcoholic**
3 **solution.**

4 Céline Lafarge^a, Manal Bitar^b, Leina El Hosry^c, Philippe Cayot^a, Elias Bou-Maroun ^{a1}

5

6 ^a*AgroSup Dijon, Univ. Bourgogne Franche-Comté, UMR PAM A02.102, Procédés Alimentaires*
7 *et Microbiologiques, F-21000 Dijon, France*

8 ^b *Université Libanaise, Faculté des Sciences IV, Laboratoire Energétique et Réactivité à*
9 *l'Echelle Nanométrique (EREN), Haouch El-Omara, Zahlé, Liban*

10 ^c *Department of Nursing and Health Sciences, Notre Dame University - Louaize, zouk Mosbeh,*
11 *Lebanon*

12

13 **Abstract**

14 The aim of this work was (i) to design the best molecularly imprinted silica (MIS) specific for
15 iprodione, a fungicide polluting water, fruits, wine and (ii) to compare the performance of the
16 optimal MIS with its analogue molecularly imprinted polymer (MIP), with the objective to
17 obtained the highest imprinting factor possible. Iprodione was widely used in viticulture. It was
18 recently banned by the European community because of its carcinogenic potential and its
19 presence in or on foods.

20 The binding capacity performance of these polymers was investigated using batch binding
21 studies in hydro alcoholic solutions (10 and 50 %). Langmuir, Freundlich and Temkin models
22 have been used to fit adsorption isotherms. The optimal MIS was obtained using APTMS as
23 functional monomer, low solvent volume and high cross linker quantity during its synthesis.

¹Corresponding author. ph. +33 3 80 77 40 80; e-mail address: elias.bou-maroun@agrosupdijon.fr

24 Increasing the quantity of crosslinker and decreasing the solvent volume during the MIS
25 synthesis enhanced the imprinting factor and the binding capacity.
26 The optimal MIS had a higher imprinting factor but a lower binding capacity than the optimal
27 MIP specific to iprodione. The imprinting factor of the optimal MIS was 135 times higher than
28 the optimal MIP. Unlike MIP, MIS kept its molecular recognition nature even under extremely
29 polar media such as the aqueous sample.

30

31 **Keywords**

32 Molecularly imprinted silica, molecularly imprinted polymer, fungicide, adsorption isotherm

33

34 **1. Introduction**

35 The worldwide increase in the usage of pesticides during the last decades has resulted in the
36 accumulation of their residues in the environment. These residues can cause serious detrimental
37 effects on human health and on the ecosystem¹. Therefore, the maximum residue limits (MRL)
38 were established by the Codex Alimentarius Commission and the European Union to regulate
39 the use of pesticides. Thus, the monitoring of these compounds is extremely important to ensure
40 that only permitted levels of pesticide are used. Several techniques have been developed for
41 pesticide detection: conventional analytical methods (gas chromatography, high performance
42 liquid chromatography, immunoassay, capillary electrophoresis) and advanced detection
43 methods such as biosensor (electrochemical, optical, piezoelectric, *etc...*)¹.

44 Although very effective, these techniques are expensive, time-consuming and difficult to
45 miniaturize for detection in the field. In this context, molecularly imprinted polymers (MIP)
46 specific to pesticides can overcome some of these difficulties, both for its extractions and
47 detections: significant reduction in extraction time and improvement in the concentration of the
48 target molecule for subsequent analysis. That is why since 2000, molecular imprinting science

49 and its applications of molecularly imprinted polymers have been attracting the interest of the
50 scientific community, hence the broad increase of literature in the field. Over 1237 references
51 within the field of molecular imprinting science and technology for the period 1931 – 2018
52 have been collected. However, numerous developments still need to be made, particularly in
53 terms of the synthesis method of molecularly imprinted silica.

54

55 For this project, we focused on the iprodione (other name glycophen, PubChem CID 37517).
56 Iprodione is a dicarboximide fungicide widely used in viticulture in most agricultural countries,
57 but also in other crops activities like fruits production, green lawns etc.. ²⁻⁴. It was banned
58 recently by the European Community because of its carcinogenic and endocrine disrupting
59 characters ⁵. Though this interdiction, iprodione must be detected because of possible residues
60 in soil. It is a very stable molecule and its degradation in the soil takes a long time ⁶. In fact, in
61 a soil treated for the first time, the time to 50% loss of iprodione was greater than 35 days.
62 Iprodione has also to be easily detected for the monitoring of possible non-authorized uses like
63 the elimination of stocks etc... Various molecular imprinted polymers (MIP) have been recently
64 developed and applied for the selective determination of residual pesticides ⁷. A brief overview
65 of this research area shows that the majority of the studied imprinted polymers are acrylate
66 based molecularly imprinted polymers (MIP) (Table 1). The most used functional monomer is
67 the methacrylic acid (MAA). It is commonly chosen by default as monomer as soon as the
68 target molecules are neutral or basic. In fact, MAA has the capacity of being an H donor and
69 acceptor with strong abilities to create dipole-dipole interactions and can develop hydrogen and
70 ionic interactions with basic molecules ⁸. MIP synthesis is relatively cheap and easy. However,
71 a severe limitation of this type of imprinting is the requirement for an organic solvent in which
72 all compounds are soluble.

73 Pesticides are generally poorly soluble in water. This chemical property is favorable to MIP
74 synthesis protocols that use organic solvents. Initially, the selection of low water soluble
75 molecules was done to reduce lixiviation in groundwater and water pollution⁹. For nebulization
76 in the fields, pesticides are dispersed in water using a surfactant¹⁰. These poorly soluble in
77 water molecules should nevertheless not be too liposoluble in order to avoid bioaccumulation.
78 Like per example pentachlorophenolas who is known to contaminate underground water¹¹ due
79 to its high solubility in water ($20 \text{ mg}\cdot\text{L}^{-1}$) when, on the other hand, chlordane and DDT are very
80 hydrophobic (water solubility 0.056 and $0.024 \text{ mg}\cdot\text{L}^{-1}$ respectively) , stable and toxic, and
81 therefore, bioaccumulate. Iprodione is relatively hydrophobic and slightly soluble in water
82 ($13.9 \text{ mg}\cdot\text{L}^{-1}$). It is more soluble in organic solvents: in ethanol ($25 \text{ g}\cdot\text{L}^{-1}$), which explains the
83 high risk of contamination of wine, in acetone ($300 \text{ g}\cdot\text{L}^{-1}$), in dimethylformaide ($500 \text{ g}\cdot\text{L}^{-1}$), or
84 in dichloromethane ($500 \text{ g}\cdot\text{L}^{-1}$).

85 A convenient alternative to MIP is sol – gel molecularly imprinted silicas (MIS), even if
86 pesticides are not very water-soluble¹². The use of a co-solvent (water miscible solvent such as
87 ethanol or acetone) can favor the solubilization of pesticide without perturbing the
88 polymerization of the silane. In fact, the synthesis of MIS is relatively easy: it can be done at
89 room temperature and atmospheric pressure. Their advantage remains in their synthesis in a
90 water / ethanol mixture, which respects one of the principles of green chemistry by using safe
91 solvents contrary to those used in MIP synthesis. Moreover, MIS are more chemically stable
92 and specific towards the target species than acrylate based MIP¹³, also, they allow faster
93 diffusion of analytes¹⁴. The interest in these materials is growing and their applications are
94 broad: phenobarbital¹³, caffeine¹⁴, nitroaromatic explosives¹⁵, pesticides in almond oil¹⁶, nitro
95 musk compounds in water¹⁷. However, the studies about MIS using fungicide as template are
96 very scare (Table 1).

97 All these studies proved the efficiency of MIP and MIS but, to the best of our knowledge, this
98 study is the first that compares the molecular imprinting of iprodione between these two types
99 of polymers. The aim of this work was to design the best MIS specific for ipriodione fungicide
100 and to compare its performance with its MIP analogue. The binging capacity performance of
101 these polymers was investigated in a hydroalcoholic solution towards iprodione.

102

103 **2. Materials and methods**

104 **2.1. Chemicals**

105 Iprodione (97%, CAS number 36734-19-7, Hazard class carcinogenicity category 2 (CMR 2),
106 H351, H400, H410), (3-Aminopropyl-)trimethoxysilane (APTMS 97%, CAS number 13822-
107 56-5, Hazard class H314, H315, H318, H319), 1-[3-(Trimethoxysilyl)propyl]urea (urea, 97%,
108 CAS number 23843-64-3, Hazard class H315, H318, H335), N-[3-
109 (Trimethoxysilyl)propyl]aniline (aniline, 97%, CAS number 3068-76-6, Hazard class H302,
110 H314, H315), tetraethoxysilane (TEOS, ≥ 99%, CAS number 78-10-4, Hazard class H226,
111 H319, H332, H335), ammonium hydroxide (NH₄OH 28 – 30%, CAS Number 1336-21-6,
112 Hazard class H314, H400), ethanol (≥ 99.8%, CAS Number: 64-17-5, Hazard class H225),
113 allylamine (98%, CAS 107-11-9, Hazard class H225, H301, H311, H331, H411), ethylene
114 glycol dimethacrylate (EGDMA, ≥ 99%, CAS number 97-90-5, Hazard class H317, H335), 2,2-
115 dimethoxy-2-phenylacetophenone (DMPAP, ≥ 99%, CAS number 24650-42-8, Hazard class
116 H302, H373, H400, H410, H412), toluene (≥ 99.8%, CAS Number: 108-88-3, Hazard class
117 reproductive toxicity category 2 (CMR 2), H225, H304, H315, H336, H361d, H373) and
118 acetonitrile (≥ 99.9%, CAS Number: 75-05-8, Hazard class H225, H302, H312, H319, H332)
119 were purchased from Sigma Aldrich, France. Water used in all experiments was deionised and
120 obtained from an Elga Ionic system PURELAB Option

121

122 **2.2. Synthesis of the sol-gel molecularly imprinted silica (MIS) and non-imprinted sol-**
123 **gel polymers silica (NIS)**

124 The synthesis protocol used for this study and the different chemical reactions that might be
125 involved in the MIS synthesis and the interactions between the MIS and iprodione have been
126 presented previously¹². MIS were prepared at 40°C in a thermostatic water bath under magnetic
127 stirring. The template molecule, iprodione, was first solubilized in ethanol. Then, water was
128 added, followed by the functional monomer and the crosslinker TEOS (tetraethoxysilane).
129 Finally, aqueous solution of ammonium hydroxide (NH₄OH, 100 mmol) was introduced. The
130 reaction mixture was left under stirring for 20 hours. Then the mixture was sonicated for 10
131 minutes. The polymers were separated from the liquid phase by centrifugation at 10 000 g for
132 10 minutes at room temperature. In order to eliminate iprodione and free the specific cavities,
133 the polymers were washed several times with pure ethanol until iprodione was no longer
134 detectable by reversed phase high performance liquid chromatography (HPLC). After washing,
135 the polymers were dried for 6 h at 60 °C. In parallel, NIS (Non Imprinted Silica) was
136 synthesized under the same synthesis conditions as those of MIS, but without using the template
137 molecule. NIS served as a control polymer.

