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**Tannery mixed liquors from an ecotoxicological and mycological point of view: Risks vs potential biodegradation application**

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*Original Citation:*

*Availability:*

This version is available <http://hdl.handle.net/2318/1660424> since 2018-02-21T14:56:09Z

*Published version:*

DOI:10.1016/j.scitotenv.2018.01.240

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(Article begins on next page)

**This is the author's final version of the contribution published as:**

Valeria Tigini, Federico Bevione, Valeria Prigione, Anna Poli, Lucrezia Ranieri, Francesco Spennati, Giulio Munz, Giovanna Cristina Varese, Tannery mixed liquors from an ecotoxicological and mycological point of view: Risks vs potential biodegradation application, *Science of the Total Environment*, 627, 2018, pagg. 835-843, DOI: 10.1016/j.scitotenv.2018.01.240

**The publisher's version is available at:**

<https://doi.org/10.1016/j.scitotenv.2018.01.240>

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**Link to this full text:**

<https://doi.org/10.1016/j.scitotenv.2018.01.240>

1 **TITLE:** Tannery mixed liquors from an ecotoxicological and mycological point of view: risks vs potential  
2 biodegradation application

3 **AUTHORS:** Valeria Tigini<sup>1\*</sup>, Federico Bevione<sup>1</sup>, Valeria Prigione<sup>1</sup>, Anna Poli<sup>1</sup>, Lucrezia Ranieri<sup>1</sup>, Francesco  
4 Spennati<sup>2</sup>, Giulio Munz<sup>2</sup>, Giovanna Cristina Varese<sup>1</sup>

5 **AFFILIATION:** <sup>1</sup> Department of Life Sciences and Systems Biology, University of Turin, viale Mattioli 25,  
6 10125 Turin, Italy. <sup>2</sup> Department of Environmental and Civil Engineering, University of Florence, via Santa  
7 Marta 3, 50139 Firenze, Italy.

8  
9 **\*CORRESPONDING AUTHOR:** Mailing address: Department of Life Sciences and Systems Biology,  
10 University of Turin, viale Mattioli, 25, 10125 Turin, Italy. Phone: +39-011-6705964. Fax: +39-011-6705962. E-  
11 mail: [valeria.tigini@unito.it](mailto:valeria.tigini@unito.it)

12  
13 **Abstract**

14 Fungi are known to be present in the activated sludge of wastewater treatment plants (WWTP). Their  
15 study should be at the base of an overall vision of the plant effectiveness and of effluents sanitary impact.  
16 Moreover, it could be fundamental for the implementation of successful bioaugmentation strategies aimed at the  
17 removal of recalcitrant or toxic compounds. This is one of the first studies on the cultivable autochthonous  
18 mycoflora present in the mixed liquors of two WWTP treating either vegetable or chromium tannery effluents.  
19 All samples showed a risk associated with potential pathogens or toxigenic species and high ecotoxicity  
20 (*Lepidium sativum* and *Raphidocelis subcapitata* were the most sensitive organisms). Diverse fungal populations  
21 developed, depending on the origin of the samples (63% of the 102 identified taxa were sample-specific). The  
22 use of a fungistatic was determinant for the isolation and, thus, for the identification of sample-specific species  
23 with a lower growth rate. The incubation temperature also affected the mycoflora composition, even though at  
24 lower extent. A selective medium, consisting of agarised wastewater, allowed isolating fungi with a  
25 biodegradation potential. *Pseudallescheria boydii*/*Scedosporium apiospermum* species complex was  
26 ubiquitously dominant, indicating a possible role in the degradation of pollutants in both WWTP. Other species,  
27 i.e. *Trichoderma* spp., *Trematosphaeria grisea*, *Geotrichum candidum*, *Lichtheimia corymbifera*, *Acremonium*  
28 *furcatum*, *Penicillium simplicissimum*, *Penicillium dangeardii*, *Fusarium solani*, *Scopulariopsis brevicaulis*  
29 potentially could be involved in the degradation of specific pollutants of vegetable or chromium tannery

30 wastewaters. However, several of these fungi are potential pathogens and their application, for an *in situ*  
31 treatment, must be carefully evaluated.

32

33 **Key Words:** Tannery wastewater, activated sludge, fungi, autochthonous mycoflora, ecotoxicity.

34

## 35 **1 Introduction**

36 The secondary treatments, which consist of biological processes operated with either suspended or  
37 attached biomasses, are generally the core of wastewater treatment plants (WWTPs) (Leyva-Diaz et al., 2017).  
38 The knowledge on composition and dynamics of microbial community has been fundamental for the  
39 development of biological treatment technologies (Orhon, 2015). However, studies were mainly focused on the  
40 bacterial fraction of these complex ecosystems, as well as mathematical models applied to describe the processes  
41 (Orhon, 2015). Recently, the literature has pointed out a consistent presence of autochthonous mycoflora in the  
42 activated sludge of WWTPs treating paper mill, vinery or municipal wastewaters (Grabinska-Loniewska et al.,  
43 1993; Awad and Kraume, 2011; Evans and Seviour, 2012). Its characterisation should be included in an overall  
44 vision of the effectiveness and impact of a treatment plant, considering functional, ecological and sanitary  
45 aspects (More et al., 2010; Awad and Kraume, 2011; Korzeniewska, 2011).

46 The role of fungal organisms in the depuration process has been recently demonstrated. In particular,  
47 fungi seem to perform a complementary action with respect to bacteria in the removal of pollutants from  
48 wastewaters and can actively interact with them (Liu et al., 2017; Svobodová et al., 2016; Anastasi et al., 2012).

49 The study of autochthonous fungi in WWTPs may acquire particular importance when recalcitrant or  
50 toxic pollutants are present in wastewaters, in order to improve depuration performance by bioaugmentation or  
51 biostimulation of naturally present fungi (More et al., 2010; Djelal and Amrane, 2013; Herrero and Stukey,  
52 2015).

53 Tannery wastewaters, regardless of the type of industrial process (chromium or vegetable), are among  
54 the most difficult to treat, basically on account of their recalcitrance and/or their toxicity towards bacteria  
55 (Lofrano et al., 2013). On the contrary, the ability of fungi in the degradation of tannery pollutants has been  
56 already demonstrated (Sharma and Malaviya, 2016; Zhang et al., 2015).

57 Besides the study of diversity and ecological function of the microbial community, a successful  
58 bioaugmentation strategy should contemplate the assessment of possible toxicity effects towards the biota  
59 (Herrero and Stukey, 2015). Ecotoxicity tests, associated with chemical and biological characterisations, can be a

60 informative tool for the efficiency evaluation and the management of the secondary treatment in WWTPs  
61 (Chapman, 2000). Nevertheless, these procedures are not so diffused at industrial level. This is mainly due to the  
62 lack of knowledge about the methods for data interpretation and to the complexity of the information that these  
63 analyses can provide (Chapman, 2000).

64 The present study is focused on the analysis of cultivable autochthonous mycobiota present in mixed  
65 liquors of the oxidation tanks of two wastewater treatment plants, which collect vegetable and chromium tannery  
66 effluents, respectively. Selective media were exploited for the isolation of fungi with biodegradation potential  
67 and/or the ability to compete with other microorganisms. Moreover, the samples were incubated at both 25 °C  
68 and 15 °C, in order to acquire information about the effect of seasonal temperature fluctuations on mycoflora  
69 development. Finally ecotoxicological aspects of the samples were assessed by means of four bioassays.

70

## 71 **2 Materials and Methods**

### 72 *2.1 Wastewaters*

73 The samples (three in total) were collected from two WWTPs located in Tuscany (Italy):

74 Co – mixed liquor from the aerobic tanks of Cuoioidepur vegetal tannery WWTP (San Miniato, Pisa,  
75 Italy).

76 F1 – effluent from the settler of the first aerobic stage of the chromium tannery WWTP of Consorzio  
77 Aquarno SpA (Santa Croce sull'Arno, Pisa, Italy).

78 F2 - mixed liquor from the second biological stage of chromium tannery wastewater treatment plant of  
79 Consorzio Aquarno SpA (Santa Croce sull'Arno, Pisa, Italy).

