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1 **Development of antifungal ingredients for dairy products: from *in vitro* screening to**
2 **pilot scale application.**

3
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32 **Abstract**

33 **Biopreservation represents a complementary approach to traditional hurdle**
34 **technologies for reducing microbial contaminants (pathogens and spoilers) in food. In**
35 **the dairy industry that is concerned by fungal spoilage, biopreservation can also be an**
36 **alternative to preservatives currently used (e.g. natamycin, potassium sorbate). The aim**
37 **of this study was to develop antifungal fermentates derived from two dairy substrates**
38 **using a sequential approach including an *in vitro* screening followed by an *in situ***
39 **validation. The *in vitro* screening of the antifungal activity of fermentates derivating**
40 **from 430 lactic acid bacteria (LAB) (23 species), 70 propionibacteria (4 species) and 198**
41 **fungi (87 species) was performed against four major spoilage fungi (*Penicillium***
42 ***commune*, *Mucor racemosus*, *Galactomyces geotrichum* and *Yarrowia lipolytica*) using a**
43 **cheese-mimicking model. The most active fermentates were obtained from *Lactobacillus***
44 ***brevis*, *Lactobacillus buchneri*, *Lactobacillus casei/paracasei* and *Lactobacillus plantarum***
45 **among the tested LAB, *Propionibacterium jensenii* among propionibacteria, and *Mucor***
46 ***lanceolatus* among the tested fungi. Then, for the 11 most active fermentates, culture**
47 **conditions were optimized by varying incubation time and temperature in order to**
48 **enhance their antifungal activity. Finally, the antifungal activity of 3 fermentates of**
49 **interest obtained from *Lactobacillus rhamnosus* CIRM-BIA1952, *P. jensenii* CIRM-**
50 **BIA1774 and *M. lanceolatus* UBOCC-A-109193 were evaluated in real dairy products**
51 **(sour cream and semi-hard cheese) at a pilot-scale using challenge and durability tests.**
52 **In parallel, the impact of these ingredients on organoleptic properties of the obtained**
53 **products was also assessed. In semi-hard cheese, application of the selected fermentates**
54 **on the cheese surface delayed the growth of spoilage molds for up to 21 days, without**
55 **any effect on organoleptic properties, *P. jensenii* CIRM-BIA1774 fermentate being the**
56 **most active. In sour cream, incorporation of the latter fermentate at 2 or 5% yielded a**

57 **high antifungal activity but was detrimental to the product organoleptic properties.**
58 **Determination of the concentration limit, compatible with product acceptability, showed**
59 **that incorporation of this fermentate at 0.4% prevented growth of fungal contaminants**
60 **in durability tests but had a more limited effect against *M. racemosus* and *P. commune***
61 **in challenge tests. To our knowledge, this is the first time that the workflow followed in**
62 **this study, from *in vitro* screening using dairy matrix to scale-up in cheese and sour**
63 **cream, is applied for production of natural ingredients relying on a large microbial**
64 **diversity in terms of species and strains. This approach allowed obtaining several**
65 **antifungal fermentates which are promising candidates for dairy products**
66 **biopreservation.**

67

68 **Keywords: fungal spoilage, biopreservation, lactic acid bacteria, propionibacteria, fungi.**

69

70 **Introduction**

71 Fungal spoilage of dairy products is responsible for significant food waste and economic
72 losses (Pitt and Hocking, 2009). Dairy products, despite their acidic pH and high content in
73 organic acids, may provide a favorable environment for the development of undesirable
74 microorganisms including fungi. Fungal spoilage is usually easy to detect due to the presence
75 of colonies or thalli at the surface of the product. Nonetheless, fungal spoilage may also be
76 non-visible resulting in flavor or texture alteration via fungal metabolism (Ledenbach and
77 Marshall, 2010), thus preventing product consumption. According to the literature, species
78 belonging to the *Penicillium*, *Mucor*, *Cladosporium*, *Candida*, *Galactomyces* and *Yarrowia*
79 genera have been identified as the most common contaminating molds and yeasts,
80 respectively (Pitt and Hocking, 2009; Garnier et al., 2017a).

81 In order to avoid or delay fungal spoilage, and hence extend product shelf life, prevention and
82 control methods are currently used by industrials. Prevention methods applied in the dairy
83 industry include good manufacturing and hygiene practices, implementation of Hazard
84 Analysis Critical Control Point (HACCP) system, and use of air filtration or packaging in
85 aseptic conditions (Garnier et al., 2017a). Control methods can involve the use of heat
86 treatment, modified atmosphere packaging or fermentation with beneficial microorganisms
87 (Garnier et al., 2017a; Leyva Salas et al., 2017; Nguyen Van Long et al., 2016; Sakkas et al.,
88 2014; Bourdichon et al., 2012). In specific dairy products such as sour cream or semi-hard
89 cheese, the addition of defined chemical preservatives with antifungal properties (e.g.
90 natamycin or organic acids and their salts) is permitted depending on the regulation in place
91 (Leyva Salas et al., 2017). However, there is a strong societal demand for “preservative-free”
92 food products since consumers are looking for more “natural” (i.e. without chemical
93 preservatives) and less heavily processed foods. Therefore, industrial groups are looking for

94 efficient solutions to replace chemical preservatives while maintaining the current shelf-life of
95 food products (Varsha et al., 2016).

96 In this context, biopreservation, defined as the use of natural or added microbiota and/or their
97 antimicrobial compounds to extend food shelf-life and increase food safety (Stiles, 1996),
98 could represent a complementary approach to reduce fungal spoilage and when applicable, an
99 alternative to chemical preservatives. The use of lactic acid bacteria (LAB) and
100 propionibacteria and/or their metabolites is particularly interesting for reducing fungal
101 spoilage in dairy products (Leyva Salas et al., 2017). Indeed, LAB and propionibacteria are
102 naturally present in many foods and have a long history of safe use in fermented foods
103 (Bourdichon et al., 2012). They produce a wide range of antifungal compounds including
104 organic acids such as acetic, lactic, phenyllactic, propionic and fatty acids as well as cyclic
105 dipeptides or proteinaceous compounds (Crowley et al., 2013, Schnürer and Magnusson,
106 2005, Lavermicocca et al., 2000). Fungal inhibition generally results from the additive and/or
107 synergistic activities of several of these compounds (Varsha et al., 2016). In addition to LAB
108 and propionibacteria, some fungi can also produce antifungal compounds such as alcohols,
109 acids, esters, and proteinaceous compounds (Delgado et al., 2016, Leyva-Salas et al., 2017),
110 and their utilization could also be compatible with some dairy technologies.

111 Commercial antifungal solutions for dairy products are currently available on the market. All
112 of them involve LAB and/or propionibacteria in single or culture combinations. However,
113 their efficiency varies according to the dairy technologies in which they are used (Leyva-Salas
114 et al., 2017; Garnier et al., 2017b). These microorganisms can be used as adjunct cultures (i.e.
115 co-inoculated with the starter culture during product manufacturing) or to produce fermentates
116 (e.g. resulting from dairy substrate fermentation) added to food as an ingredient (Varsha et al.,
117 2016; Garnier et al. 2017b).

118 While there is an increasing number of studies showing the *in vitro* antifungal activity of
119 selected microorganisms and/or their metabolites for application in dairy products or other
120 foods (Leyva-Salas et al., 2017), very few have dealt with the efficiency of such antifungal
121 ingredients in real products and their potential impact on product organoleptic properties
122 (Lynch et al., 2014, Delavenne et al., 2015). Moreover, to our best knowledge, no work on the
123 development of a biopreservation ingredient to replace natamycin (E235 in the European
124 Union) for cheese surface-treatment has been reported yet in the literature.

125 The aim of this study was to develop dairy antifungal biopreservation ingredients obtained by
126 fermentation, by selected microorganisms, of 2 dairy substrates (low-heat milk -LH- and milk
127 permeate -UF-). In this framework, a sequential approach based on *in vitro* screening and *in*
128 *situ* validation at a pilot scale on actual dairy products, namely sour cream and semi-hard-
129 cheese, was used.

130

131 **Materials and methods**

132 *2.1. Fermentate production*

133 Two different dairy substrates, UF and LH, were used to prepare fermentates. The UF
134 substrate consisted of an ultrafiltration milk permeate (T.I.A., Bollene, France) supplemented
135 with 10 g/L yeast extract (Biokar Diagnosis) and 0.5 % litmus, and filtrated at 0.22 µm
136 (VWR, Radnor, USA). The LH substrate was obtained as described by Garnier et al. (2018).
137 Both substrates were then individually inoculated by 430 LAB, 70 propionibacteria or 198
138 fungal strains obtained from the Laboratoire Universitaire de Biodiversité et Ecologie
139 Microbienne (LUBEM, Plouzané, France), the Université de Bretagne Occidentale Culture
140 Collection (UBOCC, Plouzané, France, www.univ-brest.fr/ubocc) and the CIRM-BIA (Centre
141 International de Ressources Microbienne-Bactéries d'Intérêt Alimentaire, Rennes,
142 www.collection-cirmbia.fr) culture collection (Supplementary Table S1). For LAB and

143 propionibacteria strains, respectively, LH and UF substrates were inoculated with bacterial
144 MRS and YEL broth pre-cultures (Difco, Le Pont de Chaix, France) according to Garnier et
145 al. (2018), except for *Lactobacillus amylovorus*, *Lactobacillus gasserii*, *Lactobacillus*
146 *acidophilus*, *Lactobacillus delbrueckii* and *Lactobacillus fermentum* strains which were pre-
147 cultured and incubated at 37°C. *Lactobacillus sanfranciscensis* and *Lactococcus lactis* strains
148 were pre-cultured in MRS and M17 supplemented with 20 g/L maltose, respectively (Difco,
149 Le Pont de Claix, France). For yeasts, LH and UF media were inoculated (1% v/v) after 2 pre-
150 cultures (24 h at 25°C, 120 rpm agitation speed) in Yeast Glucose Chloramphenicol (YGC)
151 broth (Difco, Le Pont de Claix, France), and incubated for 48 h in the same conditions.
152 Concerning molds, they were first cultivated on Potato Dextrose Agar (PDA) slant for 7 d at
153 25°C. After spore recovery with 0.01 % Tween 80 and enumeration using a Malassez cell, LH
154 and UF media were inoculated at 10⁴ spores/ml and incubated for 96 h at 25°C on a rotary
155 shaker at 120 rpm. Yeast and mold fermentates were centrifuged three times (8000g at
156 15 min), the cell pellets were discarded and the final supernatant was filter-sterilized at
157 0.45 µm (VWR, Radnor, USA). Fermentates were then stored at -80°C until use. For pilot
158 scale applications, fermentates were produced in 2 to 5-L flasks. Bacterial fermentates were
159 lyophilized (Virtis, Fisher, France, final residual water < 2 % after freeze drying under
160 vacuum) while fungal fermentates were prepared as previously described.

161

162 2.2. In vitro screening of antifungal activity

163 The antifungal activity of the obtained fermentates against *Mucor racemosus* UBOCC-A-
164 116002, *Penicillium commune* UBOCC-A-116003, *Galactomyces geotrichum* UBOCC-A-
165 216001 and *Yarrowia lipolytica* UBOCC-A-216006, isolated from spoiled dairy products and
166 representative of the most common dairy product spoilers (Garnier et al., 2017b), was

167 evaluated *in vitro* using a high-throughput screening method in a cheese-mimicking model as
168 described by Garnier et al. (2018).

169

170 *2.3. Optimization of culture conditions for antifungal activity enhancement*

171 Bacterial (n=12) and fungal (n=1) fermentates exhibiting the highest antifungal activity were
172 selected for an optimization step of culture conditions. Depending on the considered
173 microorganism, 5 time/temperature combinations were tested: 20, 48 and 72 h at 30°C as well
174 as 48 h at 30°C followed by 24 h at either 12°C or 43°C for LAB; 48, 72 and 96 h at 30°C as
175 well as 96 h at 30°C followed by 24 h at either 12°C or 43°C for propionibacteria and 48, 96
176 and 168 h at 25°C as well as 96 h at 25°C followed by 48 h at either 12°C or 43°C for
177 filamentous fungi. Cell concentration at the end of incubation was determined on MRS and
178 YEL agar for LAB and propionibacteria, respectively. Antifungal activities of the resulting
179 fermentates were tested as described above against the four selected target fungal spoilers.

180

181 *2.4. In situ antifungal activity*

182 *2.4.1. Antifungal activity by fermentate surface-spraying on semi-hard cheese*

183

184 Fermentates with promising antifungal activities were tested *in situ* by surface-spraying on
185 semi-hard cheeses (Table 2). Two replicate cheese trials were carried out at a pilot scale on
186 two separate weeks at the Dairy Platform of INRA (Rennes, France). Cow's milk was
187 pasteurized at 72°C for 20 s, standardized to 30 g fat/kg milk and pumped into a cylindrical
188 jacketed, stainless steel cheese vat, with variable speed cutting and stirring (Frominox, Assat,
189 France). Milk was supplemented with 36 mg Ca per kg (20 mL per 100 kg milk of a 500 g/L
190 CaCl₂ solution). A commercial starter culture consisting of *Lactococcus lactis* subsp. *lactis*
191 and *Lactococcus lactis* subsp. *cremoris* (MA016, Elimeca, Thoissey, France) was

192 resuspended in UHT semi-skimmed milk, left to rehydrate for 1 h at 20°C and added to the
193 cheese milk at 0.5 U/100 kg, i.e. $\sim 10^6$ CFU/mL. After 2 h at 12°C followed by 30 min pre-
194 ripening at 33°C (pH 6.57), 0.25 mL/kg of animal rennet (520 mg/L chymosin, Carlina
195 145/80, Dupont Danisco, Dangé, Saint Romain, France), diluted in deionized water, was
196 added. After coagulation for 29 min, curd was cut at the size of corn grains, washed with hot
197 water, cooked for 20 min at 35 °C and drained (pH 6.54). Curd was pre-pressed at 120 kPa for
198 30 min, moulded (700 g curd per mould) and pressed at 300 kPa for 30 min then 600 kPa for
199 90 min. The cheeses remained overnight in the mould, the temperature decreased from $\sim 25^\circ\text{C}$
200 to $\sim 20^\circ\text{C}$ and the pH reached 5.07 at demoulding. Cheese composition at this step was 50.8 %
201 dry matter and 49 % fat in dry matter. Cheeses were salted by immersion in a sterile brine
202 containing 33 % (w/w) NaCl, 36 mg Ca per kg, pH 5 at 20 °C for 2 h. Cheeses were left to
203 dry for one night at room temperature (20-25°C). Then, in a laminar air flow cabinet, the
204 external surface (3 mm in thickness) was removed to limit surface contamination. Cheeses
205 were then smeared once with a mixture of the following commercial cultures: *Debaryomyces*
206 *hansenii* CHOOZIT DH, *Kluyveromyces lactis* CHOOZIT KL71, and *Brevibacterium linens*
207 CHOOZIT SR3 (Danisco, Dangé Saint-Romain, France). After 2 h drying at room
208 temperature in a laminar air flow cabinet, 3 ml of fermentates (bacterial lyophilized
209 fermentates being resuspended either in sterile distilled water or in filter-sterilized *M.*
210 *lanceolatus* fermentate), alone or in combination, were sprayed on the cheese surface. On day
211 2, after a 12h drying period at room temperature following the first spraying, cheese surface
212 was inoculated with 50 spores of either *P. commune* UBOCC-A-116003 or *M. racemosus*
213 UBOCC-A 116002. Fermentate spraying was then repeated on day 3 and 5. Cheeses were
214 ripened for 6 weeks in ripening chambers at 12°C and 96% relative humidity (one ripening
215 chamber per fungal target). The ripened semi-hard cheeses had a final dry matter of 60% and
216 pH 5.5. Fungal growth was visually evaluated every day during the 6 ripening weeks. A

217 negative control (cheese without surface fermentate spraying) and a positive control (cheese
218 surface treated with 1 mg/dm² natamycin on day 2) were also included.

