



# Long-term effects of different starter yeasts on colour and natural antioxidant power of red wines

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## Abstract

Eighty-seven red wines produced from red grapes of the grape variety *Gaglioppo* from the Calabria region (vintage 2009) were analysed by standard methods after 4 and 120 months of ageing. So, a total of 29 selected starters of *Saccharomyces cerevisiae*—3 wild type, 12 monoclonal cultures, and 14 hybrids—inoculated in triplicate were studied for their effects on colour and natural antioxidant power keeping of red wine. Wine ageing decreased the red component, the colour intensity, and the DPPH values while the colour hue values increased. This research has shown that the evolution of wine ageing is affected in a very different way by the starter yeast used and has allowed choosing the best yeast strain useful to produce red wine able to endure very long-time ageing, until 10 years.

**Keywords** Long-time ageing · Red wines · *Saccharomyces cerevisiae* · Wine starter

## Introduction

Moderate but regular consumption of red wine is proven to possess a positive effect on health, due to the presence of antioxidants and protective substances [1]. During ageing, these substances undergo an evolution, which involves changes in chemical and sensory characteristics of red wines [2]; the potential relevance of these changes to wine quality and complexity was assessed [3]. Particularly, the colour seems to provide information about defects, variation of quality parameters of wines during storage and polyphenolic composition, playing an important role in the evaluation of the perceived quality of wine [4]. The relation between colour components and antioxidant properties of wine is widely proven; it was reported that phenolic composition, as well as monomeric anthocyanins and co-pigments, effect the colour stability of wine [5]. The influence of different native grape varieties [6–8], and winemaking technologies [9–14] on the evolution of the chemical characteristics was diffusely investigated. The aim of this work was to study the influence of the yeast strain used as a starter on the evolution of the

red component, colour intensity, colour hue, and antioxidant activity of red wine to assess its influence on long-term wine ageing. Several of the 29 yeast strains used and, in details, all the 14 hybrids were previously selected towards their effect on antioxidant phenolic compounds and towards a reduced absorption of wine phenolics.

## Materials and methods

### Microorganisms

Three wild type, 12 monosporal cultures, and 14 hybrid strains of *Saccharomyces cerevisiae*, specifically obtained crossing selected strains with a low aptitude to adsorb grape pigments on their parietal mannoproteins were used. In details, the 14 hybrids were previously selected towards their effect on antioxidant phenolic compounds [15] and some of them are characterised by reduced absorption of wine phenolics [16].

### Fermentation trials and analyses

Twenty kilograms of red grapes (vintage 2009) of the Calabrian cultivar *Gaglioppo* were given pre-fermentative maceration to extract pigments from skins and seeds. They were manually destemmed, crushed and macerated at 4 °C

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for 3 days, performing a punch down twice per day. The must obtained after pressing (pH 3.40, °Brix 22) was divided into aliquots of 100 mL and immediately inoculated at 5% in triplicate with 48-h precultures of each wine yeast. Micro-winemaking trials were performed at 25 °C. At the end of fermentation, the wines were refrigerated at 4 °C and racked into 125 mL plastic jars with a screw cap, under 10 ml of liquid paraffin, and keep in the dark at cellar temperature. After 4 and 120 months of ageing, the wines were analysed. The red component (Abs 520 nm), the colour intensity, and the

colour hue were evaluated according to the Glories method [17]; the percentage of DPPH inactivation were evaluated according to Alén-Ruiz method [18].

Data were elaborated as mean  $\pm$  standard deviations of three measurements. The significant differences ( $p < 0.05$ ) among samples were determined by analysis of variance (ANOVA) with Tukey's post-hoc test (SPSS Software, Version 15.0, SPSS Inc., Chicago, IL, USA).