138 Several factors, including the nature of functional monomer, molar ratios of crosslinker /
139 functional monomer / solvent were studied to optimize the synthesis of MIS. Table 2
140 summarizes the different MIS synthesized depending on the experimental conditions and the
141 structure of functional monomers tested for the synthesis of molecularly imprinted silica (MIS)
142 and for the molecularly imprinted polymers (MIP) are presented in [Figure 1](#).

143

144 **2.3. Synthesis of the molecularly imprinted polymers (MIP) and non-imprinted**
145 **polymers (NIP)**

146 The synthesis of MIP (non-covalent synthesis method) was done as previously described⁸. MIP
147 were prepared with 1 mmol of allylamine as functional monomer, 4 mmol of crosslinker
148 (EGDMA) and 0.1 mmol of template (iprodione) and the polymerization was carried out in 1
149 mL of toluene using 0.05 mmol of DMPAP initiator. In parallel, non-imprinted polymers (NIP)
150 were prepared with the same protocol but without the template. NIP served as a control
151 polymer.

152

153 **2.4. Binding properties of imprinted polymer (MIS) and non-imprinted polymer (NIS)**
154 **towards iprodione**

155 The binding capacity was estimated by batch adsorption. 10 mg of imprinted polymer (MIS 1,
156 MIS 4, MIS 5, MIS 6, MIS 7, MIS 8) or non-imprinted polymer (NIS 1, NIS 4, NIS 5, NIS 6,
157 NIS 7, NIS 8) were suspended in 20 mL of iprodione solution at 10^{-5} M (10 %, v/v,
158 ethanol/water). The mixture was stirred for two hours at 25 °C. After, the supernatant was
159 filtered using a 0.22 µm filter and analysed by HPLC for the determination of iprodione. For
160 each analysis, three replicates were done.

161

162 **2.5. Kinetic adsorption study of iprodione to MIS**

163 The kinetic profile of iprodione binding to MIS was performed in the same experimental
164 conditions than those previously described, except for the concentration of iprodione solution.
165 An iprodione solution at 5.10^{-4} M (10 %, v/v, ethanol/water) was used. At different times of
166 stirring at 25 °C, the supernatant was filtered using a 0.22 µm filter and analysed by HPLC for
167 the determination of iprodione. Three replicates were done by sample.

168

169 **2.6. Isotherm study**

170 10 mg of imprinted polymer (MIS 4, MIS 5', MIS 8 or MIP) or non-imprinted polymer (NIS 4,
171 NIS 5', NIS 8 or NIP) were suspended in 20 mL iprodione solutions at different concentration
172 10^{-5} , 5.10^{-4} , 10^{-4} , 5.10^{-4} , 10^{-3} M with ethanol/water mixture (50 %, v/v) as solvent. After one
173 hour of stirring at 25 °C, the supernatant was filtered using a 0.22 µm filter and analysed by
174 HPLC for the determination of iprodione. The results presented are the means of three
175 replicates.

176 The sorption isotherms obtained were tested with the Langmuir, Freundlich, and Temkin
177 isotherm equations. The model equations are shown [in table S1](#). The Langmuir isotherm model
178 assume that the adsorption of molecules occurs at specific homogeneous sites of the adsorbent
179 and, once a molecule occupies a site, no additional adsorption can occur there (monolayer
180 coverage). The Freundlich isotherm model assumes the molecules undergoes adsorption onto
181 the heterogeneous surface of adsorbent. This model describe a multilayer adsorption with
182 interaction between adsorbed molecules. The Temkin isotherm model assumes that the
183 adsorption heat of all molecules decreases linearly with the increase in coverage of the
184 adsorbent surface, and that adsorption is characterized by a uniform distribution of binding
185 energies, up to a maximum binding energy^{18,19}.

186

187 **2.7. High-performance liquid chromatography**

188 For HPLC iprodione analysis, a Shimadzu HPLC (LC-20AT) pump equipped with a UV-
189 Visible detector (SPD-20A), a Restek column (Pinacle II, C18 5 µm, 150 x 4.6 mm) and a pre-
190 column (C18, 5 µm, 10 x 4 mm) were used. Separations were conducted at room temperature.
191 Isocratic acetonitrile / water (60/40, v/v) was used as mobile phase and the flow rate was
192 1mL/min. Iprodione detection was done at 220 nm. A calibration curve was constructed over
193 the range 5.10^{-4} and 10^{-8} M of iprodione ($r^2 = 0.9993$). The amount of iprodione retained by the

194 polymer was calculated by the difference between the initial concentration of iprodione and the
195 free concentration of iprodione in the supernatant.

196

197 **2.8. Scanning electron microscope (SEM)**

198 The morphological characterization of the samples was performed by a scanning electron
199 microscope. The samples were suspended in ethanol. Then a drop was placed on a silicon grid
200 and examined using a Hitachi VPSU1510 scanning electron microscope. More than four views
201 were recorded by sample. Representative images were presented with the accelerating voltage
202 and the magnification used.

203

204 **2.9. Statistical analysis**

205 The Statistica V8 software was used for Anova. Significance was established at $p < 0.05$. Fisher
206 t-test was used to determine significant differences between values.

207

208 **3. Results and discussion**

209 **3.1. Synthesis of sol – gel molecularly imprinted silica (MIS) optimization**

210 An optimal MIS must satisfy the following two criteria: present a strong absorption of iprodione
211 and have a better specificity compared to NIS. Several factors, including the nature of functional
212 monomer, molar ratios of crosslinker / functional monomer / solvent were studied to optimize
213 the synthesis of MIS. Table 2 summarizes the different MIS synthesized depending on the
214 experimental conditions.

215

216 **3.1.1. Effect of functional monomer nature**

217 The choice of the functional monomer depends largely on the imprinted molecule. Indeed, it is
218 interesting to match the functionality of the functional monomer to that of the imprinted

219 molecule (template), in order to maximize the interactions between them and to create highly
220 specific cavities designed for the template molecule. The monomer must be stable and soluble
221 in the chosen solvent. In our study, three different monomers were chosen considering their
222 ability to interact with iprodione ([Figure 1](#)):

223 - (3-Aminopropyl-)trimethoxysilane (labelled APTMS). This monomer has a hydrogen bond
224 acceptor group.

225 - 1-[3-(Trimethoxysilyl)propyl]urea (labelled urea) which has a donor group and a hydrogen
226 bond acceptor group.

227 - N-[3-(Trimethoxysilyl)propyl]aniline (labelled aniline) which has a hydrogen bond acceptor
228 group and a benzene ring which can establish π - π interactions.

229

230 In a typical MIS synthesis, according to the literature ^{14,15}, the following molar ratio (1 / 4 / 20)
231 for (template / functional monomer / crosslinker) were commonly used. Following this literature
232 review, the three selected functional monomers (APTMS, urea, aniline) have been tested
233 depending on this molar ratio (1 / 4 / 20) and the following MIS labelled MIS 1, MIS 6, MIS 7
234 were obtained. The binding properties results obtained are presented in [Figure 2](#). MIS 6
235 (synthesized with aniline residue) and MIS 1 (synthesized with APTMS) showed the same
236 quantity of adsorbed iprodione (around 1 mg / g of polymer). For these two functional
237 monomers, the same type of functional monomer - iprodione interactions, hydrogen bonds,
238 were involved. On the other side, MIS 7 (synthesized with aniline residue) had an average
239 adsorption of 5.86 mg / g of polymer, five times larger than these counterparts. The binding
240 capacity of the polymer is a critical factor. In the case of aniline, the types of functional
241 monomer - iprodione interactions involved were hydrogen bonds and π - π interactions. This
242 higher retention can be explained by the π - π interactions involved between the phenyl ring of
243 aniline residue and of iprodione. This expected π - π interactions were more favorable than

244 hydrogen bonding (APTMS - iprodione and urea moieties - iprodione) for the formation of the
245 pre-polymerization complex and thus for molecular printing.

246 No NIS were obtained with urea function (NIS 6) and aniline function (NIS 7) used as
247 functional monomers with the molar ratios used. To confirm these results, the experiment was
248 done in duplicate. We also noticed that the polymerization between the samples was different
249 and consequently the MIS physical forms were different. Our experimental conditions gave
250 very small granules for MIS 1 while soft polymer monoliths were obtained for MIS 6 and MIS
251 7. Consequently, before analysis, MIS 6 and MIS 7 were crushed and ground into a powder
252 with a mortar and pestle.

253

254 As the involved interactions were different and the obtained binding capacity interesting, the
255 functional monomers aniline (MIS 7) and APTMS (MIS 1) were kept for the further studies.
256 Therefore, we can suppose that the change of the (template / functional monomer / crosslinker)
257 molar ratio and solvent volume could be a solution to obtain NIS 7.

258

259 **3.1.2. Crosslinker quantity and volume solvent effect**

260 The volume of the solvent is also a key element in the MIS synthesis. To study it, two different
261 volumes of solvents were used for the synthesis. **Figure 3** shows that the decrease of solvent
262 volume during the synthesis step with APTMS as functional monomer induced an increase of
263 the quantity of adsorbed iprodione (MIS 1 and MIS 4). This observation could be explained by
264 the dilution effect. The higher the solvent volume, the lower the reactants meeting probability,
265 the fewer the cavities specific to iprodione. Therefore, there is a great interest in decreasing the
266 solvent volume during the MIS synthesis.

