Research Note

Screening Non-Saccharomyces Yeasts as Low Ethanol Producing Starter Cultures

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Submitted for publication: October 2020
Accepted for publication: March 2021

Keywords: Ethanol, non-Saccharomyces, Wine, Aerobic, Anaerobic

INTRODUCTION

In winemaking, non-Saccharomyces yeasts are recognised as the indigenous microbial population found on the grape surface with about 10⁵ to 10⁶ CFU/g on ripe grapes (Fleet, 2003), 10³ to 10⁵ CFU/g on aseptically crushed ripe grapes (Ribèreau-Gayon & Peynaud, 1960) and 10⁴ to 10⁶ CFU/mL during fermentation (Jolly et al., 2014). The ascomycetous yeast species Hanseniaspora uvarum (anamorph Kloeckera apiculata) account for 10 to 100% relative abundance of the indigenous yeast population (Jolly et al., 2014; Bagheri et al., 2015; Shekhawat et al., 2018) with the remaining attributed to the yeast genera Hansenula/Pichia, Metschnikowia, Candida, Kluyveromyces, Schizosaccharomyces, Torulaspora and Zygosaccharomyces in varying abundance (Fleet et al., 1984; Viana et al., 2008; Manzanares et al., 2011; Jolly et al., 2014; Bagheri et al., 2015). Non-Saccharomyces yeasts are generally characterised by low fermentation vigour, low fermentation rate (Ciani & Maccarelli, 1998; Lappa et al., 2020) and low SO₂ resistance (Ciani et al., 2010).

During wine fermentation there is a sequential development of yeasts in both red and white musts, with Saccharomyces cerevisiae (S. cerevisiae) taking the lead role beyond the initial five days of fermentation (Fleet et al., 1984; Ciani et al., 2016). The dominance of the S. cerevisiae population is accompanied by the decline or death of the non-Saccharomyces population due to its sensitivity to certain metabolic compounds e.g. ethanol and killer toxins secreted by other yeasts during fermentation (Suzzi et al., 1995; Mehlomakulu et al., 2014; Vicente et al., 2020). Furthermore, the low levels of available oxygen and competition for nutrients during fermentation are growth limiting factors for non-Saccharomyces yeasts (Holm et al., 2001).

Since the dawn of the current millennium, non-Saccharomyces yeasts have gained popularity in winemaking (Jolly et al., 2014). These yeasts play an important role in the flavour and aroma development of wine when co- or sequentially inoculated with S. cerevisiae in mixed cultures (Fleet, 2003; Jolly et al., 2003; Ciani et al., 2010; Jolly et al., 2014; Varela et al., 2016). This has led to the commercial development of non-Saccharomyces starter cultures to enhance the aroma bouquet and flavour profile of wines (Ciani et al., 2010; Jolly et al., 2014; Vicente et al., 2020). These non-Saccharomyces yeasts include the genera Torulaspora, Metschnikowia and Lachancea (Ivit et al., 2016). The authors also thank the AWRI for yeasts AWRI 442 and 1159 received under a Material Transfer Agreement.

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Acknowledgements: This work was supported by the Agricultural Research Council, Winetech and the National Research Foundation (NRF), South Africa (grant numbers UID 71526 and 90103). Opinions expressed and conclusions arrived at are those of the authors and are not necessarily to be attributed to the NRF. The authors also thank the AWRI for yeasts AWRI 442 and 1159 received under a Material Transfer Agreement.
Low Ethanol Production by Non-Saccharomyces Yeasts