219

220 2.4.2. Antifungal activity by fermentate incorporation in sour cream

221 Various fermentates, alone or in combination, were also tested by incorporation in sour cream
222 (Table 2). To do so, cream (final fat 33%, dry matter 41%) was produced at a pilot scale from
223 pasteurized milk (16s at 75°C) and fermented at 23°C for 22h using 2.5 U/100 kg (10⁶
224 CFU/L) of commercial starter cultures MM100 (Elimeca, Thoissey, France). Sour cream (pH
225 4.5) was then packaged in individual 100g containers. Various fermentate concentrations
226 ranging from 0.1 to 5 % were tested according to the selected fermentate (Table 2). The
227 fermentates were added directly in each container, gently mixed and stored at 10°C overnight
228 before fungal target inoculation. A negative control (sour cream without fermentate) and a
229 positive control (sour cream containing 0.08 % potassium sorbate) were also included. For
230 challenge tests with filamentous fungi, 50 fungal spores of *P. commune* UBOCC-A-116003 or
231 *M. racemosus* UBOCC-A 116002 were inoculated on the sour cream surface followed by
232 incubation at 10°C for 4 weeks. Fungal growth was visually evaluated every day. For
233 challenge test with *Rhodotorula mucilaginosa* UBOCC-A-216004, 2 CFU/g were inoculated
234 in the sour cream, followed by gentle mixing and incubation at 10°C. Yeast growth was
235 evaluated by surface-plating after 1, 2 and 3 weeks on YGC agar incubated at 25°C for 2
236 days.

237

238 2.4.3. Durability tests

239 Durability tests were performed to evaluate fermentate antifungal activity in naturally
240 contaminated environments. For semi-hard cheese, growth of spoilage fungi was evaluated on
241 the surface of 3 different cheeses sprayed or not with selected fermentates and after ripening

242 for 6 weeks at 12°C in a ripening chamber. For sour cream, 100 g of sour cream with or
243 without fermentate, and a control containing 0.08 % potassium sorbate were spread out in 10
244 Petri dishes, exposed for 20 min to indoor air of the lunch room at INRA STLO and then
245 sealed using parafilm. Fungal spoilage at the surface was visually evaluated after 2-weeks
246 incubation at 10°C.

247

248 2.4.4. Sensory analyses

249 To evaluate the potential impact of antifungal fermentates on the sensorial properties of
250 tested products, a sorting task was performed by a panel of 39 and 29 untrained judges for
251 cheese and sour cream, respectively. Sour cream, packed in 100 g containers, was kept at 4°C
252 for 2 weeks before sensory analysis and semi-hard cheese were tested after a 6 week ripening
253 period. Products were left for 30 min at room temperature before being served and a random
254 3-digit code was assigned to each sample. Panelists were asked to group together the samples
255 perceived as the most similar, taking into account the characteristics they considered as
256 important to differentiate the products (free sorting task). Once groups were made, panelists
257 were asked to associate specific descriptors to each group (verbalization task). To ensure the
258 panelist ability to group similar samples, a random sample was tested in duplicate. Sorting
259 task data were analyzed by the Factorial Approach for Sorting Task data (FAST) using
260 multiple correspondence analysis (MCA) via the FactoMineR and SensoMineR packages
261 implemented in the R environment, according to Cadoret et al. (2009). In particular,
262 confidence ellipses were drawn to also provide validation elements

263 To define the concentration of the selected fermentate at which no sensory impact could
264 be perceived in sour cream, an acceptability test was performed with a panel of 26 untrained
265 judges. Eight fermentate concentrations ranging from 0 to 0.7 % were tested. As for sensory
266 tests, a random 3-digit code was assigned to each sample and products were left for 30 min at

267 room temperature before being served. Panelists were asked to indicate whether each sour
268 cream sample was acceptable or not for consumption.

269

270 **3. Results**

271 3.1. *Antifungal activity of fermentates after in vitro screening*

272 In the first part of this work, the antifungal activity of fermentates obtained by individual
273 culture of 698 LAB, propionibacteria or fungi in both LH and UF substrates (thus for a total
274 of 1 396 fermentates) was evaluated *in vitro* against 4 fungal targets in a cheese-mimicking
275 model. The number of fermentates exhibiting antifungal activity largely varied according to
276 the substrate used for fermentation, the tested taxon, and the fungal target (Supplementary
277 table S2).

278 LH fermentates were overall notably more inhibitory than UF fermentates with LAB
279 being the most represented microbial group among active strains. Regarding LH fermentates,
280 81 (18.9 %), 13 (3 %), and 1 (0.2 %) LAB fermentates out of the 430 tested ones, were active
281 against *P. commune*, *M. racemosus*, and *Y. lipolytica*, respectively, while no propionibacteria
282 out of the 70 tested showed any activity. For fungal fermentates, 2 (1 %) and 6 (3 %) out of
283 the 198 tested ones were active against *M. racemosus* and *G. geotrichum*, respectively. In
284 contrast, for UF fermentates, only fermentates from 8 LAB (1.8 % of tested LAB), 1
285 propionibacteria (1.4 % of tested propionibacteria) and 4 fungi (2 % of tested fungi) showed
286 an antifungal activity, and this against only one target.

287 Among the 27 tested bacterial species, *Lactobacillus buchneri* (n=34), *Lactobacillus*
288 *plantarum* (n=115) and *Lactobacillus brevis* (n=8) represented the most active species with
289 44.1, 40.8 and 37.5 % of active LH fermentates against at least one target. Noteworthy,
290 9 LAB LH fermentates showed an antifungal activity against both *M. racemosus* and
291 *P. commune*, while a *L. buchneri* L162 fermentate inhibited the latter 2 fungi and *Y. lipolytica*

292 as well. In contrast, in the tested conditions, only a few strains of *Lactobacillus reuteri* (n=42)
293 and *Propionibacterium jensenii* (n=20) showed antifungal activity, with 1 (2.4 %) and 1 (5 %)
294 active strains for LH and UF fermentates, respectively. In addition, *Leuconostoc*
295 *mesenteroides* (n=71), *Propionibacterium acidipropionici* (n=17) and *Propionibacterium*
296 *thoenii* (n=14) strains did not show any antifungal activity whatever the substrate used.

297 As mentioned above, only a few fungal fermentates showed antifungal activities and there
298 was no particular over-represented species whatever the substrate used. Indeed, for LH
299 fermentates, one isolate of *Aureobasidium pullulans* and *M. lanceolatus*, and *Exophiala* sp.,
300 *Rhodotorula minuta*, *Rhodotorula mucilaginosa*, *Torulaspora delbrueckii* and *Trichoderma*
301 *viride*, led to fermentates active against *M. racemosus* and *G. geotrichum*, respectively. For
302 UF fermentates, one isolate of *Actinomucor elegans*, *Verticillium dahliae* and *Candida tenuis*,
303 and *Trichoderma harzianum* produced fermentates active against *P. commune* and *Y.*
304 *lipolytica*, respectively.

305 Concerning the susceptibility of the fungal targets, *P. commune*, followed by *M.*
306 *racemosus* were the most frequently inhibited fungi, while *G. geotrichum* and *Y. lipolytica*
307 were only inhibited by a very small number of LAB or propionibacteria fermentates.
308 Interestingly, for fungal fermentates, *M. racemosus* and *G. geotrichum* were the most
309 sensitive targets with LH as a growth substrate whereas it was *P. commune* and *Y. lipolytica*
310 with UF substrate.

311 After *in vitro* screening, 11 strains exhibiting the most promising antifungal activity,
312 namely 9 *Lactobacillus* strains (*L. buchneri* L151, L162, L164 and L233, *L. harbinensis*
313 L172, *L. paracasei* L117 and L194, *L. plantarum* L244 and *L. rhamnosus* CIRM-BIA1952),
314 *P. jensenii* CIRM-BIA1774 and *M. lanceolatus* UBOCC-A-109193 were selected for further
315 investigation.

316

317 3.2. *Optimization of culture conditions for antifungal activity enhancement*

318 The 11 strains previously selected were inoculated and cultivated in LH and/or UF substrate
319 with 5 different time/temperature combinations, and the antifungal activity of the obtained
320 fermentates were tested against the 4 selected fungal targets in the cheese model. Increases in
321 antifungal activity against at least one fungal target were observed for all strains when culture
322 conditions were modified (Table 1). Activity improvement was more pronounced against
323 *P. commune*, followed by *R. mucilaginosa* and *M. racemosus*, whereas there was little
324 improvement against *Y. lipolytica*. The increase in time before visible growth, which varied
325 between 1 to 4 days as compared to the control depending on the tested strain, was generally
326 higher in conditions with prolonged incubation time with the exception of *L. paracasei* L117
327 fermentate for which incubation for 20 h at 30°C yielded the best antifungal activity.
328 Increases in antifungal activity were also generally related to the final cell concentration at the
329 end of the incubation even though this was not systematically observed. Finally, a final
330 incubation step at suboptimal temperatures did not improve the antifungal activity except for
331 *L. buchneri* L233, *M. lanceolatus* UBOCC-A-109193 and *P. jensenii* CIRM-BIA1774
332 fermentates for which a significant increase in antifungal activity against *P. commune* and
333 *M. racemosus*, and *M. racemosus* and *R. mucilaginosa*, respectively, was observed (Table 1).
334 After this step, 3 fermentates were selected for *in situ* applications at a pilot scale, namely
335 those of *L. rhamnosus* CIRM-BIA1952 (cultivated in LH for 48 h at 30°C) which was able to
336 delay *P. commune* and *R. mucilaginosa* growth, *P. jensenii* CIRM-BIA1774 (cultivated in UF
337 for 96 h at 30°C followed by 24 h at 12°C), which was able to delay the growth of the 4 tested
338 fungal targets, and *M. lanceolatus* UBOCC-A-109193 (cultivated in LH for 96 h at 30°C
339 followed by 48 h at 12°C) which was able to delay *M. racemosus* and *P. commune* growth.
340

341 3.3. *Antifungal activity and organoleptic impact of fermentates after surface-spraying*
342 *on semi-hard cheeses*

343 The 3 fermentates selected after the optimization step were used, alone or in combination
344 (either *L. rhamnosus* or *P. jensenii* fermentate associated with *M. lanceolatus* fermentate), for
345 surface treatment of semi-hard cheeses manufactured at a pilot-scale. The observed times to
346 visible growth of *M. racemosus* and *P. commune* after the challenge test are presented in
347 Table 2. Surface-spraying of each of the tested fermentates led to an increase in time to visible
348 growth of both fungal targets as compared to the negative control (untreated cheese), but their
349 efficiency varied. For example, the *L. rhamnosus* / *M. lanceolatus* and *P. jensenii* /
350 *M. lanceolatus* combinations increased the time to visible growth of *M. racemosus* by 3 and
351 15 days, respectively. The same combinations increased the time to visible growth of
352 *P. commune* by 2 and 7 days, respectively. The most efficient fermentate was that of
353 *P. jensenii* CIRM-BIA1774, which inhibited *M. racemosus* and *P. commune* for up to 21 and
354 14 days, respectively. No visible growth of the fungal targets was observed after natamycin
355 application during the time of the experiment (33 days). Interestingly, we did not observe any
356 effect of the fermentates on the smear development, while that of the cheese treated with
357 natamycin was considerably reduced (data not shown).

358 The strong antifungal activity of the fermentates after surface-treatment of semi-hard cheeses
359 was further confirmed by the durability test results. As shown in Figure 1, control cheeses
360 (untreated) were almost completely covered with mold after 6 week incubation at 10°C in a
361 naturally contaminated ripening chamber, whereas the fermentate treated cheeses appeared
362 with a much smaller surface covered by mold, with the exception of 1 out of 3 replicate
363 treated with *P. jensenii* fermentate.

364 The results of the multiple correspondence analysis made from cheese sensory data are
365 presented in Figure 2. The total variance explained by the first two dimensions was 62 %,

366 with Dim 1 and Dim 2 representing 34 and 28 % of variance, respectively. The panelists
367 could differentiate all cheeses except the cheese treated with *P. jensenii* fermentate which
368 could not be differentiated from other samples including the control cheese.

369

370 3.4. Antifungal activity and organoleptic impact of fermentates after incorporation in sour 371 cream

372 Tested concentrations were initially 2 and 5 % (w/w) of each fermentate and a mixture of both
373 fermentates at 2.5 % (w/w) each. Once again, the *P. jensenii* CIRM-BIA1774 fermentate,
374 alone or in combination with *L. rhamnosus* CIRM-BIA1952 fermentate, showed a high
375 antifungal activity (similar to that of potassium sorbate) against *M. racemosus* and
376 *P. commune*. It delayed their growth up to 30 days (total duration of the experiment) as
377 compared to the negative control (Table 2). All fermentates containing *P. jensenii* totally
378 inhibited *R. mucilaginosa* growth (counts <1 CFU/g) during storage, while that of
379 *L. rhamnosus* did not show any antifungal activity (Figure 3).

380 Durability tests confirmed the trends observed with the challenge tests as none of the samples
381 containing *P. jensenii* CIRM-BIA1774 fermentate showed any visible fungal contamination
382 (Figure 4). In contrast, samples containing *L. rhamnosus* CIRM-BIA1952 fermentates at 2
383 and 5 % were only slightly less contaminated than control samples with 90 and 80 % of
384 samples showing visible fungal contamination, respectively.

385 In the multiple correspondence analysis, the total variance explained by the two first
386 dimensions was 61 %, with Dim 1 and Dim 2 representing 37 and 24 % of variance,
387 respectively (Figure 5). The overlapping of the confidence ellipses of the control sample and
388 sour cream with 2 % *L. rhamnosus* fermentate showed that these samples were perceived as
389 similar by the panelists. Samples containing *P. jensenii* fermentates were grouped together
390 and clearly separated from the control on Dim 1, while sour creams containing 5 % *L.*

391 *rhamnosus* CIRM-BIA1952 fermentate were separated from the control on Dim 2, indicating
392 that panelists could perceive significant sensory differences between these samples. Sour
393 creams with *P. jensenii* CIRM-BIA1774 fermentate were described as very unpleasant,
394 strong, and acid, showing a high negative impact of this fermentate on the product flavor
395 while sour creams with 5 % *L. rhamnosus* CIRM-BIA1952 fermentate were described as dry,
396 pasty or burnt showing an impact on texture and flavour.

397 Based on these results, using an acceptability test, we investigated the concentration of
398 *P. jensenii* fermentate at which no organoleptic impact could be perceived in sour cream
399 (Supplementary Figure 1). Acceptability decreased with increasing fermentate concentrations.
400 Among the 26 panelists, 21 (80.8 %) accepted the control sour cream while only 6 (23.1 %)
401 accepted the product with 0.7 % *P. jensenii* fermentate. The 21 panelists who did not reject
402 the sour cream also accepted the sour cream containing 0.1 % *P. jensenii* fermentate, while 10
403 panelists (47.6 %) accepted that containing 0.4 % *P. jensenii* fermentate. These 2
404 concentrations were selected for further challenge and durability tests.