267

268 Another important reagent for the synthesis of molecularly imprinted silica is the amount of
269 crosslinker. The monomer and the crosslinker react mainly in aqueous solution to form silanol
270 (Si-OH) groups through hydrolysis, then siloxane bonds (Si-O-Si) are formed by condensation
271 reaction with silanol groups around the template molecule favouring the creation of a strong
272 pre-complex template/monomer and an important reticulation of the sorbent to create more-
273 well designed cavities. In other words, the crosslinker controls the morphology of the polymer:
274 gel, micro or macroporous. It also provides a mechanical stability to silicate with the template
275 molecule (rigidity), as well as a stability of the sites of interactions between the functional
276 monomer and the template molecule. Liu et al.²⁰ showed that an excess of crosslinker can
277 change the physicochemical interactions between monomers and template molecules. In fact,
278 if the network is too flexible, the template may not be retained. On the other hand, if the
279 network is too reticulated, the template diffusion may be reduced.

280 On this basis, MIS 5 was synthesized with a small volume of solvent but with an increase of
281 the crosslinker amount. MIS 5 had the highest iprodione binding capacity, three times more
282 than the other counterparts MIS 1 and MIS 4 (around 6 mg / g polymer).

283 On the contrary, with aniline as functional monomer, the trend was completely different (Figure
284 3). The increase of the crosslinker quantity and the decrease of the solvent volume implied a
285 decrease in the amount of adsorbed iprodione (MIS 7 and MIS 8). It should be noted that the
286 amount of crosslinker was greater for MIS 8 (1 / 4 / 59) than MIS 5 (1 / 4 / 20). However, contrary
287 to the previous results, a NIS was obtained (NIS 8). MIS 8 and NIS 8 were this time in powder
288 form.

289

290 To evaluate the specific binding property of MIS and NIS towards iprodione and to highlight
291 the non-specific interactions that result from the iprodione adsorption, the imprinting factor (IF)
292 has been calculated using the following equation²¹:

293

$$IF = \frac{K(MIS)}{K(NIS)} = \frac{B(MIS) \times F(NIS)}{F(MIS) \times B(NIS)}$$

294 With:

- 295 - F: the free concentration of iprodione (mol/L) in the supernatant
296 - B: the amount of iprodione bound (adsorbed) by the polymer (mg of iprodione/g of
297 polymer) calculated by difference between the initial concentration of iprodione (mol/L)
298 and F.

299 The higher the imprinting factor, the higher the specific interactions. Therefore, the imprinted
300 polymers exhibit a good performance with the template molecule. The imprinting factors were
301 approximately around 1 for MIS1, MIS 4 and MIS 5 ([Table 3](#)) meaning the absence of specific
302 cavities designed for iprodione with no significant differences ($p = 0.66$). [Table 3](#) and [Figure 3](#)
303 show that MIS 5 had the best imprinting factor and the best amount of adsorbed iprodione. This
304 observation could be explained by the increase of the specific interactions between iprodione
305 and the polymer with this molar ratio of reagent used. Therefore, with APTMS as functional
306 monomer, there is a great interest to increase the crosslinker quantity and to reduce the solvent
307 volume during the MIS synthesis. In fact, an increase of crosslinker quantity and a reduction of
308 solvent volume would normally increase the reticulation and reduce the porosity of the polymer.

309 The imprinting factor of MIS 8 was not significantly different than those obtained with APTMS
310 as a functional monomer ([Table 3](#)). MIS 8 was less selective than MIS 5 but better than MIS 4
311 ([Figure 3](#)). To try to understand this difference, the morphology of each MIS has been studied
312 by microscopy. SEM images ([Figure 4](#)) show the morphology of MIS with different
313 magnifications. MIS 5 and MIS 1 seem to be aggregates. A very fine homogeneous population
314 of about 400 nm in diameter characterized them. At the opposite, MIS 7 and MIS 8 were
315 characterized by a heterogeneous population with irregular shapes and greatly variable
316 dimensions ranging respectively from 99 μm to 952 μm for MIS 7 (with a majority of 200 μm)

317 and from 578 nm to 861 μ m for MIS 8. The heterogeneity of MIS 7 populations explained by
318 the gridding done. Due to the heterogeneity of the MIS 8 population and its larger size, this
319 specific surface area may be smaller than MIS 5 and MIS 1 and could explain the difference of
320 binding capacity observed previously by comparison.

321

322 Whatever the studied MIS, no differences were observed on the amount of adsorbed iprodione
323 between MIS and NIS ([Figure 3](#)). In order to be able to observe a clear difference between MIS
324 and NIS in the amount of adsorption iprodione and to correctly perform the isotherm studies of
325 each polymer, the concentration of iprodione solution used have to be increased. The problem
326 encountered is the low solubility of iprodione using 10% ethanol / water, (v/v) as solvent. In
327 this condition, the solubility limit of iprodione is 2.10^{-4} M. The iprodione solubility increases
328 with the increase of ethanol proportion. That is the reason why we decided to work with a
329 solution containing 50% ethanol / water (v/v) where the solubility limit of iprodione is $1.2\ 10^{-3}$
330 M. To confirm the results obtained previously, the isotherms were performed on MIS 4, MIS 5
331 and MIS 8.

332

333 **3.1.3. Isotherm study**

334 Isotherm studies were performed on both imprinted and non-imprinted polymers. Previously,
335 equilibrium binding experiments were performed to determine the time necessary to reach this
336 equilibrium ([Figure 5](#)). It is observed that the initial binding rate was very high with a very fast
337 uptake profile. In fact, the system reached an equilibrium after 20 minutes. This means that the
338 porosity of the silica matrix had a favorable effect on the diffusion time of the target molecules
339 into the recognition sites. The fact that MIS showed fast kinetics for iprodione adsorption is
340 advantageous. Based on this characterization, all furthers experiments, whatever the studied
341 MIS, were determined within 60 minutes.

343 In order to compare MIS 8 with its APTMS analogue, a new MIS, labelled MIS 5', was
344 synthesized with the same (template / functional monomer / crosslincker) ratio molar 1 / 4 / 59
345 used for MIS 8 (Table 2). **Figure 6** shows the isotherms for MIS 4, MIS 5' and MIS 8 and their
346 respective control polymer NIS as a function of iprodione solution concentrations. The results
347 show that all the MIS can bind iprodione in larger amounts than the analogous NIS and binding
348 capacity for MIS increase with the rise of iprodione concentration solution. The results obtained
349 in a 50% ethanol solution (v/v) confirm those obtained in a 10% ethanol solution (v/v): MIS 5'
350 had the highest adsorption capacity of iprodione, followed by MIS 8 and MIS 4 in decreasing
351 order of adsorption capacity. In addition to having the best iprodione binding property (around
352 25 mg of iprodione bound per g of MIS), MIS 5' had the best imprinting factor (about 271,
353 **Table 3**) meaning the presence of specific interactions between iprodione and the functional
354 monomer. This result indicates that in this case, the increase of crosslinker content enhanced
355 the specific interaction between MIS and iprodione and so show the selectivity of MIS 5'. In
356 order to get a better view on the adsorption of iprodione by MIS, the Langmuir, Freundlich and
357 Temkin isotherm models were applied to fit the experimental data. Linear regression is
358 frequently used to determine the best-fitting isotherm. The applicability and suitability of the
359 isotherm equation to the equilibrium data were compared by evaluating the values of the
360 correlation coefficients. The results are presented in **Table 4** and **Figure 7**. The regression
361 coefficients r^2 ranged from 0.83 to 0.97 (r from 0.91 to 0.98) for Freundlich model, from 0.76
362 to 0.89 (r from 0.87 to 0.94) for Temkin model and from 0.30 to 0.80 (r from 0.55 to 0.89) for
363 Langmiur model. With the Pearson's table (critical values of correlation coefficient), using a
364 value of level of significance for a two-tailed test of 0.05, and with 5 points (freedom degree =
365 3), the critical r value is 0.878. These values of regression coefficients reflect a good fit of the
366 Freundlich model and Temkin model but it can be noticed that the Langmuir model is not

367 suitable for fitting the present data. Therefore the Freundlich model is most suitable and that
368 applicability follows the order: Freundlich > Temkin model. Freundlich model is the best suited
369 model in our study suggesting that the adsorption occurs in multilayers and in heterogeneous
370 sites of this material with a non-uniform distribution of heat of adsorption over the surface^{22,23}.
371 Moreover as the experimental data fitted well to Tempkin isotherm, we can added that iprodione
372 adsorption occurred because the heat of adsorption of iprodione in the layer decreases linearly
373 because of increased surface coverage.

374

375 When the Freundlich equation has been determined to be a suitable binding isotherm model for
376 MIS, two additional binding parameters can be calculated incorporating the parameters of the
377 Freundlich: the number of binding sites, $N_{K_1-K_2}$ (Eq. 1) and the weighted average affinity,
378 $K_{K_1-K_2}$ (Eq. 2). K_1 of K_2 values are within the boundaries K_{\min} and K_{\max} as defined by Eq. 3
379^{24,25}.

380 $N_{K_{\min}-K_{\max}} = a(1 - n^2)(K_{\min}^{-n} - K_{\max}^{-n})$ Equation 1

381 $K_{K_{\min}-K_{\max}} = \left(\frac{n}{n-1}\right) \left(\frac{K_{\min}^{1-n} - K_{\max}^{1-n}}{K_{\min}^{-n} - K_{\max}^{-n}}\right)$ Equation 2

382 $K_{\max} = \frac{1}{C_{e(\min)}}$ and $K_{\min} = \frac{1}{C_{e(\max)}}$ Equation 3.

383 with C_e the free concentration of iprodione (mM) in the solution.

384

385 Using Freundlich isotherm model, no significant n values were observed between MIS 4, MIS
386 5' and MIS 8 (Table 4). A more homogeneous system will have an n value approaching unity
387 and a more heterogeneous system will have an n value approaching zero. As n values were
388 close to the value 1, MIS 4, MIS 5' and MIS 8 also show high degree of binding site
389 homogeneity.