**Table 1** Red component of the 29 wines—absorbance at 520 nm—after 4 months and 10 years

Ageing period (months)	4	120	Significance
Strains	Red component—520 nm		
RC026	<i>0.386 ± 0.020efgh</i>	0.234 ± 0.051a	**
RC026C-1A	<i>0.369 ± 0.003gh</i>	<i>0.079 ± 0.005def</i>	**
RC026C-1B	<i>0.379 ± 0.004fgh</i>	<i>0.110 ± 0.015bcdef</i>	**
RC026C-1C	<i>0.371 ± 0.000gh</i>	<i>0.116 ± 0.015bcdef</i>	**
RC026C-1D	<i>0.376 ± 0.010gh</i>	<i>0.103 ± 0.008cdef</i>	**
RC029	<i>0.390 ± 0.007efgh</i>	<i>0.090 ± 0.003cdef</i>	**
RC029A-1A	<i>0.354 ± 0.006 h</i>	<i>0.113 ± 0.013bcdef</i>	**
RC029A-1B	<i>0.388 ± 0.013efgh</i>	0.155 ± 0.062abcde	**
RC029A-1C	<i>0.372 ± 0.010gh</i>	<i>0.110 ± 0.009bcdef</i>	**
<b>RC029A-1D</b>	0.399 ± 0.006cdefg	0.147 ± 0.068abcde	**
RC029B-1A	<i>0.386 ± 0.027efgh</i>	0.148 ± 0.063abcde	**
RC029B-1B	<i>0.386 ± 0.011efgh</i>	0.137 ± 0.064abcdef	**
RC029B-1C	<i>0.369 ± 0.023gh</i>	<i>0.067 ± 0.011ef</i>	**
RC029B-1D	<i>0.361 ± 0.001gh</i>	<i>0.092 ± 0.049cdef</i>	**
RC039	<i>0.355 ± 0.016 h</i>	0.133 ± 0.067abcdef	**
RC026C-1C × RC039C-1C (4)	<i>0.379 ± 0.019fgh</i>	<i>0.031 ± 0.005f</i>	**
RC029A-1D × RC039C-1C (4)	0.396 ± 0.023defg	<i>0.123 ± 0.017abcdef</i>	**
RC029B-1C × RC039C-1C (7)	0.431 ± 0.021abcd	<i>0.113 ± 0.022bcdef</i>	**
RC029A-1D × RE078C-1C (4)	0.437 ± 0.001abc	<i>0.090 ± 0.014cdef</i>	**
RC029B-1C × RE078C-1C (4)	0.463 ± 0.021a	<i>0.100 ± 0.023cdef</i>	**
RC029B-1C × NA093B-1C (6)	0.424 ± 0.033abcde	<i>0.107 ± 0.015bcdef</i>	**
NA014C-1D × RC039C-1C (3)	<i>0.380 ± 0.034fgh</i>	0.133 ± 0.023abcdef	**
NA014C-1D × RC039C-1C (2)	<i>0.369 ± 0.005gh</i>	<i>0.126 ± 0.004abcdef</i>	**
NA015A-1B × RC039C-1C (5)	<i>0.390 ± 0.019efgh</i>	0.137 ± 0.024abcdef	**
NA015A-1B × NA093B-1C (2)	<i>0.376 ± 0.024gh</i>	<i>0.127 ± 0.016abcdef</i>	**
<b>RE049B-1A × NA093B-1C (1)</b>	0.434 ± 0.007abcd	0.188 ± 0.067abcd	**
<b>RE049B-1A × NA093B-1C (5)</b>	0.446 ± 0.025ab	0.144 ± 0.018abcde	**
RE049B-1A × RC039C-1C (8)	<i>0.385 ± 0.022efgh</i>	0.216 ± 0.016ab	**
<b>RE049B-1A × RC039C-1C (9)</b>	0.416 ± 0.005bcdef	0.202 ± 0.030abc	**
Min	0.354	0.031	
Max	0.463	0.234	
Mean	0.392	0.127	
Significance	**	**	

The italicized values are less than or equal to the mean value

The strains written in bold type exhibit in both the ageing periods values above average  
*ns* not significant

\*significant ( $p < 0.05$ ), \*\*high significant ( $p < 0.01$ )