405 For challenge tests in sour creams containing 0.1 and 0.4 % *P. jensenii* fermentate, fungal
406 growth delays were much shorter than those observed at 2 and 5 %. They corresponded to 1
407 and 3 days, and 3 and 4 days for *M. racemosus* and *P. commune*, respectively (Table 2). On
408 the contrary, no antifungal activity was observed against *R. mucilaginosa* (Figure 3).
409 Concerning durability tests, all control sour creams were contaminated, as well as sour creams
410 with 0.1% fermentate (Figure 6). Interestingly, none of the samples with 0.4% fermentate
411 showed any visible fungal contamination (Figure 6).

412

413 **4. Discussion**

414

415 In order to develop dairy antifungal biopreservation ingredients, fermentation of LH and UF
416 was performed by large array of microorganisms. LH and FH were chosen for their
417 availability since they are current products of the dairy industry, food-grade status and
418 compatibility with dairy food applications. The *in vitro* screening step of corresponding
419 fermentates revealed that several fermentates exhibited a significant antifungal activity.
420 Interestingly, the proportion of active fermentates and their antifungal activity varied
421 according to the dairy substrate. Better expression of antifungal activity was observed for LH
422 substrate (qualitatively and/or quantitatively) as compared to UF substrate. The antifungal
423 activity was not correlated to the ability of the selected microorganisms to grow in each of
424 these substrates. Indeed, ~~for a dedicated strain~~, an assessment of the final biomass on the tested
425 27 bacterial and 18 fungal strains showed that similar populations were generally reached in
426 both substrates after fermentation (10^7 - 10^9 CFU/ml for bacteria and 10^7 CFU/ml for yeasts),
427 except for filamentous fungi which generally showed ~5 times more final biomass in LH than
428 in UF (data not shown). Therefore, for most bacteria and yeasts, it is likely that the
429 differential expression in the production of antifungal activity was related to the substrate
430 composition, while, for filamentous fungi, both biomass level and/or substrate composition
431 could be involved. The individual components which are responsible remain unclear. It can be
432 underlined however that LH but not UF substrate contains milk fat and is richer in proteins,
433 both qualitatively (presence of caseins) and quantitatively (374 g/kg total nitrogen and 190
434 g/kg nonprotein nitrogen in LH versus 5.7 g/kg total nitrogen and 5.5 g/kg non-protein
435 nitrogen in UF). Fat and proteins are precursors of antifungal compounds such as fatty acids,
436 peptides, organic acids, and volatile compounds (Hidalgo et al., 2015, Théolier et al., 2013).
437 Similar observations were made in a recent study showing that production of lactic, acetic,
438 succinic, propionic, formic, and butyric acids by LAB significantly varied according to the
439 growth medium used (Özcelik et al., 2016). Concerning the proportion of antifungal strains

440 observed in the present study, 17 % of LH and 1 % UF fermentates showed a significant
441 antifungal activity against at least one fungal target. These proportions are much lower than
442 those found in previous studies. Inglin et al. (2015) found that ~30 % of 504 tested lactobacilli
443 isolates, cultivated in MRS agar, inhibited at least one of the 4 tested fungal targets. More
444 recently, Le Lay et al. (2016) reported that ~32 % of the 270 tested LAB and 50 tested
445 propionibacteria inhibited 5 fungal targets after growth in wheat flour hydrolysate agar. The
446 lower number of active strains reported in the present study can be explained by the fact that
447 fermentates instead of bacterial colonies (Inglin et al., 2015) or bacteria embedded in agar
448 medium (Le Lay et al. 2016) were used, probably resulting in a more stringent selection of
449 active isolates. In addition, the substrates used for screening were also different, for example,
450 Inglin et al. (2015) utilized MRS medium containing acetate, which is known to potentialize
451 antifungal activity (Stiles et al., 2002) while in Le Lay et al. (2016) work, pH of wheat flour
452 hydrolysate medium after LAB growth was ~3.5 (1.5 unit lower to miniaturized cheeses's
453 pH), which enhances the antifungal activity of organic acids. In this study the testing matrix
454 (cheese-mimicking model) was more closely related to an actual food product.

455 Our results confirmed the strain-dependent character of antifungal activities in terms of
456 percent of active strains as well as inhibited targets. Indeed, within each screened species,
457 strains significantly differed in their antifungal activity as reported elsewhere (Le Lay et al.,
458 2016, Cortés-Zavaletta et al. 2014, Thierry et al., 2015, Russo et al., 2017, Leyva-Salas et al.,
459 2017). For example, for *L. buchneri* (n=34), one of the most antifungal species, around 40%
460 of strains were active, while in *L. reuteri* (n=42), only 2 % of the strains were active.

461 Antifungal fermentate-producing isolates mostly belonged to *Lactobacillus* species such as
462 *L. brevis* (Axel et al. 2016), *L. buchneri* (Kharazian et al. 2017), *L. plantarum* (Cheong et al.
463 2014), *L. harbinensis* (Belguesmia et al. 2014), and *L. rhamnosus* (Fernandez et al. 2017).
464 This can be explained by the fact that *Lactobacillus* spp. produce a large range of antifungal

465 molecules such as organic acids (Brosnan et al., 2012), hydrogen peroxide, ethanol, cyclic
466 dipeptides, proteinaceous compounds and fatty acids (Luz et al., 2017; Crowley et al., 2013;
467 Lavermicocca et al., 2000). The additive or even synergistic action of these molecules, despite
468 being produced at weak concentrations, could increase the antifungal activity. Interestingly,
469 one *Propionibacterium* and 7 fungal strains also produced antifungal fermentates.
470 Propionibacteria produce propionic acid, as well as hydrogen peroxide, azelaic, phenyllactic
471 and hydroxyphenyllactic acids (Schwenninger et al., 2004, Fernandez et al., 2017; Le Lay et
472 al., 2016) and fungi are known to produce antifungal compounds acting in synergy such as
473 volatile compounds, killer proteins, antifungal peptides and lytic enzymes (Leyva-Salas et al.,
474 2017, Nùñez et al., 2015, Izgu et al., 2011, Coelho et al., 2009; Weiler and Schmitt, 2003;
475 Wheatley, 2002; Schmitt et al., 1996) (see also the review by Delgado et al., 2016). To our
476 best knowledge, this is the first time that *A. pullulans*, *C. tenuis* and *M. lanceolatus* are
477 reported for their antifungal activities. In contrast, *Trichoderma* spp. such as *T. harzianum*
478 and *T. viride* are commonly used as biocontrol agents and are known to produce both non-
479 volatile and volatile compounds like pyrones, butenolides, azaphylones, anthraquinones,
480 trichothecenes, terpenoids and steroids, as well as non-ribosomal peptides, such as
481 siderophores and peptaibols (Mukherjee et al., 2012). In future studies, it would be interesting
482 to understand which antifungal molecules are involved in the ~~antifungal activity of~~ the most
483 active fermentates and to investigate their mode of action against different fungal targets.
484 In order to enhance antifungal activities an optimization step of culture conditions was
485 included. In general, the longer the incubation time and the higher the cell concentration was,
486 the more the antifungal activity was significant. In addition to incubation time, cold or hot
487 thermal shock increased the antifungal activity of several strains. The reasons for this are
488 unclear but suboptimal temperatures could trigger or increase the production of antifungal

489 compounds as seen for example for bacteriocin production in LAB (Leal-Sánchez et al.
490 2002).

491 When selecting strains for food applications, microbial safety and regulatory
492 considerations such as Generally Recognized as Safe (GRAS) or Qualified Presumption of
493 Safety (QPS) must be considered (Bourdichon et al., 2012). Thus, the safety of the LAB and
494 propionibacteria strains selected for *in situ* tests were verified, i.e. biogenic amines production
495 and antibiotic resistance pattern. *L. brevis* L128 and *L. buchneri* L162 and L233, although
496 showing interesting antifungal properties were not kept further for *in situ* step applications
497 since they were shown to possess biogenic amines associated genes (*hdc* and *agdi* for L162
498 and L233, *agdi* and *tyrdc* for L128) and to produce histamine, putrescine and tyramine *in*
499 *vitro* (Coton et al. 2018). On the contrary, *P. jensenii* CIRM-BIA1774 and *L. rhamnosus*
500 CIRM-BIA1952, selected for the *in situ* tests were both considered as safe for dairy food
501 applications. Concerning *Mucor*, while some species are mycosis agents, others are
502 technological agents in food products and known not to produce mycotoxins (Morin-Sardin et
503 al. 2017). More specifically, *M. lanceolatus* has a long history of safe use in food as it is
504 utilized as a ripening culture in Tomme and Saint-Nectaire cheeses (Desmasures, 2014,
505 Hermet et al., 2014). *In situ* tests including challenge and durability tests are a crucial step in
506 the process of developing an antifungal ingredient since *in vitro* screening can lead to an
507 overestimation of the antifungal activity as discussed above (see also Leyva-Salas et al. 2017)
508 For challenge tests, surface-spraying of *P. jensenii* CIRM-BIA1774 fermentate on the cheese
509 surface was efficient for delaying fungal growth without any impact on cheese sensory
510 characteristics. Noteworthy, to our best knowledge, it is the first time that the use of a
511 fermentate is shown to efficiently replace natamycin. Further work would be necessary in an
512 industrial context to verify its antifungal activity in other cheese types as well as to assess
513 whether it can be produced on a large scale with an acceptable cost. In sour cream, *P. jensenii*

514 fermentate at 2 and 5 % (w/w) harbored a very high antifungal activity against the 3 tested
515 targets and prevented fungal contaminations of natural origin for up to one month. However,
516 at these high concentrations, its negative impact on sensory attributes, yielding very acid sour
517 cream with propionic odor and flavor mainly linked to high concentration of propionic acid, is
518 a major limit for its application in this product category. Nevertheless, it is interesting to
519 underline that it prevented natural contaminations at 0.4 % (w/w) with a limited impact on
520 consumer acceptance. Further work is still necessary to evaluate whether it could be used or
521 not in this product type. These results also indicate that, before performing time-consuming
522 sensorial analysis, a preliminary study to determine the maximum concentration to be used
523 without any impact on sensorial properties could have been useful. Volatile profiles could
524 also be determined on antifungal fermentates prior to sensory analyses and on products
525 subjected to sensorial analysis to develop rapid screening and quality control approaches,
526 using for example head space mass spectrometry (Makhoul et al., 2016). The use of
527 *L. rhamnosus* CIRM-BIA1952 fermentate, incorporated in sour cream or sprayed on semi-
528 hard cheeses, had no impact on product sensorial properties but yielded a limited antifungal
529 activity. However, when considering durability tests results the *L. rhamnosus* fermentate were
530 much more promising. It is worth mentioning that, for *in situ* challenge tests, 50 fungal spores
531 were inoculated, which is a worst-case scenario in comparison to natural contamination and
532 that tested products were incubated at 10°C, which is also favorable to fungal growth.
533 Concerning *M. lanceolatus*, to our knowledge, this is the first time that the antifungal activity
534 of a *M. lanceolatus* fermentate is demonstrated.

535

536 **5. Conclusion**

537 To our best knowledge, this study is the first one which describes the development of dairy-
538 based antifungal ingredients for a large number of strains and species, from *in vitro* screening

539 to pilot scale applications, including the evaluation of their impact on product organoleptic
540 properties. The obtained results provided 3 promising antifungal dairy which may be used in
541 dairy foods as part of the hurdle technology and to replace or at least limit the use of chemical
542 preservatives such as natamycin or potassium sorbate. From a fundamental point of view, the
543 identification of the molecules harboring antifungal activities and their mechanism of action
544 should be explored.

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Table 1. Effect of culture conditions on the antifungal activity of fermentates from selected lactic acid bacteria, propionibacteria and fungi against *M. racemosus* UBOCC-A-116002, *P. commune* UBOCC-A-116003, *R. mucilaginosa* UBOCC-A-216004 and *Y. lipolytica* UBOCC-A-216006. The antifungal activity is expressed as increase in time to visible growth of the fungal target (days) as compared to a control without fermentate.

Fermentation substrate	Strain	Culture conditions*	Cell concentration (log ₁₀ CFU/ml)	Increase in time to visible fungal growth (in days)				
				<i>M. racemosus</i>	<i>P. commune</i>	<i>R. mucilaginosa</i>	<i>Y. lipolytica</i>	
Low heat milk	<i>L. buchneri</i> L151	1-a	5.10 ⁷	0	0	0	0	
		2-a	6.10 ⁷	0	0	+1	0	
		3-a	2.10 ⁸	0	+1	+2	0	
		4-a	6.10 ⁷	0	0	+1	0	
		5-a	7.10 ⁷	0	0	+2	0	
	<i>L. buchneri</i> L162	1-a	1.10 ⁷	0	0	+1	0	
		2-a	4.10 ⁸	0	+1	+1	0	
		3-a	1.10 ⁸	0	+3	+1	0	
		4-a	8.10 ⁸	0	+3	+1	0	
		5-a	1.10 ⁹	0	+4	+2	0	
	<i>L. buchneri</i> L164	1-a	6.10 ⁸	0	+1	+1	0	
		2-a	3.10 ⁸	0	+1	+1	0	
		3-a	2.10 ⁸	0	0	+1	0	
		4-a	4.10 ⁸	0	+1	+1	0	
		5-a	2.10 ⁸	0	0	+1	0	
	<i>L. buchneri</i> L233	1-a	6.10 ⁷	0	+1	0	0	
		2-a	7.10 ⁶	0	+1	0	0	
		3-a	5.10 ⁸	+1	+3	+1	0	
		4-a	2.10 ⁸	0	+2	+1	0	
		5-a	4.10 ⁸	+1	+4	+2	0	
	<i>L. harbinensis</i> L172	1-a	2.10 ⁸	+1	0	+1	0	
		2-a	7.10 ⁷	0	0	0	0	
		3-a	8.10 ⁷	0	0	+2	0	
		4-a	2.10 ⁸	0	0	+1	0	
		5-a	1.10 ⁸	+1	0	+1	0	
	<i>L. paracasei</i> L117	1-a	2.10 ⁹	+1	+4	+2	0	