In the last decade, grapes are often harvested at high sugar concentration as a result of climate changes affecting the physiological development of grapes (Gonzalez et al., 2013). Thus, in winemaking; yeasts have had to adapt to stressful environments e. g. high sugar concentration through intricate regulation of stress tolerance, growth and metabolic genes (Tondini et al., 2020). Thus, the utilization of the respiratory (oxidative) metabolism of non-Saccharomyces yeasts to lower ethanol content in wine has received attention (Erten & Campbell, 2001; Gonzalez et al., 2013; Quiros et al., 2014; Contreras et al., 2015; Canonico et al., 2016; Ciani et al., 2016; Varela et al., 2015). In such experiments, aerobic fermentation is promoted over anaerobic fermentation; driving the carbon to other metabolites e. g. glycerol, organic acids or biomass instead of ethanol (Canonico et al., 2019). Apart from reducing ethanol concentration, the inoculation of non-Saccharomyces yeasts contributes to secondary aroma and flavour notes which give unique characteristics to the wine (Ivit et al., 2020). This is attributed to the Ehrlich pathway (catabolism of aromatic amino acids) and yeast secreted enzymes which aid in the catabolism of primary aroma and flavour compounds (Belda et al., 2017, Gamero et al., 2016). Known aroma compounds include alcohols, ethyl esters of fatty acids, acetate esters of higher alcohols, terpenes, sulphur compounds e. g. thiols, hydrogen sulphide, dimethyl sulphide and methanethiol. However, the production of aroma compounds is dependent on yeast species and strains (Belda et al., 2017).

Therefore, the aim of the study was to screen a selection of non-Saccharomyces yeasts for their fermentative capability under aerobic and anaerobic conditions to investigate their potential as low ethanol-producing starter cultures.

MATERIALS AND METHODS

Yeast species and culture conditions

Twenty-four yeast strains from the ARC Infruitec-Nietvoorbij gene bank and culture collection (Table 1) were aseptically streaked out on YPD (yeast peptone dextrose) agar (Biolab, Merck, South Africa) and incubated at 30°C for 3 days. A single colony from each plate was aseptically inoculated into 5 mL YPD broth (Biolab, Merck, South Africa) and incubated at 28°C with gentle agitation for 14-16 h. Each of the yeast strains was used as a pre-culture for the experiments described below.

Yeast species verification

The identities of the species were verified by a PCR method. DNA isolation was carried out by inoculating single yeast colonies in 5 mL of YM broth (10 g/L glucose, 3 g/L yeast extract, 3 g/L malt extract, 5 g/L peptone) and allowed to grow aerobically for 24-48 h at 30°C. Subsequently, these cultures were subjected to a lithium acetate (LiOAc)-SDS lysis DNA extraction method (Løkke et al., 2011). The primers NL1 (5’-GCA TAT CAAT AAG CCG GAG AAAAAAG-3’) and NL4 (5’-GGT CCG GTT GTC AGG CCAGG-3’) were used to amplify the D1/D2 region of the 26S rDNA gene (O’Donnel, 1993). The reactions were performed in 0.2 mL tubes with a final volume of 50 µL. Amplification was performed in a 3Prime thermal cycler (Techne, Bibby Scientific, Lasec, South Africa) with the following reagent concentrations: 2.5 mM dNTPs, 25 mM MgCl₂, 0.2 mM (each) primers NL1 and NL4 (IDT, Whitehead Scientific, South Africa), 0.2 µL Super-Therm Gold Taq polymerase (5U/µL) (Separations Scientific, South Africa). The following cycling conditions were applied for the amplification: 94°C, 2 min; 30 cycles of 94°C, 1 min; 51°C, 30 s and 72°C, 4 min. A final extension step of 72°C for 5 min and a final holding temperature of 7°C, 10 min was added. Samples were electrophoresed on 1.5% agarose gels and stained with ethidium bromide (EtBr) after electrophoresis. Images were visualised with a Gel Doc XR system (BioRad, South Africa). Amplification products were sent to the Central Analytical Facility (CAF) at Stellenbosch University (South Africa) for post-amplification clean-up and sequencing. Sequences were edited using FinchTV (version 1.4.0). Edited sequences Fast Adaptive Shrinkage Threshold Algorithm (FASTA format) were used to verify yeast species identity through the National Centre for Biotechnology Information (NCBI) database (https://www.ncbi.nlm.nih.gov) using the Basic Local Alignment Search Tool nucleotide (BLASTn) search function.