80 Cuoioidepur manages a consortial WWTP, where the effluents of about 100 tanneries, operating  
81 vegetable tanning process, are treated. The influent wastewaters are characterized by a high organic and nitrogen  
82 load ( $COD > 15000 \text{ mg L}^{-1}$ ), high salinity and by the presence of natural and synthetic tannins. The Cuoioidepur  
83 WWTP treats about  $5000 \text{ m}^3 \text{ d}^{-1}$  of tannery wastewaters and the treatment train is composed of: pretreatments,  
84 simultaneous equalization and sulphide oxidation with pure oxygen, primary settling, conventional suspended  
85 activated sludge (denitrification nitrification) biological stage and coagulation flocculation as tertiary treatment.  
86 The temperature of the biological reactors ranges between 19 °C and 35 °C, the hydraulic retention time (HRT)  
87 is about 3 days and the solids retention time (SRT) is usually between 50 and 70 d.

88 Aquarno is a joint-stock company by large majority private operating in the Tuscany tannery district for  
89 the treatment of chromium tannery wastewaters. The Aquarno WWTP treats about  $12000 \text{ m}^3 \text{ d}^{-1}$  of chromium

90 tannery wastewaters. The treatment train is composed of: pretreatments, aerobic activated sludge system (at low  
91 SRT to remove sulphide), second conventional activated sludge system for nitrogen and carbon removal, and  
92 Fenton tertiary treatment. The average temperature of the influent is in the range 25-30 °C, the HRT of  
93 biological sections is about 7 days and the SRT of the second biological stage is close to 30 days.

94

## 95 2.2 Chemical analyses

96 The pH was determined with a Hach-Lange's probe. The ammonium and metals were measured by  
97 means of a nitrogen analyser (TOC-L, Shimadzu) and an inductively coupled plasma mass spectrometry (ICP-  
98 MS) (Perkin Elmer), respectively. The Chemical Oxygen Demand (COD) and soluble Chemical Oxygen  
99 Demand (sCOD) were determined using Hach-Lange's cuvettes after filtration (at 0.45 µm). The Total  
100 Suspended Solids (TSS) were measured as the dry weight (1 hour at 105 °C) of the residue of the filtered  
101 sample. The Volatile Suspended Solids (VSS) were measured as the dry weight (30 min at 570 °C) of the residue  
102 of the filtered sample.

103

## 104 2.3 Ecotoxicity tests

105 A battery of four bioassays was performed in order to evaluate the toxicity of the samples. The target  
106 organisms were: the unicellular green alga (I) *Raphidocelis subcapitata* (Korshikov) Nygaard, Komárek,  
107 J.Kristiansen & O.M. Skulberg (UNI EN ISO 8692:2005); the dicotyledonous plants (II) *Cucumis sativus* L. and  
108 (III) *Lepidium sativum* L. (UNICHIM N. 1651, 2003); the monocotyledonous plant (IV) *minor* L. (ISO SO/WD  
109 20079). The samples were filtered (Whatman type 1) for the execution of algal test only. In fact, filtration was  
110 needed to avoid interference with the spectrophotometric lectures performed at the end of this test.

111 Each dose–response curve consisted of six dilutions (in triplicate for plant test and in quadruplicate for  
112 algal test) and the control was performed with four and six repetitions for plant and algal tests, respectively.

113 Significant differences between dose-effect regression lines were analysed using T test ( $p < 0.05$  for line  
114 slope,  $p < 0.001$  for translation), for all the possible pairs.

115

## 116 2.4 Isolation and identification of autochthonous mycoflora

117 Aliquots of 1 mL of each sample were placed in Petri dishes (16 cm diam.) containing 30 mL of culture  
118 medium. Three different media were used: a modified Malt Extract Agar (MEAp) (agar 20 g, glucose 2 g, malt  
119 extract 2 g, peptone 0.2 g, water up to 1 L); Dichloran Rose Bengal Agar (DRBC 31.5 g, water up to 1 L);

120 Wastewater-Agar (WA; agar 20 g, glucose 2 g, sample supernatant after 5 min at 10000 rpm up to 1 L). A set of  
121 three antibiotics was added to all media: streptomycin 0.015 g L<sup>-1</sup>, chloramphenicol 0.05 g L<sup>-1</sup>, and ampicillin  
122 0.05 g L<sup>-1</sup>. The trial was performed with 20 replicates for each medium and sample. Ten replicates were  
123 incubated at 25 °C and ten at 15 °C, in the dark.

124 At regular intervals of time, the colony forming units (CFU) were counted and the different fungal  
125 morphotypes were isolated in pure cultures. Fungi were identified conventionally, according to their  
126 macroscopic and microscopic features. After determination of their genera (Domsch et al., 1980; Kiffer and  
127 Morelet, 1997; von Arx 1981), they were transferred to the media recommended by the authors of selected genus  
128 monographs for species identification. Molecular identification was performed by amplification and sequencing  
129 of specific markers: actin for *Cladosporium* (Bensch et al., 2012);  $\beta$ -tubulin for *Penicillium* and *Aspergillus*  
130 (Glass e Donaldson 1995); D1/D2 region for yeasts (Fell et al., 2000); Internal Transcribed Spacer (ITS) for  
131 other genera (White et al., 1990). The resulting sequences were compared with reference sequences in online  
132 databases provided by the CBS-KNAW Collection (Westerdijk Fungal Biodiversity Institute, Utrecht, The  
133 Netherlands) and the NCBI National Center for Biotechnology Information (USA).

134 The nonparametric Mann-Whitney test ( $p \leq 0.05$ ) was run to assess the significance of the quantitative  
135 (fungal load) differences between all possible permutations of the trial. Differences within factors (tannery  
136 effluent, incubation temperature, and culture medium) were evaluated by applying a Permutational Multivariate  
137 Analysis of Variance (PERMANOVA;  $p < 0.05$ ) and visualised by Non-Metric Multidimensional Scaling  
138 (NMDS). The contribution of individual species (in percentage) to the diversity observed was assessed by  
139 SIMilarity PERcentage (SIMPER) analysis.

140

### 141 **3 Results and discussion**

#### 142 *3.1 Chemical analyses*

143 The results of chemical analyses are shown in Table 1. The pH of the samples ranged around neutral  
144 values, from 7.22 of F2 to 7.66 of Co. All tannery samples showed high values of COD (10000-24740 mg L<sup>-1</sup>)  
145 and sCOD (362-518 mg L<sup>-1</sup>). It is noteworthy that 50% of the sCOD was due to tannins in Co sample (Munz et  
146 al., 2009). Both in Co and F1, the TSS and VSS were very high ( $\geq 12.61$  g L<sup>-1</sup> and  $\geq 9.61$  g L<sup>-1</sup>, respectively),  
147 while in F2 these values decreased (7.79 g L<sup>-1</sup> and 5.77 g L<sup>-1</sup>, respectively). The ammonium was 278 mg L<sup>-1</sup> in  
148 F1 sample, whereas for Co and F2 it was 1.04 mg L<sup>-1</sup> and 9.65 mg L<sup>-1</sup>, respectively. Eventually, supernatant  
149 colour was dark brown for all the samples.

150 According to the literature, tannery wastewaters have very high COD, high nitrogen, and low phosphate  
151 concentrations (Prigione et al., 2009; Kim et al., 2013; Lofrano et al. 2013). On the whole, the three samples, Co,  
152 F2 e F1, were typical of tannery WWTPs, when compared to the data in the literature.

153

### 154 3.2 Sample ecotoxicity

155 In this work four ecotoxicity tests were applied in order to evaluate the effectiveness of tannery  
156 wastewater secondary treatment and the evaluation of potential impact of the samples on the environment.

157 The inhibition effects of samples on *Raphidocelis subcapitata* are shown in Figure 1. The maximum  
158 testable concentration was 70% for F2, 50% for Co and 40% for F1. At higher doses, the algal concentration was  
159 not detectable on account of the deep colour impact on the spectrophotometric analysis.