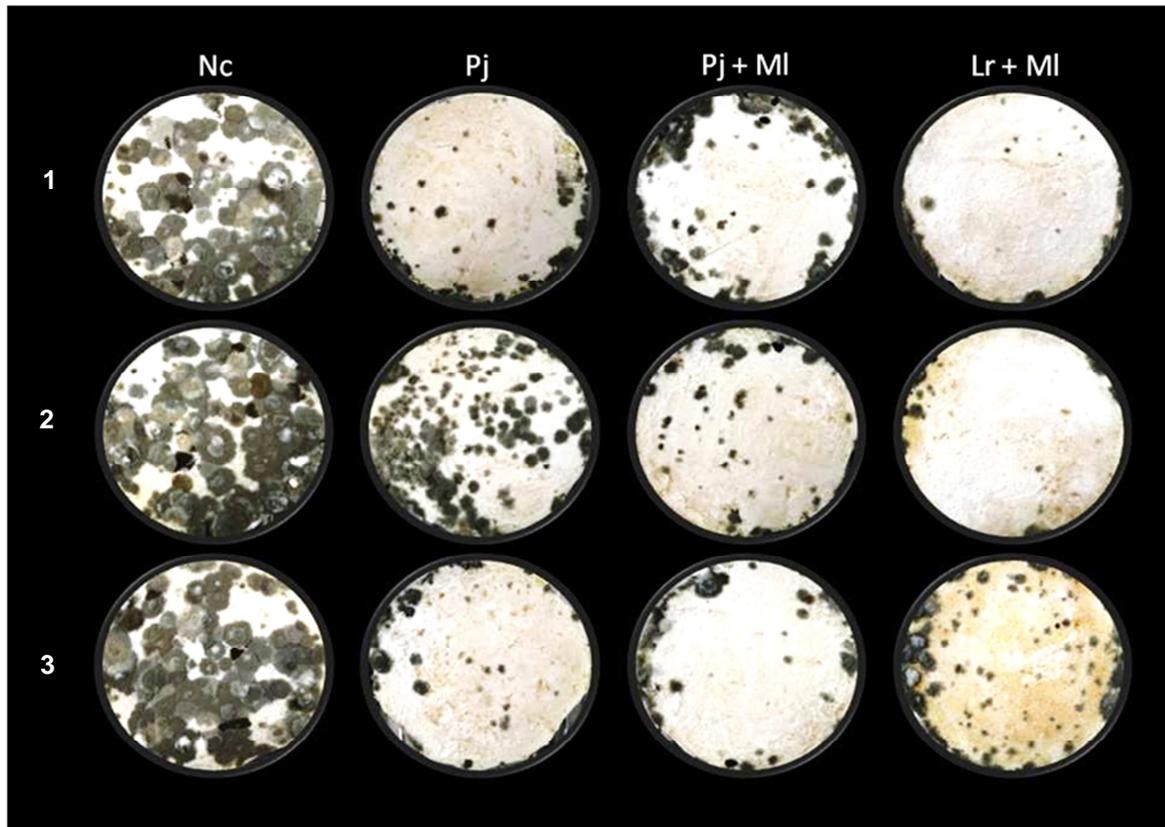
<i>L. paracasei</i> L194									
2-a	2.10 ⁹	0	+1	+2	0				
3-a	1.10 ⁸	0	+1	+1	0				
4-a	1.10 ⁹	0	+1	+2	0				
5-a	2.10 ⁹	0	0	+1	0				
1-a	3.10 ⁹	0	+2	+2	0				
2-a	2.10 ⁹	0	+1	+1	0				
3-a	3.10 ⁸	0	+1	+1	0				
4-a	2.10 ⁹	0	+1	+1	0				
5-a	2.10 ⁹	0	+1	+1	0				
<i>L. plantarum</i> L244									
1-a	7.10 ⁸	0	+1	+1	0				
2-a	5.10 ⁸	0	+1	+1	0				
3-a	2.10 ⁸	0	0	+1	0				
4-a	6.10 ⁸	0	+1	+1	0				
5-a	1.10 ⁸	0	+1	+1	0				
<i>L. rhamnosus</i> CIRM-BIA1952									
1-a	2.10 ⁹	0	+2	+2	0				
2-a	1.10 ⁹	0	+3	+2	0				
3-a	1.10 ⁹	0	+3	+1	0				
4-a	1.10 ⁹	0	+1	+1	0				
5-a	2.10 ⁹	0	+1	+2	0				
1-b	nd†	+1	0	nd	0				
2-b	nd	+2	+1	nd	0				
3-b	nd	+1	+1	nd	0				
4-b	nd	+4	+1	nd	0				
5-b	nd	0	+1	nd	0				
<i>M. lanceolatus</i> UBOCC-A-109193									
1-a	1.10 ⁷	0	0	+1	0				
2-a	4.10 ⁸	0	0	+1	0				
3-a	1.10 ⁸	0	0	0	0				
4-a	8.10 ⁸	0	0	0	0				
5-a	1.10 ⁹	0	0	0	0				
1-c	1.10 ⁷	+1	+1	+1	0				
2-c	2.10 ⁸	+2	+1	+1	0				
3-c	6.10 ⁸	+2	+1	+2	0				
4-c	8.10 ⁸	+2	+1	+2	+1				
5-c	8.10 ⁸	+2	+1	+1	0				
<i>P. jensenii</i> CIRM-BIA1774									
UF milk									
<i>L. buchneri</i> L162									
permeate									
<i>P. jensenii</i> CIRM-BIA1774									

747 *Culture conditions for lactobacilli: 1-a, 24h/30°C; 2-a, 48h/30°C; 3-a, 72h/30°C; 4-a, 48h/30°C followed by 24h/12°C; 5-a, 48h/30°C followed by 24h/43°C. Culture
748 conditions for *M. lanceolatus* UBOCC-A-109193: 1-b, 48h/25°C; 2-b, 96h/25°C; 3-b, 168h/25°C; 4-b, 96h/25°C followed by 48h/12°C; 5-b, 96h/25°C followed by

749 48h/43°C. Culture conditions for *P. jensenii* CIRM-BIA1774: 1-c, 48h/30°C; 2-c, 72h/30°C; 3-c, 96h/30°C; 4-c, 96h/30°C followed by 24h/12°C; 5-c, 96h/30°C followed by
750 24h/43°C.†nd, not determined.

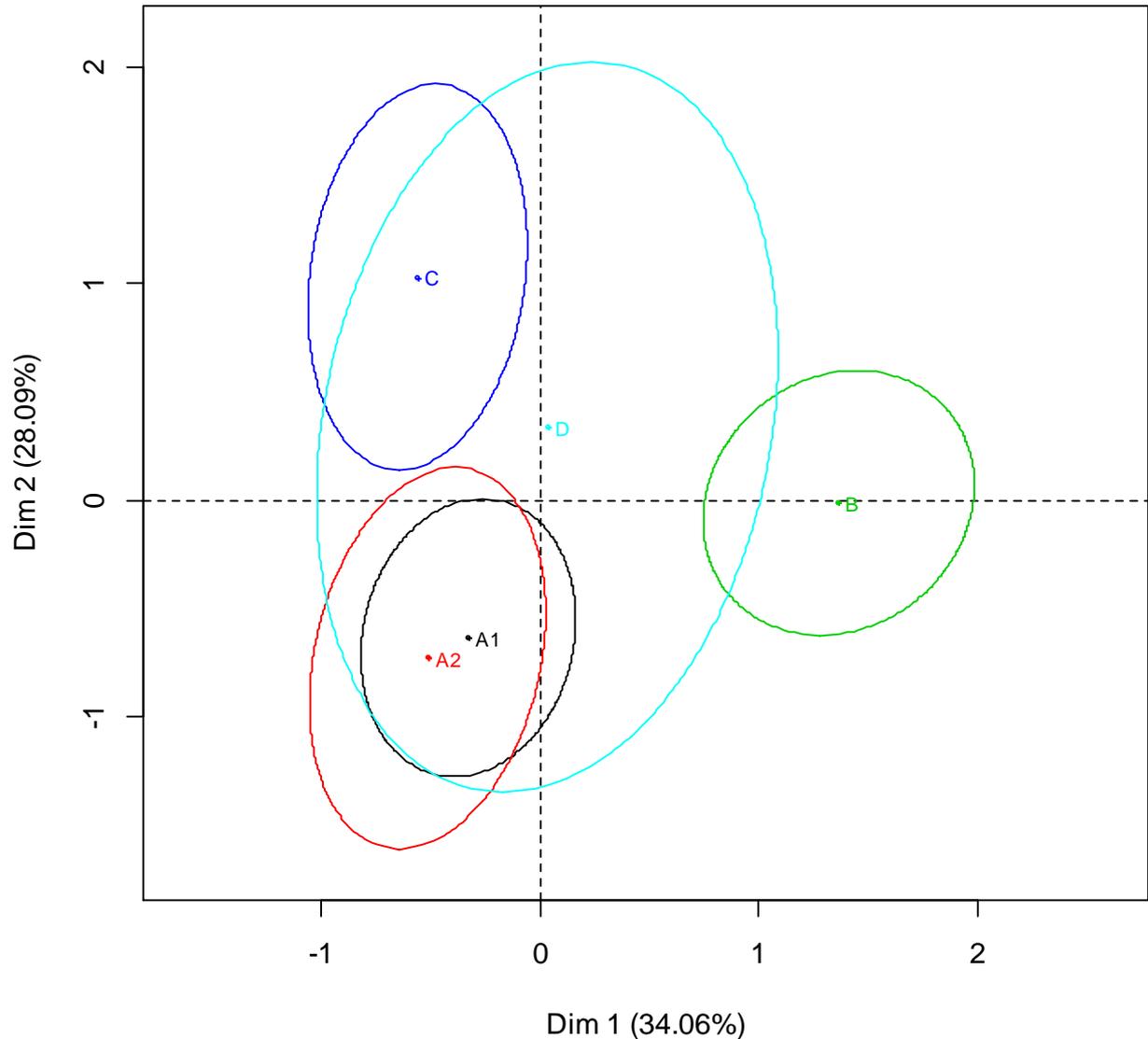
Table 2. Antifungal activity of selected fermentates against *M. racemosus* UBOCC-A-116002 and *P. commune* UBOCC-A-116003 in semi-hard cheese and sour cream.

					Time before visible fungal growth (in days)	
Product	Fermentate (fermentation substrate)	Concentration	<i>M. racemosus</i>	<i>P. commune</i>		
Semi-hard cheese	None (negative control)	-	5	7		
	<i>P. jensenii</i> CIRM-BIA1774 (UF) and <i>M. lanceolatus</i> UBOCC-A-109193 (LH)	0.63 g/dm ² and 5 ml/dm ²	20	14		
	<i>P. jensenii</i> CIRM-BIA1774 (UF)	0.63 g/dm ²	26	21		
	<i>L. rhannosus</i> CIRM-BIA1952 (LH) and <i>M. lanceolatus</i> UBOCC-A-109193 (LH)	1.26 g/dm ² and 5 ml/dm ²	8	9		
	Natamycin (positive control)	1 mg/dm ²	>33	>33		
	None (negative control)		7	8		
Sour cream	<i>L. rhannosus</i> CIRM-BIA1952 (LH)	5%	7	8		
	<i>L. rhannosus</i> CIRM-BIA1952 (LH)	2%	7	8		
	<i>P. jensenii</i> CIRM-BIA1774 (UF)	5%	30	30		
	<i>P. jensenii</i> CIRM-BIA1774 (UF)	2%	30	19		
	<i>P. jensenii</i> CIRM-BIA1774 (UF)	0.4%	10	12		
	<i>P. jensenii</i> CIRM-BIA1774 (UF)	0.1%	8	11		
	<i>L. rhannosus</i> CIRM-BIA1952 (LH) and <i>P. jensenii</i> CIRM-BIA1774 (UF)	2.5% each	>30	>30		
	Potassium sorbate (positive control)	0.08%	>30	>30		

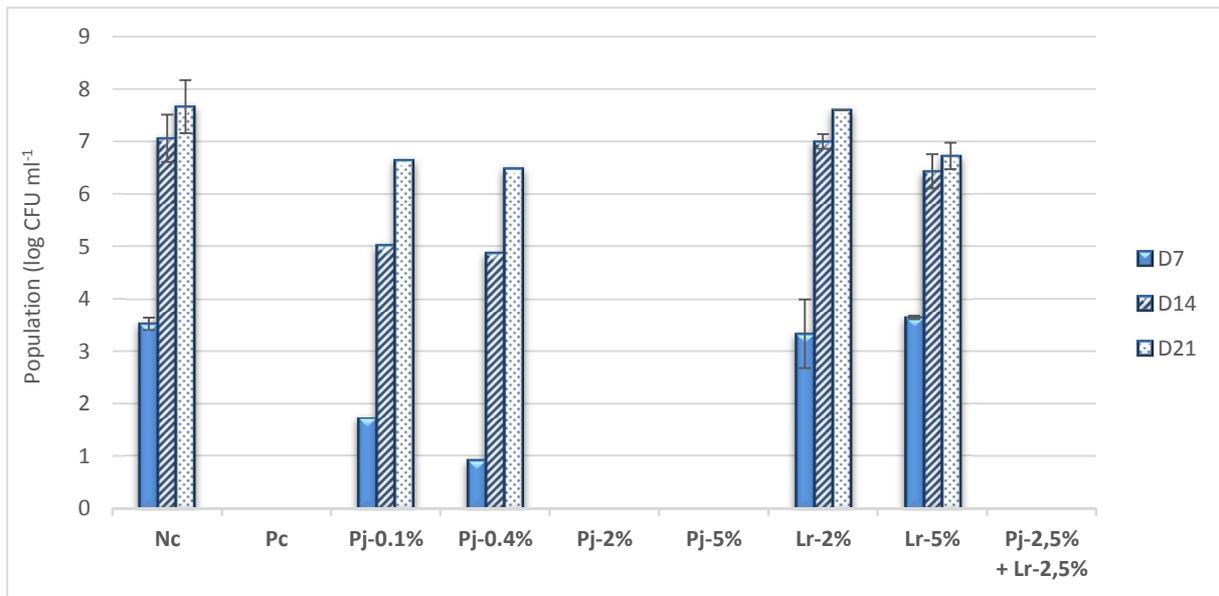


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757

758 **Figure 1.** Photographs showing semi-hard cheese surfaces treated or not (negative control,
759 Nc) by surface-spraying using *P. jensenii* CIRM-BIA1774 (Pj), *P. jensenii* CIRM-BIA1774
760 associated with *M. lanceolatus* UBOCC-A-109193 (Pj +MI) or *L. rhamnosus* CIRM-BIA1952
761 associated with *M. lanceolatus* UBOCC-A-109193 (Lr + MI), after 6 weeks of ripening at
762 10°C in a naturally contaminated environment. Numbers 1 to 3 are replicates.



763
764 **Figure 2.** Impact of cheese surface treatment with antifungal fermentates on sensorial
765 properties of semi-hard cheese determined using a sorting approach: representation of the
766 cheeses and their respective 95 % confidence ellipses in the plane defined by Dim 1 and Dim
767 2 of a multiple correspondence analysis. A1 and A2, control cheeses (without fermentate); B,
768 cheese surface-treated with a combination of 4.8 mg/dm² *L. rhamnosus* CIRM-BIA1952 and
769 10 ml/dm² *M. lanceolatus* UBOCC-A-109193 fermentates; C, cheese surface-treated with a
770 combination of 2.4 mg/dm² *P. jensenii* CIRM-BIA1774 and 10 ml/dm² *M. lanceolatus*
771 UBOCC-A-109193 fermentates and D, cheese surface-treated with 2.4 mg/dm² *P. jensenii*
772 CIRM-BIA1774 fermentate.