Killer activity screening

All the yeast strains (Table 1) were screened for killer activity on white grape juice medium prepared with commercial 100% white table grape juice (preservative-free) and 4% bacteriological agar as described in Mehlomakulu et al. (2014). The 22 non-Saccharomyces strains were screened against S. cerevisiae VIN13, as was S. cerevisiae VIN13 against the 22 non-Saccharomyces strains. Briefly, 5 µL of an exponential phase growing culture of either a S. cerevisiae or non-Saccharomyces yeast strain were spotted on a plate seeded with 10⁶ CFU/mL of a non-Saccharomyces or a S. cerevisiae culture. All plates were incubated at ambient temperature (20 - 22°C), and killer activity was observed as a zone of clearance around the spotted yeast colony. All experiments were done in biological triplicates.

Fermentative capability

The non-Saccharomyces strains were tested as axenic cultures for their fermentative capability in previously frozen Chenin blanc grape must. Chenin Blanc grapes obtained from the Nietvoorbij Research Farm (Stellenbosch, South Africa) were destemmed, crushed and pressed at 1 Bar in a small bladder press. A sedimentation enzyme (0.005 g/L Rapidase® Clear, Anchor Oenology, South Africa) with the following reagent concentrations: 2.5 mM dNTPs, 25 mM MgCl₂, 0.2 mM (each) primers NL1 and NL4 (IDT, Whitehead Scientific, South Africa), 0.2 µL Super-Therm Gold Taq polymerase (5U/µL) (Separations Scientific, South Africa). The following cycling conditions were applied for the amplification: 94°C, 2 min; 30 cycles of 94°C, 1 min; 51°C, 30 s and 72°C, 4 min. A final extension step of 72°C for 5 min and a final holding temperature of 7°C, 10 min was added. Samples were electrophoresed on 1.5% agarose gels and stained with ethidium bromide (EtBr) after electrophoresis. Images were visualised with a Gel Doc XR system (BioRad, South Africa). Amplification products were sent to the Central Analytical Facility (CAF) at Stellenbosch University (South Africa) for post-amplification clean-up and sequencing. Sequences were edited using FinchTV (version 1.4.0). Edited sequences Fast Adaptive Shrinkage Threshold Algorithm (FASTA format) were used to verify yeast species identity through the National Centre for Biotechnology Information (NCBI) database (https://www.ncbi.nlm.nih.gov) using the Basic Local Alignment Search Tool nucleotide (BLASTn) search function.

DOI: https://doi.org/10.21548/42-1-4335
TABLE 1
Yeast species used in the study.

<table>
<thead>
<tr>
<th>This study reference</th>
<th>Yeast species</th>
<th>Accession number(^1)</th>
<th>Source/Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><em>Saccharomyces cerevisiae</em></td>
<td>Y0568</td>
<td>VIN 13, Anchor yeast (commercial hybrid wine yeast; <a href="http://www.anchor.co.za">www.anchor.co.za</a>)</td>
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<td>2</td>
<td><em>Saccharomyces cerevisiae</em></td>
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<td>Unknown</td>
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<td>Juice, Germany (CBS(^2) 820)</td>
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<td>Juice, Italy (CBS 2624)</td>
</tr>
<tr>
<td>5</td>
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<td>Unknown (CBS 2625)</td>
</tr>
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<td>Y0244</td>
<td>Unknown (CSIR(^3) Y8)</td>
</tr>
<tr>
<td>8</td>
<td><em>Starmerella bacillaris</em> (<em>Candida zemplinina</em>)</td>
<td>Y1021</td>
<td>Wine, Hungary (Type strain; CBS 9494)</td>
</tr>
<tr>
<td>9</td>
<td><em>Starmerella bacillaris</em> (<em>Candida zemplinina</em>)</td>
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<td>Grape must, South Africa</td>
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<tr>
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<td>Grape must, South Africa</td>
</tr>
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<td>C40V20</td>
<td>Grape must, South Africa</td>
</tr>
<tr>
<td>14</td>
<td><em>Metschnikowia pulcherrima</em></td>
<td>Y0839</td>
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</tr>
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<td>CU-HUT(^4) 7087</td>
</tr>
<tr>
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<td>CU-IAM 12217</td>
</tr>
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<td>Unknown (CBS 1997)</td>
</tr>
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<td>Y1077</td>
<td>Unknown (CBS 7939)</td>
</tr>
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<td><em>Lipomyces starkeyi</em></td>
<td>Y1076</td>
<td>Soil, South Africa (CBS 7537)</td>
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<td>Italy (Type strain, CBS 567)</td>
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<td>22</td>
<td><em>Cyberlindnera saturnus</em></td>
<td>Y1080</td>
<td>CU-NCYC 22</td>
</tr>
<tr>
<td>23</td>
<td><em>Schizosaccharomyces pombe</em> (<em>Schizosaccharomyces malidevorans</em>)</td>
<td>C41V13</td>
<td>Australia (AWRI(^5) 442)</td>
</tr>
<tr>
<td>24</td>
<td><em>Candida zemplinina</em> (<em>C. stellata</em>)</td>
<td>C41V14</td>
<td>Australia (AWRI 1159)</td>
</tr>
</tbody>
</table>

