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1 **Selecting autochthonous lactic acid bacteria for co-inoculation in**
2 **Chinese bayberry wine production: stress response, starter cultures**
3 **application and volatilomic study**

4

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16 **ABSTRACT**

17 This study focused on isolating and characterising autochthonous lactic acid bacteria
18 (LAB) from spontaneously fermented Chinese bayberry (CB) and their potential
19 application in CB wine fermentation in co-inoculation with yeast starter cultures.
20 Numerous LAB, including *Lactiplantibacillus (Lp.) plantarum* (9), *Limosilactobacillus*
21 (*Lb.*) *fermentum* (6), *Lactococcus (Lc.) lactis* (3), *Enterococcus (Ec.) hirae* (1),
22 *Leuconostoc (Le.) mesenteroides* (1), and *Weissella (Ws.) cibaria* (1), were isolated and
23 identified. The isolated strains *Lp. plantarum* ZFM710 and ZFM715, together with *Lb.*
24 *fermentum* ZFM720 and ZFM722, adapted well to unfavourable fermentation
25 environment, including ethanol, osmolality, and acidity stresses, were selected for
26 producing CB wine by co-inoculation with *Saccharomyces cerevisiae*. During
27 fermentation, the presence of LAB promoted the development of *S. cerevisiae*, while
28 the population dynamics of LAB in different groups at different stages showed strain-
29 specific differences. Fermentation trials involving LAB yielded a lower ethanol
30 concentration except for *Lp. plantarum* ZFM715. Compared to the pure *S. cerevisiae*
31 fermented sample, the addition of LAB led to a clear modulation in organic acid
32 composition. *Lb. fermentum* strains in co-fermentation led to significant decreases in
33 each classified group of aroma compounds, while *Lp. plantarum* ZFM715 significantly
34 increased the complexity and intensity of aroma compounds, as well as the intensities
35 of fruity and floral notes. The study selects interesting strains for the design of starter
36 cultures for use in CB wine production, underlining the interest in the selection of

37 autochthonous LAB in fruit wines, with the aim of improving the adaptation of bacteria
38 to specific environmental conditions and shaping the unique traits of the finished
39 products.

40

41 **Keywords:** Chinese bayberry wine; autochthonous lactic acid bacteria; stress tolerance;
42 co-inoculation; organic acids; aroma compounds

43

44 **1 Introduction**

45 Lactic acid bacteria (LAB) have a long history of safe use in the production of
46 fermented foods. Although LAB are commonly associated with dairy products, recent
47 advancements in knowledge have revealed their potential application in non-dairy-
48 based fermented foods and, particularly, in plant-based products (Capozzi et al., 2021;
49 Ruiz Rodríguez et al., 2021). Among the products, LAB are gaining attention in the
50 segment of fruit-based wines, such as cherry wine (Sun et al., 2018), *Prunus mahaleb*
51 wine (Gerardi et al., 2019), and blueberry wine (Jigang Zhang et al., 2022), due to their
52 enzymatic activities, such as glycosidase, esterase, dehydrogenase, reductase, and
53 decarboxylase that may facilitate the transformation of precursors in raw materials to
54 shape taste and flavour of fruit wines (Cappello et al., 2017). However, only the study
55 by Sun *et al.* (2018) proposed the exploitation of an autochthonous LAB strain, but
56 without any information about the selection procedure.

57 Compared with other fermented foods, fruit winemaking environment is less
58 explored and generally regarded as less favourable for the growth and metabolism of
59 LAB, primarily due to the presence of ethanol, high acidity, high amount of indigestible
60 nutrients, and richness of inhibitor of phenolic compounds (Li et al., 2021; Rodríguez
61 et al., 2009). These stressors play a crucial role in shaping LAB development and their
62 technological exploitation (Bartle et al., 2019). Since microorganisms are the key factor
63 in determining the quality of fermented products, it is necessary to explore desirable
64 microorganisms to process the target food matrix. Isolation of autochthonous

65 microbiota from spontaneously fermented fruits has been considered an important route
66 to obtain microbial strains with satisfactory fermentative ability (Jin et al., 2022;
67 Meruvu & Harsa, 2022).

68 Chinese bayberry (*Myrica rubra*, CB), also known as Yangmei, is native to
69 southeastern China with cultivation of over 2000 years. Nowadays, CB is widely
70 distributed worldwide across tropical, subtropical, and temperate regions (Qiaozhi
71 Zhang et al., 2021). CB fruit has gained popularity among consumers due to its unique
72 sweet-sour taste, attractive colour, and exquisite flavour (Y. Zhu et al., 2020). Moreover,
73 the characteristic of being rich in nutritional and functional components, such as
74 vitamins, organic acids, dietary fibers, and phenolics, also plays a key role in
75 contributing to the high annual consumption of this fruit (Yu et al., 2015). Currently,
76 the majority of CB fruits in the market are consumed fresh. However, due to their lack
77 of protective skin and the concentrated ripening period during hot and rainy seasons,
78 CB fruits are extremely susceptible to microbial attack, resulting in substantial resource
79 waste annually. Deep processing of CB fruits into value-added wine has emerged as an
80 effective and feasible route to mitigate these issues (Cao et al., 2020). The expansion of
81 the fruit wine industry, in particular, driven by the demand for unique alcoholic
82 beverages distinct from grape wine, presents a unique opportunity and solution for
83 preserving the flavour and nutritional components of CB fruits. This development not
84 only reduces post-harvest losses but also brings multiple benefits to orchardists and
85 enterprises (Jagtap & Bapat, 2015).

86 The organoleptic quality, consumer acceptance and preference, and market value
87 of a fruit wine were determined by multiple attributes, such as ethanol, organic acids,
88 aroma compounds, and phenolic compounds (Joshi et al., 2017; Styger et al., 2011). In
89 recent years, the contribution of LAB to the increase in concentrations of health-
90 beneficial compounds, including polysaccharides, phenolics, and flavonoids, and the
91 enhancement of antioxidant capacity and colour stability have been reported in CB wine
92 productions (Y. Zhu et al., 2020; Y. Zhu, Lv, Gu, He, Chen, Ye, et al., 2022; Y. Zhu, Lv,
93 Gu, He, Chen, Zhou, et al., 2022). However, to the best of our knowledge, no research
94 has been conducted on the isolation and characterisation of potential autochthonous
95 LAB in the production of CB wines and on their effects on the profiles of particularly
96 organic acids and aroma compounds. The aim of this work was to isolate autochthonous
97 LAB strains with optimal fermentative ability to produce CB wine in combination with
98 *Saccharomyces cerevisiae*. Their fermentation kinetics in the co-inoculation during CB
99 wine fermentation was regularly monitored. Another focus was placed on the impact of
100 the isolated LAB on the profiles of organic acid and aroma compounds of CB wine
101 using HPLC and GC-MS, respectively. The experimental plan is oriented to improve
102 LAB exploitation of the unique traits of CB wines and for a better adaptation of the
103 prokaryotic resources to the specific environmental conditions associated with this
104 matrix.

105 **2 Materials and methods**

106 **2.1 Chemicals and reagents**

107 Yeast peptone dextrose (YPD), De Man, Rogosa and Sharpe (MRS), Wallerstein
108 Laboratory Differential (WLD), and Wallerstein Laboratory Nutrient (WLN) broth and
109 agar media were purchased from Qingdao Hi-Tech Industrial Park Hope Bio-
110 Technology Co., Ltd (Qingdao, China). Pyruvic acid (98%), oxalic acid (98%), tartaric
111 acid (99%), citric acid (98%), shikimic acid ($\geq 98\%$), lactic acid ($\geq 98\%$), malic acid (98%),
112 and sodium chloride ($\geq 99.5\%$) were procured from Shanghai Macklin Biochemical
113 Technology Co., Ltd (Shanghai, China). Chloramphenicol ($\geq 98\%$) and cycloheximide
114 ($\geq 98\%$) was obtained from Yuanye Biological Company (Shanghai, China). Ethanol
115 ($\geq 99.7\%$), methanol ($\geq 99\%$), formic acid ($\geq 98\%$), and acetonitrile ($\geq 99.9\%$) were sourced
116 from Merck KGaA (Darmstadt, Germany). C5–C30 saturated alkanes, ethanol,
117 bromocresol purple, and pure standards used in the qualitative and quantitative analysis
118 of aroma compounds (Supplementary Table 1), were purchased from Sigma-Aldrich
119 (St. Louis, MO). All other chemicals and reagents used in this study were of analytical
120 grade.

121 **2.2 Isolation of lactic acid bacteria**

122 Autochthonous LAB were isolated from spontaneously fermented CB juice. The
123 “Dongkui” bayberries, harvested in June 2022, were sourced from a local orchard
124 located in Xianju County, Zhejiang Province, China. To ensure the preservation of fruit
125 quality, the harvested fruits were immediately transported to the laboratory through a
126 cold chain. Subsequently, the fruits were manually pitted and squeezed using a kitchen

127 juicer (HUZK24WNM, Hurom, Korea) to obtain CB juices. The juices were
128 spontaneously fermented under aseptic conditions at 16 °C for 6 days. The spontaneous
129 fermentations were performed in triplicate. Afterwards, the fermented juices were
130 merged and promptly transferred to sterile tubes and stored at 4 °C for further
131 processing. The sample preparation processes were performed in an aseptic condition
132 to avoid contamination by microbes from surrounding environment.

133 The isolation protocol of autochthonous LAB was adapted from a previous method
134 with some modifications (Mohd Adnan & Tan, 2007). In brief, serial dilutions of
135 different spontaneously fermented CB juices were prepared using sterile saline solution
136 (0.9% NaCl, *w/v*). Afterwards, 100 µL of the diluents were spread plated on MRS agar
137 plates containing 20 mg/L bromocresol purple and 100 mg/L cycloheximide. The plates
138 were then incubated anaerobically at 37 °C for 48–72 h. Colonies with discolouration
139 rings were picked and streaked onto fresh MRS agar plates (37 °C for 48–72 h) for
140 purification. This procedure was repeated three times to obtain the purified isolates. The
141 cultures were then preserved in 50% glycerol and cryopreserved at –80 °C for further
142 molecular identification.

143 **2.3 Molecular identification of lactic acid bacteria**

144 All purified isolates were subjected to Gram staining and catalase testing. Gram-
145 positive, catalase-negative, and non-motile isolates were recognized as potential LAB.
146 These isolates were further characterised based on polymerase chain reaction (PCR).
147 The total genomic DNA was extracted using TIANamp Bacteria DNA Kit (Tiangen,

148 Beijing, China) following the manufacturer's instruction and stored at $-20\text{ }^{\circ}\text{C}$ for
149 subsequent analysis. The concentration of the extracted DNA was determined using a
150 NanoDrop ND-2000 UV-vis spectrophotometer (Thermo Fisher Scientific, Waltham,
151 MA). For molecular identification, the V3-V4 hypervariable regions of the 16S rRNA
152 gene were amplified using primers 338F (5'-TGAGTGCTAGGTGTTGGAGG-3') and
153 806R (5'-CTATCTCTAGGGTTGGCGCA-3') synthesised by Sangon Biotech Co., Ltd
154 (Shanghai, China). The PCR amplification protocol consisted of an initial denaturation
155 step of $94\text{ }^{\circ}\text{C}$ for 5 min, followed by 35 cycles at $94\text{ }^{\circ}\text{C}$ for 45 s, 35 s of annealing at
156 $58\text{ }^{\circ}\text{C}$, 30 s of extension at $72\text{ }^{\circ}\text{C}$, and a final extension at $72\text{ }^{\circ}\text{C}$ for 10 min (Behare et
157 al., 2020). The purified PCR products were pooled in equimolar ratios and subjected to
158 paired-end sequencing (2×300) on an Illumina MiSeq platform (Illumina, San Diego,
159 California) following standard protocols by Beijing Tsingke Biotech Co., Ltd (Beijing,
160 China). The sequencing results were subjected to a BLAST search from the GenBank
161 database (<http://www.ncbi.nlm.nih.gov/BLAST>).

162 **2.4 Strain tolerance tests**

163 The glycerinated bacterial cells were re-streaked onto MRS agar and incubated at
164 $37\text{ }^{\circ}\text{C}$ for 48-72 h. Then, pure LAB cultures were resuspended in fresh sterile MRS
165 broth at $37\text{ }^{\circ}\text{C}$ for 24 h. The purification procedures were carried out twice. Afterwards,
166 100 μL of each LAB suspension were inoculated into 10 mL compositional modified
167 MRS broth. For the ethanol tolerance assay, the ethanol level of MRS broth was
168 adjusted to 1%, 2%, 3%, 4%, 5%, and 6% (v/v) using ethanol solutions. In the

169 osmolality tolerance trial, the °Brix was modulated to 4, 6, 10, 12, and 14 using glucose
170 solution. For the acidity tolerance test, the pH of MRS broth was adjusted to 2, 3, and
171 4 using 5 M hydrochloric acid buffer. The incubation of the cultures was carried out in
172 microtubes at 37 °C for 16 h. Subsequently, viable cell counts were determined by
173 plating appropriate dilutions on MRS agar plates. Each procedure was carried out in
174 triplicate. The colonies were counted after incubation at 37 °C for 48–72 h and the
175 survival rate was calculated as:

$$176 \quad \text{Survival rate (\%)} = \log N_1 / \log N_0 \times 100$$

177 where N_1 represents the cell count of LAB after incubation in MRS broth with different
178 ethanol concentrations, Brix values, or pH levels, while N_0 represents the initial cell
179 count of LAB before incubation.

180 **2.5 Fermentation procedure of Chinese bayberry wines**

181 A batch of CB juices (Brix 14.0, pH 3.0) obtained from the Section 2.2 were used
182 for CB wine production. The juices were subjected to centrifugation at 4000 g for 15
183 min to remove sediment. The resulting supernatant was pasteurized at 95 °C for 5 min
184 and subsequently cooled down to 20 °C using cold water. Before fermentation, all CB
185 juices were tested for microbial count at 30 °C and 37 °C to ensure pasteurisation
186 efficiency. Commercial *S. cerevisiae* Lalvin ICV D254 (Lallemand, Inc., Montreal,
187 Canada) was used to launch alcoholic fermentation. The yeast and the isolated LAB
188 with optimal tolerances to stress were precultured in YPD and MRS broths, respectively,
189 at 30 °C (with shaking at 180 rpm) and 37 °C for 24 h to obtain seed cultures. The cells

190 were then separated by centrifugation at 4500 g for 5 min, washed three times using
191 sterile saline solution, and resuspended in pasteurized CB juices. The yeast and LAB
192 were simultaneously inoculated, both at a cell density of 10^6 CFU/mL. The
193 fermentations were carried out in 200 mL sterilized Duran bottles containing 150 mL
194 of pasteurized CB juices at a controlled temperature of 16 °C for 10 days. After
195 fermentation, the CB wines were centrifuged at 4000 g for 10 min, and the resulting
196 supernatants were collected and stored at -20 °C for further analysis. Each fermentation
197 was carried out in triplicate.