## Results and discussion

The data presented in Table 1 show the red component of examined wines. After an ageing period of 4 months, the red component ranged ( $p < 0.01$ ) from a minimum value of 0.354 (strain RC029A-1A) to a maximum value of 0.463 [strain RC029B-1C × RE078C-1C (4)]. Twenty strains (value highlighted in grey) exhibited a value  $\leq 0.392$  (the mean value). After an ageing period of 120 months, the red component ranged ( $p < 0.01$ ) from a minimum value of 0.031 [strain RC026C-1C × RC039C-1C (4)] to a maximum value of 0.234 (strain RC026). Seventeen strains (value highlighted in grey) exhibited a value  $\leq 0.127$  (the mean value). The four strains are written in bold type exhibited in both the ageing periods values above average probably because they absorbed less anthocyanins than the others. Considering the variation of the value of the red component between 4 and 120 months, for each strain it highly significantly ( $p < 0.01$ ) decreased after 10 years of ageing from a minimum of  $-39.38\%$  (strain RC026) to a maximum of  $-91.82\%$  [strain RC026C-1C × RC039C-1C (4)] and a mean value of  $-67.68\%$ .

This decrease in red component with wine ageing has also been observed by other authors. Red wines produced from five red grapes varieties of Metohija regions (Serbia) were analysed after 0, 4, 8, and 12 months of ageing for the value of the red component [19]. It always decreased too, exhibiting variations of: (a)  $-2.56\%$  after 4 months,  $-5.13\%$  after 8 months, and  $-8.97\%$  after 12 months for *Cabernet* wine; (b)  $-2.78\%$  after 4 months,  $-5.56\%$  after 8 months, and  $-8.33\%$  after 12 months for *Game* wine; (c)  $-2.75\%$  after 4 months,  $-3.67\%$  after 8 months, and  $-5.50\%$  after 12 months for *Merlot* wine; (d)  $-3.85\%$  after 4 months,  $-7.69\%$  after 8 months, and  $-9.62\%$  after 12 months for *Prokup* wine; (e)  $-1.83\%$  after 4 months,  $-3.67\%$  after 8 months, and  $-5.50\%$  after 12 months for *Vranac* wine. Red wines produced from two different grape batches, both *Cabernet Sauvignon*, of Langhorne Creek region (South Australia) with low ( $P_{\text{low}}$ ) and high ( $P_{\text{high}}$ ) initial tannin and anthocyanin concentration were analysed after 0 and 42 months of ageing for the value of the red component [20]. It always decreased too, exhibiting variations of:  $-43.11\%$  for  $P_{\text{low}}$  wine and  $-44.65\%$  for  $P_{\text{high}}$  wine. Red wines produced from red grapes of the *Cabernet Sauvignon* variety from Ribera del Duero region (Spain) were analysed after 6 and 12 months of ageing for the value of the red component [21]. It always decreased too, exhibiting a mean variation of  $-2.46\%$ .

The data presented in Table 2 show the colour intensity of examined wines. After an ageing period of 4 months, the colour intensity ranged ( $p < 0.01$ ) from a minimum value of 1.145 (strain RC026C-1B) to a maximum value of 1.443

[strain RE049B-1A × NA093B-1C (5)]. Twenty strains (value highlighted in grey) exhibited a value  $\leq 1.245$  (the mean value). After an ageing period of 120 months, the colour intensity ranged ( $p < 0.01$ ) from a minimum value of 0.147 [strain RC026C-1C × RC039C-1C (4)] to a maximum value of 1.214 [strain RE049B-1A × RC039C-1C (8)]. Sixteen strains (value highlighted in grey) exhibited a value  $\leq 0.675$  (the mean value). The four strains written in bold type exhibited in both the ageing periods values above average probably because they absorbed less pigments than the others. Considering the variation of the colour intensity between 4 and 120 months, it always decreased after 10 years of ageing for 21 strains highly significantly ( $p < 0.01$ ), for five strains significantly ( $p < 0.05$ ), and for three strains not significantly, from a minimum of  $-2.80\%$  [strain RE049B-1A × RC039C-1C (8)] to a maximum of  $-87.97\%$  [strain RC026C-1C × RC039C-1C (4)] and a mean value of  $-45.73\%$ .