Gene bank or culture collection accession number, Agricultural Research Council – Infruitec-Nietvoorbij, Stellenbosch, South Africa.  
\(^1\) CBS-KNAW Collections, Westerdijk Fungal Biodiversity Institute, Utrecht, Netherlands.  
\(^2\) Council for Science and Industrial Research, Pretoria, South Africa.  
\(^3\) Cukurova University, Adana, Turkey.  
\(^4\) Australian Wine Research Institute, Glen Osmond, Australia.

Above into 50 mL YPD broth and incubated for 48 h at 28°C under static conditions. Each flask and bottle of grape must was inoculated individually with 2.5% (\(v/v\)) of the respective inoculum. The aerobic fermentations were closed with cotton wool plugs to facilitate air movement into the flask and agitated at 140 rpm, while the anaerobic fermentations were fitted with fermentation air trap caps and not agitated. All the fermentations were incubated at ambient temperature (20-22°C) and weighed daily for 14 days for cumulative CO\(_2\) loss. Sugar consumption and alcohol production were measured using a Density meter DM 35 (Anton Paar GmbH, Austria) and Alcolyzer Wine M analysis system (Anton Paar GmbH, Austria), respectively. Sugar consumption by the yeasts for the production of 1% ethanol was calculated from the initial sugar present in the must, the residual sugar in the wine and the final ethanol value using the formula below.

\[
\text{Sugar consumed} = \frac{[\text{Sugar concentration in must at day 0} - \text{Residual sugar concentration}] \times 1}{\text{Ethanol at end of fermentation}}
\]

Sugar consumed (\(\%\)) were selected for a second series of fermentations to evaluate the aroma of fermenting musts and wines. These selected yeast strains were prepared as axenic.
cultures and fermented aerobically for five days. On the fifth day of fermentation, samples were taken for aroma evaluation. *Saccharomyces cerevisiae* strain 1 was then sequentially inoculated into the fermenting must. The inoculum of *S. cerevisiae* strain 1 was prepared and the flasks were further incubated under anaerobic conditions. The evolution of CO₂ loss for the sequential fermentations was monitored until no mass loss was recorded for three consecutive days and this was regarded as the end of fermentation.

**Sensory evaluation of fermentations**

Descriptive aroma evaluation of the partially fermented wine (five days) and finished wine (end of fermentation) was carried out using a panel of eight judges (male and female), with between 2 to 20 years of wine tasting experience with no collective training. The judges were asked to score the wine aroma on a scale of 1 (unacceptable) to 5 (acceptable), and to select the descriptors (“Fruity”, “Overripe fruit”, “Floral”, “Acidic”, “Cooked vegetables”, “Fresh vegetables”, “Spicy”, “Rotten egg”, “Solvent”, “Oxidized”, “Rotten”) that matched the aroma perceived, or to provide any other descriptors perceived. The descriptors were selected based on terminology generally used in wine tasting for positive and negative traits (Nobel et al., 1987). The partially fermented and finished wines (ca. 50 mL) were served in ISO tasting glasses at an ambient temperature of 20-22°C. Wines were coded and randomised before presentation to the judges. The scores were converted to percentages for graphical representation as the total sum a descriptor was noted by a judge per wine divided by the total number of judges; then converted to a % by multiplication with 100. Descriptor noted by a judge per wine was recorded as a count of one.