198 **2.6 Determination of microbial population dynamics**

199 Throughout the fermentation process, at specific time points (0, 2, 4, 6, 8, and 10
200 days), the population of viable yeast and LAB were assessed. The fermented samples
201 were appropriately diluted with sterile saline solution and spread on WLD agar. After
202 incubation at 37 °C for 48–72 h, the viable count of LAB was determined through the
203 plate counting method. The viable count of yeasts, on the other hand, was determined
204 by employing WLN agar supplemented with 0.1 g/L chloramphenicol after incubation
205 at 30 °C for 48 h (Tristezza et al., 2016).

206 **2.7 Determination of ethanol**

207 The concentration of ethanol in CB wines was determined by GC-FID (GC-
208 2010plus, Shimadzu, Japan) following the methodology described in our previous study
209 (S. Liu et al., 2018). Briefly, 0.2 µL of each filtrated sample was injected into an HP-
210 INNOWax column (30 m × 0.25 mm i.d., 0.25 µm, Hewlett-Packard, Avondale, PA).

211 The column temperature was initially set at 40 °C and maintained for 8 min, followed
212 by a linear increase at a rate of 10 °C/min until reaching 240 °C, which was held for 2
213 minutes. The injector and detector temperatures were set to 220 °C and 280 °C,
214 respectively. Helium was used as carrier gas at a flow rate of 1.5 mL/min with a split
215 ratio of 1:25. The quantification of ethanol was performed using calibration curves
216 constructed by the analysis of external standards of different concentrations.

217 **2.8 Determination of organic acids**

218 Qualitative and quantitative analyses of organic acids were conducted using an
219 HPLC separation module (Waters e2695, Milford, MA) equipped with an ultraviolet-
220 visible detector (UV/Vis, Waters 2998, Milford, MA). The separation was performed
221 using an Aminex HPX-87H ion exclusion column (300 mm × 7.8 mm, Bio-Rad,
222 Hercules, CA) kept at a constant temperature of 35 °C. The mobile phase was 5 mmol/L
223 H₂SO₄ at a flow rate of 0.6 mL/min. Prior to analysis, all samples were filtered using
224 filters with a pore diameter of 0.45 µm. The injection volume was 20 µL. The
225 chromatographic peaks of analytes were validated at 210 nm by comparison of retention
226 times with their corresponding standards. Concentrations were calculated based on the
227 peak area using an external standard method.

228 **2.9 Determination of aroma compounds**

229 The aroma compounds were analysed using headspace solid-phase
230 microextraction coupled with gas chromatography-mass spectrometry (HS-SPME-GC-
231 MS). Ten millilitres of sample, 1.0 g of NaCl, and 10 µL of 4-methyl-2-pentanol (8.11

232 mg/mL, internal standard) were added into a 20 mL headspace vial incubated at 50 °C
233 for 30 min. The conditioned SPME fiber (2 cm, 50/30 μm DVB/CAR/PDMS, Supelco,
234 PA) was inserted into the vial for extraction at 50 °C for 30 min. Aroma compounds
235 were separated by GC-MS (Agilent 7890A-5975C, Santa Clara, CA) equipped with a
236 DB-WAX column (0.5 μm, 60 m × 0.25 mm, Agilent, Santa Clara, CA) under a split-
237 less injection mode. Helium was used as carrier gas at a flow rate of 1.0 mL/min. The
238 heating program was performed as follows: 35 °C for 3 min, increased to 160 °C at a
239 rate of 2 °C/min, increased to 200 °C at a rate of 3 °C/min, increased to 240 °C at a rate
240 of 4 °C/min and maintained for 5 min. The injection port temperature was set at 240 °C.
241 The MS was operated in scan mode and EI ionization method (70 eV) with a 4.58 scan/s
242 frequency over the range from 30.00 to 500.00 amu. The temperatures of ion source
243 and quadrupole were 230 °C and 150 °C, respectively. Aroma compounds were
244 identified by comparing retention indices (RIs) and accurate mass-to-charge ratio (m/z)
245 of fragment ion peaks with those of authentic standards and the data reported in the
246 literature and NIST database. The concentrations of analytes were calculated using
247 calibration curves built with authentic standards from nine different concentrations in
248 synthetic CB wine (pH 3.0, ethanol 4.5%, malic acid 5 g/L, succinic acid 3g/L, citric
249 acid 3 g/L, tartaric acid 1 g/L). Internal standard was added for correcting any possible
250 variations in SPME fiber performance. The aroma compounds without authentic
251 standards were quantitated using the calibration curves built by the standards in the
252 same chemical group with similar chemical structures. To estimate the organoleptic

253 contribution of aroma compounds to the overall flavour of the CB wines, the odour
254 activity values (OAV) were calculated according to the ratio of compound concentration
255 to threshold value. The compounds with $OAV > 1$ are considered to contribute to the
256 overall aroma of samples.

257 **2.10 Statistical analysis**

258 Statistical analysis was conducted using SPSS 26.0 software, and the results were
259 expressed as the mean \pm standard deviation based on three replicates. Significant
260 differences between groups were determined by ANOVA and Tukey's test at a
261 confidence level of 95%. Distribution of aroma compounds in each group was
262 visualized using an online tool (<https://www.chiplot.online>).

263 **3. Results and Discussion**

264 **3.1 Characterisation of isolated autochthonous lactic acid bacteria**

265 A total of 32 isolates were recovered from the spontaneously fermented CB.
266 Among them, 21 isolates were tentatively identified as LAB on the basis of cellular
267 morphology, Gram staining positivity, and catalase negativity. Thereafter, these 21
268 isolates were identified and categorized into six LAB species by 16S rRNA gene
269 sequencing. Of which, nine isolates were identified as *Lactiplantibacillus (Lp.)*
270 *plantarum* and designated as ZFM710, ZFM711, ZFM712, ZFM713, ZFM714,
271 ZFM715, ZFM716, ZFM717, and ZFM718. Similarly, isolates of ZFM720, ZFM721,
272 ZFM722, ZFM723, ZFM724, and ZFM725 were identified as *Limosilactobacillus (Lb.)*
273 *fermentum*. ZFM730, ZFM731, and ZFM732 were identified as *Lactococcus (Lc.)*

274 *lactis*, while ZFM733, ZFM734, and ZFM735 as *Enterococcus (Ec.) hirae*,
275 *Leuconostoc (Le.) mesenteroides*, and *Weissella (Ws.) cibaria*, respectively. These LAB
276 species have also been isolated from raw and spontaneously fermented fruits, such as
277 grape, blueberry, apple, melon, cherry, and red dragon (Di Cagno et al., 2013; Meruvu
278 & Harsa, 2022; Yien Ong et al., 2012).

279 **3.2 Strain tolerance to conditions simulating Chinese bayberry wine environment**

280 In this study, the organic acid and sugar contents of CB led to an acidic and
281 osmotically challenging environment, respectively, that may hamper the LAB growth.
282 Moreover, given that sugars are gradually converted into ethanol during fermentation,
283 it becomes crucial to also evaluate the LAB's tolerance to ethanol. The evaluation of
284 tolerance of these strains under the conditions that simulate CB wine fermentation is
285 therefore a key approach for determining their suitability in CB wine production.

286 *3.2.1 Ethanol tolerance*

287 With a preliminary experiment, it has been proved that the complete fermentation
288 of CB juice using *S. cerevisiae* led to an ethanol concentration of approximately 4.5%.
289 Thus, for the ethanol tolerance assessment designed in this study, the ethanol
290 concentrations were set at the ranges of 1%–6% (Fig. 1A). Generally, the ethanol
291 tolerances of the isolated *Lp. plantarum* and *Lb. fermentum* strains were stronger than
292 that of other isolated LAB strains. Particularly, *Lp. plantarum* ZFM710 and ZFM715,
293 as well as *Lb. fermentum* ZFM720 and ZFM722, exhibited survival rates exceeding 90%
294 at ethanol concentrations between 1% and 5%, indicating their great inherent capacity

295 for ethanol tolerance. Interestingly, in some cases, the survival rates of several strains
296 were greater than 100%, which is in line with the stimulatory effects on LAB growth
297 sometimes reported for ethanol in wine (Ribéreau-Gayon et al., 2006). Although the
298 survival rates of these four strains decreased with the ethanol concentration increased
299 to 6%, the rates remained still higher than 80%. These findings are not surprising for
300 *Lp. plantarum*, given that selected strains of this species carry out malolactic
301 fermentation in wine (about 12%–14% ethanol content) (Capozzi et al., 2021).
302 Conversely, *Lb. fermentum* is not generally isolated in grape fermentations (Capozzi et
303 al., 2021), but its presence has been reported in fermentations of other plant matrices,
304 in association with yeasts, justifying a certain degree of alcohol tolerance (Kaur et al.,
305 2014; Papalexandratou et al., 2013). In effect, particularly in *Lp. plantarum*, the ethanol
306 stress response has been investigated, elucidating some genes/proteins involved in the
307 protection of bacterial cells against this chemical stressor (van Bokhorst-van de Veen
308 et al., 2011). In contrast to *Lp. plantarum* and *Lb. fermentum*, the other isolated strains
309 generally displayed lower survival rates at higher ethanol concentrations. For example,
310 the survival rates of *Lc. lactis* ZFM731 and ZFM732, *Le. mesenteroides* ZFM734, and
311 *Ws. cibaria* ZFM735 dropped to below 10% at 6% ethanol, indicating their poorer
312 ethanol tolerance to the CB wine fermentation environment. In general, the results
313 confirmed the species- and strain-dependent behaviour in the stress response among
314 LAB (Papadimitriou et al., 2016).

315 3.2.2 Osmolality tolerance

316 A preliminary evaluation suggested that the initial Brix value of approximately 12
317 of CB juice, reduced to about 4.5 once finished alcoholic fermentation by *S. cerevisiae*.
318 Therefore, a hyperosmotic experiment (in the range of °Brix 4–14) was designed with
319 the aim to investigate the osmolality tolerance of LAB in the high osmotic environment
320 caused by high sugar content at the early stages of winemaking. This study revealed
321 that there were differences in the optimal sugar concentration for the growth of each
322 strain. For example, the survival rates of all the isolated LAB strains increased
323 obviously along with the Brix raising from 4 to 6 (Fig. 1B). However, a higher sugar
324 concentration was found to be detrimental to their survival, particularly when the Brix
325 level exceeded 10–12. . However, there were still some strains that maintained a
326 survival rate of over 70% at Brix 14. Especially noteworthy is *Lp. plantarum* ZFM710,
327 ZFM715, and ZFM716, *Lb. fermentum* ZFM722 and ZFM725, and *Lc. lactis* ZFM730,
328 which exhibit a survival rate higher than 90%. The discrepancy in survival rates of these
329 bacteria is probably associated with aptitude of the bacteria to counteract dehydration
330 importing osmolytes (Papadimitriou et al., 2016). In a study of isolates from other plant
331 matrices, *Lactobacilli* species were found the most tolerant LAB to osmotic stress,
332 suggesting the relevance of the strain-dependent effect in explaining observed
333 variability (Fessard & Remize, 2019).

334 3.2.3 Acidity tolerance

335 In addition to ethanol and osmolality stresses, acidity stress emerged as an

336 important factor affecting the fermentation performance of LAB strains. The initial pH
337 of CB juice used in this study was approximately 3. The preliminary trials indicated
338 that the consumption of sugar and synthesis or degradation of organic acids during
339 alcoholic fermentation caused slight fluctuations in pH values. Therefore, to evaluate
340 the acidity tolerance of the LAB strains, a pH range of 2–4 was selected. In general,
341 under the acidity environment, the survival rates of the isolated *Lp. plantarum*, *Lb.*
342 *fermentum*, and *Lc. lactis* strains were better than that of *Ec. hirae*, *Le. mesenteroides*,
343 and *Ws. cibaria* (Fig. 1C). The increase in pH was beneficial for the survival of these
344 bacteria, particularly during the transition from pH 3 to pH 4. At the condition of pH 4,
345 more than 80% of *Lp. plantarum* ZFM710, ZFM714, and ZFM715, as well as *Lb.*
346 *fermentum* ZFM720 and ZFM722 were still surviving, showing greater viability than
347 other strains. Interestingly, some studies have reported that LAB strains with robust
348 ethanol tolerance tend to possess weak acidity tolerance (Wang et al., 2022). However,
349 in contrast to those findings, our study revealed that the four strains (*Lp. plantarum*
350 ZFM710 and ZFM715, *Lb. fermentum* ZFM720 and ZFM722) exhibited stronger
351 ethanol tolerance simultaneously coupled with higher acidity tolerance, also suggesting
352 a possible crosstalk in related stress response mechanisms and potential cross
353 protection (Yang et al., 2021).

354 In summary, based on the results of ethanol, osmolality, and acidity tolerance tests,
355 the isolated strains *Lp. plantarum* ZFM710 and ZFM715, along with *Lb. fermentum*
356 ZFM720 and ZFM722, demonstrated superior abilities to tolerate the simulated CB

357 wine fermentation environment. Therefore, these four bacteria were selected for co-
358 inoculation with yeast to investigate their fermentation characteristics and the impact
359 on chemical profiles of CB wines.