This decrease in colour intensity with wine ageing has also been observed by other authors. Red wines produced from five red grapes varieties of Metohija regions (Serbia) were analysed after 0, 4, 8, and 12 months of ageing for the colour intensity [19]. It decreased too, excluding the *Cabernet* wine, exhibiting variations of: (a) 0% after 4 and 8 months, and 1.80% after 12 months for *Cabernet* wine; (b)  $-0.62\%$  after 4 and 8 months, and  $-1.85\%$  after 12 months for *Game* wine; (c)  $-1.33\%$  after 4 and 8 months, and  $-1.77\%$  after 12 months for *Merlot* wine; (d) 0% after 4 months,  $-4.96\%$  after 8 months, and  $-2.48\%$  after 12 months for *Prokup* wine; (e)  $-0.45\%$  after 4, 8, and 12 months for *Vranac* wine. Eighty-four bottled samples of red wines, all produced using red grapes of *Listán negro* variety in the Canary Islands, were analysed after 12 and 24 months of ageing for the colour density [22]. It always decreased too, exhibiting, compared to the values after 12 months, a mean value variation of  $-21.84\%$ . *Tempranillo* wines made with grapes from two different vineyards of Rioja Alta (Spain) were analysed after 55 and 720 days of ageing for the colour intensity [23]. It always decreased too exhibiting, compared to the values after 55 days, a mean value variation of  $-11.25\%$ .

The data presented in Table 3 show the colour hue of examined wines. After an ageing period of 4 months, the colour hue ranged ( $p < 0.01$ ) from a minimum value of 1.729 (strain RC026C-1B) to a maximum value of 1.987 (strain RC029A-1A). Thirteen strains (value highlighted in grey) exhibited a value  $\geq 1.857$  (the mean value). After an ageing period of 120 months, the colour hue ranged ( $p < 0.01$ ) from a minimum value of 2.476 (strain RC026) to a maximum value of 6.712 (strain RC029B-1C). Thirteen strains (value highlighted in grey) exhibited a value  $\geq 4.179$  (the mean value). The ten strains written in bold type exhibited in both the ageing periods values below average because they