**Statistical analyses**

Data (randomised and continuous) were subjected to analysis of variance (ANOVA) using General Linear Models Procedure (PROC GLM) of SAS software (Version 9.4; SAS Institute Inc, Cary, USA). Shapiro-Wilk test was performed on the standardized residuals from the model to verify normality after outliers were removed (Shapiro and Wilk, 1965). Fisher’s least significant difference was calculated at the 5% level to compare treatment means (Ott and Longnecker, 2010). A probability level of 5% was considered significant for all significance tests.

**RESULTS AND DISCUSSION**

The yeast species used in this study (Table 1), by no means exhaustive, include a broader range of yeast than those normally investigated for wine production (Jolly et al., 2014) and contain some yeasts that have received less attention than the commercial non-*Saccharomyces* wine yeasts such as *Tordaspora delbrueckii*, *Metschnikowia pulcherrima* and *Lachancea thermotolerans*. Furthermore, these yeasts have been isolated from diverse areas and substrates.

The identity of these yeasts, as listed in Table 1, was verified by sequencing the D1/D2 region amplification products (data not shown) (O’Donnell, 1993). These yeast species and strains used in the study have been reported in lower alcohol production and/or wine fermentations (Erten & Campbell, 2001; Quiros et al., 2014; Varela, personal communication, 2014; Contreras et al., 2015; Englezos et al., 2016).

**Killer activity screening**

*S. cerevisiae* strains 1 and 2 (a laboratory reference strain) and the 22 non-*Saccharomyces* yeast strains and species were screened for killer activity against each other in white grape juice medium. None of the non-*Saccharomyces* yeast strains exhibited killer activity against the commercial wine yeast *S. cerevisiae* strain 1, except for *C. saturnus* strain 17. *S. cerevisiae* strain 1 was antagonistic towards *Cyberlindnera jadinii* strain 21, clearly exhibiting its killer positive trait as reported by the yeast producer. The genetic origin of the killer toxin secreted by strain 1 is not disclosed by the producer as either K1, K2, K28 or Klus. *S. cerevisiae* strains with the Klus genetic origin are antagonistic towards *S. cerevisiae* and non-*Saccharomyces* yeasts, as reported by Rodriguez-Cousiño et al. (2011). However, *S. cerevisiae* strain 1, as a commercial yeast, is routinely used in winemaking with no reported adverse effects on fermentation. Non-*Saccharomyces* yeasts are reported to secrete proteinaceous antimicrobial compounds, termed killer toxins, against other yeast species within the same environment (Philliskirk & Young, 1975; Heard & Fleet, 1987; Palpacelli et al., 1991; van Vuuren & Jacobs, 1992; Lowes et al., 2000; Melhomakulu et al., 2014).

*C. jadinii* is referred to by its anamorph (*Candida utilis*) in literature and is used in the production of single-cell protein (Lee & Kim, 2001; Ibrahim et al., 2004). However, in view of the results from this study, mixed culture fermentations of *S. cerevisiae* strain 1 with *C. jadinii* strain 21 would need careful consideration.

**Fermentative capability**

When all the non-*Saccharomyces* yeasts were tested for their fermentative capability as axenic cultures under aerobic and anaerobic conditions, the strains were found to variably ferment grape must. Under aerobic conditions (Fig. 1), the *Lipomyces tetrasporus* strain 19 and *L. starkeyi* strain 20 had the highest residual sugar, i.e. 192.57 and 196.00 g/L, respectively, at the end of the 14-day fermentation. This was followed by *Cyberlindnera jadinii* strain 21 and *Wickerhamomyces anomalous* strain 11 with a residual sugar of 89.00 and 95.23 g/L at the same period, respectively although the latter had fermented 50% of the sugar by day four (data not shown) (Fig. 1). After 14 days of fermentation, yeasts had completed the fermentation (residual sugar <2 g/L). These were *S. cerevisiae* strain 1, *Candida zemplinina* strain 24, *Saccharomyces ludwigii* strain 6, and *C. zemplinina* strains 8 and 9. In contrast, the *S. ludwigii* strains 3, 4, 5 and 7, *S. cerevisiae* strain 2, *Candida stellata* strain 15, *Wickerhamomyces subpelliculosus* strain 18 and *Schizosacharomyces pombe* strain 23 had <10 g/L but >2 g/L residual sugar at day 14 (Fig. 1).