360 **3.3 Effect of simultaneous inoculation on the population dynamics of strains**

361 Together with the main abiotic factors, also the most relevant biotic determinants
362 are crucial in the characterisation. Between two organisms exist different interaction
363 patterns due to their different adaptations to fermentation environment and metabolite-
364 mediated interactions (Chang Chen et al., 2022). For example, the metabolites of LAB,
365 such as carbon dioxide, pyruvate, propionate, and succinate, have potential to enhance
366 yeast growth, while yeast-generated vitamins or amino acids can facilitate the growth
367 of LAB (Y. Liu et al., 2017). Nevertheless, mutual inhibition between yeast and LAB
368 has also been observed in some studies. Specific compounds derived from LAB, like
369 4-hydroxy-phenyl lactic acid and cyclic peptide, can impede yeast growth. Conversely,
370 substances such as alcohol and fatty acids produced by yeast possess the ability to
371 hinder the growth of LAB (Y. Liu et al., 2017). The competition for essential nutrients
372 required for growth and metabolism is another way to influence the growth of a
373 particular strain (Ivey et al., 2013). Regarding the CB wine fermented with pure *S.*
374 *cerevisiae* Lalvin ICV D254 culture, the yeast displayed a typical growth pattern
375 characterised by development until day 2, followed by a slow growth with a gradual
376 entry into the stationary phase, reaching the maximum population of approximately 7.8
377 log CFU/mL, and maintaining the plateau phase for a total 6 days. Subsequently, the

378 loss of biomass to 7.4 log CFU/mL indicated *S. cerevisiae* may have completed its life
379 cycle and entered the death phase (Fig. 2A).

380 With regard to the effect of simultaneous inoculation on the population dynamics
381 of *S. cerevisiae*, at the early fermentation stage, in all cases, the viable count of yeast
382 reached a maximum population of approximately 8.0 log CFU/mL within the timeframe
383 of 4–6 days, maintaining high cell viability during the mid-late stage of fermentation
384 (Fig. 2B–E). The compatibility of *S. cerevisiae* and LAB has also been reported in the
385 early stage of Negroamaro wine fermentation (Tristezza et al., 2016). However, at the
386 late stage of fermentation, compared to the kinetics of pure *S. cerevisiae*, the population
387 of *S. cerevisiae* in the co-inoculated groups is generally higher (7.6–8.0 log CFU/mL),
388 indicating that the presence of LAB promoted the development of the yeast population,
389 which may be due to the metabolism of LAB providing a favourable pH environment
390 for the growth of *S. cerevisiae* (Luan et al., 2021).

391 The microbial kinetics of LAB in different simultaneous inoculation groups at
392 different stages showed strain-specific differences. Regarding *Lp. plantarum*,
393 significant diversity in population dynamics was observed between the two strains, as
394 the abundances of ZFM715 remains relatively unchanged throughout fermentation (Fig.
395 2C), while for ZFM710 has highlighted a significant decrease in abundance during the
396 first 4 days (Fig. 2B). Interestingly, the aforementioned tolerance experiments have
397 demonstrated that ZFM710 displayed great ethanol, osmolality, and acidity tolerances.
398 Therefore, the dramatic decline in the viable count of ZFM710 during the mid-

399 fermentation period may be attributed to competition for nutrients or its high sensitivity
400 to certain metabolites released by *S. cerevisiae* (Jialan Zhang et al., 2023). Gradually,
401 ZFM710 recovered the initial concentration, probably in conjunction with the reduction
402 of the key fermentation phase by the yeasts, following a profile often reported for LAB
403 in oenology, with a reduction phase at the peak of alcoholic fermentation (Ribéreau-
404 Gayon et al., 2006). Similar trends have also been observed in the isolated strain *Lb.*
405 *fermentum* ZFM720 (Fig. 2D). On the opposite, Sc-ZFM722 exhibited a dramatic
406 decrease, particularly after 4 days (Fig. 3E). This evidence could be connected to
407 several aspects: *i*) various bioactive compounds produced by *S. cerevisiae* (e.g.
408 medium-chain fatty acids, proteins, and peptides) can significantly inhibit LAB strains
409 involved in multi-species fermentation (Lucio et al., 2018); *ii*) the depletion of amino
410 acids and vitamins resulting from the consumption by *S. cerevisiae* might have induced
411 starvation phenomena (Y. Liu et al., 2017), or *iii*) the simultaneous presence of multiple
412 stressors could yield different effects compared to single stress conditions
413 (Papadimitriou et al., 2016).

414 **3.4 Effect of simultaneous inoculation on physicochemical properties of Chinese**

415 **bayberry wines**

416 *3.4.1 Ethanol*

417 *Ethanol is one of the most prominent metabolites of fermentation and is a significant*
418 *contributor to the unique flavour of alcoholic beverages. The Sc-ZFM715 sample*
419 *exhibited an increase in the production of ethanol (Fig. 3A). It is well known that, under*
420 *specific conditions, L. plantarum can follow heterofermentative metabolism to*
421 *synthesise ethanol through the pentose phosphate pathway (Quatravaux et al., 2006),*
422 *but in this situation, an equimolar production of acetic acid should occur. Some studies*
423 *have reported that specific strains of Lp. plantarum in a complex microflora can utilize*
424 *citrate metabolism to sustain their growth, reducing the reliance on sugar metabolism*
425 *for vitality. This characteristic allows Lp. plantarum to utilize fewer sugars, ensuring*
426 *that a greater amount of sugar is available for S. cerevisiae to convert into ethanol*
427 *(Jung et al., 2022). Moreover, mutually stimulating interactions between S. cerevisiae*
428 *and Lactobacilli have been already reported in sourdough, suggesting that carbon*
429 *source are among the chemical classes that can be involved in explaining the positive*
430 *interaction (Siewewerts et al., 2018). Hence, the slight but statistically significant*
431 *increase may thus be attributable to the characteristics of carbohydrate metabolism*
432 *and/or stimulating effect of S. cerevisiae on the growth profile of this Lp. plantarum*
433 *strain, which in the light of this evidence appears to be particularly interesting and*
434 *worthy of future investigations.*

3.4.2 Organic acids

435 Fig. 3B–K shows the impact of different inoculation categories on the composition
436 of organic acids in CB products. A total of 10 organic acids were detected in CB juice
437 and wines. In CB juice, citric acid, malic acid, succinic acid, and tartaric acid are the
438 predominant organic acids, accounting for 56.1%, 22.8%, 13.6%, and 4.7% of the total
439 organic acids, respectively. The result aligns with a previous study in scientific literature
440 (H. Yu et al., 2018), contributing to defining the characteristics of the raw material that
441 are relevant for the transformation in CB wine. Pure fermentation with *S. cerevisiae*
442 significantly increased the content of organic acids, which was primarily due to the
443 elevated levels of citric acid, acetic acid, and pyruvic acid. Similar enhancement effects
444 of *S. cerevisiae* on these three organic acids have been reported in pomegranate wine
445 (Berenguer et al., 2016), lychee wine (D. Chen & Liu, 2014), and bilberry wine (S. Liu
446 et al., 2018). In contrast, the concentration of other organic acids, especially succinic
447 acid, malic acid, and tartaric acid, decreased significantly by 94.7%, 54.9%, and 59.4%,
448 respectively. The reduction of succinic acid by *S. cerevisiae* in the production of
449 alcoholic beverage represents consolidated evidence (Chidi et al., 2018). A reduction of
450 malic acid (by about 25%) has recently been reported for *S. cerevisiae* Lalvin ICV D254
451 in wine (Englezos et al., 2020). Tartaric degradation has also been reported in the
452 literature, but the intensity highlighted in this study deserves further investigation and
453 does not exclude precipitation phenomena (Gao & Fleet, 1995).

454 Compared to the pure *S. cerevisiae* sample, the participation of LAB led to a
455 dramatic decrease in total organic acids, primarily resulting from the degradation of

456 citric acid with a reduction of approximately 65%. This phenomenon can be attributed
457 to the ability of LAB to utilize citrate metabolism to sustain growth in a complex
458 microbial community, rather than relying solely on sugar metabolism for vitality (Jung
459 et al., 2022). In addition, a significant reduction in concentration was also present in
460 malic acid, succinic acid, tartaric acid, and ascorbic acid. However, as expected, the
461 content of lactic acid increased significantly due to the so-called malolactic
462 fermentation and the production of lactic acid from other carbon sources (Capozzi et
463 al., 2021).

464 Regarding the effect of intergeneric differences of LAB on organic acid profile,
465 no significant differences were observed in total organic acid between the *Lp.*
466 *plantarum* and *Lb. fermentum* groups. Only acetic acid and lactic acid exhibited
467 significant differences, with the involvement of *Lb. fermentum*, particularly ZFM722,
468 resulting in higher production of these organic acids compared to *Lp. plantarum*. As the
469 heterofermentative strains, the higher production of acetic acid and lactic acid by *Lb.*
470 *fermentum* has also been detected in fermented blueberry juice and vegetable juice (Li
471 et al., 2021; Szutowska, 2020). In terms of the impact of strain differences on the
472 organic acid composition, overall, minimal variations were observed. However, the
473 participation of *Lp. plantarum* ZFM710 and *Lb. fermentum* ZFM722 resulted in a
474 higher lactic acid production compared to *Lp. plantarum* ZFM715 and *Lb. fermentum*
475 ZFM720, respectively, while *Lb. fermentum* ZFM722 produced higher level of acetic
476 acid than ZFM720.

477 **3.5 Effect of simultaneous inoculation on aroma compound profile of Chinese**
478 **bayberry wines**

479 To complete the evaluation of the impact of the microbial resources used on the
480 CB wine quality, a comprehensive analysis of aroma compounds was conducted using
481 HS-SPME-GC/MS, resulting in the identification of 144 different compounds. These
482 aroma compounds were categorized into 7 groups, namely higher alcohols (n = 41),
483 esters (n = 30), terpenes (n = 26), acids (n = 12), ketones (n = 9), aldehydes (n = 6),
484 phenols (n = 5), and other compounds (n = 15). Among them, 114 and 117 aroma
485 compounds were exclusively detected in CB juice and wines, respectively (Table 1). In
486 CB juice, the dominant aroma compound groups were higher alcohols, esters, and
487 ketones, which accounted for 31.0%, 30.7%, and 15.7% of the total aroma compounds,
488 respectively. The result is in agreement with a previous study profiling the aroma
489 compounds in diverse CB cultivars (H. Cheng et al., 2016). However, after fermentation,
490 the aroma compound profiles of CB underwent dramatic changes, with higher alcohols,
491 esters, and acids becoming the major components, contributing 61.9%–67.4%,
492 17.5%–20.8%, and 10.8%–14.1% to the total aroma compounds, respectively. To
493 visualize the distribution of aroma compounds among the CB products, a heatmap
494 based on the normalized data was established (Supplementary Fig. 1). The results
495 showed that after fermentation, the concentrations of higher alcohols, acids, esters,
496 aldehydes, and phenols increased significantly, ranging from approximately 18.9–21.7,
497 52.7–96.6, 4.4–7.4, 1.5–2.4, and 0.9–2.5 times higher, respectively, than that in CB

498 juice. It has been reported that more than 1000 aroma compounds are found in wine,
499 while approximately 400 of them are generated from fermentation (Duan et al., 2018).
500 Most of the generated compounds are secondary aroma compounds, which are the
501 components formed as a result of yeast and bacteria development due to either the
502 normal metabolism of sugars and amino acids or the transformation of aroma
503 compound precursors by enzymes during glycolysis, proteolysis, or lipolysis
504 (Waterhouse et al., 2016). The increase in concentration of secondary aroma
505 compounds has also been reported in wines carried out by pure *S. cerevisiae* or
506 simultaneous inoculation of *S. cerevisiae* and LAB (Ruiz et al., 2019; Tristezza et al.,
507 2016). However, the total terpene and ketone contents showed significant declines after
508 fermentation. Especially, some indigenous terpenes and ketones in CB juice reduced to
509 the undetectable levels after fermentation. The loss of these aroma compounds has also
510 been reported in the production of wine, beer, and other alcoholic beverages, which
511 could be explained by their bioconversion by microorganisms, adsorption by microbial
512 cells, binding with microbial cell wall components, or precipitation with the must slurry
513 (Holt et al., 2019; Mingorance-Cazorla et al., 2003).

514 With regard to the effect of LAB on the aroma compound profiles of CB wines,
515 compared to pure *S. cerevisiae* inoculation, the co-inoculated *Lp. plantarum* in CB wine
516 production did not significantly reduce the intensity of aroma compounds. Particularly
517 noteworthy is the remarkable enhancement brought about by *Lp. plantarum* ZFM715
518 in total aroma compound content in CB wine, primarily evidenced by a significant

519 increase in concentrations of higher alcohols, acids, volatile phenols, and esters.
520 Furthermore, in comparison to the co-inoculation pattern of yeast and *Lb. fermentum*,
521 the participation of *Lp. plantarum* increased the concentrations of aroma compounds
522 such as higher alcohols, esters, and acids. The findings are consistent with previous
523 results obtained from pure *Lp. plantarum* fermented foods, such as walnut milk
524 (Wenhan Liu et al., 2022), noni juice (Y. Cheng et al., 2021), and bog bilberry juice (M.
525 Wei et al., 2018). Moreover, the elevation in accumulation of aroma compounds has
526 also been reported in *S. cerevisiae*-*Lp. plantarum* co-inoculated alcoholic beverages,
527 such as black raspberry wine (Wenli Liu et al., 2020), mulberry wine (Qing Zhang et
528 al., 2020), and Fiano wine (Lombardi et al., 2020). On the contrary, in comparison to
529 the Sc sample, the participation of *Lb. fermentum* in co-fermentation led to a significant
530 decrease in total aroma compound content, reflected in the content of each classified
531 group. It is well known that *Lb. fermentum* is a species of heterofermentative LAB with
532 the potential to generate aroma compounds to enhance the complexity and intensity of
533 aroma compounds in fermented foods, such as yogurt (Chen Chen et al., 2017), mixed
534 fruit and vegetable juices (Cui et al., 2019), and sugar cane spirit (Duarte et al., 2011).
535 While, there is limited information available on the effect of *Lb. fermentum* and *S.*
536 *cerevisiae* co-inoculation on the composition of aroma compounds of fruit wines.
537 However, a reduction in aroma compound levels has been reported in the production of
538 Ghanaian maize dough (Annan et al., 2003). We speculated that the reduction in total
539 aroma compounds may be attributed to the growth inhibition of *Lb. fermentum* and *S.*

540 *cerevisiae* on the basis of their amino acids and carbohydrate metabolisms, or result
541 from the change in activities of some synthetic and hydrolytic enzymes representing
542 aroma compound synthesis and hydrolysis. Therefore, more studies are needed to
543 explore the effect of interactions between *Lb. fermentum* and *S. cerevisiae* on the change
544 in aroma compound profile during CB wine fermentation.