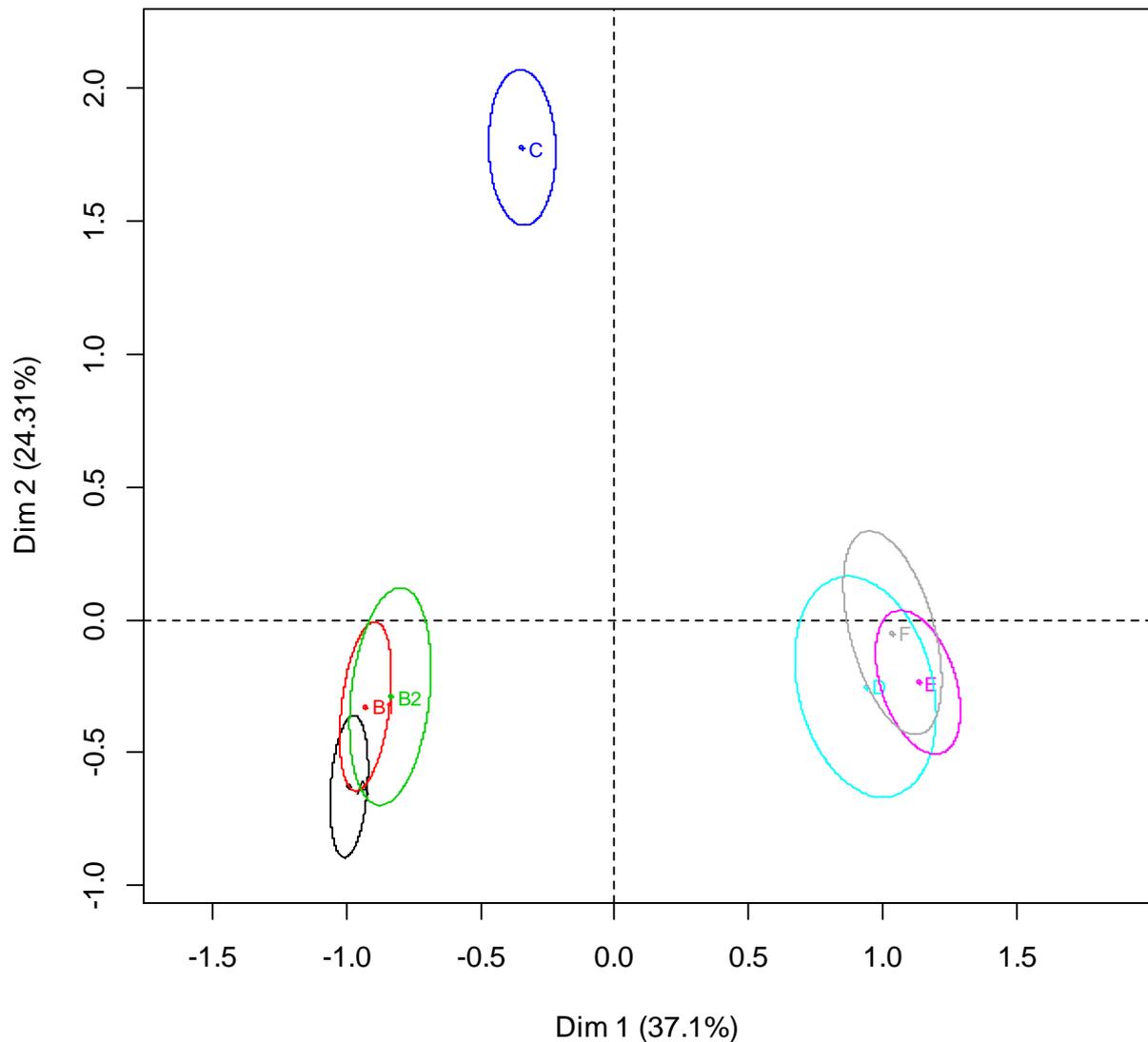
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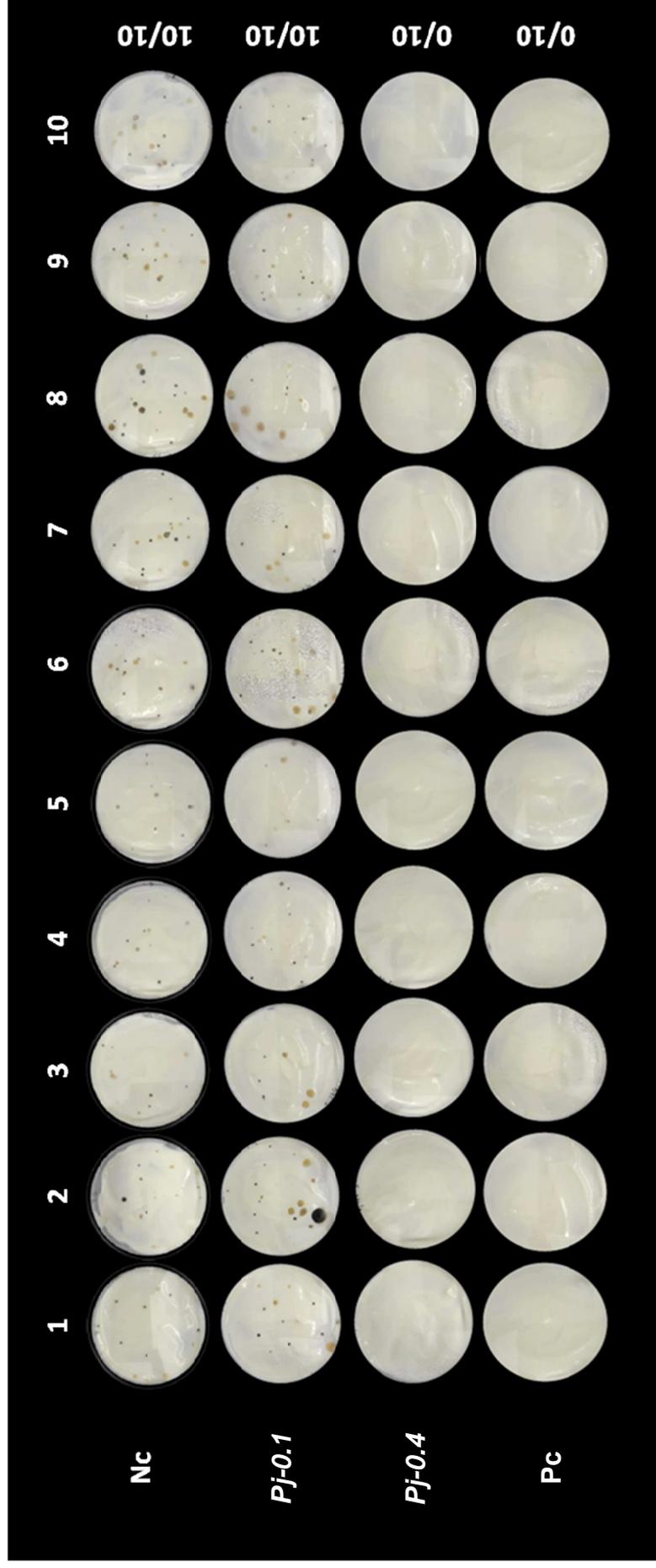
775 **Figure 3.** Growth of *R. mucilaginosa* UBOCC-A-216004 in sour cream after incorporation or
 776 not of *P. jensenii* CIRM-BIA1774 and/or *L. rhamnosus* CIRM-BIA1952 fermentates. Nc,
 777 negative control (sour cream without fermentate); Pc, positive control (sour cream with 0.08
 778 % potassium sorbate); Pj-2, *P. jensenii* fermentate at 2 % w/w; Pj-5, *P. jensenii* fermentate at
 779 5 % w/w, Lr-2, *L. rhamnosus* fermentate at 2 % w/w; L-5, *L. rhamnosus* fermentate at 5 %
 780 w/w; Pj-2.5+Lr-2.5, mixture of *P. jensenii* and *L. rhamnosus* fermentates at 2.5 % w/w each.



782 **Figure 4.** Photographs showing sour cream surfaces in which fermentates of *P. jensenii*
783 CIRM-BIA1774 (2 % and 5%), *L. rhamnosus* CIRM-BIA1952 (2 and 5 %) and mixture of
784 *P. jensenii* and *L. rhamnosus* at 2.5 % each were incorporated. Negative controls
785 corresponded to sour cream samples without fermentate. Samples were stored for 2 weeks at
786 4°C, naturally contaminated in an indoor environment (20 min) and stored again for 2 weeks
787 at 10°C. Nc, Negative control; Pj-2, *P. jensenii* fermentate at 2% w/w; Pj-5, *P. jensenii*
788 fermentate at 5 % w/w, Lr-2, *L. rhamnosus* fermentate at 2% w/w; Lr-5, *L. rhamnosus*
789 fermentate at 5 % w/w; Pj-2.5 + Lr-2.5, mixture of *P. jensenii* and *L. rhamnosus* fermentates
790 at 2.5 % w/w each. Numbers 1 to 10 are replicates. Score at the bottom of the figure
791 correspond to the number of contaminated cream / total number of cream.
792



793
 794 **Figure 5.** Impact of the incorporation of antifungal fermentates on sensorial traits of sour
 795 cream determined using a sorting approach: representation of the sour creams and their
 796 respective 95 % confidence ellipses in the plane defined by Dim 1 and Dim 2 of a multiple
 797 correspondence analysis. A, control sour cream (without fermentate); B1 and B2, sour cream
 798 with 2 % *L. rhamnosus* CIRM-BIA1952 fermentate, C, sour cream with 5 % *L. rhamnosus*
 799 CIRM-BIA1952 fermentate; D, sour cream with 2 % *P. jensenii* CIRM-BIA1774 fermentate,
 800 E, sour cream with 5 % of *P. jensenii* CIRM-BIA1774 fermentate; F, sour cream with 2.5 %
 801 *L. rhamnosus* CIRM-BIA1952 and 2.5 % of *P. jensenii* CIRM-BIA1774 fermentates.



802

803 **Figure 6.** Photographs showing sour cream surfaces in which *P. jensenii* CIRM-BIA1774 fermentates were incorporated at 0.1 (Pj-0.1) and 0.4
 804 (Pj-0.4) %. Negative control (Nc) correspond to sour cream samples without fermentate and positive control (Pc) to sour cream samples
 805 containing 0.08 % potassium sorbate. Samples were stored for 2 weeks at 4°C, naturally contaminated in an indoor environment and stored again
 806 for 2 weeks at 10°C. Numbers 1 to 10 are replicates. Scores correspond to number of contaminated sour cream/ total number of sour cream.

807

Supplementary Table S1. List of tested microorganisms

Species	Strain	Species	Strain
<i>Lactobacillus acidophilus</i>	CIRM-BIA443	<i>Lactobacillus casei/paracasei</i>	L101
<i>Lactobacillus acidophilus</i>	CIRM-BIA445	<i>Lactobacillus casei/paracasei</i>	L102
<i>Lactobacillus acidophilus</i>	CIRM-BIA448	<i>Lactobacillus casei/paracasei</i>	L103
<i>Lactobacillus acidophilus</i>	CIRM-BIA1674	<i>Lactobacillus casei/paracasei</i>	L106
<i>Lactobacillus amylovorus</i>	CIRM-BIA669	<i>Lactobacillus casei/paracasei</i>	L107
<i>Lactobacillus brevis</i>	L128	<i>Lactobacillus casei/paracasei</i>	L108
<i>Lactobacillus brevis</i>	L30	<i>Lactobacillus casei/paracasei</i>	L109
<i>Lactobacillus brevis</i>	L31	<i>Lactobacillus casei/paracasei</i>	L110
<i>Lactobacillus brevis</i>	CIRM-BIA608	<i>Lactobacillus casei/paracasei</i>	L112
<i>Lactobacillus brevis</i>	CIRM-BIA932	<i>Lactobacillus casei/paracasei</i>	L117
<i>Lactobacillus brevis</i>	CIRM-BIA933	<i>Lactobacillus casei/paracasei</i>	L118
<i>Lactobacillus brevis</i>	CIRM-BIA1523	<i>Lactobacillus casei/paracasei</i>	L119
<i>Lactobacillus brevis</i>	CIRM-BIA1531	<i>Lactobacillus casei/paracasei</i>	L120
<i>Lactobacillus buchneri</i>	L111	<i>Lactobacillus casei/paracasei</i>	L121
<i>Lactobacillus buchneri</i>	L137	<i>Lactobacillus casei/paracasei</i>	L122
<i>Lactobacillus buchneri</i>	L147	<i>Lactobacillus casei/paracasei</i>	L124
<i>Lactobacillus buchneri</i>	L149	<i>Lactobacillus casei/paracasei</i>	L127
<i>Lactobacillus buchneri</i>	L151	<i>Lactobacillus casei/paracasei</i>	L129
<i>Lactobacillus buchneri</i>	L162	<i>Lactobacillus casei/paracasei</i>	L13
<i>Lactobacillus buchneri</i>	L164	<i>Lactobacillus casei/paracasei</i>	L130
<i>Lactobacillus buchneri</i>	L169	<i>Lactobacillus casei/paracasei</i>	L136
<i>Lactobacillus buchneri</i>	L170	<i>Lactobacillus casei/paracasei</i>	L138
<i>Lactobacillus buchneri</i>	L192	<i>Lactobacillus casei/paracasei</i>	L139
<i>Lactobacillus buchneri</i>	L203	<i>Lactobacillus casei/paracasei</i>	L140
<i>Lactobacillus buchneri</i>	L212	<i>Lactobacillus casei/paracasei</i>	L142
<i>Lactobacillus buchneri</i>	L217	<i>Lactobacillus casei/paracasei</i>	L143
<i>Lactobacillus buchneri</i>	L233	<i>Lactobacillus casei/paracasei</i>	L144
<i>Lactobacillus buchneri</i>	L239	<i>Lactobacillus casei/paracasei</i>	L148
<i>Lactobacillus buchneri</i>	L243	<i>Lactobacillus casei/paracasei</i>	L150
<i>Lactobacillus buchneri</i>	L245	<i>Lactobacillus casei/paracasei</i>	L157
<i>Lactobacillus buchneri</i>	L25	<i>Lactobacillus casei/paracasei</i>	L158
<i>Lactobacillus buchneri</i>	L265	<i>Lactobacillus casei/paracasei</i>	L159
<i>Lactobacillus buchneri</i>	L271	<i>Lactobacillus casei/paracasei</i>	L16
<i>Lactobacillus buchneri</i>	L273	<i>Lactobacillus casei/paracasei</i>	L161
<i>Lactobacillus buchneri</i>	L277	<i>Lactobacillus casei/paracasei</i>	L179
<i>Lactobacillus buchneri</i>	L278	<i>Lactobacillus casei/paracasei</i>	L184
<i>Lactobacillus buchneri</i>	L290	<i>Lactobacillus casei/paracasei</i>	L186
<i>Lactobacillus buchneri</i>	L56	<i>Lactobacillus casei/paracasei</i>	L188
<i>Lactobacillus buchneri</i>	L84	<i>Lactobacillus casei/paracasei</i>	L19
<i>Lactobacillus buchneri</i>	L90	<i>Lactobacillus casei/paracasei</i>	L194
<i>Lactobacillus buchneri</i>	L99	<i>Lactobacillus casei/paracasei</i>	L196
<i>Lactobacillus buchneri</i>	CIRM-BIA659	<i>Lactobacillus casei/paracasei</i>	L199
<i>Lactobacillus buchneri</i>	CIRM-BIA1324	<i>Lactobacillus casei/paracasei</i>	L208
<i>Lactobacillus buchneri</i>	CIRM-BIA1514	<i>Lactobacillus casei/paracasei</i>	L209
<i>Lactobacillus buchneri</i>	CIRM-BIA1515	<i>Lactobacillus casei/paracasei</i>	L211
<i>Lactobacillus buchneri</i>	CIRM-BIA1516	<i>Lactobacillus casei/paracasei</i>	L215