160 The recorded data were almost linearly distributed only for F2 and Co samples (see  $R^2 > 0.9$  in Figure 1).  
161 On the contrary, F1 points seem to be distributed according to an S-shaped curve ( $R^2 < 0.9$ ). The three tannery  
162 effluents showed no significant differences among angular coefficients of dose-effect regression lines, indicating  
163 a similar toxicity effect for the three samples. However, this elaboration is possible only for positive inhibition  
164 values, which are the minority of the recorded data. Thus, the scarcity of data exploitable for statistical analysis  
165 affected the reliability of this elaboration.

166 The results about the ecotoxicity test with *Lepidium sativum* and *Cucumis sativus* are shown in Figure  
167 2.

168 The phytotoxicity tests towards terrestrial dicotyledons (Figure 2) indicated a clear linearity between  
169 doses and effects only for F2 ( $R^2 > 0.9$ ). On the contrary, Co and F1 points are quite scattered indicating no linear  
170 relation between dose and effect, in particular towards *C. sativum*. Moreover, most of the tested dilutions  
171 resulted in negative inhibition effect (biostimulation), decreasing the number of effective data for statistical  
172 elaboration. No significant difference among angular coefficients of dose-effect regression lines was found. Also  
173 in this case, as for the algal test, the limited number of doses showing effects with positive value affected the  
174 strength of statistical elaboration.

175 *L. minor*, the tested aquatic monocotyledon, was not sensitive towards the three samples with the 0%  
176 inhibition of fronds number. Also the plant dry weight was not significantly affected by the exposition to the  
177 samples, with an average inhibition ranging from -17% to 8%.

178 By comparing the observed data, a first consideration on the sensitivity of the tested organisms towards  
179 this kind of wastewaters can be drawn. Among the three plants, *L. sativum* was the most sensitive, with



180 inhibition of 65-90% at 80% sample dose. Its higher sensitivity with respect to *C. sativus* and *L. minor* was  
181 already signalled in a study on the landfill leachate (Tigini et al., 2014). On the contrary, *L. minor* was the least  
182 sensitive, pointing out its inadequacy for the ecotoxicity assessment of different kinds of wastewaters (Tigini et  
183 al., 2014; Tigini et al., 2016). Instead the alga showed high sensitivity to the sample, comparable to *L. sativum*.  
184 The alga has been previously signalled as particularly sensitive towards textile effluents (Bedoui et al., 2015,  
185 Novotný et al., 2006). However, a comparison with the other organisms is hard to define, on account of the  
186 limits due to the analytical interference caused by the samples colour. On the other hand, this aquatic organism  
187 can relieve the so-called physical toxicity, e.g. the growth inhibition due to the decrease of light penetration that  
188 turns in the reduction of photosynthesis. Moreover, the unicellular alga could be more exposed to sample toxicity  
189 on account of its distinctive higher surface/volume ratio. Eventually, the presence of protozoa with dimension  
190 under 11  $\mu\text{m}$ , not retained by the paper filter, could have preyed the alga, reducing its growth rate at the end of  
191 the experiment.

192 Another consideration can be drawn on the effectiveness of the second phase of biological treatment of  
193 chromium tannery wastewaters (comparing F1, sampled before the second aerobic stage treatment, and F2,  
194 sampled from the mixed liquor of the second aerobic stage treatment), in terms of toxicity removal. Despite the  
195 ammonium drastically decreased, the algal test did not relieve significant difference (T test) both in slope and  
196 translation of their regression lines. On the contrary, both the terrestrial plant tests underlined a difference in the  
197 translation of the two regression lines, with an increase in wastewater toxicity after the treatment between 35-  
198 38%. The reasons of this toxicity increase should be deeper investigated, since all the main chemical features  
199 decreased after the treatment, but the phosphorous (which should not reasonably be responsible for this toxicity  
200 increase).

201 Interestingly, no difference in chromium (F2) and vegetable (Co) tannery samples of mixed liquor was  
202 detected by all tested organisms. This indicates that chromium in treated tannery wastewater is not of concern.  
203 Chromium is generally present in low concentration and in trivalent form, the less toxic one (Prigione et al.,  
204 2009). Actually, hexavalent chromium is mostly adsorbed on the activated sludge flocks. Thus, the alga could  
205 not come in contact with this pollutant, since we tested the supernatant in order to avoid spectrophotometric  
206 interference. In the other tests, we analysed the entire samples, because in these cases sample turbidity did not  
207 represent an analytical limitation. However, pollutants adsorbed on activated sludge flocks could be not  
208 bioavailable to the test organisms. As a consequence, even in this case the toxicity due to these components  
209 could be not detectable.

210 Noteworthy, at the maximum concentration, all the samples were highly toxic, even exceeding the legal  
211 threshold value (i.e. 50% for the Italian law D.L. 152/06 and further modifications). This could be due to the Cl<sup>-</sup>  
212 concentration, which exceeded 2900 mg L<sup>-1</sup> in all the samples. As a consequence, a last comment is addressed to  
213 the use of dewater excess sludge and treated wastewaters in agriculture. This procedure is seen as a desirable  
214 option, in the light of Directive 2008/98/EC, which gives added value to wastes through their integrated  
215 management, moved by the aspiration to the reduction of mineral fertilizer use (Zhang et al., 2015). The  
216 hypothesized multiple benefits for agriculture and the environment are actually to be confirmed, by evaluating  
217 also the toxicity of these wastes. On the base of the obtained results, the tested samples are still heavily toxic for  
218 different terrestrial plants. The present results are in line with another study, which warns on the possible  
219 inappropriateness of direct application of activated sludge and treated effluents (Alvarenga et al., 2007).  
220 Moreover, the assessment of their impact on the human health should be evaluated.

221

### 222 3.3 Characterisation of cultivable autochthonous fungi

223 The total fungal load of the three wastewaters was particularly high, ranging from 2630 CFU 100 mL<sup>-1</sup>  
224 (Co on WA 15 °C) to 11020 CFU 100 mL<sup>-1</sup> (F2 on DRBC 25 °C). On the whole, a total of 102 fungi were  
225 isolated from the three samples (complete list in Table A of Supplementary materials). The most abundant  
226 species and their percentage contribution to intragroup (each column) similarity are reported in Table 2.

227 There are few studies focusing on the characterisation of the cultivable mycobiota associated to tannery  
228 industries. Most of them are referred to the contamination of work environments, i.e. indoor/outdoor air,  
229 superficies, raw materials, etc. (Skóra et al., 2014; Gutarowska et al., 2014; Castellanos-Arevalo et al., 2016). In  
230 others, the mycoflora associated to samples of the final effluent was characterised (Prigione et al., 2009).  
231 Nevertheless, a common key aspect emerged about tanneries as high-risk work environments, due to the massive  
232 presence of fungal propagules in bioaerosol, up to 2800 CFU m<sup>-3</sup> (Skóra et al., 2014).

233 As far as we know, this work is one of the first reported studies focusing on a detailed analysis of the  
234 cultivable fungi present in influents and mixed liquors of a tannery WWTP.

235 In this study, several opportunistic pathogenic fungi, such as *Aspergillus fumigatus*, *Candida tropicalis*,  
236 *Geotrichum candidum*, *Lichtheimia corymbifera*, *Rhodotorula* sp., and *Pseudallescheria boydii*/*Scedosporium*  
237 *apiospermum* species complex were isolated. These fungi are emerging pathogens with an incredibly high  
238 ecological success in the last decades. They are often associated with polluted sites and their rapid spread is  
239 particularly alarming on account of their increasing impact on humans (Rougeron et al., 2015). Moreover,

240 several potential toxigenic species have been identified in this study, in particular *Aspergillus flavus* (see Table  
241 A, in Supplementary material).

242 Besides potential pathogens and toxicogenic species, even the presence of other fungi, characterised by  
243 high sporulating rate, can be considered of concern. Actually, they consistently contribute to the bioaerosol with  
244 0.65-2.1 µm diameter (classified as PM 2.5), which is one of the main professional risk factors in this field. In  
245 particular, five filamentous fungi have been determined as indicator of high health risk in tannery work  
246 environments according to their prevalence, source of isolation and health implications (Sokora et al., 2014).  
247 Noteworthy, two of them, *Cladosporium cladosporioides* and *Penicillium crustosum*, were found in this work,  
248 too.