**Table 2** Colour intensity of the 29 wines after 4 months and 10 years

Ageing period (months)	4	120	Significance
Strains	Colour intensity		
RC026	<i>1.189 ± 0.059ef</i>	0.898 ± 0.120ab	*
RC026C-1A	<i>1.168 ± 0.018ef</i>	<i>0.518 ± 0.010bc</i>	**
RC026C-1B	<i>1.145 ± 0.006f</i>	<i>0.605 ± 0.060b</i>	**
RC026C-1C	<i>1.151 ± 0.033f</i>	<i>0.626 ± 0.071b</i>	**
RC026C-1D	<i>1.176 ± 0.048ef</i>	<i>0.591 ± 0.032b</i>	**
RC029	1.258 ± 0.009bcdef	<i>0.572 ± 0.017bc</i>	**
RC029A-1A	<i>1.169 ± 0.014ef</i>	<i>0.650 ± 0.057b</i>	**
RC029A-1B	<i>1.211 ± 0.058def</i>	0.721 ± 0.190b	*
RC029A-1C	<i>1.177 ± 0.004ef</i>	<i>0.602 ± 0.023b</i>	**
RC029A-1D	<i>1.235 ± 0.038cdef</i>	0.706 ± 0.220b	*
RC029B-1A	<i>1.209 ± 0.055def</i>	0.746 ± 0.212b	*
RC029B-1B	<i>1.187 ± 0.017ef</i>	0.679 ± 0.188b	*
RC029B-1C	<i>1.199 ± 0.025ef</i>	<i>0.517 ± 0.015bc</i>	**
RC029B-1D	<i>1.188 ± 0.036ef</i>	<i>0.612 ± 0.144b</i>	**
RC039	<i>1.165 ± 0.039ef</i>	<i>0.593 ± 0.366b</i>	ns
RC026C-1C × RC039C-1C (4)	<i>1.222 ± 0.063cdef</i>	<i>0.147 ± 0.036c</i>	**
RC029A-1D × RC039C-1C (4)	<i>1.236 ± 0.063cdef</i>	<i>0.650 ± 0.067b</i>	**
RC029B-1C × RC039C-1C (7)	1.365 ± 0.103abc	<i>0.613 ± 0.068b</i>	**
RC029A-1D × RE078C-1C (4)	1.374 ± 0.040abc	<i>0.576 ± 0.074bc</i>	**
RC029B-1C × RE078C-1C (4)	1.437 ± 0.052a	<i>0.582 ± 0.053bc</i>	**
RC029B-1C × NA093B-1C (6)	1.353 ± 0.084abcd	<i>0.665 ± 0.067b</i>	**
NA014C-1D × RC039C-1C (3)	<i>1.234 ± 0.064cdef</i>	0.727 ± 0.089b	**
NA014C-1D × RC039C-1C (2)	<i>1.206 ± 0.004def</i>	0.719 ± 0.002b	**
NA015A-1B × RC039C-1C (5)	<i>1.205 ± 0.046def</i>	0.713 ± 0.091b	**
NA015A-1B × NA093B-1C (2)	<i>1.232 ± 0.064cdef</i>	0.706 ± 0.041b	**
<b>RE049B-1A × NA093B-1C (1)</b>	1.392 ± 0.041ab	0.948 ± 0.324ab	ns
<b>RE049B-1A × NA093B-1C (5)</b>	1.443 ± 0.067a	0.760 ± 0.053b	**
<b>RE049B-1A × RC039C-1C (8)</b>	1.249 ± 0.042bcdef	1.214 ± 0.198a	ns
<b>RE049B-1A × RC039C-1C (9)</b>	1.318 ± 0.009abcde	0.911 ± 0.020ab	**
Min	1.145	0.147	
Max	1.443	1.214	
Mean	1.245	0.675	
Significance	**	**	

The italicized values are less than or equal to the mean value

The strains written in bold type exhibit in both the ageing periods values above average

ns not significant

\*significant ( $p < 0.05$ ), \*\*high significant ( $p < 0.01$ )

better-protected wine from ageing. Considering the variation of the colour hue between 4 and 120 months, it always increased after 10 years of ageing for 20 strains highly significantly ( $p < 0.01$ ), for six strains significantly ( $p < 0.05$ ), and for three strain not significantly, from a minimum of 27.07% (strain RC039) to a maximum of 248.13% (strain RC029B-1C) and a mean value of 124.13%.

This increase in colour hue with wine ageing has also been observed by other authors. Red wines produced from five red grapes varieties of Metohija regions (Serbia) were analysed after 0, 4, 8, and 12 months of ageing for the colour

hue [19]. It increased too exhibiting variations of: a) 5.88% after 4 months, 9.41% after 8 months, and 16.47% after 12 months for *Cabernet* wine; (b) 4.82% after 4 months, 9.64% after 8 months, and 13.25% after 12 months for *Game* wine; (c) 2.33% after 4 months, 3.49% after 8 months, and 5.81% after 12 months for *Merlot* wine; (d) 18.52% after 4 months, 11.11% after 8 months, and 23.46% after 12 months for *Prokup* wine; (e) 2.47% after 4 months, 6.17% after 8 months, and 9.88% after 12 months for *Vranac* wine. Eighty-four bottled samples of red wines, all produced using red grapes of *Listán negro* variety in the Canary Islands,