390 On the other hand, important variations were observed for the parameter K_F (**Table 4**). The K_F
391 values show that the MIS 5' had significantly the highest binding capacity following by MIS 8
392 and then MIS 4. The comparison of the average number of binding sites N confirms that MIS
393 5' displayed significantly much higher binding capacities (31,8 $\mu\text{mol/g}$) than MIS 8 and MIS
394 4 (p value = 0,0157). Moreover, the average association constant $K_{K\min-K\max}$ is around two times
395 greater for the MIS 5' than for MIS 8 and MIS 4 (p value = 0, 0046). No significant differences
396 were observed for MIS 8 and MIS 4 about the value of N and $K_{K\min-K\max}$. This higher capacity
397 for MIS 5' should be attributed to a gain in the specific sites in line with this higher imprinting
398 factor.

399 The experimental data fitted well to Tempkin isotherm indicating that iprodione adsorption
400 occurred because the heat of adsorption of iprodione in the layer decreases linearly because of
401 increased surface coverage^{18,19}. No significant K_T values were observed between MIS 4, MIS
402 5' and MIS 8 (**Table 4**, p value = 0, 418) meaning a constant maximum bonding energy
403 whatever the MIS. The calculated values of sorption heat, B value and b value, were
404 significantly different for MIS 4 as opposed to MIS 5' and MIS 8, which had similar values.
405 Very low values of b obtained in the present study suggesting that the uptake of iprodione onto
406 MIS was by physisorption. In fact, the physisorption processes are reported to have adsorption
407 energies less than -40 kJ/mol and characterized by very weak forces, such as Van der Waals
408 forces and hydrogen bonding^{26,27}.

409 On the basis of these results, MIS 5' was chosen as the best MIS and these performances were
410 compared to that of an analogue MIP.

411

412 **3.2. Comparison of MIS MIP performances**

413 A MIP was synthesized using a functional monomer analogous to APTMS. Allylamine was
414 chosen (**Figure 1**). Previous studies were performed to determine the optimal (template /

functional monomer / crosslinker) molar ratio. Isotherm studies were performed on MIS 5' and optimized MIP (Figure 8). The results show that MIS 5' and optimized MIP can bind iprodione and the binding capacity increased with the rise of iprodione solution concentration. The quantity of iprodione adsorbed was very different between MIS 5' (around 25 mg/g polymer) and MIP (around 120 mg/g polymer). It was 5 times lower for MIS than for MIP.

However, the difference in the adsorption of iprodione between MIS and NIS was greater than the difference between NIP and MIP. In fact, the imprinting factor was of 271 for MIS and only 2 for MIP (Table 3). MIS 5' presented a high specific recognition of iprodione. The imprinting factor of MIP is in agreement with the previous study⁸, where a value of 2.40 was determined. The imprinting factor of MIS is considerably higher than ones reported in the literature for molecularly imprinted sorbent materials, ranging from 0.8 to 39.85^{12,14,28}. The large imprinting factor value of this MIS is an indication of the great analytical potential of silica-based molecularly imprinted materials. This high selectivity is promising for further development in this area. Our hypothesis to explain this difference of imprinting factors between MIP and MIS is the homogeneity of the silica polymer. MIS 5' show high degree of binding site homogeneity (*n* value 0.86). MIP had an *n* value of 0.47 meaning a binding site heterogeneity (Table 4). At the opposite, for the binding affinity (K_F), which refers to the strength of binding interaction, MIP had a higher binding capacity (K_F of 490) than the MIS 5' (K_F of 202). We can supposed that this higher binding capacity could be due to non-specific interactions. The imprinting factor takes into account the non-specific interactions which are due to the interaction between the template and the crosslinker. The average number of binding sites N confirms this assumption: MIS 5' displayed significantly much lower binding capacities (31,8 $\mu\text{mol/g}$) than MIP (229 $\mu\text{mol/g}$). Moreover, the average association constant $K_{K\text{min}-K\text{max}}$ is around five times greater for the MIP than for MIS 5'.

439 The values obtained from the Temkin isotherm were: $K_T = 75 \text{ g}/\mu\text{mol}$ and $312 \text{ g}/\mu\text{mol}$ for
440 respectively MIS 5' and MIP and b values = 104 J/mol and 40 J/mol for respectively MIS 5'
441 and MIP, indicating that the adsorption of iprodione onto MIS or MIP occurred via
442 physisorption involving low energies interactions between iprodione - MIS and between
443 iprodione - MIP.

444

445 Scarce are the papers describing the comparison between MIS and MIP. A direct comparison
446 between MIS and MIP was performed for the analysis of propranolol²⁹. The findings were that
447 the MIP exhibited higher uptake towards propranolol, but this was accompanied by a high
448 degree of nonspecific binding. The MIS had lower uptake, but remarkably lower nonspecific
449 binding (<10%). Another comparative study of the potential of MIP and MIS for molecular
450 imprinting of 2-aminopyridine showed that the MIP retained approximately 50% of the
451 template in rebinding studies in chloroform compared to 100% for the MIS. However, this
452 higher affinity for the MIS was accompanied by a higher degree of non-specific binding. While
453 the MIP performed poorly in acetonitrile, the MIS maintained a high degree of discrimination
454³⁰.

455

456 **4. Conclusion**

457 The optimal MIS was obtained with APTMS as functional monomer, low solvent volume and
458 high crosslinker quantity during its synthesis. It showed a very fast uptake profile for iprodione.
459 The data modeling revealed that the adsorption process follows the Freundlich model. The
460 optimal MIS had a higher imprinting factor but a lower binding capacity than the optimal MIP
461 specific to iprodione. The imprinting factor of MIS was 135 times higher than MIP. Unlike
462 MIP, MIS kept its molecular recognition nature even under extremely polar media such as the
463 aqueous sample. This work emphasizes the high potential of MIS as molecularly imprinted

464 materials for analytical applications and provides promising insights into the future
465 development of MIS. Practically, MIS is as simple as MIP to prepare. MIS technology seems
466 to allow more specific binding than MIP but less sensitivity. To compensate the lower
467 sensitivity compared to MIP, a bigger column for SPE and more MIS quantity plus a bigger
468 volume of sample during the loading phase would be necessary to identify traces in a beverage
469 (wine for ex.) or in washing water of fruits. The next step to the study is to assess the selectivity
470 of MIP and MIS towards pesticides.

471

472 **Funding sources and acknowledgements**

473 This work was supported by the Regional Council of Burgundy and the European Union via
474 FEDER (“Fonds Européen de Développement Régional”) funding. We are grateful to AgroSup
475 Dijon for co-funding this research program. The authors thank Alison Vezel for her contribution
476 to this work.

477

478 **Conflict of interest statement**

479 The authors declare that there is no conflict of interest. No conflicts, informed consent, human
480 or animal rights are applicable for this work.

481

482 **References**

- 483 1. Samsidar, A., et al., Trends in Food Science & Technology (2018) 71, 188
- 484 2. Cabras, P., and Angioni, A., Journal of Agricultural and Food Chemistry (2000) 48 (4),
485 967
- 486 3. Scheyer, A., et al., Atmospheric Environment (2007) 41 (17), 3604
- 487 4. Golge, O., and Kabak, B., Journal of Food Composition and Analysis (2015) 41, 86

- 488 5. Regulation EU 2091., Commission Implementing Regulation (EU) 2017/2091 of 14
- 489 November 2017 concerning the non-renewal of approval of the active substance iprodione, in
- 490 accordance with Regulation (EC) No 1107/2009 of the European Parliament and of the Council
- 491 concerning the placing of plant protection products on the market, and amending Commission
- 492 Implementing Regulation (EU) No 540/2011 (Text with EEA relevance). Union, O. J. o. t. E.,
- 493 (ed.) (2017)
- 494 6. Slade, E. A., et al., Pesticide Science (1992) 35 (1), 95
- 495 7. Speltini, A., et al., Analytica Chimica Acta (2017) 974, 1
- 496 8. Bitar, M., et al., Reactive and Functional Polymers (2015) 94, 17
- 497 9. Pereira, V. J., et al., Bioscience Journal (2016) 32 (3), 627
- 498 10. Czarnota, M., and Thomas, P., Cooperative extension from the University of Georgia
- 499 (2013) 1314
- 500 11. Data taken from www.atsdr.cdc.gov, d. a. F.,
- 501 12. Bitar, M., et al., Food Chemistry (2019) 293, 226
- 502 13. Pilau, E. J., et al., Journal of the Brazilian Chemical Society (2008) 19, 1136
- 503 14. da Costa Silva, R. G., and Augusto, F., Journal of Chromatography A (2006) 1114 (2),
- 504 216
- 505 15. Lordel, S., et al., Journal of Chromatography A (2010) 1217 (43), 6674
- 506 16. Boulanouar, S., et al., Analytica Chimica Acta (2018) 1018, 35
- 507 17. Lopez-Nogueroles, M., et al., Talanta (2013) 110, 128
- 508 18. J, S. P., et al., Brazilian Journal of Chemical Engineering (2011) 28 (2), 295
- 509 19. Ayawei, N., et al., Journal of Chemistry (2017) 2017 (ID 3039817)
- 510 20. Liu, Z., et al., Acta Biomaterialia (2010) 6 (6), 2003
- 511 21. Spivak, D. A., Advanced Drug Delivery Reviews (2005) 57 (12), 1779
- 512 22. ABDEL-GHANI, N. T., et al., Journal of the Chilean Chemical Society (2017) 62, 3505