249

### 250 3.3.1 Effect of sample origin

251 Quantitative (fungal load) differences among the three samples were significant in most cases (Figure  
252 3).

253 Co had a lower fungal load with respect of F2 and F1. It showed a similar fungal load to F2 only in  
254 MEA 15 °C and to F1 only in DRBC 15 °C. As regards the comparison between the two samples coming from  
255 chromium tannery, F2 and F1, they had different fungal loads (with the sole exception of WA 25 °C). However,  
256 which of them achieved the highest fungal load depended on the trial (F2>F1 in MEAp 25 °C, DRBC 25 °C, and  
257 DRBC 15°C; whereas F2<F1 in MEAp 15 °C, and WA 15 °C).

258 The three samples were qualitatively different, too. Among the 102 taxa, only 20 were common to all  
259 the samples. Their origin can be likely ascribable to air or working surfaces and they accidentally can be grown  
260 in WWTPs tanks. Actually, some of them are common air contaminant (e.g.. *Cladosporium* spp., *Penicillium*  
261 spp., and *Trichoderma* spp.), and can be easily sampled from outdoor environments (Skóra et al., 2014). Others  
262 are well known agents of deterioration of tanned leathers or chemicals used in this kind of industries, e.g.  
263 *Chaetomium globosum*, *Aspergillus* spp., *Fusarium* spp. (Orlita, 2004).

264 On the contrary, most of the isolated taxa were exclusive of a single sampling site. In particular, 30  
265 were exclusive of Co, 11 were exclusive of F2, and 26 were exclusive of F1.

266 The differences recorded in the fungal composition of the three tanks indicate the development of three  
267 separated ecological niches. Actually, activated sludge in WWTPs tends to form a characteristic community  
268 mainly in relation to the influent composition (Evans and Seviour, 2012). This was particularly evident with the  
269 medium DRBC, on which the fungi of the three samples showed a similarity lower than 26% (Figure 4).

270 Probably, this result was due to the inhibition of fast growing fungi caused by DRBC medium that turned in the  
271 development of sample-specific fungi.

272

### 273 3.3.2 *Effect of medium*

274 Selective media with low glucose concentration (MEAp) or fungistatic (DRBC) were adopted, in order  
275 to limit the rapid growing fungi. Actually in preliminary exploring trials they were particularly abundant in all  
276 the samples. Nevertheless, these fast growing fungi still caused the failure of isolation of some fungal colonies  
277 with a slower growth rate (indicated as “unidentified” and with taxon name ending with sp. in Table 2 and in  
278 Table A of Supplementary material). Moreover, a medium containing wastewater (WA) as principal source of  
279 carbon was used in order to select fungi with a biodegradation potential toward the main organic compounds  
280 present in the samples. The use of different media significantly affected both fungal load (Figure 3) and  
281 biodiversity (Figure 5). Intergroup dissimilarity percentages (PERANOVA test) were in the ranges of 77-100%  
282 in Co, 51-77% in F2 and 61-96% in F1.

283 In four out of six cases, samples inoculated on DRBC showed the highest fungal load. The two  
284 exceptions were Co 25 °C and F1 15 °C, in which fungal load detected on DRBC was not significantly higher  
285 with respect to other media. The higher fungal load retrieved on DRBC is probably due to its higher nutrient's  
286 concentration (up to 25 fold for N source and five fold for C source) with respect to the other media, in which  
287 the low nutrient concentration could represent a limiting factor for fungal growth. Besides, higher peptone  
288 concentration could activate fungal propagules of dormant species (Thanh and Nout, 2004).

289 In two cases of particular interest (F2 15 °C and F1 25 °C), WA showed a significantly higher fungal  
290 load with respect to MEdp. Actually WA has the same glucose concentration, but lacks of malt and peptone.  
291 Moreover, it definitively exercised a selection due to the toxicity of the wastewater used to prepare the culture  
292 medium.

293 Among the most frequent taxa, some highly sporulating fungi are present. Thus, the fungal load of these  
294 fungi could be overestimated, due to the culture dependent method used for the isolation and identification of  
295 fungi (Evans and Seviour, 2012). However, the massive presence of these fungi in such selective medium  
296 indicates at least a great tolerance to pollutants in WWTPs tanks.

297 DRBC was the richest medium in terms of taxa diversity (17-25 taxa), whereas, MEdp showed the  
298 lowest fungal biodiversity (9-21 taxa). Surprisingly, WA showed also a good biodiversity (11-21 taxa). The  
299 presence of toxic or recalcitrant substrates generally leads to the reduction of microbial biodiversity in favour of

300 the development of few species capable of tolerating such limiting factors (Cudowski et al., 2015). However, the  
301 relative abundance changed drastically, since the dominant species on WA (*Scedosporium apiospermum* up to  
302 62% in Co, *Pseudallescheria boydii* up to 51% in F1 and 52% in F2) were sporadically counted in other media  
303 (0-20%). These species, which are an anamorphic and teleomorphic forms, respectively, belonging to the  
304 *Pseudallescheria boydii* species complex, have been already signalled to degrade several xenobiotics (Claussen  
305 and Schmidt, 1998; Ishii et al., 2009; Santos and Linardi, 2004) and are typically present in human-impacted  
306 areas (Rougeron et al., 2015).

307 Even other species, present in lower percentages (8-20%), have interesting degradation capability, i.e.  
308 *Trematosphaeria* (Mabrouk et al., 2012), *Scopulariopsis* (Verma et al., 2017) and *Geotrichum* (Ayed et al.,  
309 2016).

310 The use of WA culture medium, thus, decreased the species stochastically present, enhancing the  
311 development of a few species probably active in the degradation of pollutants in the WWTPs. These fungal  
312 species could potentially belong to the theoretical 20% of determinative species in the community that cause the  
313 80% of the WWTP effectiveness, according the 20-80% ratio among cause-effect relationship (Pareto law). The  
314 knowledge of this determinative 20% species is at the base of a successful bioaugmentation strategy, since not  
315 all the species retrieved in a certain environment can effectively degrade of pollutants (Herrero and Stuckey,  
316 2015). However, since most of them imply a concrete risk for human health, their massive exploitation in open  
317 WWTPs should be accurately evaluated.

318 Intuitively, the fungi isolated from the WA media consisting of chromium tannery samples, which are  
319 subsequent in the same plant (F1 and F2) showed the highest similarity (48.6%). Whereas Co was significantly  
320 different, with similarity to both F1 and F2 lower than 29% (Figure 4). The species in Co that mostly contributed  
321 to Co dissimilarity towards the other two samples were: *T. virens*, *S. apiospermum*, *T. asperellum*, *T. grisea* and  
322 *T. capillare*. These species could be potentially involved in tannins degradation.

323 On the other hand, in chromium tannery samples, the species that mostly contributed to F1/F2  
324 dissimilarity towards Co were: *G. candidum*, *P. boydii*, *L. corymbifera*, *A. furcatum*, *T. chromospermum*, *P.*  
325 *simplicissimum*, *P. dangeardii*, *F. solani*, *S. brevicaulis*. These species, instead, could be rather involved in the  
326 degradation of pollutants present in chromium tannery wastewaters. None of these species have been reported  
327 for bioremediation of tannery wastewaters. However, several *Trichoderma* species have been signalled in the  
328 literature for biosorption of hexavalent chromium from tannery wastewaters (Shukla and Vankar, 2014).  
329 Moreover, other species of *Penicillium* and *Fusarium*, isolated from contaminated soil, have been used for

330 bioremediation experiment of tannery wastewater (Sharma and Malaviya, 2016). The role of the fungi isolated in  
331 the present study should be investigated with specific bioremediation experiments, in order to validate this  
332 hypothesis.

333

### 334 *3.4 Cultivable autochthonous fungi – effect of incubation temperature*

335 The effect of temperature on bacterial composition of activated sludge was recently assessed (Niu et al.,  
336 2015). However, no study about the effect of temperature on fungal community in WWTPs has been performed.