**Table 3** Colour hue of the 29 wines after 4 months and 10 years

Ageing period (months)	4	120	Significance
Strains	Colour hue		
<b>RC026</b>	1.776 ± 0.001cde	2.476 ± 0.394d	*
RC026C-1A	1.848 ± 0.005abcde	5.380 ± 0.280abc	**
RC026C-1B	1.729 ± 0.011e	4.204 ± 0.260abcd	**
<b>RC026C-1C</b>	1.791 ± 0.090bcde	4.034 ± 0.116abcd	**
RC026C-1D	1.825 ± 0.048abcde	4.437 ± 0.157abcd	**
RC029	1.895 ± 0.042abcde	5.103 ± 0.009abcd	**
RC029A-1A	1.987 ± 0.022a	4.474 ± 0.675abcd	**
<b>RC029A-1B</b>	1.811 ± 0.050abcde	3.403 ± 1.064bcd	*
RC029A-1C	1.849 ± 0.074abcde	4.185 ± 0.299abcd	**
<b>RC029A-1D</b>	1.774 ± 0.053cde	3.643 ± 1.080bcd	*
<b>RC029B-1A</b>	1.811 ± 0.071abcde	3.792 ± 0.947bcd	*
<b>RC029B-1B</b>	1.775 ± 0.045cde	3.830 ± 1.196abcd	*
RC029B-1C	1.928 ± 0.134abcd	6.712 ± 1.491a	**
RC029B-1D	1.946 ± 0.084abcd	6.066 ± 2.194ab	*
RC039	1.984 ± 0.031ab	2.521 ± 1.595 cd	ns
RC026C-1C × RC039C-1C (4)	1.897 ± 0.006abcde	3.086 ± 2.309 cd	ns
<b>RC029A-1D × RC039C-1C (4)</b>	1.786 ± 0.034cde	3.886 ± 0.280abcd	**
<b>RC029B-1C × RC039C-1C (7)</b>	1.822 ± 0.068abcde	4.139 ± 0.688abcd	**
RC029A-1D × RE078C-1C (4)	1.808 ± 0.074abcde	5.293 ± 0.495abcd	**
RC029B-1C × RE078C-1C (4)	1.761 ± 0.015de	4.639 ± 0.912abcd	**
RC029B-1C × NA093B-1C (6)	1.864 ± 0.036abcde	5.040 ± 0.341abcd	**
NA014C-1D × RC039C-1C (3)	1.939 ± 0.102abcd	4.091 ± 0.434abcd	**
NA014C-1D × RC039C-1C (2)	1.966 ± 0.048abc	4.341 ± 0.214abcd	**
<b>NA015A-1B × RC039C-1C (5)</b>	1.786 ± 0.035cde	3.793 ± 0.403bcd	**
NA015A-1B × NA093B-1C (2)	1.952 ± 0.036abcd	4.189 ± 0.466abcd	**
RE049B-1A × NA093B-1C (1)	1.877 ± 0.132abcde	3.484 ± 0.207bcd	**
RE049B-1A × NA093B-1C (5)	1.899 ± 0.017abcde	3.815 ± 0.378bcd	**
RE049B-1A × RC039C-1C (8)	1.933 ± 0.057abcd	4.173 ± 0.587abcd	**
<b>RE049B-1A × RC039C-1C (9)</b>	1.839 ± 0.019abcde	2.952 ± 0.594 cd	ns
Min	1.729	2.476	
Max	1.987	6.712	
Mean	1.857	4.179	
Significance	**	**	

The italicized values are greater than or equal the mean value

The strains written in bold type exhibit in both the ageing periods values below average  
*ns* not significant

\*significant ( $p < 0.05$ ), \*\*high significant ( $p < 0.01$ )

were analysed after 12 and 24 months of ageing for the colour hue [22]. It always increased too exhibiting, compared to the values after 12 months, a mean value variation of 2.41%. *Tempranillo* wines made with grapes from two different vineyards of Rioja Alta (Spain) were analysed after 55 and 720 days of ageing for the colour hue [23]. It always increased too exhibiting, compared to the values after 55 days, a mean value variation of 8.95%.