- 513 23. Bayuo, J., et al., *Journal of Applied Chemistry* (2011) 11 (11), 18
- 514 24. Umpleby, R. J., et al., *Journal of Chromatography B* (2004) 804 (1), 141
- 515 25. García-Calzón, J. A., and Díaz-García, M. E., *Sensors and Actuators B: Chemical*
- 516 (2007) 123 (2), 1180
- 517 26. Kiran, B., and Kaushik, A., *Biochemical Engineering Journal* (2008) 38 (1), 47
- 518 27. Araújo, C. S. T., et al., *Microchemical Journal* (2018) 137, 348
- 519 28. Guo, L.-q., et al., *Reactive and Functional Polymers* (2011) 71 (12), 1172
- 520 29. Marx, S., and Liron, Z., *Chemistry of Materials* (2001) 13 (10), 3624
- 521 30. Cummins, W., et al., *Analytica Chimica Acta* (2005) 542 (1), 52
- 522 31. Data taken from mipdatabase.com: (http://mipdatabase.com/all_items.php). (date
523 accessed May 29 2019)
- 524 32. Sun, X., et al., *Journal of Chromatography A* (2019) 1586, 1
- 525 33. Sun, X., et al., *Talanta* (2019) 196, 47
- 526 34. Koeber, R., et al., *Analytical Chemistry* (2001) 73 (11), 2437
- 527 35. Chapuis, F., et al., *Journal of Chromatography A* (2003) 999 (1), 23
- 528 36. Ferrer, I., et al., *Analytical Chemistry* (2000) 72 (16), 3934
- 529 37. Pap, T. m., et al., *Journal of Chromatography A* (2002) 973 (1), 1
- 530 38. Turiel, E., et al., *Analytical Chemistry* (2001) 73 (21), 5133
- 531 39. Chapuis, F., et al., *Journal of Chromatography B* (2004) 804 (1), 93
- 532 40. Zamora, O., et al., *Analytical and Bioanalytical Chemistry* (2009) 393 (6), 1745
- 533 41. Khan, S., et al., *Food Chemistry* (2016) 199, 870
- 534 42. Díaz-Álvarez, M., et al., *Analytica Chimica Acta* (2019) 1045, 117
- 535 43. Baggiani, C., et al., *Journal of Chromatography A* (2007) 1141 (2), 158
- 536 44. Cacho, C., et al., *Talanta* (2009) 78 (3), 1029
- 537 45. Zhao, F., et al., *Journal of Chromatography B* (2017) 1064, 143

- 538 46. Du, T., et al., *Journal of Chromatography B* (2014) 951-952, 104
- 539 47. Xu, X., et al., *Journal of Chromatography B* (2015) 988, 182
- 540 48. Bou-Maroun, E., et al., *Sensors and Actuators B: Chemical* (2017) 244, 24
- 541 49. Gomes Costa Silva, R., et al., *Journal of Separation Science* (2010) 33 (9), 1319
- 542

543 **Figure captions**

544

545 **Figure 1:** Structure of functional monomers tested for the synthesis of molecularly imprinted
546 silica (MIS) (a, b, c) and for the molecularly imprinted polymers (MIP) (d) and structure of
547 iprodione (template, e)

548 (a) (3-Aminopropyl)trimethoxysilane

549 (b) 1-[3-(Trimethoxysilyl)propyl]urea

550 (c) N-[3-(Trimethoxysilyl)propyl]aniline

551 (d) allylamine

552 (e) iprodione

553

554 **Figure 2:** Binding capacity of polymer toward iprodione for MIS 1, MIS 6 and MIS 7 per 10
555 mg of polymer in a solution of iprodione at 10^{-5} M (10% ethanol / water, v/v). Bars represent
556 standard deviation.

557

558 **Figure 3:** Binding capacity of polymer towards iprodione for MIS 1, MIS 4, MIS 5, MIS 7 and
559 MIS 8 and their control polymer NIS respective per 10 mg of polymer in a solution of iprodione
560 at 10^{-5} M (10% ethanol / water, v/v). Bars represent standard deviation.

561

562 **Figure 4:** SEM images of (a) MIS 1, (b) MIS 5, (c) MIS 8 and (d) MIS 7. Scale bar and
563 magnifications are mentioned on the SEM images.

564 **Figure 5:** Kinetic adsorption of MIS to iprodione solution (50% ethanol / water, v/v). Bars
565 represent standard deviation.

566

567 **Figure 6:** Binding isotherme of MIS 4, MIS 5' and MIS 8 toward iprodione at 25°C after 1h of
568 contact time with solution of iprodione (50% ethanol / water, v/v). Bars represent standard
569 deviation.

570

571 **Figure 7:** Isotherms models of the adsorption of iprodione by MIS 4. Sorption isotherms
572 obtained at 25°C after 1h of contact time with solution of iprodione (50% ethanol / water, v/v)

573 **(a) Langmuir plot**

574 **(b) Freundlich plot**

575 **(c) Temkin plot**

576

577 **Figure 8:** Binding isotherme of MIS 5' and MIP toward iprodione at 25°C after 1h of contact
578 time with solution of iprodione (50% ethanol / water, v/v). Bars represent standard deviation.

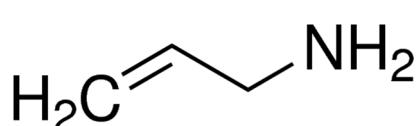
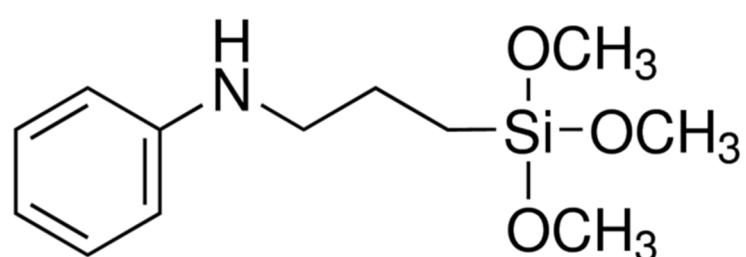
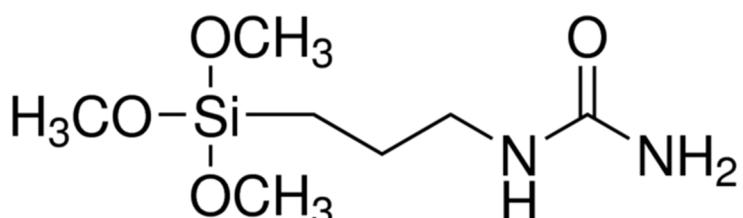
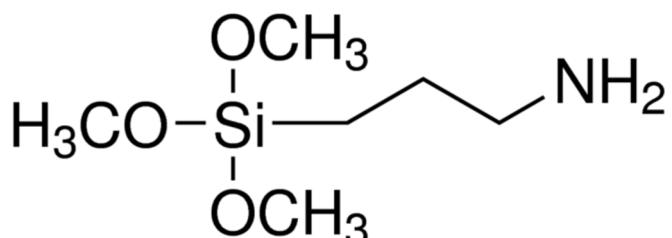
579

580

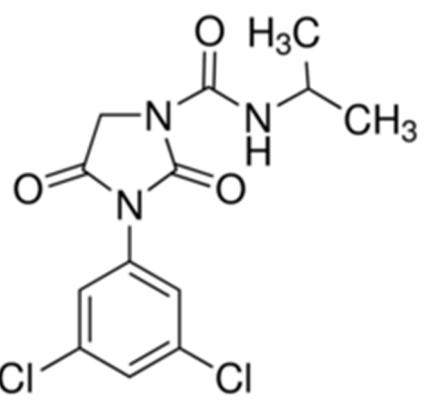
581 **Figure 1**

582

583 (a)



596 (e)