337 The incubation temperature significantly affected the fungal load in five cases out of nine (CFU in  
338 greater number at 15 °C for Co on DRBC and for F1 on MEAp; CFU in greater number at 25 °C for F2 on  
339 MEAp and DRBC and for F1 on DRBC) (Figure 3). The temperature affected the biodiversity too, since the  
340 PERANOVA test pointed out significant differences in all cases. However, the intragroup similarity was 60-81%  
341 for both the temperatures. This turned in a low intergroup dissimilarity percentage 29-60%, with the exception of  
342 F1 cultured on MEAp and DRBC, which achieved respectively 85% and 74% dissimilarity between the two  
343 incubation temperatures. This is visible in Figure 4, in which the two incubation temperature of F1 on MEAp  
344 and DRBC are clearly distinct (intergroup similarity lower than 40%). Temperature does not seem to determine  
345 differences in mycoflora development as medium does, which is graphically evident in Figure 5.

346 Seasonal variations in bacterial composition in activated sludge treating tannery wastewater have been  
347 already observed, in particular during the summer. However, this phenomenon seems to be more related to the  
348 different influent composition and load during that period than to the high temperature (Giordano et al., 2016).  
349 Actually, starvation period can definitively modify the bacterial composition of the activated sludge (Cabezas et  
350 al., 2009). This could be true also for fungi, whose cellular structure (with a wall cell) protects them from  
351 environmental stress.

352

## 353 **4 Conclusions**

354 This is one of the first detailed studies on the cultivable fungi present in mixed liquors in chromium and  
355 vegetable tannery WWTPs aimed at developing novel bioremediation applications. Strong differences in  
356 mycoflora indicated the development of specific fungal population in each treatment tank. This study raised  
357 some questions about the risk associated with both potential pathogens / toxigenic species and high ecotoxicity,  
358 regardless the origin or the stage of depuration. In such kind of samples, the identification of sample-specific  
359 species with lower growth rate is strongly linked to the use of fungistatic. Contrarily, incubation temperature, in

360 the range of seasonal fluctuations, does not substantially contribute to the development of different fungal  
361 species.

362 In further studies, the use of culture-independent methods based on next-gen sequencing (e.g. 454,  
363 SOLiD, and illumina, etc.) is needed, in order to achieve the complete identification of the fungi present in these  
364 kinds of samples, which are considerably rich in microorganisms.

365 From the applicative point of view, instead, a selective medium, consisting of agarised wastewater as  
366 principal source of carbon, allowed to select fungal strains that can be potentially exploited for bioaugmentation  
367 or biostimulation, with different suitability for vegetable or chromium tannery wastewaters. However, several of  
368 these species are potential pathogens and, thus, their application for *in situ* treatment must be evaluated with  
369 caution.

370

### 371 **Acknowledgements**

372 This work was supported by University of Turin, Fondazione CRT and by Ministero dell'Istruzione,  
373 dell'Università e della Ricerca (MIUR) with the FIRB project RBF13V3CH\_002 with the title "*In situ*  
374 bioaugmentation to exploit the combination of fungi and bacteria for recalcitrant compounds removal".

375 The Authors thanks Cuoiodepur Spa (San Miniato, Pisa, Italy) and Consorzio Aquarno SpA (Santa  
376 Croce sull'Arno, Pisa, Italy) which provided the samples.

377

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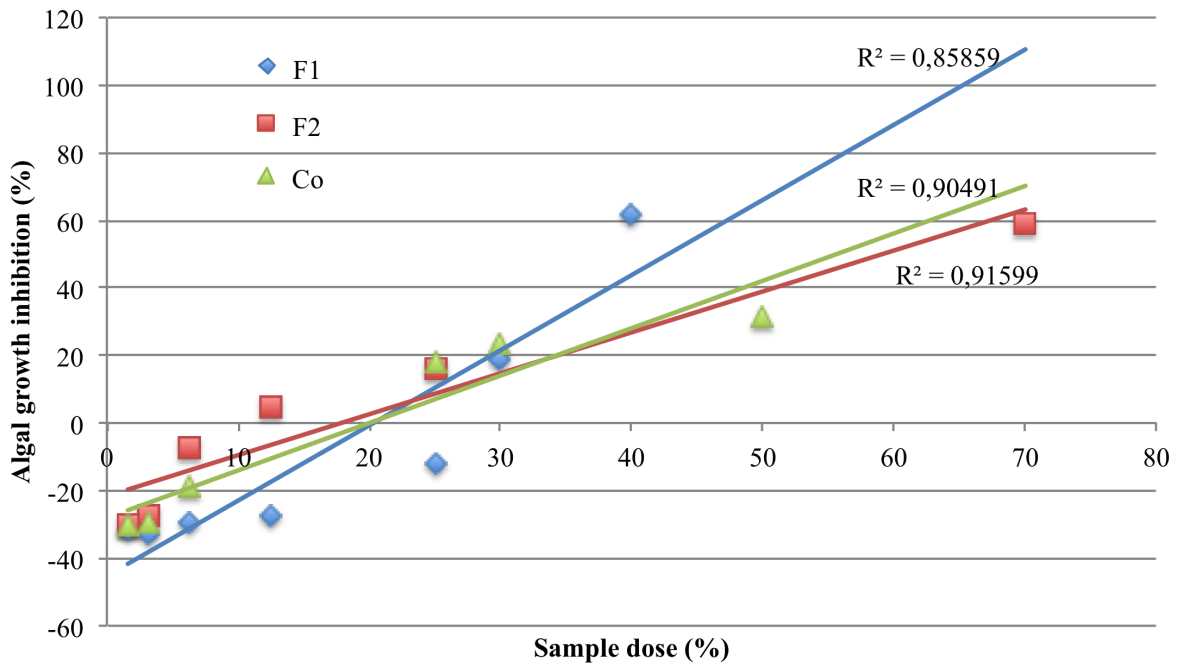
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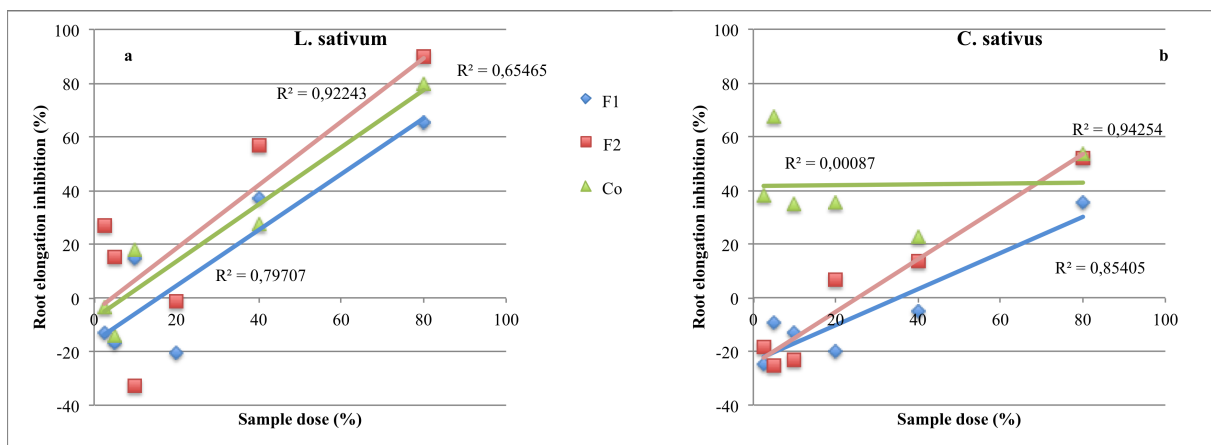
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498

499 **Figure 1. Algal growth inhibition caused by the three tannery effluents (Co, F1, and F2).**