545 The organoleptic properties of fermented beverages are intricately governed by the
546 content and composition of odour-active compounds. The manifestation of these
547 compounds in the global aroma profile is contingent upon their respective odour
548 thresholds. Consequently, discerning their impact on the overarching flavour profile
549 necessitated the consideration of the compounds only surpassing their individual odour
550 thresholds (Guth, 1997). In order to comprehensively elucidate the influence of
551 inoculation patterns on aroma distinctiveness in CB products, the OAVs of the
552 constituent aroma compounds were systematically investigated.

553 Among the 144 detected aroma compounds, 36 compounds, including 9 alcohols,
554 12 esters, 8 terpenes, 2 ketones, 3 phenols and 2 others, were identified as odour-active
555 compounds with OAVs greater than 1 in both CB juice and wines (Supplementary Table
556 2). The olfactory characters of these compounds were described using a series of odour
557 descriptors drawn from pertinent literature (Supplementary Table 2). Accordingly, six
558 distinct odour series, namely solvent, fruity, floral, herbaceous, fatty, and balsamic,
559 were elucidated. The application of these odour series facilitated an exploration of
560 potential correlation between the quantitative data obtained through HS-SPME-GC-MS

561 and the olfactory fingerprint of the CB samples.

562 Fig. 4 illustrates the predicted aroma profiles of the five CB products grounded in
563 the aforementioned six mentioned aroma series. Only OAVs greater than 1 were
564 considered in the cumulative OAV (\sum OAV). After fermentation, the intensities of fruity,
565 floral, and balsamic aromas exhibited noteworthy increases. The elevations in floral
566 and fruity intensities were primarily attributed to the conspicuous rise in the levels of
567 esters after fermentation, especially 3-ethoxy-1-propanol, linalool, 2-phenylethanol,
568 cedrol, isopentyl acetate, ethyl 3-phenylpropanoate, and ethyl (*E*)-cinnamate. The
569 augmentation of balsamic intensity was primarily emanated from the increases in
570 concentrations of ethyl (*E*)-cinnamate, 4-ethyl-2-methoxyphenol, and 2-methoxy-4-
571 vinylphenol. Such enhancements in aroma intensities align with common observations
572 in fermented fruit beverages like grape wine, cider, durian wine, and bilberry wine (S.
573 Liu et al., 2019; J. Wei et al., 2020; Welke et al., 2014; J. Zhu et al., 2015). Conversely,
574 the intensities of solvent and herbaceous notes witnessed substantial reductions. The
575 declines were predominantly linked to a substantial reduction in dimethyl sulfide level.
576 Dimethyl sulfide, known for its low threshold and association with cabbage-like, sulfur,
577 and gasoline odors, is a major off-flavour in particularly heated food products (J. Zhu
578 et al., 2015). Previous studies have highlighted a significant increase in dimethyl sulfide
579 concentration in the fruit juices subjected a heating process, which is resulted from the
580 rapid conversion of S-methylmethionine sulfonium, the precursor of dimethyl sulfide,
581 during thermal treatment (Moreno-Arribas & Polo, 2009). Hence, in this study, the

582 escalated dimethyl sulfide content in CB juice may arise not only from CB fruits but
583 also from pasteurization, as the primary reason. Dimethyl sulfide, being highly volatile,
584 can easily dissipate during fermentation, especially amid substantial CO₂ production.
585 The growth of yeast during fermentation generates a considerable amount of CO₂,
586 potentially explaining the significant reduction in dimethyl sulfide in CB wines
587 (Moreno-Arribas & Polo, 2009).

588 With regard to the influence of different inoculation patterns on the aroma
589 characteristics of CB wines, discernible variations were predominantly observed in
590 fruity and floral notes. Notably, the Sc-ZFM715 sample exhibited the highest intensities
591 in fruity and floral notes. This primarily stemmed from the participation of *Lp.*
592 *plantarum* ZFM715, which significantly increased the content of esters, particularly
593 ethyl hexanoate, isopentyl acetate, ethyl decanoate, ethyl 9-decenoate, ethyl 3-
594 phenylpropanoate, and ethyl (*E*)-cinnamate. These substances were identified as the
595 major contributors to the increase in \sum OAV for fruity and floral odours. In comparison
596 to *Lb. fermentum*, the inoculation of *Lp. plantarum* demonstrated a more pronounced
597 effect on enhancing fruity intensity, which is in concordance with observations in other
598 fruit beverages (Brizuela et al., 2019; Y. Chen et al., 2017).

599 **4 Conclusion**

600 Chinese bayberry is extremely susceptible to microbial attack, processing the
601 fruits into value-added wines is an effective and feasible route to reduce resource waste
602 caused by post-harvest loss, improving sustainability in this food chain. LAB have been

603 verified to shape quality feature of fruit wines. However, currently, high-efficient LAB
604 strains for the fermentation of Chinese bayberry wine are lacking. Hence, this study
605 isolated interesting autochthonous LAB strains from spontaneously fermented Chinese
606 bayberry, also as a strategy to find bacteria adapted to the specific fermentative
607 environment and to improve the unique traits of this alcoholic beverage particularly
608 connected to a certain productive geography. Among the 21 isolated LAB, *Lp.*
609 *plantarum* ZFM710 and ZFM715, as well as *Lb. fermentum* ZFM720 and ZFM722
610 exhibited greater tolerance to ethanol, osmolality, and acidity stresses than others. They
611 were used to ferment Chinese bayberry wine in co-inoculation with *S. cerevisiae*.
612 During fermentation, the simultaneous inoculation of LAB and yeast influenced the
613 growth and metabolism of each strain, resulting in changes in fermentation kinetics,
614 organic acid composition, and final ethanol concentration. The participation of LAB
615 impacted the aroma compound profile of Chinese bayberry wines, as well. LAB strains,
616 especially *Lp. plantarum* ZFM715, contributed to the enhancement of aroma
617 compound's complexity and intensity, including esters, alcohols, and acids. Moreover,
618 the intensities of fruity and floral odours of the SC-ZFM715 Chinese bayberry wine
619 increased attributed to the participation of ZFM715. This study demonstrated the
620 potential application of autochthonous LAB strains, particularly the selected *Lp.*
621 *plantarum* and *Lb. fermentum* strains, for the design of tailored starter cultures for
622 Chinese bayberry wine production. On the other hand, observations made with Chinese
623 bayberries in this study can provide model information to be exploited with other

624 similar berry materials.

625

626 **DECLARATION OF COMPETING INTEREST**

627 The authors declare no competing financial interest

628

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635 **FIGURE CAPTIONS**

636 **Fig. 1.** Tolerance ability of the 21 isolated lactic acid bacteria strains to the conditions
637 simulating Chinese bayberry wine environment. A: tolerance test to ethanol (1%, 2%,
638 3%, 4%, 5%, and 6%, v/v); B: tolerance test to osmolality (Brix 4, 6, 10, 12, and 14);
639 C: tolerance test to acidity (pH 2, 3, and 4). Histograms are the means of three
640 independent experiments.

641 **Fig. 2.** Microbial population dynamics during Chinese bayberry wine fermentation. A:
642 pure fermentation with *S. cerevisiae* (Sc); B and C: simultaneous fermentation of *S.*
643 *cerevisiae* and *Lp. plantarum* ZFM710 and ZFM715, respectively; D and E:
644 simultaneous fermentation of *S. cerevisiae* and *Lb. fermentum* ZFM720 and ZFM722,
645 respectively. Data are the means of three independent experiments \pm standard
646 deviations (n = 3) analysed in triplicate.

647 **Fig. 3.** Concentration of ethanol (A) and organic acids (B–K) in Chinese bayberry juice
648 and wines fermented with pure *S. cerevisiae* (Sc), *S. cerevisiae* and *Lp. plantarum*
649 (ZFM710 and ZFM715) mixed inoculum, or *S. cerevisiae* and *Lb. fermentum* (ZFM720
650 and ZFM722) mixed inoculum. Different superscript letters are considered significantly
651 different at $P < 0.05$ (ANOVA with Tukey's test). Data are the means of three
652 independent experiments \pm standard deviations (n = 3) analysed in triplicate.

653 **Fig. 4.** Predicted aromatic profiles, calculated as the sum of odour activity values
654 (OAVs) of aroma compounds greater than 1, of Chinese bayberry juice and wines
655 fermented with pure *S. cerevisiae* (Sc), *S. cerevisiae* and *Lp. plantarum* (ZFM710 and
656 ZFM715) mixed inoculum, or *S. cerevisiae* and *Lb. fermentum* (ZFM720 and ZFM722)
657 mixed inoculum. Different letters in the same odour series represent significant
658 differences ($p < 0.05$).

659

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966

967 Table 1. Concentrations ($\mu\text{g/L}$) of aroma compounds detected in Chinese bayberry juice and wines

Compound	Code	RI	RI*	Juice	Sc	Sc-ZFM710	Sc-ZFM715	Sc-ZFM720	Sc-ZFM722
Alcohols									
1-propanol	AL1	1056	1042	324.7 \pm 1.0b	5320.2 \pm 422.9a	6415.2 \pm 2211.3a	4770.2 \pm 67.4a	5279.1 \pm 174a	5033.7 \pm 435.1a
2-butanol	AL2	1061	1047	783.3 \pm 2.1	-	-	-	-	-
2-methyl-1-propanol	AL3	1116	1098	2873.3 \pm 64.7d	26314.8 \pm 2218.6a	26195.8 \pm 1256.2a	23017.2 \pm 2.2ab	21954.0 \pm 1252.8b	19878.5 \pm 499.4c
3-methyl-1-butanol	AL4	1222	1211	718.5 \pm 18.7d	57091.2 \pm 1974.7ab	54050.4 \pm 1528.0b	61178.9 \pm 820.6da	49137.2 \pm 6118.7bc	47665.0 \pm 327.6c
1-pentanol	AL5	1261	1240	28.1 \pm 0.4	-	-	-	-	-
2-heptanol	AL6	1324	1310	13.1 \pm 0.0	-	-	-	-	-
1-hexanol	AL7	1360	1352	2884.6 \pm 17.6a	2476.3 \pm 141.9bc	2613.9 \pm 157.7b	2608.8 \pm 65.2bc	2136.0 \pm 38.1c	1843.9 \pm 36.9d
3-ethoxy-1-propanol	AL8	1383	1369	-	7634.1 \pm 329.7b	7186.7 \pm 1226.7b	9462.9 \pm 1190.1a	7422.6 \pm 637.6b	7254.0 \pm 353.2b
(Z)-3-hexenol	AL9	1389	1390	51.1 \pm 0.7	-	-	-	-	-
2-octanol	AL10	1421	1412	11.4 \pm 0.2	-	-	-	-	-
1-heptanol	AL11	1461	1448	13.1 \pm 0.1b	53.6 \pm 1.0b	50.7 \pm 2.7bc	61.8 \pm 0.2a	43.8 \pm 0.1c	53.0 \pm 2.6b
6-methyl-5-hepten-2-ol	AL12	1465	1478	2.2 \pm 0.1	-	-	-	-	-
2-nonanol	AL13	1528	1522	4.6 \pm 0.0c	10.0 \pm 0.2a	7.6 \pm 0.1b	8.9 \pm 0.0b	8.2 \pm 0.6b	-
linalool	AL14	1548	1542	69.7 \pm 0.7d	402.1 \pm 6.3b	397.3 \pm 25.7b	439.2 \pm 21.0a	242.5 \pm 8.0c	230.1 \pm 2.3c
1-octanol	AL15	1565	1556	13.7 \pm 0.2d	114.3 \pm 2.4b	108.0 \pm 2.7b	129.9 \pm 4.4a	83.9 \pm 7.2c	84.1 \pm 7.7c
menthol	AL16	1589	1629	-	41.9 \pm 0.6d	35.4 \pm 0.5d	44.6 \pm 0.2c	70.8 \pm 4.5a	54.3 \pm 0.5b
4-terpineol	AL17	1613	1598	-	483.1 \pm 40.0b	489.4 \pm 9.4b	585.4 \pm 14.4a	416.3 \pm 3.2c	436.1 \pm 10.6c
levomenthol	AL18	1654	1651	23.8 \pm 0.3d	66.5 \pm 3.0b	63.0 \pm 2.6b	80.4 \pm 6.8a	56.6 \pm 3.4c	55.7 \pm 0.1c
1-nonanol	AL19	1669	1658	-	10 \pm 0.3ab	9.3 \pm 0.2b	10.7 \pm 0.0a	7.8 \pm 0.2c	8.2 \pm 0.2c
(Z)-3-nonenol	AL20	1696	1688	7.7 \pm 0.1	-	-	-	-	-
α -terpineol	AL21	1710	1691	90.0 \pm 2.9d	287.6 \pm 21.5b	293.0 \pm 12.2b	353.9 \pm 1.3a	280.0 \pm 7.6b	197.3 \pm 14.4c
α -phellandren-8-ol	AL22	1471	1421	6.4 \pm 0.1d	8.5 \pm 0.3bc	8.7 \pm 0.2b	9.9 \pm 0.4a	8.0 \pm 0.2bc	8.0 \pm 0.0c
(E,Z)-3,6-nonadienol	AL23	1763	1731	-	13.4 \pm 0.7b	13.3 \pm 0.5a	15.1 \pm 0.2a	13.2 \pm 0.7b	12.2 \pm 0.4c
1-decanol	AL24	1772	1752	-	59.4 \pm 0.1a	44.6 \pm 1.8c	54.6 \pm 2.0b	33.3 \pm 1.8c	35.2 \pm 1.4c
β -citronellol	AL25	1781	1764	-	119.8 \pm 13.9b	120.9 \pm 1.7b	135.2 \pm 11.7a	89.1 \pm 5.3c	86.2 \pm 5.0c
β -phellandren-8-ol	AL26	1798	1778	13.1 \pm 0.1e	41.1 \pm 0.4a	37.4 \pm 3.4b	42.8 \pm 0.1ab	32.6 \pm 0.2c	25.5 \pm 0.7d
α -santalol	AL27	1848	1843	29.5 \pm 0.5d	81.2 \pm 1.9b	87.0 \pm 4.6bc	109.6 \pm 7.2a	91.1 \pm 1.2b	83.6 \pm 1.9c
geraniol	AL28	1865	1847	18.6 \pm 0.1d	64.0 \pm 3.1b	62.6 \pm 0.5b	73.1 \pm 1.5a	48.7 \pm 4.4c	46.0 \pm 2.1c
2-phenylethanol	AL29	1940	1908	3483.9 \pm 69.2c	165111.9 \pm 679.7b	155753.9 \pm 2716.1b	195066.7 \pm 12865.3a	149312.7 \pm 5959.7b	150745.4 \pm 5188.8b
cubebol	AL30	1959	1964	9.5 \pm 0.3	-	-	-	-	-