<i>Lactobacillus buchneri</i>	CIRM-BIA1525	<i>Lactobacillus casei/paracasei</i>	L220
<i>Lactobacillus casei/paracasei</i>	L1	<i>Lactobacillus casei/paracasei</i>	L222
<i>Lactobacillus casei/paracasei</i>	L100	<i>Lactobacillus casei/paracasei</i>	L224
<i>Lactobacillus casei/paracasei</i>	L225	<i>Lactobacillus casei/paracasei</i>	L69
<i>Lactobacillus casei/paracasei</i>	L226	<i>Lactobacillus casei/paracasei</i>	L7
<i>Lactobacillus casei/paracasei</i>	L227	<i>Lactobacillus casei/paracasei</i>	L72
<i>Lactobacillus casei/paracasei</i>	L228	<i>Lactobacillus casei/paracasei</i>	L73
<i>Lactobacillus casei/paracasei</i>	L229	<i>Lactobacillus casei/paracasei</i>	L74
<i>Lactobacillus casei/paracasei</i>	L23	<i>Lactobacillus casei/paracasei</i>	L75
<i>Lactobacillus casei/paracasei</i>	L230	<i>Lactobacillus casei/paracasei</i>	L82
<i>Lactobacillus casei/paracasei</i>	L231	<i>Lactobacillus casei/paracasei</i>	L85
<i>Lactobacillus casei/paracasei</i>	L232	<i>Lactobacillus casei/paracasei</i>	L86
<i>Lactobacillus casei/paracasei</i>	L234	<i>Lactobacillus casei/paracasei</i>	L93
<i>Lactobacillus casei/paracasei</i>	L237	<i>Lactobacillus casei/paracasei</i>	L95
<i>Lactobacillus casei/paracasei</i>	L24	<i>Lactobacillus delbrueckii</i>	L160
<i>Lactobacillus casei/paracasei</i>	L240	<i>Lactobacillus delbrueckii</i>	L218
<i>Lactobacillus casei/paracasei</i>	L242	<i>Lactobacillus farciminis</i>	CIRM-BIA1634
<i>Lactobacillus casei/paracasei</i>	L247	<i>Lactobacillus fermentum</i>	CIRM-BIA42
<i>Lactobacillus casei/paracasei</i>	L249	<i>Lactobacillus fermentum</i>	CIRM-BIA666
<i>Lactobacillus casei/paracasei</i>	L250	<i>Lactobacillus gasseri</i>	CIRM-BIA665
<i>Lactobacillus casei/paracasei</i>	L252	<i>Lactobacillus gasseri</i>	CIRM-BIA1437
<i>Lactobacillus casei/paracasei</i>	L253	<i>Lactobacillus gasseri</i>	CIRM-BIA1438
<i>Lactobacillus casei/paracasei</i>	L257	<i>Lactobacillus gasseri</i>	CIRM-BIA1447
<i>Lactobacillus casei/paracasei</i>	L261	<i>Lactobacillus harbinensis</i>	L172
<i>Lactobacillus casei/paracasei</i>	L263	<i>Lactobacillus pentosus</i>	CIRM-BIA660
<i>Lactobacillus casei/paracasei</i>	L264	<i>Lactobacillus pentosus</i>	CIRM-BIA853
<i>Lactobacillus casei/paracasei</i>	L266	<i>Lactobacillus pentosus</i>	CIRM-BIA854
<i>Lactobacillus casei/paracasei</i>	L267	<i>Lactobacillus pentosus</i>	CIRM-BIA1490
<i>Lactobacillus casei/paracasei</i>	L269	<i>Lactobacillus perolens/harbinensis</i>	L191
<i>Lactobacillus casei/paracasei</i>	L27	<i>Lactobacillus perolens/harbinensis</i>	L244
<i>Lactobacillus casei/paracasei</i>	L270	<i>Lactobacillus perolens/harbinensis</i>	L283
<i>Lactobacillus casei/paracasei</i>	L274	<i>Lactobacillus plantarum</i>	L10
<i>Lactobacillus casei/paracasei</i>	L276	<i>Lactobacillus plantarum</i>	L11
<i>Lactobacillus casei/paracasei</i>	L279	<i>Lactobacillus plantarum</i>	L12
<i>Lactobacillus casei/paracasei</i>	L281	<i>Lactobacillus plantarum</i>	L123
<i>Lactobacillus casei/paracasei</i>	L284	<i>Lactobacillus plantarum</i>	L125
<i>Lactobacillus casei/paracasei</i>	L287	<i>Lactobacillus plantarum</i>	L14
<i>Lactobacillus casei/paracasei</i>	L288	<i>Lactobacillus plantarum</i>	L145
<i>Lactobacillus casei/paracasei</i>	L289	<i>Lactobacillus plantarum</i>	L146
<i>Lactobacillus casei/paracasei</i>	L3	<i>Lactobacillus plantarum</i>	L15
<i>Lactobacillus casei/paracasei</i>	L32	<i>Lactobacillus plantarum</i>	L152
<i>Lactobacillus casei/paracasei</i>	L37	<i>Lactobacillus plantarum</i>	L155
<i>Lactobacillus casei/paracasei</i>	L38	<i>Lactobacillus plantarum</i>	L156
<i>Lactobacillus casei/paracasei</i>	L40	<i>Lactobacillus plantarum</i>	L163
<i>Lactobacillus casei/paracasei</i>	L47	<i>Lactobacillus plantarum</i>	L167
<i>Lactobacillus casei/paracasei</i>	L51	<i>Lactobacillus plantarum</i>	L17
<i>Lactobacillus casei/paracasei</i>	L52	<i>Lactobacillus plantarum</i>	L171
<i>Lactobacillus casei/paracasei</i>	L57	<i>Lactobacillus plantarum</i>	L173
<i>Lactobacillus casei/paracasei</i>	L58	<i>Lactobacillus plantarum</i>	L174
<i>Lactobacillus casei/paracasei</i>	L59	<i>Lactobacillus plantarum</i>	L175
<i>Lactobacillus casei/paracasei</i>	L61	<i>Lactobacillus plantarum</i>	L176

<i>Lactobacillus casei/paracasei</i>	L62	<i>Lactobacillus plantarum</i>	L18
<i>Lactobacillus casei/paracasei</i>	L68	<i>Lactobacillus plantarum</i>	L180
<i>Lactobacillus plantarum</i>	L181	<i>Lactobacillus plantarum</i>	L43
<i>Lactobacillus plantarum</i>	L182	<i>Lactobacillus plantarum</i>	L45
<i>Lactobacillus plantarum</i>	L183	<i>Lactobacillus plantarum</i>	L46
<i>Lactobacillus plantarum</i>	L193	<i>Lactobacillus plantarum</i>	L48
<i>Lactobacillus plantarum</i>	L195	<i>Lactobacillus plantarum</i>	L49
<i>Lactobacillus plantarum</i>	L198	<i>Lactobacillus plantarum</i>	L5
<i>Lactobacillus plantarum</i>	L20	<i>Lactobacillus plantarum</i>	L50
<i>Lactobacillus plantarum</i>	L200	<i>Lactobacillus plantarum</i>	L53
<i>Lactobacillus plantarum</i>	L201	<i>Lactobacillus plantarum</i>	L53
<i>Lactobacillus plantarum</i>	L202	<i>Lactobacillus plantarum</i>	L54
<i>Lactobacillus plantarum</i>	L204	<i>Lactobacillus plantarum</i>	L6
<i>Lactobacillus plantarum</i>	L205	<i>Lactobacillus plantarum</i>	L6
<i>Lactobacillus plantarum</i>	L206	<i>Lactobacillus plantarum</i>	L63
<i>Lactobacillus plantarum</i>	L207	<i>Lactobacillus plantarum</i>	L64
<i>Lactobacillus plantarum</i>	L21	<i>Lactobacillus plantarum</i>	L65
<i>Lactobacillus plantarum</i>	L210	<i>Lactobacillus plantarum</i>	L65
<i>Lactobacillus plantarum</i>	L216	<i>Lactobacillus plantarum</i>	L66
<i>Lactobacillus plantarum</i>	L219	<i>Lactobacillus plantarum</i>	L70
<i>Lactobacillus plantarum</i>	L22	<i>Lactobacillus plantarum</i>	L71
<i>Lactobacillus plantarum</i>	L221	<i>Lactobacillus plantarum</i>	L76
<i>Lactobacillus plantarum</i>	L241	<i>Lactobacillus plantarum</i>	L77
<i>Lactobacillus plantarum</i>	L246	<i>Lactobacillus plantarum</i>	L8
<i>Lactobacillus plantarum</i>	L248	<i>Lactobacillus plantarum</i>	L87
<i>Lactobacillus plantarum</i>	L251	<i>Lactobacillus plantarum</i>	L88
<i>Lactobacillus plantarum</i>	L254	<i>Lactobacillus plantarum</i>	L88
<i>Lactobacillus plantarum</i>	L255	<i>Lactobacillus plantarum</i>	L89
<i>Lactobacillus plantarum</i>	L256	<i>Lactobacillus plantarum</i>	L9
<i>Lactobacillus plantarum</i>	L258	<i>Lactobacillus plantarum</i>	L96
<i>Lactobacillus plantarum</i>	L259	<i>Lactobacillus plantarum</i>	L98
<i>Lactobacillus plantarum</i>	L26	<i>Lactobacillus plantarum</i>	CIRM-BIA466
<i>Lactobacillus plantarum</i>	L260	<i>Lactobacillus plantarum</i>	CIRM-BIA652
<i>Lactobacillus plantarum</i>	L268	<i>Lactobacillus plantarum</i>	CIRM-BIA845
<i>Lactobacillus plantarum</i>	L272	<i>Lactobacillus plantarum</i>	CIRM-BIA850
<i>Lactobacillus plantarum</i>	L28	<i>Lactobacillus plantarum</i>	CIRM-BIA855
<i>Lactobacillus plantarum</i>	L282	<i>Lactobacillus plantarum</i>	CIRM-BIA1105
<i>Lactobacillus plantarum</i>	L285	<i>Lactobacillus plantarum</i>	CIRM-BIA1106
<i>Lactobacillus plantarum</i>	L286	<i>Lactobacillus plantarum</i>	CIRM-BIA1108
<i>Lactobacillus plantarum</i>	L29	<i>Lactobacillus plantarum</i>	CIRM-BIA1109
<i>Lactobacillus plantarum</i>	L291	<i>Lactobacillus plantarum</i>	CIRM-BIA1110
<i>Lactobacillus plantarum</i>	L292	<i>Lactobacillus plantarum</i>	CIRM-BIA1111
<i>Lactobacillus plantarum</i>	L293	<i>Lactobacillus plantarum</i>	CIRM-BIA1419
<i>Lactobacillus plantarum</i>	L294	<i>Lactobacillus plantarum</i>	CIRM-BIA1420
<i>Lactobacillus plantarum</i>	L298	<i>Lactobacillus plantarum</i>	CIRM-BIA1520
<i>Lactobacillus plantarum</i>	L299	<i>Lactobacillus reuteri</i>	L154
<i>Lactobacillus plantarum</i>	L35	<i>Lactobacillus reuteri</i>	L165
<i>Lactobacillus plantarum</i>	L36	<i>Lactobacillus reuteri</i>	L177
<i>Lactobacillus plantarum</i>	L39	<i>Lactobacillus reuteri</i>	L178
<i>Lactobacillus plantarum</i>	L4	<i>Lactobacillus reuteri</i>	L185
<i>Lactobacillus plantarum</i>	L41	<i>Lactobacillus reuteri</i>	L187

<i>Lactobacillus plantarum</i>	L41	<i>Lactobacillus reuteri</i>	L189
<i>Lactobacillus reuteri</i>	L190	<i>Lactococcus lactis</i>	L168
<i>Lactobacillus reuteri</i>	L197	<i>Lactococcus lactis</i>	L2
<i>Lactobacillus reuteri</i>	L213	<i>Leuconostoc citreum</i>	CIRM-BIA742
<i>Lactobacillus reuteri</i>	L214	<i>Leuconostoc citreum</i>	CIRM-BIA852
<i>Lactobacillus reuteri</i>	L223	<i>Leuconostoc citreum</i>	CIRM-BIA1453
<i>Lactobacillus reuteri</i>	L235	<i>Leuconostoc citreum</i>	CIRM-BIA1454
<i>Lactobacillus reuteri</i>	L236	<i>Leuconostoc citreum</i>	CIRM-BIA1455
<i>Lactobacillus reuteri</i>	L238	<i>Leuconostoc citreum</i>	CIRM-BIA1456
<i>Lactobacillus reuteri</i>	L262	<i>Leuconostoc citreum</i>	CIRM-BIA1457
<i>Lactobacillus reuteri</i>	L275	<i>Leuconostoc mesenteroides</i>	L104
<i>Lactobacillus reuteri</i>	L280	<i>Leuconostoc mesenteroides</i>	L113
<i>Lactobacillus reuteri</i>	L295	<i>Leuconostoc mesenteroides</i>	L114
<i>Lactobacillus reuteri</i>	L296	<i>Leuconostoc mesenteroides</i>	L115
<i>Lactobacillus reuteri</i>	L297	<i>Leuconostoc mesenteroides</i>	L116
<i>Lactobacillus reuteri</i>	L33	<i>Leuconostoc mesenteroides</i>	L126
<i>Lactobacillus reuteri</i>	L44	<i>Leuconostoc mesenteroides</i>	L131
<i>Lactobacillus reuteri</i>	L55	<i>Leuconostoc mesenteroides</i>	L132
<i>Lactobacillus reuteri</i>	L60	<i>Leuconostoc mesenteroides</i>	L133
<i>Lactobacillus reuteri</i>	L67	<i>Leuconostoc mesenteroides</i>	L134
<i>Lactobacillus reuteri</i>	L78	<i>Leuconostoc mesenteroides</i>	L135
<i>Lactobacillus reuteri</i>	L79	<i>Leuconostoc mesenteroides</i>	L141
<i>Lactobacillus reuteri</i>	L80	<i>Leuconostoc mesenteroides</i>	CIRM-BIA694
<i>Lactobacillus reuteri</i>	L81	<i>Leuconostoc mesenteroides</i>	CIRM-BIA740
<i>Lactobacillus reuteri</i>	L83	<i>Leuconostoc mesenteroides</i>	CIRM-BIA847
<i>Lactobacillus reuteri</i>	L91	<i>Leuconostoc mesenteroides</i>	CIRM-BIA1146
<i>Lactobacillus reuteri</i>	L92	<i>Leuconostoc mesenteroides</i>	CIRM-BIA1147
<i>Lactobacillus reuteri</i>	L94	<i>Leuconostoc mesenteroides</i>	CIRM-BIA1153
<i>Lactobacillus reuteri</i>	L97	<i>Leuconostoc mesenteroides</i>	CIRM-BIA1154
<i>Lactobacillus reuteri</i>	CIRM-BIA522	<i>Leuconostoc mesenteroides</i>	CIRM-BIA1155
<i>Lactobacillus reuteri</i>	CIRM-BIA696	<i>Leuconostoc mesenteroides</i>	CIRM-BIA1156
<i>Lactobacillus reuteri</i>	CIRM-BIA911	<i>Leuconostoc mesenteroides</i>	CIRM-BIA1159
<i>Lactobacillus reuteri</i>	CIRM-BIA912	<i>Leuconostoc mesenteroides</i>	CIRM-BIA1176
<i>Lactobacillus reuteri</i>	CIRM-BIA929	<i>Leuconostoc mesenteroides</i>	CIRM-BIA1185
<i>Lactobacillus reuteri</i>	CIRM-BIA1439	<i>Leuconostoc mesenteroides</i>	CIRM-BIA1187
<i>Lactobacillus reuteri</i>	CIRM-BIA1534	<i>Leuconostoc mesenteroides</i>	CIRM-BIA1191
<i>Lactobacillus rhamnosus</i>	CIRM-BIA607	<i>Leuconostoc mesenteroides</i>	CIRM-BIA1192
<i>Lactobacillus rhamnosus</i>	CIRM-BIA909	<i>Leuconostoc mesenteroides</i>	CIRM-BIA1193
<i>Lactobacillus rhamnosus</i>	CIRM-BIA910	<i>Leuconostoc mesenteroides</i>	CIRM-BIA1194
<i>Lactobacillus rhamnosus</i>	CIRM-BIA913	<i>Leuconostoc mesenteroides</i>	CIRM-BIA1228
<i>Lactobacillus rhamnosus</i>	CIRM-BIA930	<i>Leuconostoc mesenteroides</i>	CIRM-BIA1229
<i>Lactobacillus rhamnosus</i>	CIRM-BIA1107	<i>Leuconostoc mesenteroides</i>	CIRM-BIA1230
<i>Lactobacillus rhamnosus</i>	CIRM-BIA1112	<i>Leuconostoc mesenteroides</i>	CIRM-BIA1231
<i>Lactobacillus rhamnosus</i>	CIRM-BIA1113	<i>Leuconostoc mesenteroides</i>	CIRM-BIA1232
<i>Lactobacillus rhamnosus</i>	CIRM-BIA1436	<i>Leuconostoc mesenteroides</i>	CIRM-BIA1233
<i>Lactobacillus sakei</i>	CIRM-BIA467	<i>Leuconostoc mesenteroides</i>	CIRM-BIA1234
<i>Lactobacillus sakei</i>	CIRM-BIA892	<i>Leuconostoc mesenteroides</i>	CIRM-BIA1235
<i>Lactobacillus sakei</i>	CIRM-BIA1559	<i>Leuconostoc mesenteroides</i>	CIRM-BIA1236
<i>Lactobacillus sanfranciscensis</i>	CIRM-BIA1357	<i>Leuconostoc mesenteroides</i>	CIRM-BIA1237
<i>Lactobacillus zeae</i>	CIRM-BIA524	<i>Leuconostoc mesenteroides</i>	CIRM-BIA1238
<i>Lactobacillus zeae</i>	CIRM-BIA525	<i>Leuconostoc mesenteroides</i>	CIRM-BIA1239