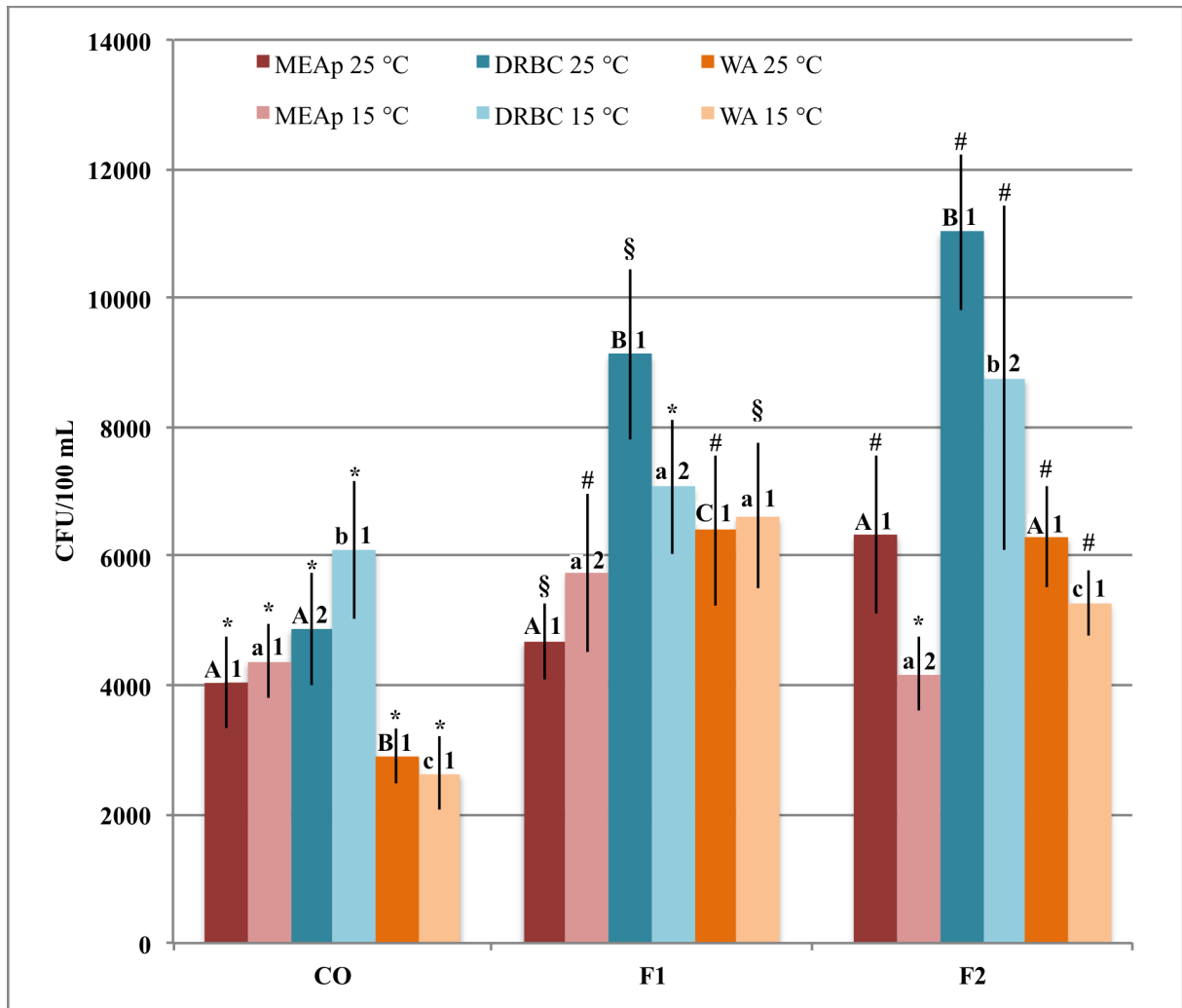
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502 **Figure 2. Phytotoxicity caused by the three tannery effluents (Co, F1, and F2).**

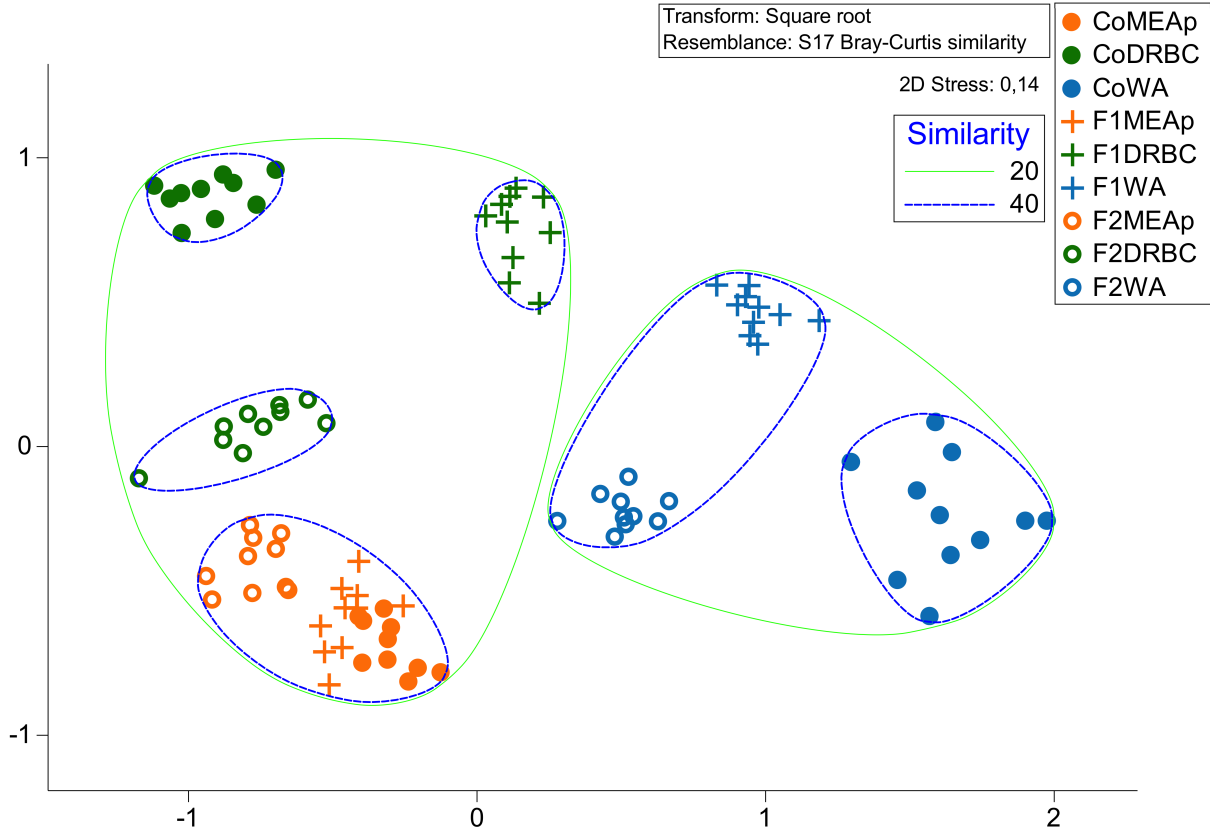
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505 Figure 3. Total fungal load of the three samples (Co, F1, and F2) inoculated on three different media  
 506 (MEAp, DRBC, and WA) and incubated at two temperatures (25 °C and 15 °C). Capital letters indicate  
 507 significant differences among fungal loads observed on different culture media at 25 °C incubation; small  
 508 letters indicate significant differences among fungal loads observed on different culture media at 15 °C  
 509 incubation; numbers indicate significant differences between incubation temperature; symbols indicates  
 510 significant differences among sample origins (Mann Whitney,  $P \leq 0.05$ ).