1-dodecanol	AL31	1986	1984	11.0±0.5c	27.2±0.8ab	36.0±1.7a	33.7±8.0a	21.0±0.6b	24.1±0.3b
3-phenyl-1-propanol	AL32	2077	2059	5.1±0.1	-	-	-	-	-
viridiflorol	AL33	2092	2091	66.1±3.5d	225.3±6.9b	234.8±12.9b	448.1±11.0a	177.5±0.7c	236.9±21.3bc
cedrol	AL34	2100	2100	12.7±0.1c	26.8±0.4b	26.9±0.3b	32.3±2.2a	30.8±0.4ab	33.8±1.1a
spathulenol	AL35	2128	2129	11.8±0.4e	17.7±0.1c	14.5±0.2d	25.7±1.6b	27.9±1.0a	14.3±0.9d
δ-cadinol	AL36	2237	2242	20.4±0.5	-	-	-	-	-
intermedeol	AL37	2289	2264	11.9±0.3	-	-	-	-	-
juniper camphor	AL38	2297	2320	13.8±0.2c	36.1±3.0a	33.3±0.4a	34.7±2.4a	26.9±0.7ab	20.6±0.4bc
caryophylladienol II	AL39	2327	2324	28.0±0.7e	120.3±0.5b	106.9±4.8bc	136.0±2.5a	77.4±1.1d	93.5±6.1cd
eudesma-4(15),7-dien-1β-ol	AL40	2368	2370	48.7±0.0d	77.3±0.6c	100.7±2.6b	107.9±3.3a	43.3±1.9d	49.9±3.0d
β-santalol	AL41	2404	2391	48.0±1.5d	143.5±3.2d	154.8±13.9b	215.0±1.1a	104.5±3.5c	114.6±12.5c
total				11751.4±187.9e	266479.2±5878.9b	254752.1±9201.4bc	299293.5±15114.6a	237276.6±14239.2cd	234423.5±6936.5d
Esters									
ethyl acetate	E1	895	884	7294.0±57.9c	41403.6±852.1a	38978.0±821.2a	41954.8±1333.6a	31023.2±210.2b	32406.4±369.7b
isobutyl acetate	E2	1022	1007	8.1±0.2c	30.1±1.2a	26.5±0.2a	29.7±0.1a	22.0±0.5b	23.3±1.0b
ethyl butanoate	E3	1049	1035	-	966.3±28.6ab	881.7±5.4b	1163.1±7.4a	626.3±26.8c	707.9±2.8c
diethyl carbonate	E4	1119	1105	1236.2±50.8	-	-	-	-	-
isopentyl acetate	E5	1133	1118	41.4±0.2d	1861.3±74.8b	1638.2±87.7b	2332.8±37.5a	1209.2±3.3c	1197.2±64.3c
ethyl hexanoate	E6	1238	1233	-	1108.3±21.5b	1060.8±65.2b	1538.3±96.3a	527.1±1.4c	725.6±66.4c
propyl hexanoate	E7	1318	1322	-	112.9±0.3a	108.8±1.2b	110.4±0.9ab	105.5±0.6c	107.9±0.4d
ethyl octanoate	E8	1434	1434	-	5649.4±242a	4814.4±19.1b	5107±573.5b	2593.6±117.7c	2780.7±101.3c
linalyl formate	E9	1509	1570	-	54.0±0.4b	51.2±2.0ab	61.2±4.0a	55.6±1.9ab	50.2±2.1b
ethyl nonanoate	E10	1537	1524	-	144.2±13.3a	133.6±12.2ab	111.2±8.5b	140.4±7.0a	99.2±2.2c
ethyl decanoate	E11	1642	1636	-	3222.8±247.3a	2186.3±35.0c	2961±286.8b	2016.7±178.4d	1730.4±18.1d
isopentyl octanoate	E12	1663	1659	-	94.3±0.5a	83±4.3ab	87.3±4.0ab	79.3±8.3bc	68.2±1.9c
ethyl benzoate	E13	1680	1657	-	71.0±4.5bc	67.6±0.9bc	79.3±2.1b	59.0±3.1c	109.5±1.4a
ethyl 9-decenoate	E14	1697	1692	-	3024.6±354.6a	2413.8±32.8b	3372.9±290.5a	1743.9±65.7c	1896.1±62.9a
1,3-propanediol diacetate	E15	1756	1700	-	73.1±2.4c	88.0±8.2b	121.4±2.2a	82.2±1.1bc	83.9±2.7bc
ethyl phenylacetate	E16	1801	1784	-	11.1±0.0a	10.4±0.1b	10.6±0.1a	10.3±0.1b	9.9±0.1c
ethyl 2-hydroxy-3-methylbutanoate	E17	1430	1426	15.6±0.4	-	-	-	-	-
ethyl 2-hydroxy-4-methylpentanoate	E18	1542	1547	98.4±0.2	-	-	-	-	-
(Z)-3-hexenyl butanoate	E19	1782	1459	8.6±0.0	-	-	-	-	-
ethyl 3-hydroxybutanoate	E20	1822	1518	-	314.8±12.5b	370.9±9.6ab	408.5±4.0a	354.7±3.3ab	373.8±17.3ab
3-methylbutyl decanoate	E21	1874	1863	-	36.6±0.4	-	-	-	-
ethyl 3-phenylpropanoate	E22	1907	1887	614.8±47.3e	12721.6±23.0bc	13255.6±1445.5b	18739.3±52.8a	9918.3±65.8d	11016.7±1422.0cd
ethyl 3-hydroxyhexanoate	E23	1910	1663	-	119.4±1.6	-	-	-	-

3-phenylpropyl acetate	E24	1968	1971	-	14.5±0.2b	14.1±0.6b	16.0±0.2a	11.9±0.1c	11.3±0.3c
ethyl 3-hydroxytridecanoate	E25	2125	2433	-	4204.4±146.2b	4113.6±62.7b	7251.2±97.9a	3040.7±130.9c	2071.1±148.0d
ethyl (<i>E</i>)-cinnamate	E26	2164	2157	15.3±0.1c	48.9±6.1ab	45.9±2.3ab	60.4±3.5a	36.9±2.8b	35.9±3.8b
diethyl nonanedioate	E27	2236		-	96.0±8.0b	100.4±10.6b	127.3±7.5a	48.6±2.4c	56.6±3.5c
ethyl hexadecanoate	E28	2270	2250	239.7±16.3d	3805.4±18.9bc	3405.9±256.0c	6585.2±565.0a	4188.0±193.5bc	4130.9±40.4b
kessyl acetate	E29	2307	2387	1612.0±30.5d	3271.7±75.2bc	2892.1±224.4c	4060.2±112.0a	3745.4±394.0ab	2838.1±165.0c
dibutyl phthalate	E30	2610	2680	434.9±27.7d	3198.2±43.9a	1400.8±63.2b	1358.4±75.2bc	1109.3±34.2c	1546.8±52.4bc
total				11619.1±231.8d	85659±2179.6a	78141.6±3170.5b	97647.6±3565.4a	62748.1±1453.0c	64077.7±2550.2c
Terpenes									
β-myrcene	T1	1166	1161	16.3±0.4d	42.5±2.6ab	34.3±1.3c	45.1±3.7a	37.1±2.5c	43.1±0.7bc
α-phellandrene	T2	1171	1167	11.5±0.1	-	-	-	-	-
limonene	T3	1199	1204	16.6±0.4a	48.3±3.4bc	36.3±1.2cd	34.3±0.9d	32.8±1.6d	41.0±1.1b
β-phellandrene	T4	1210	1210	10.2±0.1	23.7±1.0	-	-	-	-
γ-terpinene	T5	1248	1245	19.7±0.2d	70.0±2.6a	67.8±6.8b	72.9±1.0ab	67.2±2.5ab	56.8±1.7c
p-cymene	T6	1273	1266	35.4±0.6c	111.7±1.3a	96.1±2.3b	93.8±0.1b	90.8±0.1b	98.7±1.6b
terpinolene	T7	1284	1284	13.1±0.0c	45.7±1.2a	39.3±3.2b	42.3±0.2b	44.4±2.3a	39.9±2.9b
1-isopropenyl-4-methylbenzene	T8	1440	1438	48.3±0.0c	93.6±4.9a	87.7±7.7b	97.1±1.9a	93.6±5.2a	90.2±0.3b
(<i>E,E</i>)-2,6-dimethyl-1,3,5,7-octatetraene	T9	1460	1459	9.3±0.2c	27.0±1.2a	19.4±0.2b	25.7±1.6ab	22.7±2.4b	24.5±1.1b
(+)-cyclosativene	T10	1478	1470	10.7±0.4	-	-	-	-	-
β-patchoulene	T11	1494	1470	30.8±2.8b	33.2±0.4b	45.3±3.0a	25±0.4c	31.2±0.1bc	7.1±0.01bc
δ-elemene	T12	1489	1510	13.2±0.8	-	-	-	-	-
elixene	T13	1537	1514	13.9±0.0	-	-	-	-	-
(<i>E</i>)-9-epi-β-caryophyllene	T14	1575	1572	12.8±0.4	-	-	-	-	-
γ-caryophyllene	T15	1585	1589	118.9±5.9a	-	-	29.0±2.1b	-	-
longifolene	T16	1591	1595	26.2±0.3	-	-	-	-	-
(-)-β-elemene	T17	1597	1596	20.9±1.0	-	-	-	-	-
β-caryophyllene	T18	1610	1610	1672.5±49.1a	108.8±11.9d	148.6±6.5c	204.3±4.8d	112.9±0.1b	110.6±5.7cd
δ-guaiene	T19	1622	1642	21.2±1.3	-	-	-	-	-
γ-elemene	T20	1628	1636	70.6±4.4	-	-	-	-	-
aromadendrene	T21	1636	1635	13.9±0.1	-	-	-	-	-
alloaromadendrene	T22	1664	1663	65.8±3.9	-	-	-	-	-
γ-gurjunene	T23	1676	1674	20.7±0.2	-	-	-	-	-
α-humulene	T24	1687	1688	42.0±0.0	-	-	-	-	-
γ-selinene	T25	1690	1690	11.4±0.1	-	-	-	-	-
α-selinene	T26	1746	1744	22.9±0.4c	25.2±1.0ab	-	29.9±0.7a	24.6±0.6bc	24.8±0.5bc
total				2364.4±70.5a	627.4±33.8b	570.1±29.6d	719.8±20.1b	551.0±17.6c	560.7±15.8e

Acid									
propanoic acid	AC1	1541	1535	-	-	-	-	5105.8±174.6	-
butanoic acid	AC2	1630	1624	-	7286.7±11.0b	7017.0±42.1b	8723.5±258.1a	6219.8±473.5c	5944.0±217.2c
3-methylbutanoic acid	AC3	1674	1665	48.4±0.4c	110.1±3.0b	110.8±5.3b	139.5±1.9a	112.6±2.5b	111.4±4.1b
hexanoic acid	AC4	1856	1840	65.4±0.2e	2382.5±131.9b	2137.8±109.5c	2869.5±70.7a	1989.7±85.7cd	1810.2±6.8d
2-ethylhexanoic acid	AC5	1962	1969	96.8±0.0	-	-	-	-	-
heptanoic acid	AC6	1964	1939	38.1±0.0c	71.5±0.3ab	73.2±2.6a	74.8±0.1a	70.1±3.5b	72.0±0.9b
octanoic acid	AC7	2075	2054	121.7±0.5d	13399.1±815.5b	12532.6±441.8b	17247.1±513.3a	11415.3±278.2c	10135.8±360.0c
(<i>Z,Z</i>)-9,12-octadecadienoic acid	AC8	2515	3590	52.6±0.7e	95.7±3.3b	98.9±3.9b	113.7±0.1a	88.6±1.2c	81.8±1.3d
nonanoic acid	AC9	2179	2154	123.5±4.2d	501.8±24.7b	465.6±7.6bc	664.3±29.9a	418.3±31.6c	438.1±30.2c
decanoic acid	AC10	2286	2285	74.0±2.1d	12392.5±430.2b	14372.5±426.5b	23473.1±934.9a	11505.6±503.4c	11087.6±120.4c
9-decenoic acid	AC11	2340	2341	56.2±0.4e	7924.2±299.2bc	7994.6±109.1d	14299.1±615.1a	7354.2±100.4d	7472.4±85.5cd
dodecanoic acid	AC12	2499	2486	20.6±0.7d	270.1±8.0c	674.1±74.2a	422.5±14.3b	217.8±4.4c	253.8±11.0c
total				697.3±9.2d	44434.4±1727.2b	45477.2±1222.6b	68027.0±2438.5a	44497.7±1658.9c	37407.0±837.4c
Ketones									
acetone	K1	823	808	1114.5±1.9	-	-	-	-	-
3-pentanone	K2	985	986	26.5±0.9	-	-	-	-	-
4-methyl-2-pentanone	K3	1015	1012	32.5±0.8	-	-	-	-	-
3-hydroxy-2-butanone	K4	1142	1139	4742.0±58.6	-	-	-	-	-
6-methyl-5-hepten-2-one	K5	1341	1339	7.9±0.0d	13.3±0.0b	14.0±1.3b	14.4±0.4a	10.6±0.0c	11.0±0.3c
2-nonanone	K6	1390	1376	-	13.8±0.6a	10.9±0.4c	12.4±0.7b	8.0±0.2d	9.0±0.1d
piperitone	K7	1753	1721	4.1±0.1d	7.3±0.1b	7.6±0.3b	8.8±0.3a	6.8±0.1c	6.5±0.3c
(<i>Z</i>)-jasnone	K8	1950	1923	7.6±0.0c	26.3±0.2a	20.5±0.2b	29.8±1.2a	23.9±1.2b	23.6±0.3b
2-hydroxy-5-methylacetophenone	K9	2223	2187	3.6±0.0	-	-	-	-	-
total				5938.8±62.4d	60.7±0.9a	53.1±2.1b	65.5±2.5a	49.2±1.5bc	50.2±1.0c
Aldehydes									
acetaldehyde	A1	707	705	1259.0±25.0	3657.0±199.8	3511.1±133.9	4401.6±166.6	3322.5±56.6	3194.6±53.4
(<i>E,E</i>)-2,4-nonadienal	A2	1694	1649	21.7±0.0d	22.0±0.0b	22.0±0.0b	22.1±0.0a	21.9±0.0c	21.9±0.0c
benzaldehyde	A3	1531	1518	21.7±0.0d	21.8±0.0b	21.8±0.0a	21.8±0.0bc	21.8±0.0c	21.8±0.0c
3,4-dimethylbenzaldehyde	A4	1809	1809	-	21.8±0.0a	21.7±0.0b	21.8±0.0a	21.8±0.0a	21.7±0.0b
3,5-dimethylbenzaldehyde	A5	1837	1837	22.3±0.0d	39.7±2.0a	35.9±1.4b	40.3±0.5a	37.9±0.7b	33.3±0.7c
methyl (<i>2E</i>)-4-isopropylidene-7-methyl-6-methylene-2-octenoate	A6	1885	1886	21.7±0.0	-	-	-	-	-
total				1346.3±25.1d	3762.3±201.8a	3612.5±135.3b	4507.6±167.2a	3425.8±57.4b	3293.2±54.2c
Phenols									
4-ethyl-2-methoxyphenol	P1	2055	2030	1344.6±4.4d	2530.9±90.2b	2508.8±12.7bc	3012.3±116.8a	2591.5±56.9bc	2464.9±55.5c