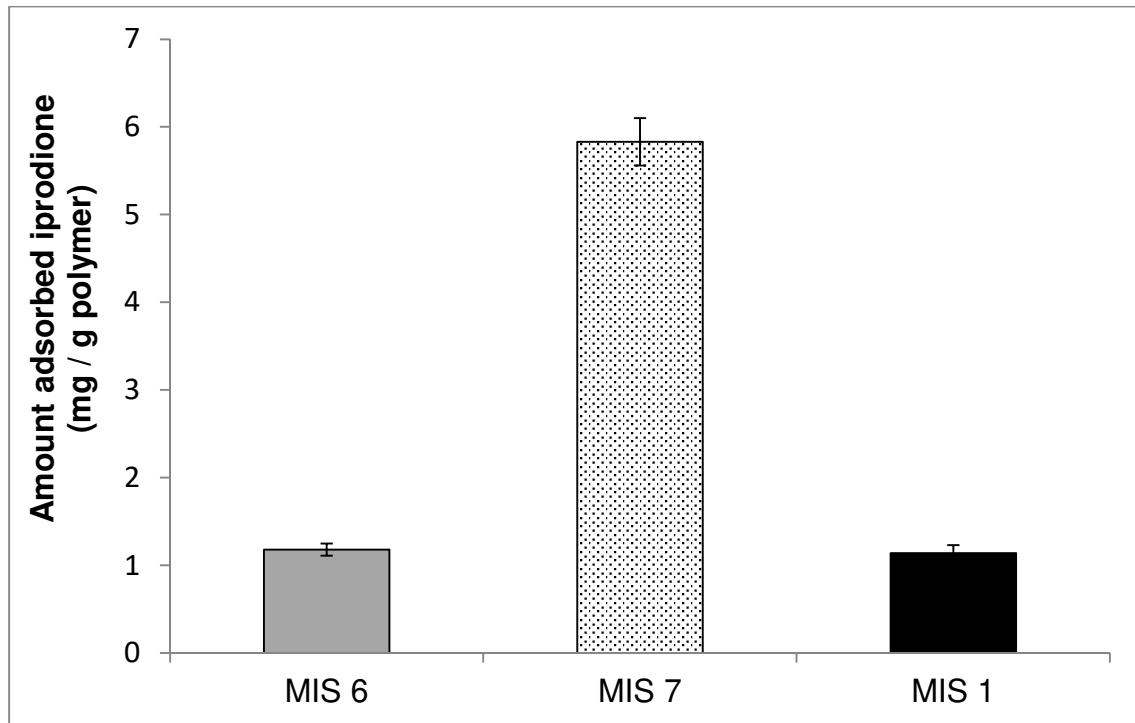


597

598

599 **Figure 2**

600



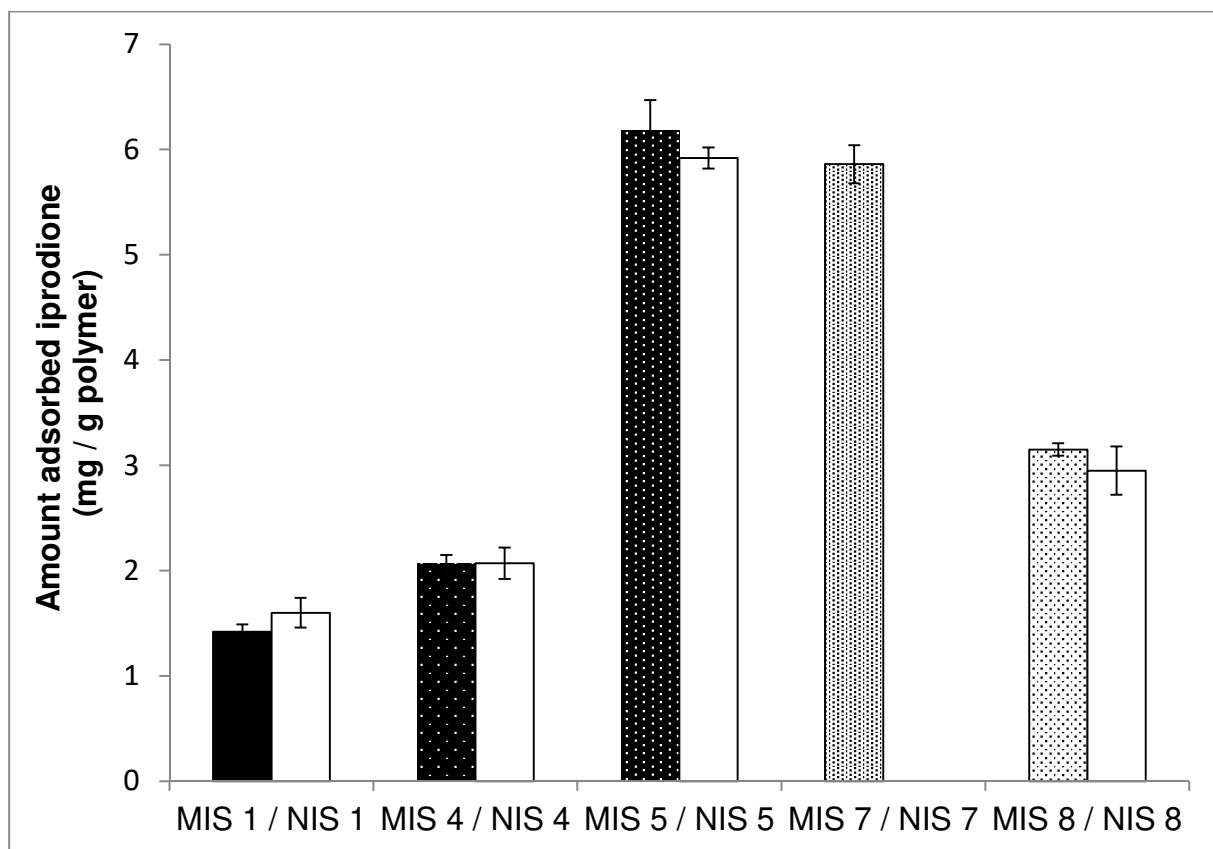
601

602

603

604 **Figure 3**

605

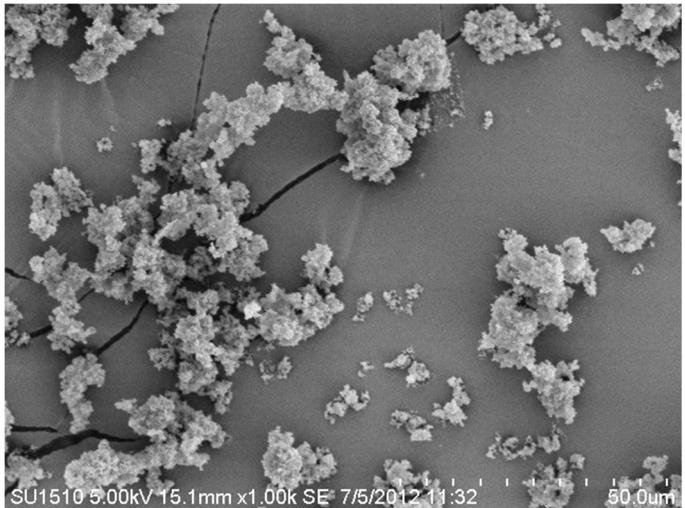


606

607

608 **Figure 4**

609 **a)**

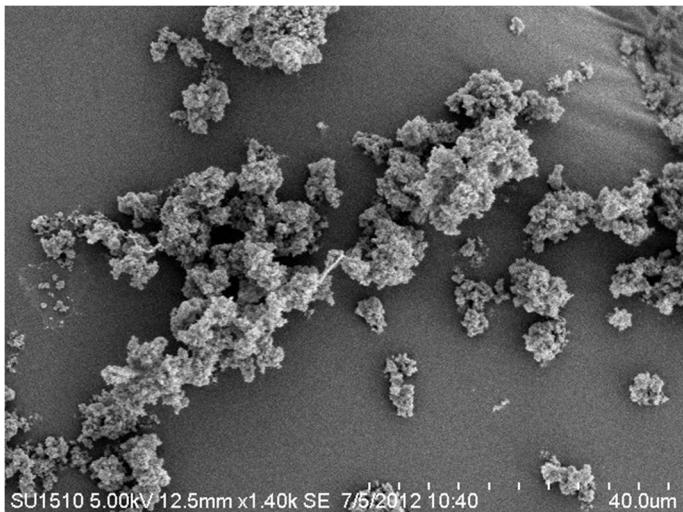


610

611

612

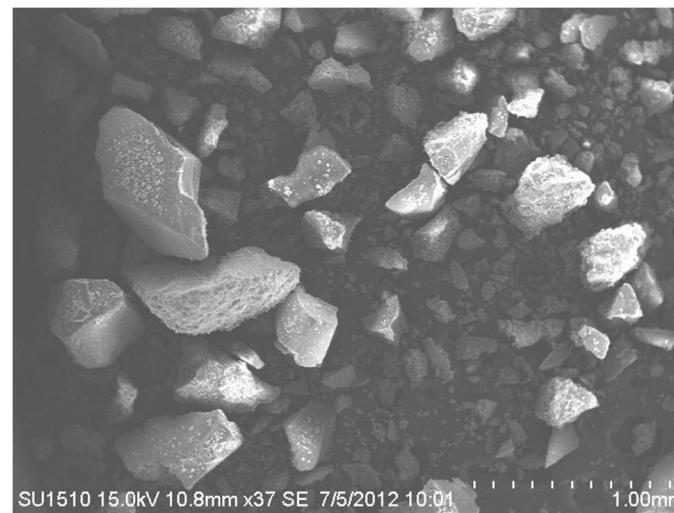
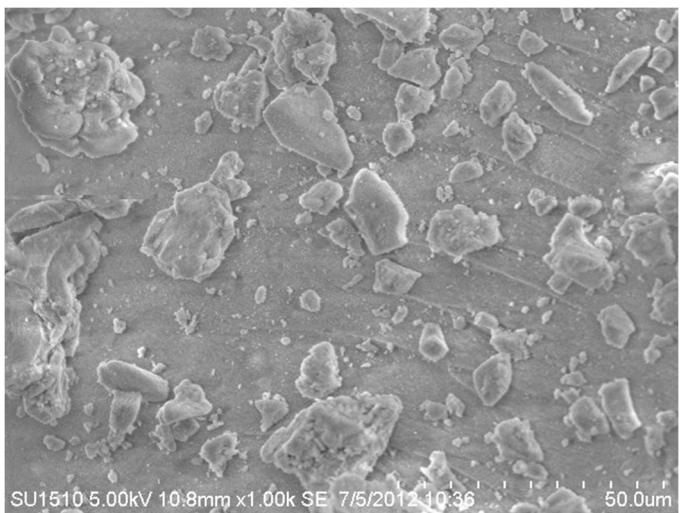
b)



613

614

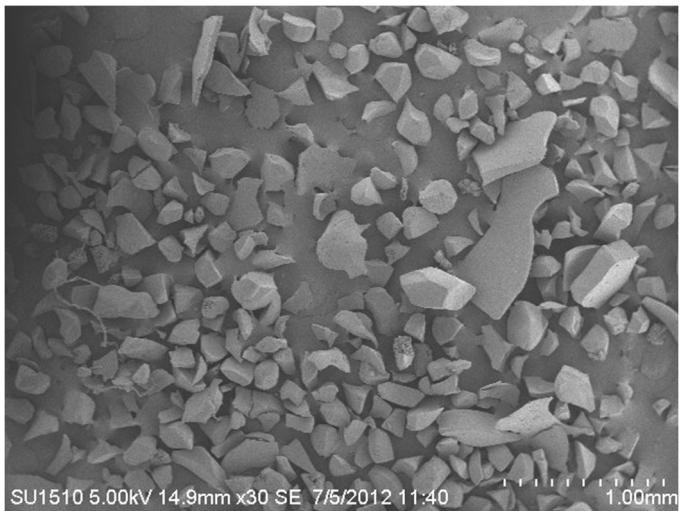
c)



615

616

d)