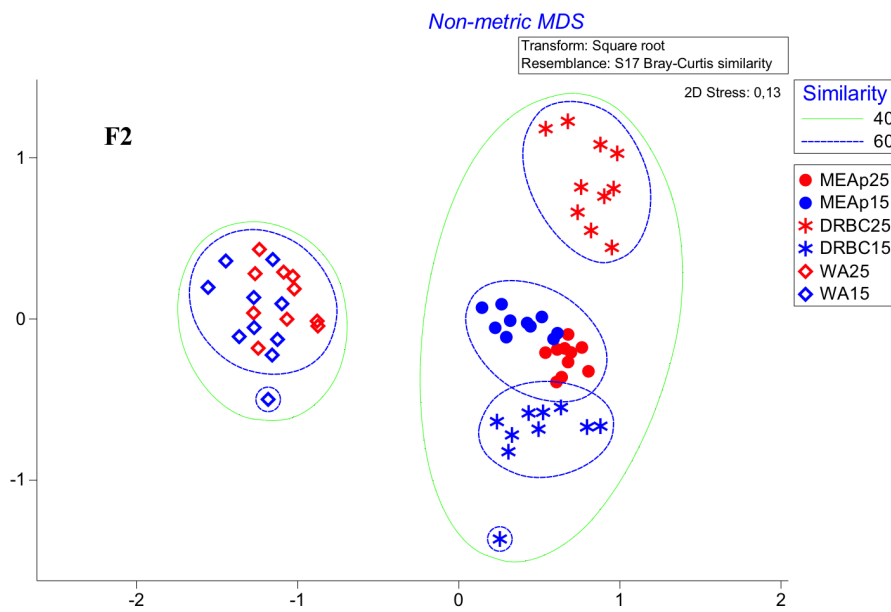
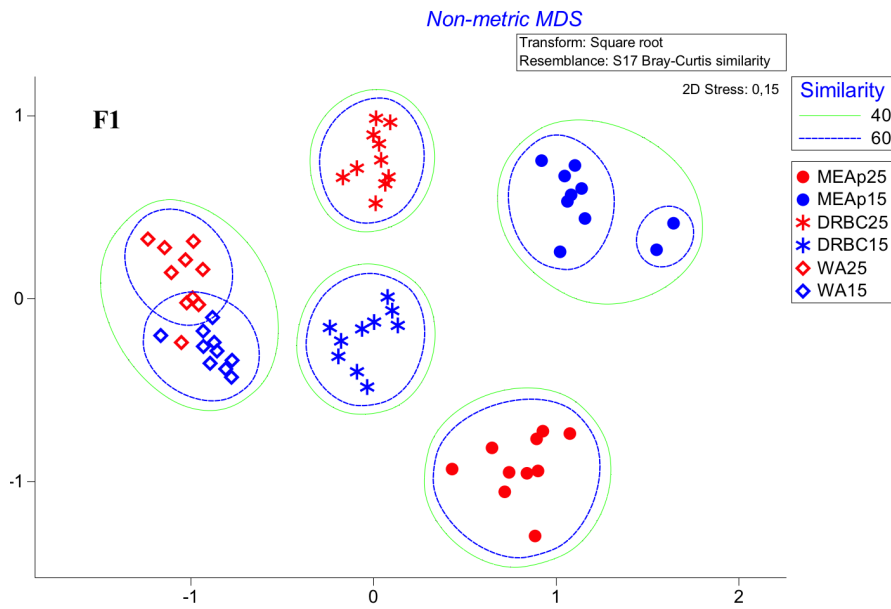
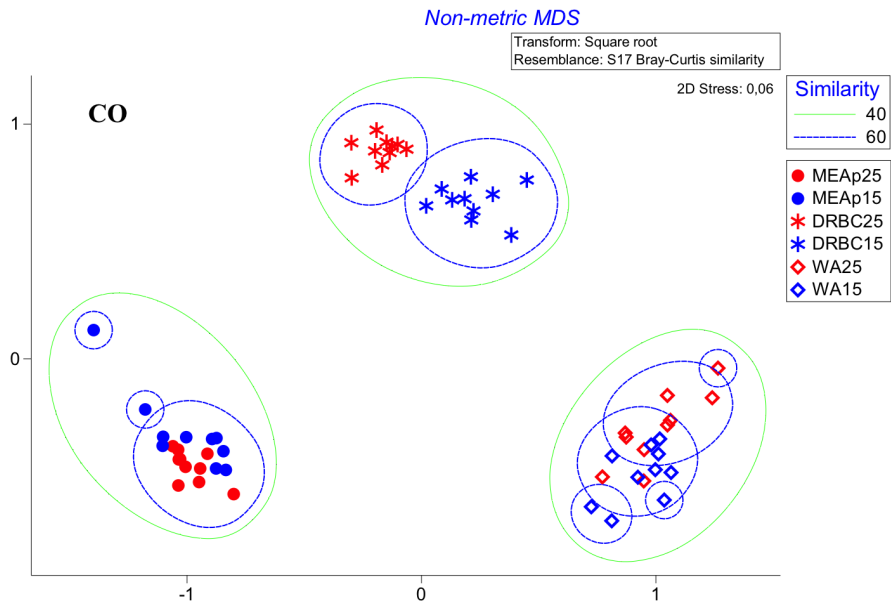
Non-metric MDS



511

512 **Figure 4. Graphical representation of similarity among the sample on the three culture media (MEAP,**  
513 **DRBC and WA for the three samples (Co, F1 and F2) incubated at 25 °C.**

514



516 **Figure 5. Graphical representation of similarity among all the trials (temperatures and culture media) for**  
 517 **the three samples (Co, F1 and F2).**

518

519 **Table 1. Samples chemical features.**

520

	Co	F1	F2
pH	7.66	7.33	7.22
Ammonium [mg L <sup>-1</sup> ]	1.04	278	9.65
Total phosphorus [mg L <sup>-1</sup> ]	5.92	2.43	3.46
Chlorides [mg L <sup>-1</sup> ]	2906	4100	4218
COD [mg L <sup>-1</sup> ]	14280	24740	10000
SCOD [mg L <sup>-1</sup> ]	362	760	518
TSS [g L <sup>-1</sup> ]	12.93	12.61	7.49
VSS [g L <sup>-1</sup> ]	10.78	9.61	5.77

528

529

530

531 **Table 2: List of the most abundant species retrieved. For each sample (Co, F1, F2), medium (MEAp,**  
 532 **DRBC, WA), and incubation temperature (25, 15 °C), contribution in percentage to the intragroup (each**  
 533 **column) similarity and total number of taxa are reported.**

534

	Sample	Co						F1						F2								
		MEAp		DRBC		WA		MEAp		DRBC		WA		MEAp		DRBC		WA				
		25	15	25	15	25	15	25	15	25	15	25	15	25	15	25	15	25	15			
Contribution (%) to intragroup similarity	<i>Acremonium furcatum</i>																			27		
	<i>Aspergillus niveus</i>																				19	
	<i>Candida tropicalis</i> var. <i>tropicalis</i>								35													
	<i>Cladosporium</i> sp.											12										
	<i>Fusarium solani</i>				9																	
	<i>Geotrichum candidum</i>	48	41						67							63	48	24	38	34	34	
	<i>Lichtheimia corymbifera</i>									30												
	<i>Penicillium simplicissimum</i>	21	21	14					37	28	11				16		13					
	<i>Pseudallescheria boydii</i>						35			20	12	36	22								47	42
	<i>Scedosporium apiospermum</i>				22	60	40				42	12	19									
	<i>Scopulariopsis brevicaulis</i>											12	13									
	<i>Trematosphaeria grisea</i>					21																
	<i>Trichoderma asperellum</i>			29	33																	
	<i>Trichoderma capillare</i>	17	13						12													
	<i>Trichoderma chromospermum</i>			12	8						15				17		12	18				
	<i>Trichoderma virens</i>			26											20							
Undetermined														43								
<b>Total n° of taxa</b>	12	18	21	19	16	20	13	21	23	17	19	21	10	9	25	17	11	20				



535  
536  
537  
538

**Table A: List of the taxa retrieved. For each sample (Co, F1, F2), medium (MEAp, DRBC, WA), and incubation temperature (25, 15 °C), the abundance of single taxa and average of total load (both expressed as CFU/mL), and total number of taxa are reported.**