methyl cinnamate	P2	2060	2046	4.4±0.0d	5.7±0.0b	5.7±0.2b	6.4±0.3a	5.6±0.1b	5.2±0.0c
4-ethylphenol	P3	2195	2195	1384.5±2.5e	5385.8±30.9a	4063.4±50.3b	6171.2±312.3a	3463±103.7c	2640.4±5.0d
2-methoxy-4-vinylphenol	P4	2227	2212	-	149.3±5.0b	149.3±11.5b	218.6±8.8a	113.7±5.9c	131.2±15.0c
2,4-di-tert-butylphenol	P5	2315	2330	9.0±0.0d	70.3±3.1b	46.8±4.4c	85.6±9.6a	77.6±2.2ab	80±0.8ab
total				2742.5±6.9d	8142.0±129.2b	6774.0±79.1c	9494.1±447.9a	6251.5±168.9c	5321.8±76.3c
Others									
octadecane	O1	1797	1800	-	12.1±0.4b	-	-	14.7±0.5a	-
nonadecane	O2	1899	1900	-	8.5±0.2a	8.3±0.3a	7.0±0.0b	8.4±0.1a	-
patchoulane	O3	2037	2060	5.5±0.0d	8.0±0.0b	8.0±0.4b	9.6±0.6a	6.2±0.2c	6.5±0.1c
β-caryophyllene oxide	O4	1973	1979	24.4±0.2d	26.6±0.3c	37.0±0.4a	33.0±1.2b	23.2±1.6d	25.8±2.0d
humulene epoxide II	O5	1996	2066	28.0±0.2e	55.2±2.3c	61.7±4.7b	71.4±0.2a	32.9±0.3d	39.1±2.3d
limonene diepoxide	O6	2026	2059	4.8±0.0	-	-	-	-	-
vulgarone B	O7	2194	2222	16.4±0.4d	31.1±2.3a	29.0±0.7b	27.7±1.1b	25.8±0.3b	23.2±1.9c
2-pentylfuran	O8	1234	1235	23.1±0.1d	33.8±1.1b	29.7±0.7c	39.5±2.0a	29.5±0.1c	31.5±0.6c
trans-linalool oxide	O9	1478	1449	9.7±0.0	-	-	-	-	-
2,3-dihydrobenzofuran	O10	2398	2389	4.5±0.0d	51.9±1.6b	45.6±0.9ac	66.6±4.8a	40.3±0.2c	46.2±0.8bc
4-hydroxybutanoic acid lactone	O11	1644	1646	732.4±4.1	-	-	-	-	-
4-hydroxynonanoic acid lactone	O12	2064	2051	175.5±5.4c	-	753.7±11.5b	970.6±2.3a	806.7±8.6b	785.1±46.8b
4-hydroxydecanoic acid lactone	O13	2113	2103	15.1±0.0c	-	26.6±0.2b	31.1±0.7a	22.0±1.7b	27.3±4.4b
dimethyl sulfide	O14	754	773	346.8±10.8	-	-	-	-	-
methionol	O15	1736	1723	-	2424.0±57.8a	-	2266.6±90.6b	2118.8±186.2ab	1584.3±21.8c
total				1386.4±21.4d	2651.2±65.9c	999.7±19.7b	3523.1±103.5a	3128.5±199.8b	2568.9±80.6b
ALL				37846.0±615.2d	411816.2±10217.4b	390380.4±13860.4b	483278.2±21859.8a	357928.3±17796.3c	347703.0±10552.0c

968 Sc: Chinese bayberry wine fermented with pure *Saccharomyces (S.) cerevisiae*; Sc-ZFM710 and Sc-ZFM715: Chinese bayberry wine fermented
969 with mixed inoculum of *S. cerevisiae* and *Lactiplantibacillus (Lp.) plantarum* ZFM710 or *Lp. plantarum* ZFM715; Sc-ZFM720 and Sc-ZFM722:
970 Chinese bayberry wine fermented with mixed inoculum of *S. cerevisiae* and *Limosilactobacillus (Lb.) fermentum* ZFM720 or *Lb. fermentum*
971 ZFM722.

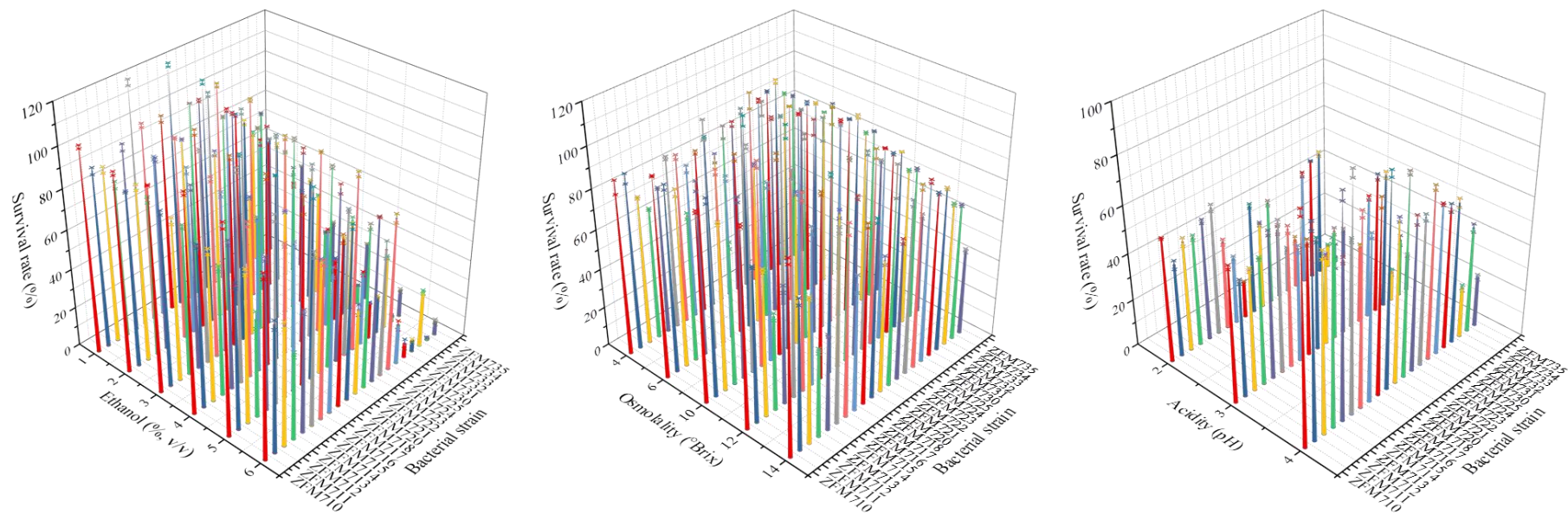
972 RI*: retention index of compounds reported in NIST database.

973 Results represent the mean ± SD (n = 3). Values in the same raw with different letters are significantly different ($p < 0.5$).

974 -: not detected

975

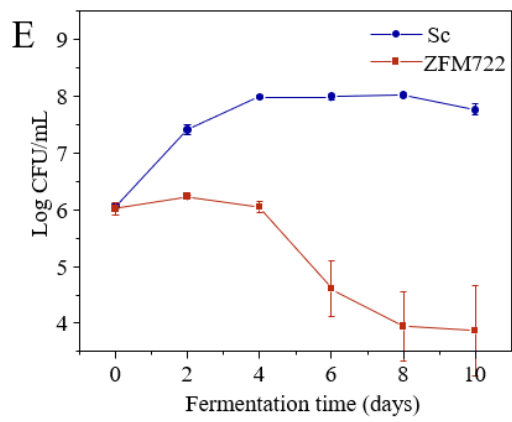
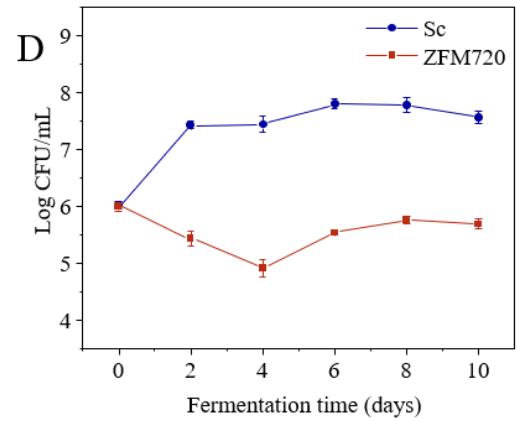
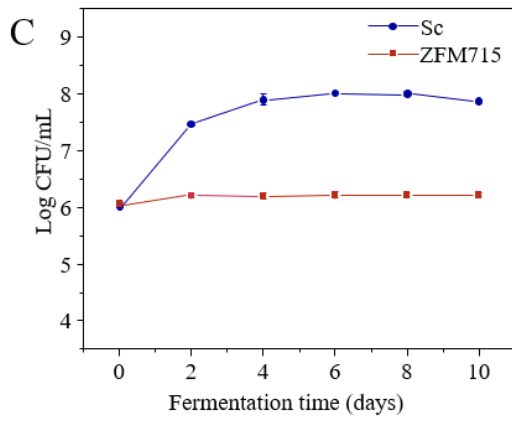
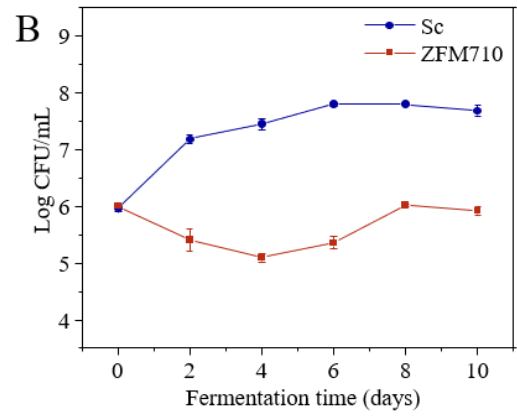
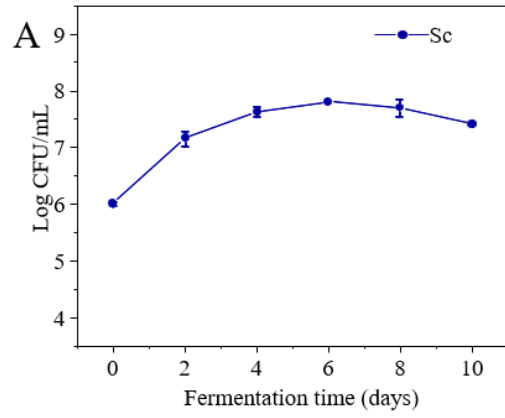
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978 **Fig. 1**