<i>Leuconostoc mesenteroides</i>	CIRM-BIA1242	<i>Propionibacterium freudenreichii</i>	CIRM-BIA12
<i>Leuconostoc mesenteroides</i>	CIRM-BIA1244	<i>Propionibacterium freudenreichii</i>	CIRM-BIA41
<i>Leuconostoc mesenteroides</i>	CIRM-BIA1245	<i>Propionibacterium freudenreichii</i>	CIRM-BIA118
<i>Leuconostoc mesenteroides</i>	CIRM-BIA1246	<i>Propionibacterium freudenreichii</i>	CIRM-BIA1324
<i>Leuconostoc mesenteroides</i>	CIRM-BIA1249	<i>Propionibacterium freudenreichii</i>	CIRM-BIA141
<i>Leuconostoc mesenteroides</i>	CIRM-BIA1250	<i>Propionibacterium freudenreichii</i>	CIRM-BIA508
<i>Leuconostoc mesenteroides</i>	CIRM-BIA1251	<i>Propionibacterium freudenreichii</i>	CIRM-BIA509
<i>Leuconostoc mesenteroides</i>	CIRM-BIA1252	<i>Propionibacterium freudenreichii</i>	CIRM-BIA510
<i>Leuconostoc mesenteroides</i>	CIRM-BIA1259	<i>Propionibacterium freudenreichii</i>	CIRM-BIA512
<i>Leuconostoc mesenteroides</i>	CIRM-BIA1260	<i>Propionibacterium freudenreichii</i>	CIRM-BIA514
<i>Leuconostoc mesenteroides</i>	CIRM-BIA1261	<i>Propionibacterium freudenreichii</i>	CIRM-BIA515
<i>Leuconostoc mesenteroides</i>	CIRM-BIA1262	<i>Propionibacterium freudenreichii</i>	CIRM-BIA527
<i>Leuconostoc mesenteroides</i>	CIRM-BIA1264	<i>Propionibacterium freudenreichii</i>	CIRM-BIA683
<i>Leuconostoc mesenteroides</i>	CIRM-BIA1265	<i>Propionibacterium freudenreichii</i>	CIRM-BIA686
<i>Leuconostoc mesenteroides</i>	CIRM-BIA1266	<i>Propionibacterium freudenreichii</i>	CIRM-BIA687
<i>Leuconostoc mesenteroides</i>	CIRM-BIA1267	<i>Propionibacterium freudenreichii</i>	CIRM-BIA688
<i>Leuconostoc mesenteroides</i>	CIRM-BIA1268	<i>Propionibacterium freudenreichii</i>	CIRM-BIA690
<i>Leuconostoc mesenteroides</i>	CIRM-BIA1269	<i>Propionibacterium freudenreichii</i>	CIRM-BIA692
<i>Leuconostoc mesenteroides</i>	CIRM-BIA1270	<i>Propionibacterium jensenii</i>	CIRM-BIA39
<i>Leuconostoc mesenteroides</i>	CIRM-BIA1271	<i>Propionibacterium jensenii</i>	CIRM-BIA455
<i>Leuconostoc mesenteroides</i>	CIRM-BIA1272	<i>Propionibacterium jensenii</i>	CIRM-BIA1347
<i>Leuconostoc mesenteroides</i>	CIRM-BIA1302	<i>Propionibacterium jensenii</i>	CIRM-BIA1431
<i>Leuconostoc mesenteroides</i>	CIRM-BIA1304	<i>Propionibacterium jensenii</i>	CIRM-BIA1432
<i>Leuconostoc mesenteroides</i>	CIRM-BIA1305	<i>Propionibacterium jensenii</i>	CIRM-BIA1494
<i>Leuconostoc mesenteroides</i>	CIRM-BIA1314	<i>Propionibacterium jensenii</i>	CIRM-BIA1505
<i>Leuconostoc mesenteroides</i>	CIRM-BIA1315	<i>Propionibacterium jensenii</i>	CIRM-BIA1507
<i>Leuconostoc mesenteroides</i>	CIRM-BIA1317	<i>Propionibacterium jensenii</i>	CIRM-BIA1658
<i>Leuconostoc mesenteroides</i>	CIRM-BIA1318	<i>Propionibacterium jensenii</i>	CIRM-BIA1660
<i>Leuconostoc mesenteroides</i>	CIRM-BIA1320	<i>Propionibacterium jensenii</i>	CIRM-BIA1661
<i>Leuconostoc mesenteroides</i>	CIRM-BIA1326	<i>Propionibacterium jensenii</i>	CIRM-BIA1774
<i>Pediococcus pentosaceus</i>	L42	<i>Propionibacterium jensenii</i>	CIRM-BIA1775
<i>Pediococcus pentosaceus</i>	CIRM-BIA1701	<i>Propionibacterium jensenii</i>	CIRM-BIA1777
<i>Propionibacterium acidipropionici</i>	CIRM-BIA64	<i>Propionibacterium jensenii</i>	CIRM-BIA1778
<i>Propionibacterium acidipropionici</i>	CIRM-BIA609	<i>Propionibacterium jensenii</i>	CIRM-BIA1779
<i>Propionibacterium acidipropionici</i>	CIRM-BIA928	<i>Propionibacterium jensenii</i>	CIRM-BIA1781
<i>Propionibacterium acidipropionici</i>	CIRM-BIA1384	<i>Propionibacterium jensenii</i>	CIRM-BIA1782
<i>Propionibacterium acidipropionici</i>	CIRM-BIA1424	<i>Propionibacterium jensenii</i>	CIRM-BIA1785
<i>Propionibacterium acidipropionici</i>	CIRM-BIA1425	<i>Propionibacterium jensenii</i>	CIRM-BIA1794
<i>Propionibacterium acidipropionici</i>	CIRM-BIA1427	<i>Propionibacterium thoenii</i>	CIRM-BIA40
<i>Propionibacterium acidipropionici</i>	CIRM-BIA1535	<i>Propionibacterium thoenii</i>	CIRM-BIA1329
<i>Propionibacterium acidipropionici</i>	CIRM-BIA1652	<i>Propionibacterium thoenii</i>	CIRM-BIA1423
<i>Propionibacterium acidipropionici</i>	CIRM-BIA1656	<i>Propionibacterium thoenii</i>	CIRM-BIA1429
<i>Propionibacterium acidipropionici</i>	CIRM-BIA1664	<i>Propionibacterium thoenii</i>	CIRM-BIA1433
<i>Propionibacterium acidipropionici</i>	CIRM-BIA1762	<i>Propionibacterium thoenii</i>	CIRM-BIA1435
<i>Propionibacterium acidipropionici</i>	CIRM-BIA1763	<i>Propionibacterium thoenii</i>	CIRM-BIA1500
<i>Propionibacterium acidipropionici</i>	CIRM-BIA1764	<i>Propionibacterium thoenii</i>	CIRM-BIA1663
<i>Propionibacterium acidipropionici</i>	CIRM-BIA1765	<i>Propionibacterium thoenii</i>	CIRM-BIA1786
<i>Propionibacterium acidipropionici</i>	CIRM-BIA1769	<i>Propionibacterium thoenii</i>	CIRM-BIA1788
<i>Propionibacterium acidipropionici</i>	CIRM-BIA1770	<i>Propionibacterium thoenii</i>	CIRM-BIA1789
<i>Propionibacterium freudenreichii</i>	CIRM-BIA10	<i>Propionibacterium thoenii</i>	CIRM-BIA1790
<i>Propionibacterium thoenii</i>	CIRM-BIA1791	<i>Gliocladium deliquescens</i>	UBOCC-A-101174

<i>Propionibacterium thoenii</i>	CIRM-BIA1793	<i>Gliocladium roseum</i>	UBOCC-A-101175
<i>Actinomucor elegans</i>	UBOCC-A-101333	<i>Gliocladium</i> sp.	UBOCC-A-102025
<i>Actinomucor elegans</i>	UBOCC-A-102005	<i>Gliocladium virens</i>	UBOCC-A-101176
<i>Actinomucor elegans</i>	UBOCC-A-106035	<i>Gliomastix murorum</i>	UBOCC-A-101178
<i>Aureobasidium pullulans</i>	UBOCC-A-101091	<i>Gliomastix murorum</i>	UBOCC-A-101179
<i>Aureobasidium pullulans</i>	UBOCC-A-101092	<i>Lodderomyces elongisporus</i>	UBOCC-A-214062
<i>Aureobasidium pullulans</i>	UBOCC-A-108047	<i>Meyerozyma guilliermondii</i>	L1lev7
<i>Aureobasidium pullulans</i>	UBOCC-A-108048	<i>Meyerozyma guilliermondii</i>	L2lev17
<i>Aureobasidium pullulans</i>	UBOCC-A-108056	<i>Meyerozyma guilliermondii</i>	UBOCC-A-214105
<i>Aureobasidium pullulans</i>	UBOCC-A-108057	<i>Meyerozyma guilliermondii</i>	UBOCC-A-208004
<i>Aureobasidium pullulans</i>	UBOCC-A-111234	<i>Mucor bruneogriseus</i>	UBOCC-A-109204
<i>Candida catenulata</i>	L1lev3	<i>Mucor bruneogriseus</i>	UBOCC-A-109205
<i>Candida davisiana</i>	UBOCC-A-214090	<i>Mucor bruneogriseus</i>	UBOCC-A-109206
<i>Candida haemulonis</i>	UBOCC-A-214059	<i>Mucor bruneogriseus</i>	JBOCC-A-109207
<i>Candida methapsilosis</i>	L1lev6	<i>Mucor bruneogriseus</i>	UBOCC-A-109208
<i>Candida parapsilosis</i>	UBOCC-A-214083	<i>Mucor bruneogriseus</i>	UBOCC-A-109209
<i>Candida parapsilosis</i>	L1lev5	<i>Mucor bruneogriseus</i>	UBOCC-A-109210
<i>Candida parapsilosis</i>	UBOCC-A-214060	<i>Mucor fragilis</i>	UBOCC-A-109196
<i>Candida pseudoglaebosa</i>	UBOCC-A-214089	<i>Mucor fragilis</i>	UBOCC-A-109199
<i>Candida sorbophila</i>	UBOCC-A-214111	<i>Mucor fragilis</i>	UBOCC-A-113030
<i>Candida tenuis</i>	UBOCC-A-214064	<i>Mucor fuscus</i>	UBOCC-A-101355
<i>Candida zeylanoides</i>	L2lev6	<i>Mucor fuscus</i>	UBOCC-A-109194
<i>Candida zeylanoides</i>	UBOCC-A-214114	<i>Mucor fuscus</i>	UBOCC-A-109195
<i>Chaetomium dolichotrichum</i>	UBOCC-A-101010	<i>Mucor fuscus</i>	UBOCC-A-109202
<i>Chaetomium funicola</i>	UBOCC-A-101011	<i>Mucor fuscus</i>	UBOCC-A-110148
<i>Chaetomium globosum</i>	UBOCC-A-101012	<i>Mucor griseocyanus</i>	UBOCC-A-102010
<i>Cleistothelobolus nipigonensis</i>	UBOCC-A-214079	<i>Mucor hiemalis</i>	UBOCC-A-101359
<i>Cryptococcoccus curvatus</i>	UBOCC-A-214084	<i>Mucor hiemalis</i>	UBOCC-A-101360
<i>Cryptococcoccus curvatus</i>	UBOCC-A-214094	<i>Mucor hiemalis</i>	UBOCC-A-102003
<i>Cryptococcoccus albidus</i>	UBOCC-A-214081	<i>Mucor hiemalis</i>	UBOCC-A-109197
<i>Cryptococcoccus diffluens</i>	UBOCC-A-214070	<i>Mucor hiemalis</i>	UBOCC-A-111119
<i>Cryptococcus magnus</i>	UBOCC-A-214092	<i>Mucor hiemalis</i>	UBOCC-A-112185
<i>Cryptococcus uzbekistanensis</i>	UBOCC-A-214131	<i>Mucor lanceolatus</i>	UBOCC-A-109193
<i>Cystofilobasidium infirmominiatum</i>	UBOCC-A-214077	<i>Mucor mucedo</i>	UBOCC-A-101361
<i>Debaryomyces hansenii</i>	L1lev4	<i>Mucor mucedo</i>	UBOCC-A-101362
<i>Debaryomyces hansenii</i>	UBOCC-A-214074	<i>Mucor plumbeus</i>	UBOCC-A-109203
<i>Exophiala castellanii</i>	UBOCC-A-214056	<i>Mucor plumbeus</i>	UBOCC-A-111125
<i>Exophiala dermatitidis</i>	UBOCC-A-214076	<i>Mucor plumbeus</i>	UBOCC-A-111126
<i>Exophiala</i> sp.	UBOCC-A-101133	<i>Mucor plumbeus</i>	UBOCC-A-111128
<i>Exophiala</i> sp.	UBOCC-A-108008	<i>Mucor plumbeus</i>	UBOCC-A-111129
<i>Exophiala</i> sp.	UBOCC-A-108012	<i>Mucor plumbeus</i>	UBOCC-A-111132
<i>Exophiala</i> sp.	UBOCC-A-108017	<i>Mucor racemosus</i>	UBOCC-A-101366
<i>Exophiala</i> sp.	UBOCC-A-108021	<i>Mucor racemosus</i>	UBOCC-A-102017
<i>Exophiala</i> sp.	UBOCC-A-108022	<i>Mucor racemosus</i>	UBOCC-A-109186
<i>Exophiala</i> sp.	UBOCC-A-108025	<i>Mucor racemosus</i>	UBOCC-A-109211
<i>Exophiala</i> sp.	UBOCC-A-108026	<i>Mucor racemosus</i>	UBOCC-A-109212
<i>Exophiala</i> sp.	UBOCC-A-108035	<i>Mucor racemosus</i>	UBOCC-A-109213
<i>Exophiala</i> sp.	UBOCC-A-108059	<i>Mucor</i> sp.	UBOCC-A-110121
<i>Exophiala xenobiotica</i>	UBOCC-A-214088	<i>Mucor</i> sp.	UBOCC-A-112143
<i>Phoma betae</i>	UBOCC-A-111053	<i>Schizosaccharomyces pombe</i>	UBOCC-A-201052
<i>Phoma glomerata</i>	UBOCC-A-101141	<i>Schizosaccharomyces pombe</i>	UBOCC-A-201053