The data presented in Table 4 show DPPH value of examined wines. After an ageing period of 4 months, the DPPH ranged ( $p < 0.01$ ) from a minimum value of 29.00% (strain

RC029) to a maximum value of 51.12% [strain RE049B-1A × NA093B-1C (5)]. Eleven strains (value highlighted in grey) exhibited a value  $\leq 41.71\%$  (the mean value). After an ageing period of 120 months, the DPPH ranged ( $p < 0.01$ ) from a minimum value of 9.66% (strain RC026C-1D) to a maximum value of 18.57% [strain RE049B-1A × RC039C-1C (8)]. Seventeen strains (value highlighted in grey) exhibited a value  $\leq 13.04\%$  (the mean value). The eight strains are written in bold type exhibited in both the ageing periods values above average because they better-protected wine from the lowering of the antioxidant activity. Considering

**Table 4** DPPH of the 29 wines after 4 months and 10 years

Ageing period (months)	4	120	Significance
Strains	DPPH (% of inactivation)		
<b>RC026</b>	48.61 ± 1.18ab	14.60 ± 1.06bcde	**
RC026C-1A	43.62 ± 10.68abcd	<i>12.37 ± 0.60defghi</i>	**
<b>RC026C-1B</b>	47.33 ± 0.80ab	13.83 ± 0.34cdef	**
RC026C-1C	47.70 ± 1.71ab	<i>10.09 ± 0.33hi</i>	**
RC026C-1D	48.45 ± 1.44ab	<i>9.66 ± 1.14i</i>	**
RC029	<i>29.00 ± 2.76d</i>	<i>11.82 ± 0.62efghi</i>	**
RC029A-1A	<i>30.81 ± 1.80 cd</i>	<i>12.02 ± 0.26efghi</i>	**
RC029A-1B	<i>29.25 ± 8.06d</i>	<i>12.25 ± 0.88defghi</i>	*
RC029A-1C	<i>40.30 ± 7.47abcd</i>	16.87 ± 0.04ab	**
RC029A-1D	<i>34.60 ± 9.88bcd</i>	13.36 ± 2.00cdefg	**
RC029B-1A	<i>40.61 ± 2.51abcd</i>	<i>12.70 ± 0.86defgh</i>	**
RC029B-1B	44.30 ± 2.62abc	<i>12.33 ± 0.41defghi</i>	**
RC029B-1C	42.92 ± 1.37abcd	<i>11.33 ± 0.42fghi</i>	**
RC029B-1D	43.51 ± 2.80abcd	<i>11.99 ± 0.86efghi</i>	**
RC039	44.63 ± 2.94abc	<i>11.72 ± 0.82efghi</i>	**
<b>RC026C-1C × RC039C-1C (4)</b>	44.80 ± 6.89abc	14.12 ± 0.90bcdef	**
<b>RC029A-1D × RC039C-1C (4)</b>	45.91 ± 0.50ab	13.91 ± 0.70cdef	**
RC029B-1C × RC039C-1C (7)	42.48 ± 2.54abcd	<i>10.62 ± 0.72ghi</i>	**
<b>RC029A-1D × RE078C-1C (4)</b>	41.78 ± 1.77abcd	16.03 ± 0.50abc	**
RC029B-1C × RE078C-1C (4)	<i>37.86 ± 5.58abcd</i>	<i>11.95 ± 0.66efghi</i>	**
<b>RC029B-1C × NA093B-1C (6)</b>	44.27 ± 2.03abc	15.05 ± 0.93bcd	**
NA014C-1D × RC039C-1C (3)	<i>36.99 ± 5.85abcd</i>	14.15 ± 0.98bcdef	**
NA014C-1D × RC039C-1C (2)	<i>36.92 ± 6.82abcd</i>	14.18 ± 0.89bcdef	**
<b>NA015A-1B × RC039C-1C (5)</b>	45.72 ± 4.37ab	15.12 ± 0.70bcd	**
NA015A-1B × NA093B-1C (2)	<i>40.42 ± 7.09abcd</i>	<i>12.07 ± 0.80efghi</i>	**
RE049B-1A × NA093B-1C (1)	<i>38.20 ± 1.09abcd</i>	<i>12.47 ± 0.41defghi</i>	**
RE049B-1A × NA093B-1C (5)	51.12 ± 0.24a	<i>12.27 ± 0.41defghi</i>	**
<b>RE049B-1A × RC039C-1C (8)</b>	42.01 ± 0.22abcd	18.57 ± 1.33a	**
RE049B-1A × RC039C-1C (9)	45.61 ± 1.14abc	<i>10.67 ± 2.19ghi</i>	**
Min	29.00	9.66	
Max	51.12	18.57	
Mean	41.71	13.04	
Significance	**	**	