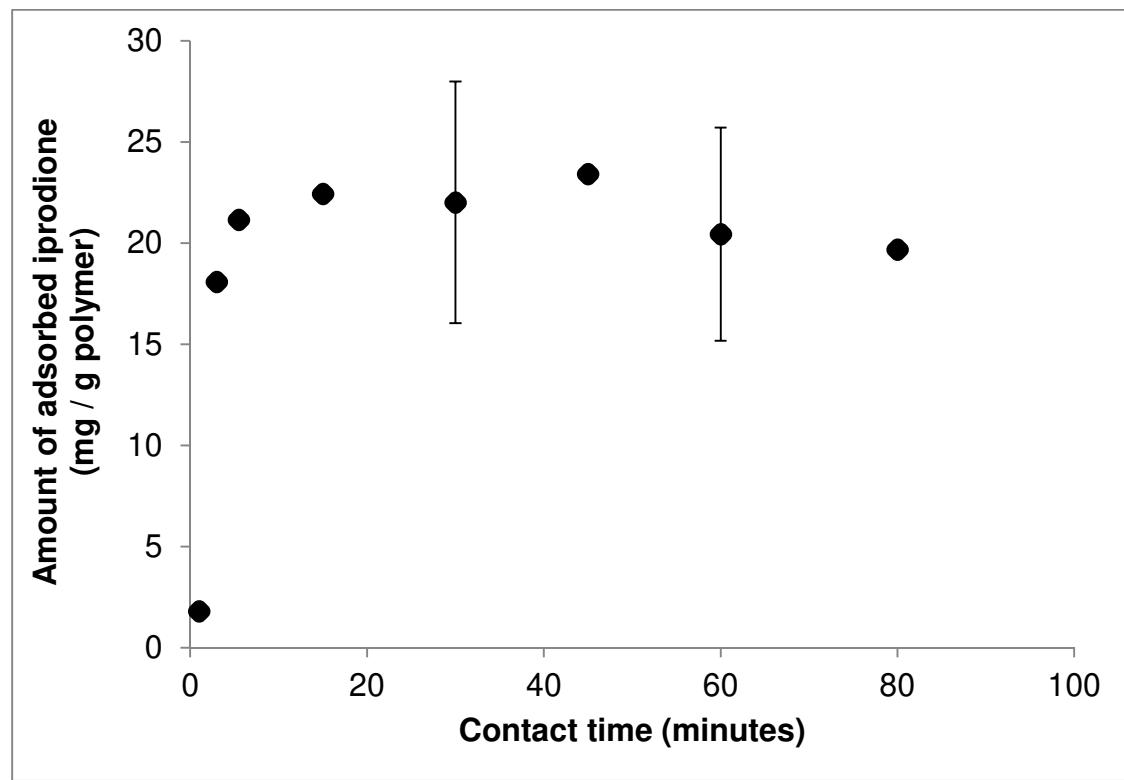
617

SU1510 5.00kV 14.9mm x30 SE 7/5/2012 11:40 1.00mm

618

619

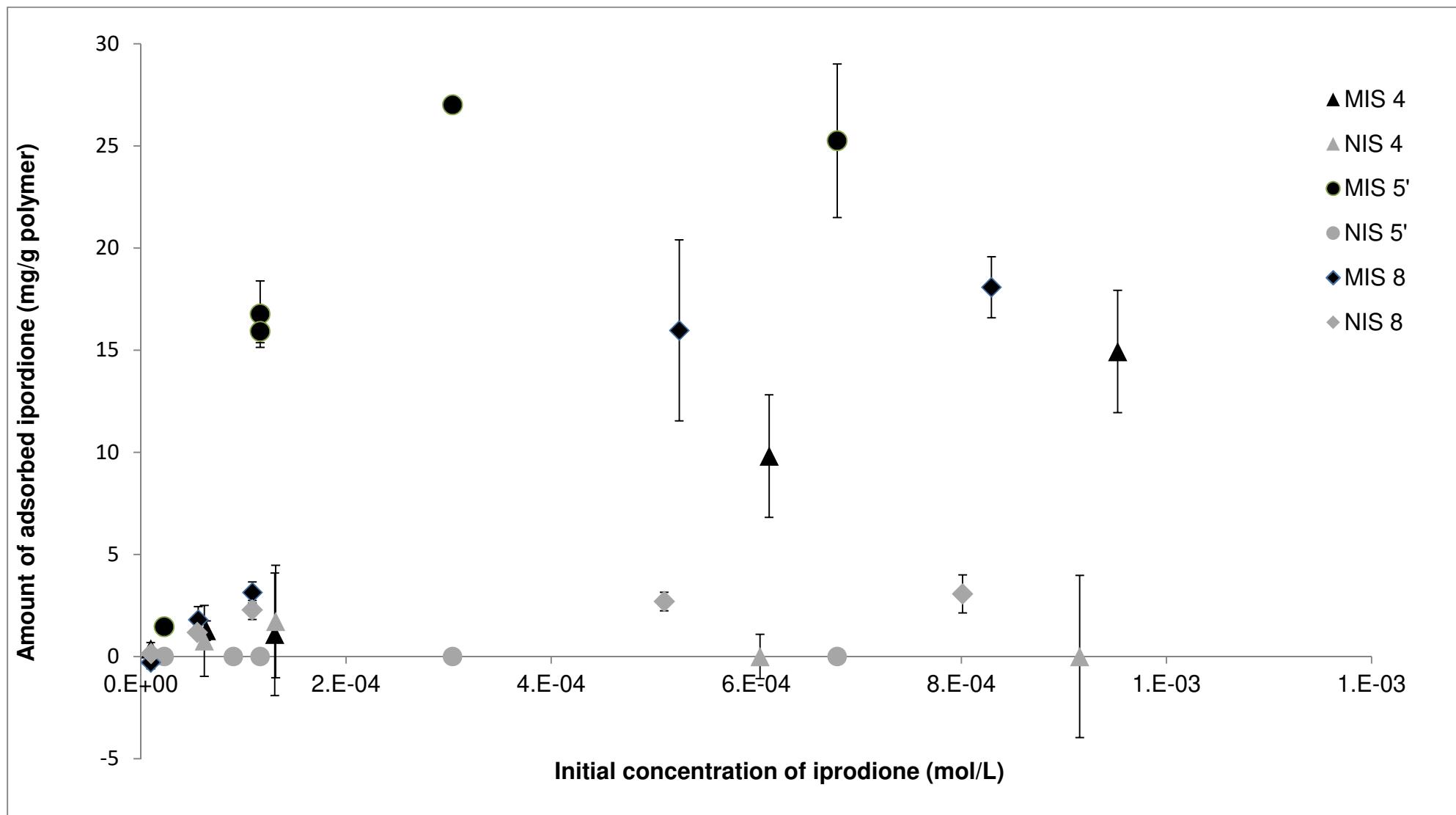
Figure 5



620

621

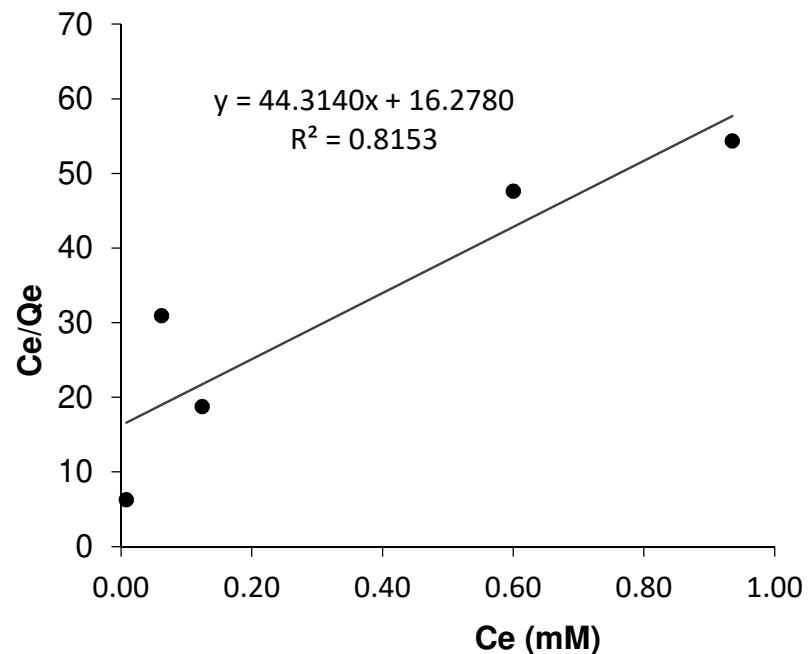
622

Figure 6

623

624 **Figure 7**

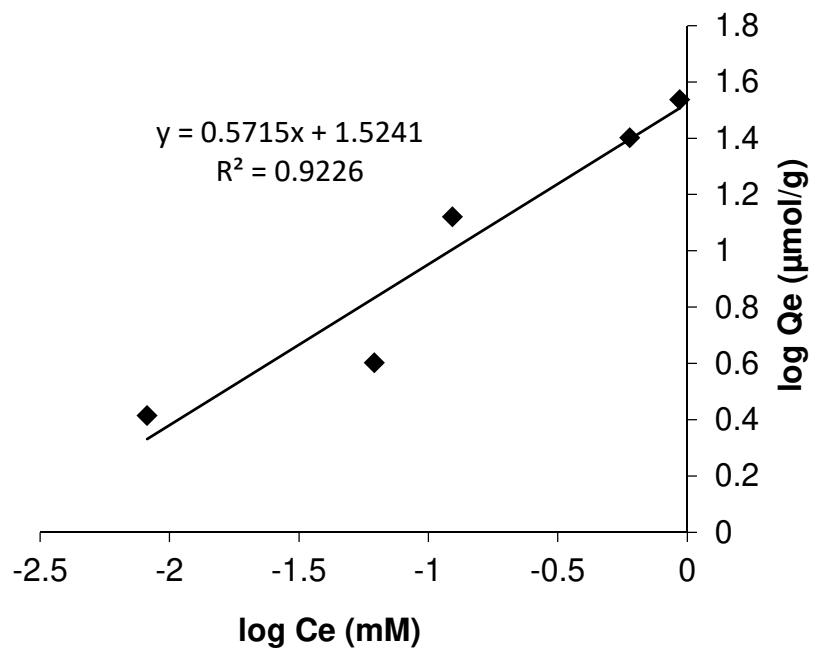
625 (a)



626

627

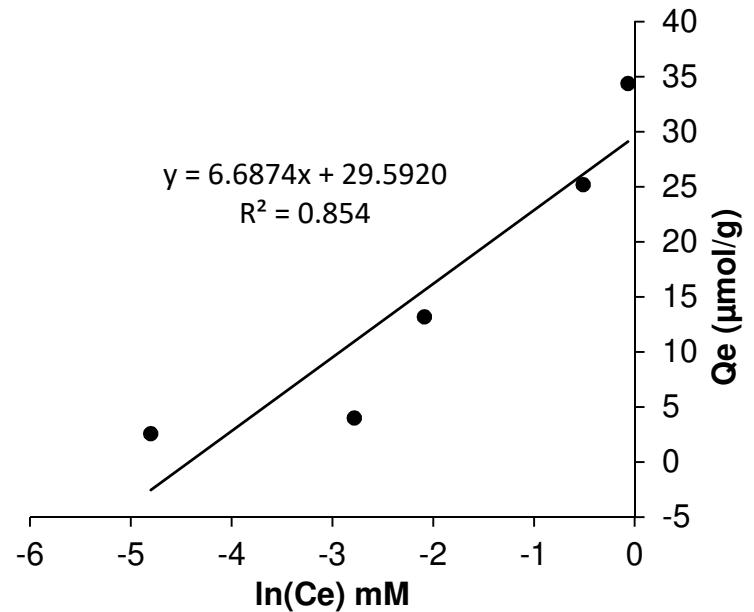
628 (b)



629

630

631 (c)