<i>Phoma</i> sp.	UBOCC-A-102026	<i>Sporobolomyces roseus</i>	UBOCC-A-214093
<i>Phoma</i> sp.	UBOCC-A-109091	<i>Sporobolomyces roseus</i>	UBOCC-A-214078
<i>Phoma valerianellae</i>	UBOCC-A-101242	<i>Torulaspota delbrueckii</i>	L2lev7
<i>Phoma valerianellae</i>	UBOCC-A-101243	<i>Torulaspota delbrueckii</i>	L2lev3
<i>Phoma valerianellae</i>	UBOCC-A-101244	<i>Torulaspota delbrueckii</i>	L1lev2
<i>Pichia anomala</i>	UBOCC-A-201001	<i>Torulaspota delbrueckii</i>	UBOCC-A-214128
<i>Pichia anomala</i>	UBOCC-A-205011	<i>Trichoderma harzianum</i>	UBOCC-A-101288
<i>Pichia anomala</i>	UBOCC-A-212007	<i>Trichoderma harzianum</i>	UBOCC-A-101289
<i>Pichia anomala</i>	UBOCC-A-212008	<i>Trichoderma harzianum</i>	UBOCC-A-111253
<i>Pichia anomala</i>	UBOCC-A-212011	<i>Trichoderma harzianum</i>	UBOCC-A-111254
<i>Pichia burtonii</i>	UBOCC-A-212009	<i>Trichoderma koningii</i>	UBOCC-A-101290
<i>Pichia fermentans</i>	UBOCC-A-201032	<i>Trichoderma viride</i>	UBOCC-A-101292
<i>Pichia fermentans</i>	UBOCC-A-201033	<i>Trichoderma viride</i>	UBOCC-A-111251
<i>Pichia membranifaciens</i>	UBOCC-A-214071	<i>Trichoderma viride</i>	UBOCC-A-111252
<i>Pichia norvegensis</i>	UBOCC-A-201034	<i>Trichoderma viride</i>	UBOCC-A-112152
<i>Pseudozyma</i> sp.	UBOCC-A-214138	<i>Trichosporon asahii</i>	UBOCC-A-214080
<i>Rhizomucor pusillus</i>	UBOCC-A-101365	<i>Trichosporon coremiiforme</i>	UBOCC-A-214058
<i>Rhizomucor pusillus</i>	UBOCC-A-111202	<i>Trichosporon dulcitum</i>	UBOCC-A-214085
<i>Rhodotorula laryngis</i>	UBOCC-A-214057	<i>Trichosporon montevidense</i>	UBOCC-A-214068
<i>Rhodotorula minuta</i>	UBOCC-A-214082	<i>Verticillium albo-atrum</i>	UBOCC-A-101303
<i>Rhodotorula mucilaginosa</i>	UBOCC-A-214069	<i>Verticillium albo-atrum</i>	UBOCC-A-101304
<i>Rhodotorula mucilaginosa</i>	UBOCC-A-214075	<i>Verticillium albo-atrum</i>	UBOCC-A-101305
<i>Rhodotorula mucilaginosa</i>	UBOCC-A-214091	<i>Verticillium albo-atrum</i>	UBOCC-A-101306
<i>Rhodotorula mucilaginosa</i>	UBOCC-A-214102	<i>Verticillium albo-atrum</i>	UBOCC-A-101307
<i>Rhodotorula slooffiae</i>	UBOCC-A-214103	<i>Verticillium dahliae</i>	UBOCC-A-101308
<i>Rhodotorula slooffiae</i>	UBOCC-A-214073	<i>Verticillium dahliae</i>	UBOCC-A-101309
<i>Rhodotorula vanillica</i>	UBOCC-A-214104	<i>Verticillium dahliae</i>	UBOCC-A-101310
<i>Saccharomyces bailii</i>	UBOCC-A-201004	<i>Verticillium dahliae</i>	UBOCC-A-101311
<i>Saccharomyces bailii</i>	UBOCC-A-201035	<i>Verticillium dahliae</i>	UBOCC-A-101312
<i>Saccharomyces bailii</i>	UBOCC-A-205008	<i>Verticillium dahliae</i>	UBOCC-A-101313
<i>Saccharomyces carlsbergensis</i>	UBOCC-A-201036	<i>Verticillium dahliae</i>	UBOCC-A-101314
<i>Saccharomyces carlsbergensis</i>	UBOCC-A-201038	<i>Verticillium dahliae</i>	UBOCC-A-101315
<i>Saccharomyces carlsbergensis</i>	UBOCC-A-205034	<i>Verticillium dahliae</i>	UBOCC-A-101316
<i>Saccharomyces cerevisiae</i>	UBOCC-A-214061	<i>Verticillium dahliae</i>	UBOCC-A-101317
<i>Saccharomyces cerevisiae</i>	UBOCC-A-201006	<i>Verticillium dahliae</i>	UBOCC-A-101318
<i>Saccharomyces cerevisiae</i>	UBOCC-A-201039	<i>Verticillium intertextum</i>	UBOCC-A-101319
<i>Saccharomyces cerevisiae</i>	UBOCC-A-201040	<i>Verticillium lecanii</i>	UBOCC-A-101320
<i>Saccharomyces cerevisiae</i>	UBOCC-A-201041	<i>Verticillium lecanii</i>	UBOCC-A-108019
<i>Saccharomyces cerevisiae</i>	UBOCC-A-205009	<i>Verticillium lecanii</i>	UBOCC-A-108023
<i>Saccharomyces cerevisiae</i>	UBOCC-A-201042	<i>Verticillium nigrescens</i>	UBOCC-A-101322
<i>Saccharomyces kluyveri</i>	UBOCC-A-201045	<i>Verticillium nonalfalfae</i>	UBOCC-A-112135
<i>Saccharomyces ludwigii</i>	UBOCC-A-205010	<i>Verticillium tricorpus</i>	UBOCC-A-101323
<i>Saccharomyces rouxii</i>	UBOCC-A-201046	<i>Wickerhamomyces anomalus</i>	UBOCC-A-214106
<i>Saccharomyces uvarum</i>	UBOCC-A-201047	<i>Zygosaccharomyces bailii</i>	UBOCC-A-201062
<i>Saccharomyces uvarum</i>	UBOCC-A-201048	<i>Zygosaccharomyces mellis</i>	UBOCC-A-201063
<i>Saccharomyces uvarum</i>	UBOCC-A-201049	<i>Zygosaccharomyces rouxii</i>	UBOCC-A-201064
<i>Saccharomyces uvarum</i>	UBOCC-A-201050	<i>Zygosaccharomyces rouxii</i>	UBOCC-A-209001
<i>Saccharomyces uvarum</i>	UBOCC-A-201051	<i>Zygosaccharomyces</i> sp.	UBOCC-A-202008

Supplementary Table S2. Antifungal activity of fermentates from lactic acid bacteria, propionibacteria and fungi grown in low heat milk (LH) and ultrafiltration milk permeate (UF) against *M. racemosus* UBOCC-A-116002, *P. commune* UBOCC-A-116003, *G. geotrichum* UBOCC-A-216001 and *Y. lipolytica* UBOCC-A-216006 after *in vitro* screening in miniaturized cheeses.

Taxon	Number of isolates	Number of active* fermentates obtained on LH					Number of active fermentates obtained on UF				
		<i>M. racemosus</i>	<i>P. commune</i>	<i>G. geotrichum</i>	<i>Y. lipolytica</i>	More than one target (%)	<i>M. racemosus</i>	<i>P. commune</i>	<i>G. geotrichum</i>	<i>Y. lipolytica</i>	More than one target (%)
<i>Lactobacillus acidophilus</i>	4	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Lactobacillus amylovorus</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Lactobacillus brevis</i>	8	1	3	0	0	1 (12.5)	0	0	0	0	0 (0)
<i>Lactobacillus buchneri</i>	34	3	15	0	1	3 (8.8)	0	3	0	0	0 (0)
<i>Lactobacillus casei/paracasei</i>	112	4	12	0	0	2 (1.8)	0	0	0	0	0 (0)
<i>Lactobacillus delbruecki</i>	2	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Lactobacillus farciminis</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Lactobacillus fermentum</i>	2	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Lactobacillus gasseri</i>	4	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Lactobacillus harbinensis</i>	1	1	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Lactobacillus pentosus</i>	4	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Lactobacillus perolens/harbinensis</i>	3	1	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Lactobacillus plantarum</i>	115	3	47	0	0	3 (2.6)	0	0	0	0	0 (0)
<i>Lactobacillus reuteri</i>	42	0	1	0	0	0 (0)	0	0	0	0	0 (0)
<i>Lactobacillus rhamnosus</i>	9	0	3	0	0	0 (0)	0	0	0	0	0 (0)
<i>Lactobacillus sakei</i>	3	0	0	0	0	0 (0)	0	0	0	1	0 (0)
<i>Lactobacillus sanfranciscensis</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Lactobacillus zeae</i>	2	0	0	0	0	0 (0)	0	0	0	1	0 (0)
<i>Lactococcus lactis</i>	2	0	0	0	0	0 (0)	0	0	0	2	0 (0)
<i>Leuconostoc citreum</i>	7	0	0	0	0	0 (0)	0	1	0	0	0 (0)
<i>Leuconostoc mesenteroides</i>	71	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Pediococcus pentosaceus</i>	2	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Propionibacterium acidopropionici</i>	17	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Propionibacterium freudenreichii</i>	19	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Propionibacterium jensenii</i>	20	0	0	0	0	0 (0)	1	0	0	0	0 (0)
<i>Propionibacterium thoenii</i>	14	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Actinomucor elegans</i>	3	0	0	0	0	0 (0)	0	1	0	0	0 (0)
<i>Aureobasidium pullulans</i>	7	1	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Candida catenulata</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Candida davisiana</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Candida haemulonis</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Candida methapsilosis</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Candida parapsilosis</i>	3	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Candida pseudoglebosa</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Candida sorbophila</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Candida tenuis</i>	1	0	0	0	0	0 (0)	0	0	0	1	0 (0)
<i>Candida zeylanoides</i>	2	0	0	0	0	0 (0)	0	0	0	0	0 (0)

<i>Chaetomium dolichotrichum</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Chaetomium funicola</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Chaetomium globosum</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Cleistothelobolus nipigonensis</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Cryptococcus albidus</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Cryptococcus curvatus</i>	2	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Cryptococcus diffluens</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Cryptococcus magnus</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Cryptococcus uzbekistanensis</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Cystofilobasidium infirmominiatum</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Debaryomyces hansenii</i>	2	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Exophiala castellanii</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Exophiala dermatidis</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Exophiala xenobiotica</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Exophiala sp.</i>	10	0	0	2	0	0 (0)	0	0	0	0	0 (0)
<i>Gliocladium deliquescens</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Gliocladium roseum</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Gliocladium virens</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Gliocladium sp.</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Gliomastix murorum</i>	2	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Lodderomyces elongisporus</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Meyerozyma guilliermondii</i>	4	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Mucor brunneogriseus</i>	7	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Mucor fragilis</i>	3	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Mucor fuscus</i>	5	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Mucor griseocyanus</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Mucor hiemalis</i>	6	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Mucor lanceolatus</i>	1	1	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Mucor mucedo</i>	2	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Mucor plumbeus</i>	6	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Mucor racemosus</i>	6	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Mucor sp.</i>	2	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Phoma betae</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Phoma glomerata</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Phoma valerianellae</i>	3	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Phoma sp.</i>	2	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Pichia anomala</i>	5	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Pichia burtonii</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Pichia fermentans</i>	2	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Pichia membranifaciens</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Pichia norvegensis</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Pseudozyma sp.</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Rhizomucor pusillus</i>	2	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Rhodotorula laryngis</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Rhodotorula minuta</i>	1	0	0	1	0	0 (0)	0	0	0	0	0 (0)
<i>Rhodotorula mucilaginoso</i>	4	0	0	1	0	0 (0)	0	0	0	0	0 (0)
<i>Rhodotorula slooffiae</i>	2	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Rhodotorula vanillica</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Saccharomyces carlsbergensis</i>	3	0	0	0	0	0 (0)	0	0	0	0	0 (0)

<i>Saccharomyces cerevisiae</i>	7	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Saccharomyces kluyveri</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Saccharomyces ludwigii</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Saccharomyces uvarum</i>	5	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Schizosaccharomyces pombe</i>	2	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Sporobomyces roseus</i>	2	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Torulaspora delbrueckii</i>	4	0	0	1	0	0 (0)	0	0	0	0	0 (0)
<i>Trichoderma harzianum</i>	4	0	0	0	0	0 (0)	0	0	0	1	0 (0)
<i>Trichoderma koningii</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Trichoderma viride</i>	4	0	0	1	0	0 (0)	0	0	0	0	0 (0)
<i>Trichosporon asahii</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Trichosporon coremiiforme</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Trichosporon dulcimum</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Trichosporon montevidense</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Verticillium albo-atrum</i>	5	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Verticillium dahliae</i>	11	0	0	0	0	0 (0)	0	1	0	0	0 (0)
<i>Verticillium intertextum</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Verticillium lecanii</i>	3	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Verticillium nigrescens</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Verticillium nonalfalfae</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Verticillium tricorpus</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Wickerhamomyces anomalus</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Zygosaccharomyces bailii</i>	4	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Zygosaccharomyces mellis</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Zygosaccharomyces rouxii</i>	3	0	0	0	0	0 (0)	0	0	0	0	0 (0)
<i>Zygosaccharomyces sp.</i>	1	0	0	0	0	0 (0)	0	0	0	0	0 (0)
Total bacteria	500	13	81	0	1	9 (1.8)	1	4	0	4	0 (0)
Total fungi	198	2	0	6	0	0 (0)	0	2	0	2	0 (0)
Total	698	15	81	6	1	9 (1.3)	1	6	0	6	0 (0)

* Delayed growth or total inhibition of the fungal target in comparison with the negative control.

Supplementary figure 1. Acceptability test for sour cream inoculated with increased concentrations of *P. jensenii* CIRM-BIA1774 fermentate ranging from 0.1 to 0.7 %. Results corresponding to the 21 of 26 panelists accepting the the control (sour cream without fermentate addition).