Under anaerobic conditions, all the non-*Saccharomyces* yeast strains performed poorly. All had high residual sugars, i.e. >105.5 g/L at day four, while *S. cerevisiae* strain 1 was the exception with 78.47 g/L of residual sugar (data not shown). At day 14, *S. cerevisiae* strains 1 and 2 had a residual
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DOI: https://doi.org/10.21548/42-1-4335

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FIGURE 1
Residual sugar (g/L) and ethanol concentration (% v/v) on day 14 of aerobic fermentation for Chenin blanc wines produced with different yeast strains (see Table 1). Values are averages of three replicates and the error bars indicate the standard error. Bars within the graph with the same letters do not differ significantly (p ≤ 0.5) for residual sugar (indicated in bold) and ethanol (indicated in italics), respectively.

Sugar of 6.63 g/L and 33.83 g/L, respectively. The residual sugar concentration of *S. ludwigi* strains 3, 4, 5 and 7, and *S. pombe* strain 23 fermentations was between 69.07 g/L and 107.93 g/L. The rest of the non-Saccharomyces fermentations showed residual sugar concentration >110 g/L (Fig. 2).

Liu et al. (2013) reported that the non-Saccharomyces yeasts – *C. stellata* (*C. zemplinina*), *K. apiculata* (*H. uvarum*) and *C. pulcherrima* (*M. pulcherrima*) were slow fermenters. The aforementioned authors found that the wines had residual sugar between 24.8 g/L and 158.9 g/L, similar to what was found in this study under aerobic and anaerobic conditions (Figs. 1 and 2, respectively). However, in this study the non-Saccharomyces yeasts; *C. zemplinina* and *S. ludwigi* displayed a fermentative metabolism in aerobic conditions, which was comparable to that of *S. cerevisiae*. Jolly et al. (2006) grouped non-Saccharomyces yeasts found in grape must and during fermentation into mainly oxidative yeasts; apiculate yeasts with low fermentative activity and yeasts with fermentative metabolism. In this study, *S. ludwigi*, *S. pombe*, *C. zemplinina* and *W. subpelliculosus* exhibited oxidative behaviour while *L. tetrasporus* and *L. starkeyi* can be characterised as non-fermenting yeasts.

During winemaking, sugar consumption is correlated with ethanol production. At day 14, the highest ethanol concentration between 10.0% and 10.5% for the aerobic fermentations were detected for *S. cerevisiae* strain 2, *C. stellata* strain 15 and *S. pombe* strain 23, while the lowest ethanol concentration of <5% was detected for *H. uvarum* strain 10, *W. anomalous* strains 11 and 19, and *Lipomyces starkeyi* strain 20. An ethanol concentration between 5.8% and 9.9% was detected for the rest of the yeast species studied (Fig. 1). Anaerobic fermentation resulted in 11.9% and 10.4% ethanol at day 14 for the *S. cerevisiae* strains 1 and 2, respectively (Fig. 2). Ethanol production of between 5.2% and 8.2% was detected for the *S. ludwigi* strains 3, 4, 5, 6 and 7, and *S. pombe* strain 23.

Sugar consumption from the axenic fermentations for the production of 1% ethanol was calculated from the initial sugar present in the must and the residual sugar in the wine. In the axenic fermentations, at the end of fermentation under both aerobic and anaerobic conditions, it was found that the non-Saccharomyces yeasts consumed sugar similarly to the *S. cerevisiae* strains, except for *L. tetrasporus* strain 19, *L. starkeyi* strain 20 and *C. jadinii* strain 21 (anaerobic only) (Figs. 3.1 and 3.2). The *S. cerevisiae* strains consumed approximately 22 g/L to 17 g/L to produce 1% ethanol under aerobic and anaerobic conditions, respectively. The non-fermenting yeasts *L. tetrasporus* strain 19 and *L. starkeyi* strain 20 consumed >30 g/L under both aerobic and anaerobic conditions with *C. jadinii* strain 21 consuming 46.6 g/L of sugar under the anaerobic conditions only. *H. uvarum* strain 10, *W. anomalous* strain 13, *M. pulcherrima* strain 14 and *C. zemplinina* strain 15 consumed <19.7 g/L, compared to the *S. cerevisiae* strains 1 and 2 under aerobic conditions (Fig. 3.1), whereas *S. ludwigi* strain 5 consumed 18.6 g/L of sugar, which is similar to that of *S. cerevisiae* strains 1 and 2 under anaerobic conditions (Fig. 3.2).