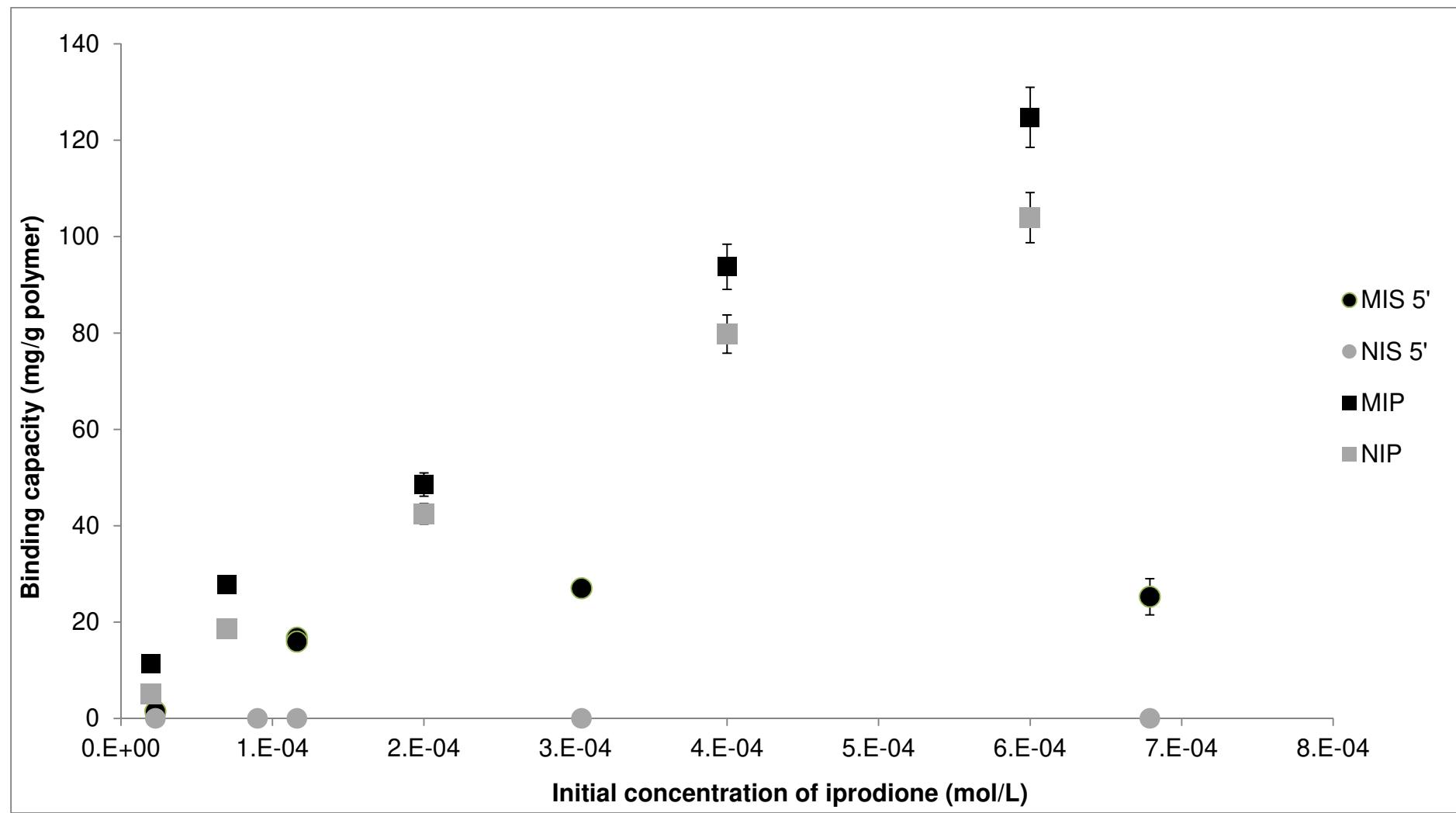


632

633

634

635

Figure 8

636

637

Table 1: Nature of molecularly imprinted polymer using fungicide as template

Nature of molecularly imprinted polymer	Template	Nature of sample	Functional monomer	Reference
Molecularly imprinted polymer (MIP)	imidazole fungicides (climbazole, clotrimazole, miconazole)	river water	methacrylic acid (MAA)	³²
	dicarboximide fungicide (iprodione)	white wine	methacrylamide (MAM)	⁸
	imidazole fungicide (climbazole)	river and tap water	methacrylic acid (MAA)	³³
	triazine (terbutylazine)	river water	methacrylic acid (MAA)	³⁴
	triazine (terbutylazine)	surface waters and an industrial effluent	methacrylic acid (MAA)	³⁵
	triazine (terbutylazine)	groundwater	methacrylic acid (MAA)	³⁶
	triazine (terbutylazine)	river water	methacrylic acid (MAA)	³⁷
	triazine (terbutylazine)	tap water and groundwater	methacrylic acid (MAA)	³⁸
	triazine (terbutylazine)	grape juice and soil extract	methacrylic acid (MAA)	³⁹
	benzimidazole fungicide (thiabendazole)	river and tape water	methacrylic acid (MAA)	⁴⁰
	chlorinated fungicide (fenarimol)	apple, banana, and tomato	methacrylic acid (MAA)	⁴¹
	benzimidazole fungicide (thiabendazole and carbendazim)	orange peel	methacrylic acid (MAA)	⁴²
	anilinopyrimidine fungicide (pyrimethanil)	red wine	methacrylic acid (MAA)	⁴³
	benzimidazole fungicide (thiabendazole)	spiked river, tap and well water	methacrylic acid (MAA)	⁴⁴
Molecularly imprinted sol-gel polymer (MIS)	triazole fungicides (triadimefon)	cucumber	methacrylic acid (MAA)	⁴⁵
	triazole fungicide (difenoconazole)	tap water and grape juice	methacrylic acid (MAA)	⁴⁶
	morpholine fungicide (dimethomorph)	ginseng powder	methacrylic acid (MAA)	⁴⁷
	dicarboximide fungicide (iprodione)	white wine	(3-Aminopropyl)trimethoxysilane (APTMS)	¹²
	dicarboximide fungicide (iprodione)	hydroalcoholic medium	(3-Aminopropyl)trimethoxysilane (APTMS)	⁴⁸

	Triazine (atrazine)	sugar cane juice	(3-Aminopropyl)trimethoxysilane (APTMS)	⁴⁹
--	---------------------	------------------	--	---------------

639

640 **Table 2:** Samples codes of different MIS and NIS synthesized for this study depending on different natures of functional monomers and different
641 molar ratios of reagents.

template / functional monomer / crosslinker molar ratio	1/4/20	1/4/20	1/4/50	1/4/59	1/4/20	1/4/20	1/4/59
Functional monomer	APTMS	APTMS	APTMS	APTMS	Urea	Aniline	Aniline
Ethanol / water ratio (mL)	2.3 / 1.3	1.15 / 0.44	1.15 / 0.44	1.15 / 0.44	2.3 / 1.3	2.3 / 1.3	1.15 / 0.44
Code number of MIS synthetized	MIS 1	MIS 4	MIS 5	MIS 5'	MIS 6	MIS 7	MIS 8
Code number of NIS synthetized	NIS 1	NIS 4	NIS 5	NIS 5'	NIS 6	NIS 7	NIS 8

642

643

644 **Table 3:** Imprinting factors obtained for MIS ans MIP depending on the nature of the solution (10 % or 50 % (v/v) ethanol / water solution). In
645 each line, mean values were calculated using three repetitions \pm standard deviation. Means with different superscripts (a – c) are significantly
646 different at $p < 0.05$ using Fisher t-test.

647

Nature of the solution	MIS 1	MIS 4	MIS 5	MIS 5'	MIS 6	MIS 7	MIS 8	MIP
from 10 % (v/v) ethanol/water solution	0.96 ± 0.11	0.99 ± 0.07	1.15 ± 0.42	nd	nd	nd	1.13 ± 0.06	nd
from 50 % (v/v) ethanol/water solution	nd	$99 \pm 31^{\text{b}}$	nd	$271 \pm 43^{\text{c}}$	nd	nd	$6 \pm 2^{\text{a}}$	$2 \pm 0.1^{\text{a}}$

648

649 **Table 4:** Adsorption isotherms constants from Langmuir, Freundlich, Temkin models obtained at 25°C with 50 % (v/v) ethanol / water solution.
 650 In each line, mean values were calculated using three repetitions \pm standard deviation. Means with different superscripts (a – c) are significantly
 651 different at $p < 0.05$ using Fisher t-test.

652

Isotherms	Constants	MIS 4	MIS 5'	MIS 8	MIP
Freundlich	r ²	0.91 \pm 0.02	0.83 \pm 0.05	0.93 \pm 0.03	0.97 \pm 0.05
	n	0.75 \pm 0.17 ^a	0.86 \pm 0.04 ^a	0.91 \pm 0.10 ^a	0.47 \pm 0.02 ^b
	K _F (mM ⁻¹)	38 \pm 5 ^a	202 \pm 35 ^c	76 \pm 11 ^b	490 \pm 24 ^d
	K _(K MIN – K MAX) (mM ⁻¹)	3.6 \pm 0.4 ^a	6.3 \pm 0.3 ^b	3.8 \pm 0.2 ^a	32 \pm 1.6 ^c
	N (μ mol/g)	12 \pm 5.2 ^a	31.8 \pm 6.7 ^b	15.5 \pm 1.8 ^a	229 \pm 11.5 ^c
Temkin	r ²	0.76 \pm 0.09	0.89 \pm 0.09	0.89 \pm 0.09	0.82 \pm 0.04
	K _T (g/ μ mol)	57 \pm 23 ^a	75 \pm 14 ^a	75 \pm 14 ^a	312 \pm 15 ^b
	B ((μ mol/g)/mM)	9.3 \pm 2.5 ^a	24.5 \pm 4.4 ^b	24.5 \pm 4.4 ^b	62 \pm 3 ^c
Langmuir	b (J/mol)	282 \pm 81 ^c	104 \pm 19 ^b	104 \pm 19 ^b	40 \pm 2 ^a
	r ²	0.30 \pm 0.45	0.61 \pm 0.13	0.43 \pm 0.36	0.80 \pm 0.04

653

Sol-gel
Molecularly Imprinted Polymer
MIS specific for Iprodione

Vs.

Acrylate
Molecularly Imprinted Polymer
MIP specific for Iprodione