The italicized values are less than or equal the mean value

The strains written in bold type exhibit in both the ageing periods values above average

*ns* not significant

\*significant ( $p < 0.05$ ), \*\*high significant ( $p < 0.01$ )

the variation of the DPPH value between 4 and 120 months, it always decreased after 10 years of ageing for 28 strains highly significantly ( $p < 0.01$ ) and for one strain significantly ( $p < 0.05$ ) from a minimum of -55.80% [strain RE049B-1A × RC039C-1C (8)] to a maximum of -80.06% (strain RC026C-1D) and a mean value of -68.11%.

This decrease in DPPH value with wine ageing has also been observed by other authors. Red wines produced from three red grapes varieties from the South-Slovakian wine-growing region from the village of Strekov were analysed after 3, 7, 11, 19, and 28 months of ageing for the DPPH

value [24]. It decreased too, excluding the *Cabernet Sauvignon* wine, exhibiting variations, compared to the values after 3 months, of: (a) - 1.79% after 7 months, - 3.45% after 11 months, - 8.41% after 19 months, and - 38.76% after 28 months for *Alibernet* variety; (b) - 0.49% after 7 months, 0.25% after 11 months, - 6.13% after 19 months, and - 6.26% after 28 months for *Cabernet Sauvignon* variety; (c) - 1.70% after 7 months, - 20.60% after 11 months, - 15.06% after 19 months, and - 22.87% after 28 months for *Torysa* variety.

Globally considering the analytical characteristics of the studied wines after the ageing period of 120 months, it is evident that there is a very high biodiversity among the tested yeast strains. Seven strains—RC026C-1A, RC026C-1D, RC029, RC029A-1A, RC029B-1C, RC029B-1D, RC029B-1C × RE078C-1C (4)—exhibit fermentation behaviour worse than average for all the tested parameters. Seven strains—RC026C-1B, RC026C-1C, RC029A-1C, RC029B-1C × RC039C-1C (7), RC029A-1D × RE078C-1C (4), RC029B-1C × NA093B-1C (6), NA015A-1B × NA093B-1C (2)—exhibit fermentation behaviour better than average for only one of the tested parameters. Four strains—RC039, RC026C-1C × RC039C-1C (4), RC029A-1D × RC039C-1C (4), NA014C-1D × RC039C-1C (2)—exhibit fermentation behaviour better than average for two of the tested parameters. Six strains—RC029A-1B, RC029B-1A, RC029B-1B, RE049B-1A × NA093B-1C (1), RE049B-1A × NA093B-1C (5), RE049B-1A × RC039C-1C (9)—exhibit fermentation behaviour better than average for three of the tested parameters. Five strains—RC026, RC029A-1D, NA014C-1D × RC039C-1C (3), NA015A-1B × RC039C-1C (5), RE049B-1A × RC039C-1C (8)—exhibit fermentation behaviour better than average for all the tested parameters.

## Conclusion

This research has shown that the evolution of wine ageing is affected in a very different way by the starter yeast used and has allowed choosing the best yeast strain useful to produce red wine able to endure very long-time ageing, until 10 years. Data clearly show that after 120 months of ageing wine variability linked to the starter biodiversity is notably increased.

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## Declarations

**Conflict of interest** The authors declare that they have no conflict of interest.

**Compliance with ethical requirements** This article does not contain any studies with human or animal subjects.

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