*S. cerevisiae* is Crabtree positive, therefore can ferment sugars under respiro-fermentative conditions (Garcia et al., 2016), as was found in this study. *S. ludwigi* is characterised as being a fermentative species (Ciani & Picciotti, 1995; Ciani & Maccarelli, 1998), yielding 12.63% ethanol on
ควบคุมการผลิตแอลコฮอล์จากไม่ใช่ชนิด Saccharomyces โบกิ้ง

**FIGURE 2**
Residual sugar (g/L) and ethanol concentration (% v/v) on day 14 of anaerobic fermentation for Chenin blanc wines produced with different yeast strains (see Table 1). Values are averages of three replicates and the error bars indicate the standard error. Bars within the graph with the same letters do not differ significantly (p ≤ 0.5) for residual sugar (indicated in bold) and ethanol (indicated in italics), respectively.

**FIGURE 3.1**
Sugar consumed to produce 1% (v/v) ethanol under aerobic conditions at the end of fermentation (day 14) for Chenin blanc wines produced with different yeast strains (see Table 1). Values are averages of three replicates and the error bars indicate the standard error. Bars within the graph with the same letters do not differ significantly (p ≤ 0.5).
average and between 0.2 and 1.4 g CO₂/day over a period of three days. This metabolic activity is reported to be similar to that of *S. cerevisiae* (Ciani & Maccarelli, 1998). Similar findings were found in this study where the *S. ludwigii* strains 3, 4, 5 and 7 competed with *S. cerevisiae* strain 1 in sugar consumption and ethanol production.

Although grape must fermentation through the glycolysis pathway yields ethanol as the main by-product, sugar consumption by non-*Saccharomyces* yeasts is characterised by the production of other metabolites in order to maintain redox balance (Goold *et al*., 2017). In this study, sugar consumption similar to that of *S. cerevisiae* by some of the non-*Saccharomyces* yeasts was observed. This was linked to a lower ethanol yield, which can be regarded as a positive attribute in the quest to identify low ethanol yeast starter cultures. The lower ethanol yield is attributed to the low internal redox balance, as some of the carbon flux is directed to the formation of other primary and secondary metabolites. 

**Sensory profiles**

A basic aroma profiling of the fermenting must and wine using the non-*Saccharomyces* yeast strains was carried out. The purpose was to screen for yeasts producing off-odours, and thereby eliminating them as potential candidate organisms in further studies.

More than 56% of the judges found the fermenting wine at day four prepared from axenic cultures of the strains acceptable, except for the must inoculated with strain 13 (*W. anomalus*). The highest score, i.e. 88% for acceptability and tropical fruit aroma was given to for strain 17 (*C. saturnus*). The fermenting wines were also described as having a spicy aroma by 38% of the judges. Strain 13 (*W. anomalus*), was found by 43%, 29% and 43% of the judges to have fruity, overripe and floral notes, respectively (Fig. 4.1).

In sequentially inoculated wines (Fig. 4.2), a fruity aroma was detected by 65% of the judges for the strains 1 (*S. cerevisiae*), 3 (*S. ludwigii*), 4 (*S. ludwigii*), 12 (*W. anomalus*) and 22 (*C. saturnus*). Strain 17 (*C. saturnus*), was found by 43%, 29% and 43% of the judges to have fruity, overripe and floral notes, respectively (Fig. 4.2). Volatile acidity was identified in strain 13 (*W. anomalus*) by 29% of the judges, with none of the judges identifying this aroma attribute in strains 3 (*S. ludwigii*), 4 (*S. ludwigii*), and 17 (*C. saturnus*). Wines prepared with strains 13
(W. anomalus) and 24 (S. bacillaris) were identified by 100% of judges to have a solvent odour, while 78% of judges identified this sensory attribute in wine prepared with strain 22 (C. saturnus). All wines had some degree of oxidation as indicated by 43% of the judges (Fig. 4.2), however, this may have been an outcome of the small fermentation volumes used.