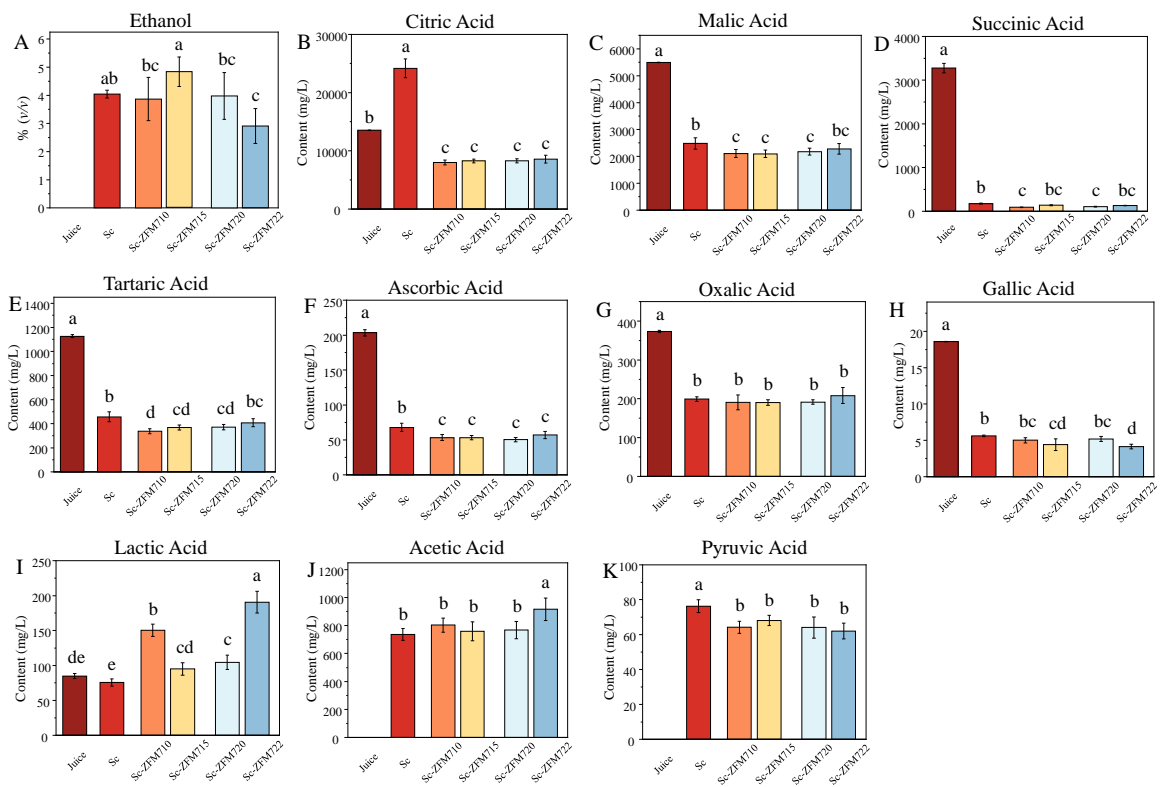
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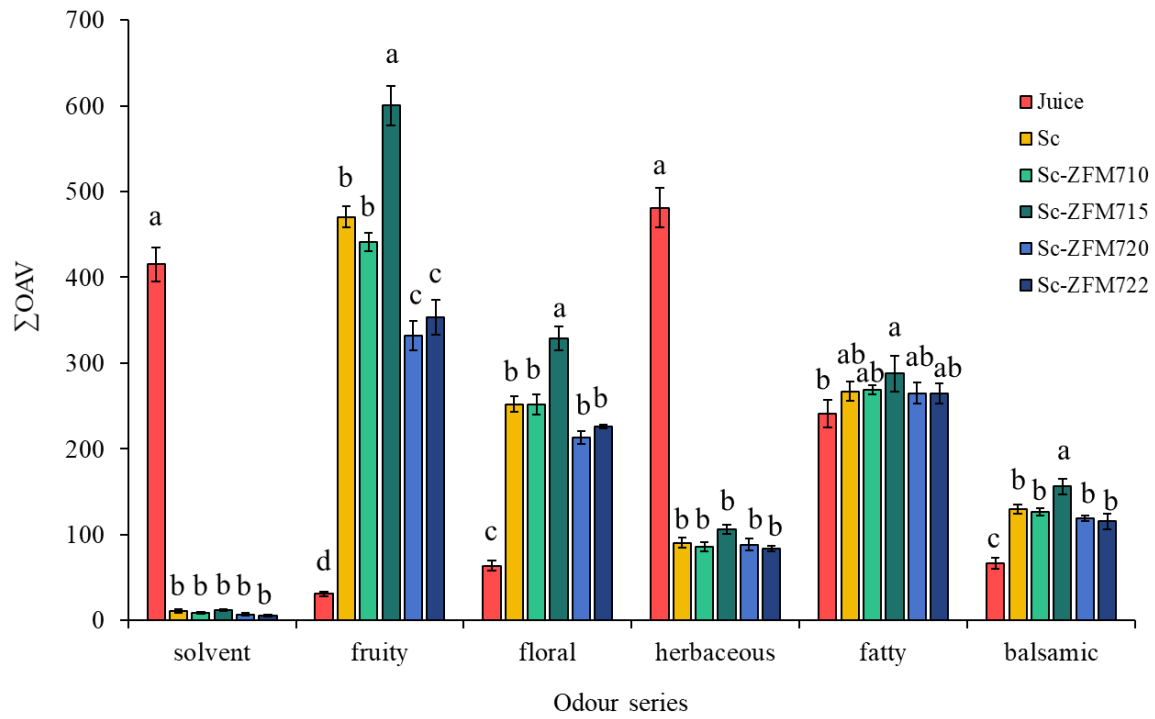


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981 **Fig. 2**

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 987 **Fig. 4**
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Supplementary

Selecting autochthonous lactic acid bacteria for co-inoculation in Chinese bayberry wine production: stress response, starter cultures application and volatilomic study

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Supplementary Table 1. Pure standards used in the qualitative and quantitative analysis of aroma compounds

Standard	Category	Purity
4-methyl-2-pentanol	Alcohols	98%
1-propanol	Alcohols	≥99.9%
2-methyl-1-propanol	Alcohols	≥99%
1-butanol	Alcohols	≥99.7%
1-pentanol	Alcohols	≥99%
3-methyl-1-butanol	Alcohols	≥98%
1-hexanol	Alcohols	≥99%
2-heptanol	Alcohols	≥98%
3-ethoxy-1-propanol	Alcohols	97%
(<i>Z</i>)-3-hexenol	Alcohols	98%
1-octanol	Alcohols	≥99%
(<i>E</i>)-2-hexenol	Alcohols	96%
1-heptanol	Alcohols	≥98%
2-nonanol	Alcohols	≥99%
2-ethyl-1-hexanol	Alcohols	≥99.6%
methionol	Alcohols	98%
2-phenylethanol	Alcohols	≥99%
1-decanol	Alcohols	≥98%
ethyl acetate	Esters	99.8%
propyl acetate	Esters	≥99.5%
butyl acetate	Esters	≥99%
ethyl 2-methylpropanoate	Esters	≥99%
ethyl 3-hydroxybutanoate	Esters	≥98%
2-methylpropyl acetate	Esters	≥99%
ethyl butanoate	Esters	≥99.5%
ethyl heptanoate	Esters	≥99%
ethyl nonanoate	Esters	≥98%
ethyl 3-methylbutanoate	Esters	≥98%
methyl hexanoate	Esters	≥99%
ethyl hexanoate	Esters	≥99%
3-methylbutyl octanoate	Esters	≥98%
ethyl 2-hydroxypropanoate	Esters	≥98%
ethyl octanoate	Esters	≥99%
ethyl decanoate	Esters	≥99%
2-phenylethyl acetate	Esters	≥99%
ethyl 3-phenylpropanoate	Esters	99%
ethyl dodecanoate	Esters	≥98%
propanoic acid	Acids	≥99.5%
2-methylpropanoic acid	Acids	≥99.5%
butanoic acid	Acids	≥99%
pentanoic acid	Acids	≥99.8%

hexanoic acid	Acids	≥99.5%
heptanoic acid	Acids	≥99%
2-methylpropanoic acid	Acids	≥99%
2-ethylhexanoic acid	Acids	≥99%
butane-2,3-dione	Ketones	≥99%
(3 <i>S</i>)-3-hydroxy-1-phenylbutan-2-one	Ketones	≥97%
6-methyl-5-hepten-2-one	Ketones	99%
acetaldehyde	Aldehydes	≥99.5%
hexanal	Aldehydes	≥98%
3-ethylphenol	Phenols	98.07%
2-methoxyphenol	Phenols	≥99%
2-methoxy-4-methylphenol	Phenols	99%
2,6-dimethoxyphenol	Phenols	99%
1-methyl-4-prop-1-en-2-ylcyclohexene	Terpenes	≥97%
1-methyl-4-propan-2-ylidenecyclohexene	Terpenes	≥97%
3,7-dimethylocta-1,6-dien-3-ol	Terpenes	97%
α-terpineol	Terpenes	≥96%
1,2-xylene	Benzenes	≥99%
benzaldehyde	Benzenes	≥99%

Supplementary Table 2. Odour thresholds ($\mu\text{g/L}$), odour descriptors, and odour series of aroma compounds and comparison in odour activity values (OAVs) among the Chinese bayberry juice and wines.

Compound	Code	Odour threshold ($\mu\text{g/L}$) ^a	Odour descriptor ^a	Odour series ^b	OAV					
					Juice	Sc	Sc-ZFM710	Sc-ZFM715	Sc-ZFM720	Sc-ZFM722
Alcohols										
1-propanol	AL1	306000	alcohol, must, plastic, pungent	1	<1	<1	<1	<1	<1	<1
2-butanol	AL2	50000	alcohol, solvent, wine	1	<1	-	-	-	-	-
2-methyl-1-propanol	AL3	40000	alcohol, nail polish	1	<1	<1	<1	<1	<1	<1
3-methyl-1-butanol	AL4	30000	alcohol, nail polish	1	0.0 \pm 0.0d	1.9 \pm 0.1ab	1.8 \pm 0.0b	2.0 \pm 0.0a	1.6 \pm 0.2bc	1.6 \pm 0.0c
1-pentanol	AL5	64000	almond, balsamic	6	<1	-	-	-	-	-
2-heptanol	AL6	200	citrus, coconut	2	<1	-	-	-	-	-
1-hexanol	AL7	8000	woody, green, herbaceous	4	<1	<1	<1	<1	<1	<1
3-ethoxy-1-propanol	AL8	100	fruity	2	-	76.3 \pm 3.3b	71.9 \pm 12.3b	94.6 \pm 12.0a	74.2 \pm 6.4b	72.5 \pm 3.5b
(Z)-3-hexenol	AL9	400	grass, green, green leaf, herbaceous	4	<1	-	-	-	-	-
2-octanol	AL10	3000	spicy, green, herbal	4	<1	-	-	-	-	-
1-heptanol	AL11	2500	oily	5	<1	<1	<1	<1	<1	<1
6-methyl-5-hepten-2-ol	AL12	2000	herbaceous, pungent	4	<1	-	-	-	-	-
2-nonanol	AL13	58	fruity, green	2,4	<1	<1	<1	<1	<1	-
linalool	AL14	15	citrus, floral, sweet, grape-like	2,3	4.6 \pm 0.0d	26.8 \pm 0.4b	26.5 \pm 1.7b	29.3 \pm 1.4a	16.2 \pm 0.5c	15.3 \pm 0.2c
1-octanol	AL15	800	citrus, fruity	2	<1	<1	<1	<1	<1	<1
menthol	AL16	128	lemon, mint	2,4	-	<1	<1	<1	<1	<1
4-terpineol	AL17	250	lilac, floral, sweet	3	-	1.9 \pm 0.2b	2.0 \pm 0.0b	2.3 \pm 0.0a	1.7 \pm 0.0c	1.7 \pm 0.0c
levomenthol	AL18	-		-	-	-	-	-	-	-
1-nonanol	AL19	600	detergent	1	-	<1	<1	<1	<1	<1
(Z)-3-nonenol	AL20	70000	floral, green, pungent	3,4	<1	-	-	-	-	-
α -terpineol	AL21	250	lily, sweet, cake	3	0.4 \pm 0.0d	1.2 \pm 0.1b	1.2 \pm 0.0b	1.4 \pm 0.0a	1.1 \pm 0.0b	0.8 \pm 0.0c

α -phellandren-8-ol	AL22	4.6		-	1.4±0.0d	1.8±0.0bc	1.9±0.0b	2.2±0.0a	1.9±0.0b	1.7±0.0c
(E,Z)-3,6-nonadienol	AL23	200	cucumber	4	-	<1	<1	<1	<1	<1
1-decanol	AL24	400	fat, oil, plastic	5	-	<1	<1	<1	<1	<1
β -citronellol	AL25	100	rose	2	-	1.2±0.1b	1.2±0.0b	1.3±0.1a	<1	<1
β -phellandren-8-ol	AL26	-		-	-	-	-	-	-	-
α -santalol	AL27	-		-	-	-	-	-	-	-
geraniol	AL28	30	floral, geranium, lemon peel, passion fruit	2,3	<1	2.1±0.1b	2.1±0.0b	2.4±0.0a	1.6±0.1c	1.5±0.1c
2-phenylethanol	AL29	10000	honey, rose	3	0.4±0.0c	16.5±0.1b	15.6±0.3b	19.5±1.3a	14.9±0.6b	15.1±0.5b
cubebol	AL30	-		-	-	-	-	-	-	-
1-dodecanol	AL31	1000	fat, wax	5	<1	<1	<1	<1	<1	<1
3-phenyl-1-propanol	AL32	9	anise, cinnamon, fruit	6	<1	-	-	-	-	-
viridiflorol	AL33	-	green, sweet	4	-	-	-	-	-	-
cedrol	AL34	0.5	sweet	3	25.4±0.2c	53.6±0.8b	53.8±0.6b	64.6±4.4a	61.6±0.8ab	67.6±2.2a
spathulenol	AL35	-	fruit, herb	2,4	-	-	-	-	-	-
δ -cadinol	AL36	-	herb, spice	4,6	-	-	-	-	-	-
intermedeol	AL37	-		-	-	-	-	-	-	-
juniper camphor	AL38	-	camphorwood	6	-	-	-	-	-	-
caryophylladienol II	AL39	-		-	-	-	-	-	-	-
eudesma-4(15),7-dien-1 β -ol	AL40	-		-	-	-	-	-	-	-
β -santalol	AL41	-		-	-	-	-	-	-	-
Esters										
ethyl acetate	E1	12000	fruit, grape, pineapple	2	<1	3.4±0.1a	3.2±0.1a	3.5±0.1a	2.6±0.0b	2.7±0.0b
isobutyl acetate	E2	1600	sweet, fruity, apple, banana	2	<1	<1	<1	<1	<1	<1
ethyl butanoate	E3	400	apple, banana, strawberry	2	-	2.4±0.01ab	2.2±0.0b	2.9±0.0a	1.6±0.1c	1.8±0.0c
diethyl carbonate	E4	-		-	-	-	-	-	-	-
isopentyl acetate	E5	30	apple, banana, pear	2	1.4±0.0d	62.0±1.5b	54.6±2.9b	77.8±1.2a	40.3±0.1c	39.9±2.1c