	Taxa	Co						F1						F2					
		MEAp		DRBC		WA		MEAp		DRBC		WA		MEAp		DRBC		WA	
		25	15	25	15	25	15	25	15	25	15	25	15	25	15	25	15	25	15
1	<i>Absidia glauca</i> Hagem							0.1											
2	<i>Acremonium berkeleyanum</i> (P. Karst.) W. Gams					0.1													
3	<i>Acremonium furcatum</i> Moreau & V. Moreau ex W. Gams	0.1													33.9				
4	<i>Acrostalagmus luteoalbus</i> (Link) Zare, W. Gams & Schroers										0.1								
5	<i>Ascodesmis macrospora</i> W. Obrist										0.1								
6	<i>Aspergillus caespitosus</i> Raper & Thom												0.3	0.4	0.2				
7	<i>Aspergillus candidus</i> Link						0.1	0.1	0.1	0.1	0.6	0.1							
8	<i>Aspergillus carneus</i> (Tiegh.)					0.1													
9	<i>Aspergillus clavatus</i> Desm.		0.3	0.2	0.1	0.1			0.1	0.1									
10	<i>Aspergillus flavus</i> Link								0.2	0.2			0.2						
11	<i>Aspergillus fumigatus</i> Fresen.		0.1	0.7	0.1							0.1			0.2				
12	<i>Aspergillus neoniveus</i> Samson	1.4	0.7																
13	<i>Aspergillus niger</i> Tiegh.									0.1									
14	<i>Aspergillus niveus</i> Blochwitz							0.1							0.2	11.7			
15	<i>Aspergillus ochraceus</i> K. Wilh.			2.4	1.5			0.2	0.1	1.3	0.3	0.6	0.3	0.1	6	0.2	0.4		
16	<i>Aspergillus ostianus</i> Wehmer															0.1			
17	<i>Aspergillus sojae</i> Sakag. & K.									0.1									
18	<i>Aspergillus terreus</i> Thom	0.1	3.4	0.1	0.2														
19	<i>Aspergillus versicolor</i> (Vuill.) Tirab.					0.1													
20	<i>Aureobasidium</i> sp.						0.1												
21	<i>Basifimbria</i> sp.						0.5								0.1				
22	<i>Bjerkandera adusta</i> (Willd.) P. Karst.				0.1														

23	<i>Botryotrichum piluliferum</i> Sacc. & Marchal								0.1										
24	<i>Byssochlamys lagunculariae</i> (C. Ram) Samson, Houbraken & Frisvad					0.2													
25	<i>Byssochlamys nivea</i> Westling													0.1					
26	<i>Candida tropicalis</i> var. <i>tropicalis</i>	1.6	0.1					14.2									0.2		
27	<i>Chaetomium bostrychodes</i> Zopf							0.1											
28	<i>Chaetomium elatum</i> Kunze							0.4										0.2	
29	<i>Chaetomium globosum</i> Kunze ex Fr.				0.1	0.3		0.2		0.7	0.3	0.5						0.1	
30	<i>Chaetomium homopilatum</i> Omvik		0.1			0.2					4.1	3.6					0.2	4.5	
31	<i>Chaetomium pilosum</i> (C. Booth & Shipton) X.W. Wang & Crous										0.2	0.5							
32	<i>Chaetomium</i> sp.				0.4														
33	<i>Chaetomium tarraconense</i> Stchigel					0.3													
34	<i>Cladosporium cladosporioides</i> (Fresen.) G.A. de Vries					0.5		0.4											
35	<i>Cladosporium pseudocladosporioides</i> Bensch							1.1											
36	<i>Cladosporium</i> sp.				3.8	0.1					3.9					4.6	3.5	2.2	
37	<i>Cladosporium xylophilum</i> Bensch, Shabunin, Crous & U. Braun,											3.3							
38	<i>Clonostachys solani</i> f. <i>nigrovirens</i> (J.F.H. Beyma) Schroers			0.2															
39	<i>Coelomycetes</i> sp.							0.3				0.1							
40	<i>Cryptococcus humicola</i> (Dasz.) Golubev					0.2													
41	<i>Emericellopsis terricola</i> J.F.H. Beyma,											0.1						0.1	
42	<i>Eurotium</i> sp.											0.2							
43	<i>Fusarium keratoplasticum</i> D. Geiser, O'Donnell, Short et Zhang							7.2											
44	<i>Fusarium solani</i> (Mart.) Sacc.			0.1	4.2	0.2		1.9	0.2	0.1	0.2	1.3	3.3	0.1	0.2	0.8	2.8		1.8
45	<i>Geotrichum candidum</i> Link	24.2	22.2					38.3	0.3	0.3	1.4		0.3	50	26.4	28	53.1	19.2	14.6
46	<i>Gliocladium</i>	1.4	0.1																



	Thom																		
72	<i>Penicillium simplicissimum</i> (Oudem.) Thom	5.1	5.4	3.8	2.5			2.3	26.4	25.6	4.6			3.2	3.5	16.1	1.8		
73	<i>Penicillium</i> sp.			0.8	0.1			0.1	0.7	0.1	0.4		0.6			0.1	0.2		
74	<i>Petriella guttulata</i> G.L. Barron & Cain											0.1							
75	<i>Phoma sorghina</i> (Sacc.) Boerema, Dorenb. & Kesteren							0.1											
76	<i>Phoma</i> sp.					0.4													
77	<i>Pseudallescheria boydii</i> (Shear) McGinnis, A.A. Padhye & Ajello				1.1	3.1	7.6		15.4	3.9	32.8	17.5						32.6	25
78	<i>Rhodotorula</i> sp.		1.6																
79	<i>Sagenomella diversispora</i> (J.F.H. Beyma) W. Gams	0.7	0.3																
80	<i>Sagenomella</i> sp.							0.1											
81	<i>Sarocladium strictum</i> (W. Gams) Summerbell																	0.2	
82	<i>Scedosporium apiospermum</i> (Sacc.) Sacc. ex Castell. & Chalm.				12	17.9	9.5			39.3	5.7	11.4		2.4	0.4	0.7	4.2	0.7	
83	<i>Scedosporium aurantiacum</i> Gilgado					1.0	0.2									0.1	1.6	0.1	
84	<i>Scolecobasidium</i> sp.					0.1	0.7												
85	<i>Scopulariopsis brevicaulis</i> (Sacc.) Bainier								0.1		4.4	5		0.1	0.4	0.5	0.7	1.3	
86	<i>Sporormiella minima</i> (Auersw.) S.I. Ahmed & Cain														0.1	0.1		0.1	
87	<i>Stachybotrys chartarum</i> (Ehrenb.) S. Hughes																		0.2
88	<i>Talaromyces flavus</i> (Klöcker) Stolk & Samson			0.7															
89	<i>Talaromyces</i> sp.															0.1			
90	<i>Talaromyces wortmannii</i> (Klöcker) C.R. Benj.															0.7			
91	<i>Thelebolus</i> sp.						0.1												0.2
92	<i>Trematosphaeria grisea</i> (J.E. Mackinnon, Ferrada & Montemartini) S.A. Ahmed, W.W.J. van de Sande, A. Fahal & de Hoog					4.4	4.3												0.5
93	<i>Trichoderma asperelloides</i> Samuels								0.1										
94	<i>Trichoderma asperellum</i>			17.3	23.6				1.8	0.2						0.5	0.1		

	Samuels, Lieckf. & Nirenberg																		
95	<i>Trichoderma capillare</i> Samuels & C.P. Kubicek	3.9	1.7	0.1				1.3	0.2	9.0									
96	<i>Trichoderma chromospermum</i> P. Chaverri & Samuels			4.0	3.6				3.0		6.8			4.3	1.8	9.8	8.7		
97	<i>Trichoderma harzianum</i> Rifai			0.7												0.2			
98	<i>Trichoderma virens</i> (J.H. Mill., Giddens & A.A. Foster) Arx			13.8	4.1			0.1	1.2	0.8	1.6	0.1		4.7	6.8	0.8	1.1		
99	<i>Trichosporon</i> sp.			0.1	0.4														
100	Undetermined	0.4	4.1	2.6	2.6	0.3	0.6	1.4	0.2	2	10.2	7.9	18.7						0.1
101	<i>Westerdykella dispersa</i> (Clum) Cejp & Milko						0.1												
102	<i>Westerdykella</i> sp.																		0.1
	<b>Total n° of taxa</b>	12	18	21	19	17	20	13	21	23	17	19	21	10	9	25	17	11	20
	<b>Average of total CFU/mL</b>	<u>40.5</u>	<u>43.7</u>	<u>48.7</u>	<u>60.9</u>	<u>29</u>	<u>26.3</u>	<u>46.7</u>	<u>57.4</u>	<u>91.2</u>	<u>70.7</u>	<u>64</u>	<u>66.1</u>	<u>63.3</u>	<u>41.7</u>	<u>110.2</u>	<u>87.6</u>	<u>62.9</u>	<u>52.7</u>

539

540 Species common to all samples are underlined in blue; species exclusively present in Co are

541 underlined in red; species exclusively present in F1 are underlined in purple; species

542 exclusively present in F2 are underlined in green.

543

544