Valente et al. (2018) reported that the aroma sensory attributes: acid/acidity, tropical, fruit, ripe fruit and spice were mentioned more than 50 times for Chenin blanc wines (n=39) from 2008 - 2014 by the John Platter Wine Guide to South African wines. Indeed, in this current study the same aroma attributes were mentioned by the judges, albeit this study was over a shorter period. Valente et al. (2018) further highlighted that residual sugar affected the sensory attributes of Chenin blanc wines. Unwooded dry wines (residual sugar <5 g/L) and semi-dry (residual sugar >5g/L but <12g/L) wines had 56% and 13%, respectively, association with juicy, guava, floral, acid, peach, pineapple and tropical aroma sensory attributes according to the judges. In this study, anaerobically fermented musts prepared only with S. cerevisiae strain 1 exhibited residual sugar of 6.63 g/L, i.e. semi-dry according to Valente et al. (2018). This semi-dry wine exhibited the same aroma attributes observed by Valente et al. (2018) (Fig. 4.2). Under aerobic conditions, strains 1 (S. cerevisiae), 12 (W. anomalus), 17 (C. saturnus) and 22 (C. saturnus) exhibited tropical aroma (Fig. 4.1). Only the wine prepared with strain 1 reached dryness under aerobic conditions (Fig. 1). When strain 1 (S. cerevisiae) was used in sequential fermentations with the non-Saccharomyces yeasts, the finished wines exhibited aromas such as fruity, floral and overripe fruit (Fig. 4.2). These wines were fermented to dryness over 21 days (data not shown).

Currently, non-Saccharomyces yeasts such as T. delbrueckii (BiodivaTD291™, Prelude™, Zymaflore® Alpha), L. thermotolerans (Viniflora®Concerto™), M. pulcherrima (Flavia™ Mps346), Pichia khyveri (Frootzen®) and S. pombe (ProMalic®) are commercially available. These yeasts are reported to reduce acetic acid, degrade malic acid, improve wine aroma and enhance glycerol content (Ciani et al., 2010) through their metabolism and interactions during co- or sequential inoculation with S. cerevisiae or other yeasts (Ciani & Comitini, 2015). The interactions found in this study warrant further investigation into whether these yeasts can be used as low ethanol starter cultures.

CONCLUSIONS

This study investigated the production of ethanol by non-Saccharomyces yeasts under aerobic and anaerobic conditions. Although the wines did not ferment to dryness, fermentation under aerobic conditions yielded higher ethanol than that found under anaerobic conditions. This study

![FIGURE 4.1](image-url)

Aroma profile of fermenting wine produced with axenic cultures of S. cerevisiae (strain 1) and non-Saccharomyces (strains 3, 12, 13, 17, 22 and 24) under aerobic conditions (day 4 of fermentation).
revealed that the fermentative non-\textit{Saccharomyces} yeasts produce less ethanol (1% to 2%) under aerobic and anaerobic conditions in comparison to \textit{S. cerevisiae}. The optimal yeast under aerobic conditions was strain 13 (\textit{W. anomalus}) with regards to ethanol yield. The aroma profiles of the fermenting and finished wines was similar to that reported for Chenin blanc wines produced using \textit{S. cerevisiae} cultures. Some of the yeasts e.g. strains 3, 12 and 17 used in this study could potentially be co- or sequentially inoculated with \textit{S. cerevisiae} to lower the ethanol content of wine and have a positive impact on the aroma and flavour of the wine. However, subsequent studies need to be conducted on the volatile and non-volatile compounds, as well as a full flavour evaluation of the musts and wines in order to elucidate the use of these non-\textit{Saccharomyces} yeasts as starter cultures and whether the yeasts would have an effect on wine style.

\textbf{LITERATURE CITED}