ethyl hexanoate	E6	14	fruity, green apple, banana, brandy	2	-	79.2±1.5b	75.8±4.7b	109.9±6.9a	37.7±0.1c	51.8±4.7c
propyl hexanoate	E7	-	berry, fruit, pineapple	2	-	-	-	-	-	-
ethyl octanoate	E8	580	apricot, banana, fresh, fruit	2	-	9.7±0.5a	8.3±0.0b	8.8±1.0b	4.5±0.2c	4.8±0.2c
linalyl formate	E9	-	citrus, coriander	2	-	-	-	-	-	-
ethyl nonanoate	E10	1300	banana, fruit, grape	2	-	<1	<1	<1	<1	<1
ethyl decanoate	E11	200	fruit, grape	2	-	16.1±1.2a	10.9±0.2c	19.8±1.4b	10.1±0.9d	8.7±0.1d
isopentyl octanoate	E12	152	baked apple	2	-	<1	<1	<1	<1	<1
ethyl benzoate	E13	56	fruity	2	-	1.3±0.1bc	1.2±0.0bc	1.4±0.0b	1.1±0.1c	2.0±0.0a
ethyl 9-decenoate	E14	100	fruity	2	-	30.2±3.5a	24.1±0.3b	33.7±2.9a	17.4±0.7c	19.0±0.6a
1,3-propanediol diacetate	E15	-		-	-	-	-	-	-	-
ethyl phenylacetate	E16	470	floral, fruit, honey, rose, sweet	2,3	-	<1	<1	<1	<1	<1
ethyl 2-hydroxy-3-methylbutanoate	E17	1000		-	<1	-	-	-	-	-
ethyl 2-hydroxy-4-methylpentanoate	E18	51	black currant, fruity	2	1.9±0.0	-	-	-	-	-
(Z)-3-hexenyl butanoate	E19	-	apple, green	2,4	-	-	-	-	-	-
ethyl 3-hydroxybutanoate	E20	21000	grape, marshmallow, medicine	2,4	-	<1	<1	<1	<1	<1
3-methylbutyl decanoate	E21	-	wax	5	-	-	-	-	-	-
ethyl 3-phenylpropanoate	E22	125	flower, fruit, honey, sweet	2,3	4.9±0.4e	101.8±0.2bc	106.0±11.6b	149.9±0.4a	79.3±0.5d	88.1±11.4cd
ethyl 3-hydroxyhexanoate	E23	270	floral, fresh, fruit, passion fruit	2,3	-	<1	-	-	-	-
3-phenylpropyl acetate	E24	100		-	-	<1	<1	<1	<1	<1
ethyl 3-hydroxytridecanoate	E25	-		-	-	-	-	-	-	-
ethyl (E)-cinnamate	E26	1.1	balsamic, cinnamon, flower, honey, sweet	2,3,6	13.9±0.1c	44.4±5.5ab	41.7±2.1ab	54.9±3.2a	33.5±2.5b	32.6±3.4b
diethyl nonanedioate	E27	-		-	-	-	-	-	-	-
ethyl hexadecanoate	E28	1500	waxy, greasy	5	<1	2.5±0.0bc	2.3±0.2c	4.4±0.4a	2.8±0.1bc	2.7±0.0b
kessyl acetate	E29	-		-	-	-	-	-	-	-

dibutyl phthalate	E30	-		-	-	-	-	-	-	-
Terpenes										
β -myrcene	T1	15	balsamic, fruit, geranium, herb, must	2,4,6	1.1±0.0d	2.8±0.2ab	2.3±0.1c	1.0±0.2a	2.5±0.2c	2.9±0.0bc
α -phellandrene	T2	40	citrus, mint, pepper, turpentine	2,6	<1	-	-	-	-	-
limonene	T3	200	balsamic, citrus, fruit	1,6	<1	<1	<1	<1	<1	<1
β -phellandrene	T4	36	mint, turpentine	6	<1	<1	-	-	-	-
γ -terpinene	T5	260	bitter, citrus, gasoline, resin, turpentine	2,6	<1	<1	<1	<1	<1	<1
p-cymene	T6	11.4	citrus, fresh	2	3.1±0.0d	9.8±0.1a	8.4±0.2bc	8.2±0.0bc	8.0±0.0bc	8.7±0.1b
terpinolene	T7	41	pine, sweet	6	<1	1.1±0.0a	1.0±0.1b	1.0±0.0b	1.1±0.1a	1.0±0.1b
1-isopropenyl-4-methylbenzene	T8	85	citrus, pine	2,6	<1	1.1±0.0a	1.0±0.1b	1.1±0.0a	1.1±0.1a	1.1±0.0b
(E,E)-2,6-dimethyl-1,3,5,7-octate traene	T9	-		-	-	-	-	-	-	-
(+)-cyclosativene	T10	-		-	-	-	-	-	-	-
β -patchoulene	T11	-		-	-	-	-	-	-	-
δ -elemene	T12	-	sweet, wood	4	-	-	-	-	-	-
elixene	T13	-		-	-	-	-	-	-	-
9-epi-caryophyllene	T14	-		-	-	-	-	-	-	-
γ -caryophyllene	T15	-	spice, wood	4,6	-	-	-	-	-	-
longifolene	T16	2	flower, vegetable	3,4	13.1±0.2	-	-	-	-	-
(-)- β -elemene	T17	4		-	5.2±0.3	-	-	-	-	-
β -caryophyllene	T18	150	spice, wood	4,6	11.1±0.3a	<1	1.0±0.0c	1.4±0.0b	<1	<1
δ -guaiene	T19	-		-	-	-	-	-	-	-
γ -elemene	T20	-	green, oil, wood	4,5,6	-	-	-	-	-	-
aromandendrene	T21	-		-	-	-	-	-	-	-
alloaromadendrene	T22	-	wood	4	-	-	-	-	-	-
γ -gurjunene	T23	-		-	-	-	-	-	-	-

α -humulene	T24	160	balsamic, spice, wood	4,6	<1	-	-	-	-	-
γ -selinene	T25	-	wood	4	-	-	-	-	-	-
α -selinene	T26	-	wood	4	-	-	-	-	-	-
Acids										
propanoic acid	AC1	8100	pungent, rancid, soy	5	-	-	-	-	<1	-
butanoic acid	AC2	10000	butter, cheese, must, rancid, sour	5	-	<1	<1	<1	<1	<1
3-methylbutanoic acid	AC3	3000	cheese, fat, fecal	5	<1	<1	<1	<1	<1	<1
hexanoic acid	AC4	3000	cheese, goat, pungent	5	<1	<1	<1	<1	<1	<1
2-ethylhexanoic acid	AC5	-		-	-	-	-	-	-	-
heptanoic acid	AC6	420	apricot, floral, rancid, sour, sweat	3,5	-	-	-	-	-	-
octanoic acid	AC7	10000	cheese, fat, rancid	5	<1	<1	<1	<1	<1	<1
(Z,Z)-9,12-octadecadienoic acid	AC8	-		-	-	-	-	-	-	-
nonanoic acid	AC9	3000	fatty	5	<1	<1	<1	<1	<1	<1
decanoic acid	AC10	1000	fatty, rancid, soap	5	<1	12.4±0.4b	14.4±0.4b	23.5±0.9a	11.5±0.5c	11.1±0.1c
9-decenoic acid	AC11	1000	rancid, fatty	5	<1	7.9±0.3b	8.0±0.1b	14.3±0.6a	7.4±0.1b	7.5±0.1b
dodecanoic acid	AC12	1000	fat, metal, wax	5	<1	<1	<1	<1	<1	<1
Ketones										
acetone	K1	10000	chemical, ether, hay, nauseating, pungent	1	<1	-	-	-	-	-
3-pentanone	K2	40	ether	1	<1	-	-	-	-	-
4-methyl-2-pentanone	K3	700	strawberry, sweet, varnish	2	<1	-	-	-	-	-
3-hydroxy-2-butanone	K4	150000	buttery, cream	5	<1	-	-	-	-	-
6-methyl-5-hepten-2-one	K5	68	citrus, strawberry	2	<1	<1	<1	<1	<1	<1
2-nonanone	K6	41	fragrant, fruit	2	-	<1	<1	<1	<1	<1
piperitone	K7	1870000	fresh, mint	4	<1	<1	<1	<1	<1	<1
(Z)-jasmone	K8	7	floral	3	1.1±0.0c	3.8±0.0ab	2.9±0.0bc	4.2±0.2a	3.4±0.2b	3.4±0.0b
2-hydroxy-5-methylacetophenon	K9	-		-	-	-	-	-	-	-

e

Aldehydes

acetaldehyde	A1	110000	ripe apple, pungent	1,2	<1	<1	<1	<1	<1	<1
(E,E)-2,4-nonadienal	A2	0.09	deep fried, fat, waxy	5	241.1±0.1d	244.4±0.3b	244.4±0.1b	245.6±0.0a	243.3±0.4c	243.3±0.3c
benzaldehyde	A3	35	almond, bitter, bitter almond	1,6	<1	<1	<1	<1	<1	<1
3,4-dimethylbenzaldehyde	A4	2000	fragrant, bitter almond	6	<1	<1	<1	<1	<1	<1
3,5-dimethylbenzaldehyde	A5	50		-	<1	<1	<1	<1	<1	<1

4-isopropylidene-7-methyl-6-met

hylene-2-octenoic acid, methyl ester

A6 - - - - - - - - - -

Phenols

4-ethyl-2-methoxyphenol	P1	33	clove, horse, medicine	4,6	40.7±0.1d	76.7±2.7b	76.0±0.4bc	91.3±3.5a	78.3±1.7bc	74.7±1.7c
methyl cinnamate	P2	1650	balsamic, strawberry	2,6	<1	<1	<1	<1	<1	<1
4-ethylphenol	P3	610	horse manure, leather, medicine, phenol	1,4	2.3±0.0e	8.8±0.1a	6.7±0.1b	10.1±0.5a	5.7±0.2c	4.3±0.0d
2-methoxy-4-vinylphenol	P4	40	clove, cooked, curry, phenol, smoke	6	-	3.7±0.1b	3.7±0.3b	5.5±0.2a	2.8±0.1c	3.3±0.4c
2,4-di-tert-butylphenol	P5	330000		-	<1	<1	<1	<1	<1	<1

Others

octadecane	O1	-	alkane	1	-	-	-	-	-	-
nonadecane	O2	-	alkane	1	-	-	-	-	-	-
patchoulane	O3	-		-	-	-	-	-	-	-
β-caryophyllene oxide	O4	-	herb, must, spice, sweet, wood	4,6	-	-	-	-	-	-
humulene epoxide II	O5	-	floral, must, spice	3,6	-	-	-	-	-	-
limonene diepoxide	O6	-		-	-	-	-	-	-	-
vulgarone B	O7	-		-	-	-	-	-	-	-
2-pentylfuran	O8	167	floral, fruit, green, green bean	2,3,4	<1	<1	<1	<1	<1	<1
trans-linalool oxide	O9	100	citrus, earth, flower, fresh, leaf	2,3,4	<1	-	-	-	-	-

2,3-dihydrobenzofuran	O10	500		-	<1	<1	<1	<1	<1	<1
4-hydroxybutanoic acid lactone	O11	50000	caramel, cheese, fruit, roasted nut, sweat	2,5	<1	-	-	-	-	-
4-hydroxynonanoic acid lactone	O12	-	apricot, cocoa, coconut, peach, sweet	2,5	-	-	-	-	-	-
4-hydroxydecanoic acid lactone	O13	-	apricot, fat, fruit, peach, pleasant	2,5	-	-	-	-	-	-
dimethyl sulfide	O14	0.84	cabbage-like, sulfur, gasoline	1,4	412.9±12.9	-	-	-	-	-
methionol	O15	1000	cooked potato, garlic	4	-	2.4±0.1a	-	2.3±0.0b	2.1±0.2ab	1.6±0.0c

Sc: Chinese bayberry wine fermented with pure *Saccharomyces (S.) cerevisiae*; Sc-ZFM710 and Sc-ZFM715: Chinese bayberry wine fermented with mixed inoculum of *S. cerevisiae* and *Lactiplantibacillus (Lp.) plantarum* ZFM710 or *Lp. plantarum* ZFM715; Sc-ZFM720 and Sc-ZFM722: Chinese bayberry wine fermented with mixed inoculum of *S. cerevisiae* and *Limosilactobacillus (Lb.) fermentum* ZFM720 or *Lb. fermentum* ZFM722.

Results represent the mean ± SD (n = 3). Values in the same raw with different letters are significantly different ($p < 0.05$).

^a Odour descriptors and odour thresholds of aroma compounds were obtained from the below literatures.

^b Five aroma series are 1: solvent, 2: fruity, 3: floral, 4: herbaceous, 5: fatty, 6: balsamic.

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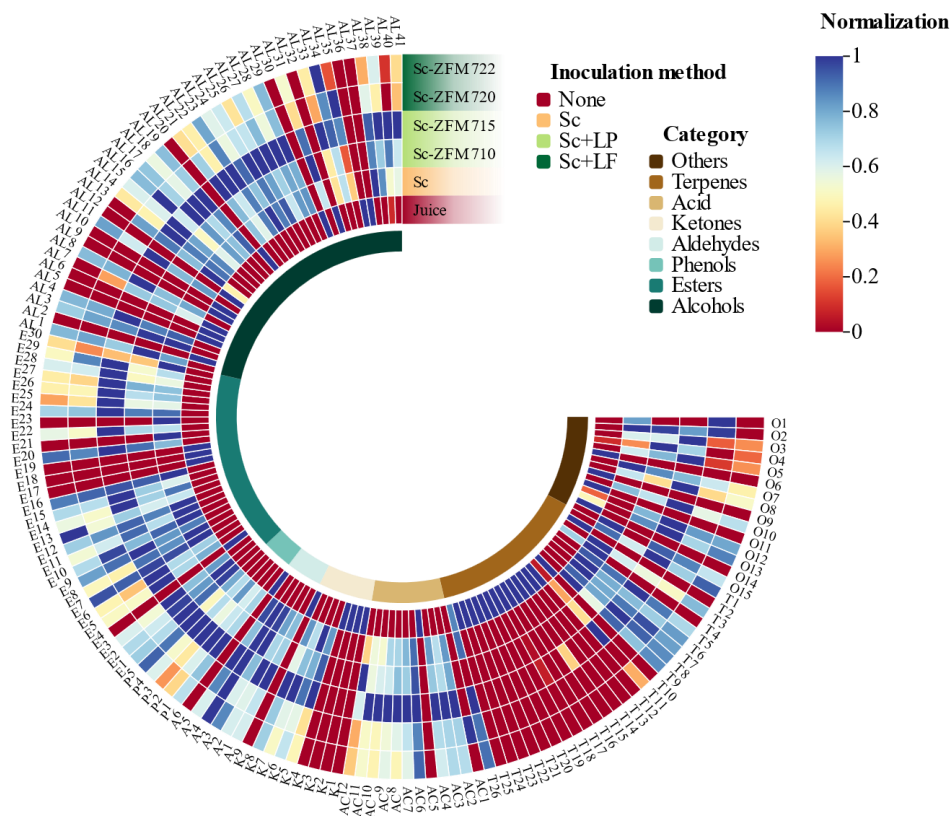
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Supplementary Fig. 1. Heatmap of distribution of each aroma compound (n = 144) detected in Chinese bayberry juice and wines made from different inoculation patterns using GC-MS. Colour coding from red to blue indicates the relative concentrations of aroma compounds from low to high. The variable codes of aroma compounds refer to those in Table 1.