The Australian Wine Research Institute

AWRI COMMERCIAL SERVICES
SO MUCH MORE THAN A GREAT LAB

AWRI Report

VINOLOK Closure Evaluation

Closure Performance Benchmarking

60-month Report

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1. Introduction

The Australian Wine Research Institute (AWRI) was engaged to carry out a closure benchmarking trial for a newly developed Vinolok low-top closure. A series of physical, chemical and sensory tests have been applied to wines sealed with the new (18.5mm) closure, and performance compared with the older (18.2mm) design Vinolok closure, as well as screw-cap (Saran/tin) and natural cork (Ref. 2) closures at regular intervals over a period of 60 months. This report includes an updated summary of all the analysis carried out on the wines up to and including 60 months post-bottling.

2. Materials and Methods

Bottling and initial chemical tests were carried out during April 2014. 60-month analysis was conducted in April 2019. Table 1 provides a summary of the testing schedule:

Table 1: Testing Schedule Summary

Analytical Test	***At Bottling***	***3-Month***	***9-Month***	***12-Month***	***18-Month***	***24-Month***	***36-Month***	***60-Month***
Basic Chemical Attributes	×		×	×		×	×	×
Free and Total SO_2	×	×	×	×	×	×	×	×
Total Packaged Oxygen (TPO)	×	×						
Wine Colour	×	×	×	×	×	×	×	×
Oxygen Transmission Rate (OTR)				×		×		×
Low Molecular Weight Sulfides (LMWS)	×		×	×		×	×	×
Sensory Analysis (aroma & palate)				×		×	×	×

2.1 Wine Storage

For the first 36-months of the trial, all bottled wine samples have been stored at the Hickinbotham-Roseworthy Wine Science Laboratory cellar, adjacent to the AWRI. The storage conditions are in darkness at a temperature of approximately 17°C and 55 % relative humidity. Post-completion of the 36-month timepoint, samples have been stored offsite at Wineworks Australia (Lonsdale, South Australia) at a temperature of between 15 and 20°C. Samples were freighted from Wineworks Australia for subsampling on the 20th of March 2019.

2.2 Closure Benchmarking

2.2.1 Chemical Analyses

All chemical analyses were performed by AWRI Commercial Services' NATA accredited (ISO 17025 certified) wine laboratory. All chemical analyses were performed by trained staff in accordance with NATA accredited quality assurance measures including standards, blanks, duplicates and control samples. The quality control measures were required to meet established criteria before acceptance of the analytical data. The uncertainty of measurement (UOM) inherent in the analytical data is shown in brackets below.

WineScan was used to measure the following basic chemical attributes of three replicate samples:

- % Alcohol (± 0.1% v/v)
- pH (± 0.05)
- Titratable acidity (± 0.1 g/L)
- Volatile acidity (± 0.04 g/L)
- Glucose/Fructose (± 0.3 g/L)
- Specific Gravity (± 0.0002)

Free and total sulfur dioxide (SO_2) was measured on three replicate samples using Thermo Fisher Discrete Analyser (Gallery; UOM ± 4 mg/L).

White and red wine colour measurement was performed on three replicate samples utilising absorbance measurements at 280, 320 and 420nm on a Varian UV/Visible spectrophotometer. This method utilises standardised wine pH and alcohol concentration to enable the determination of the following parameters:

- Hue (± 5%)
- Wine colour density (± 5% a.u.)
- Chemical Age 1 (± 5%)
- Chemical Age 2 (± 5%)
- Free anthocyanins (± 10% mg/L)
- Pigmented Tannin (± 5% a.u.)
- Total phenolics (± 10% a.u.)
- Total pigment (± 10% a.u.)

LMWS compound analysis was conducted on three replicate samples using static headspace sampling combined with an Agilent gas chromatograph fitted with a sulfur chemi-luminescence detector (GC-SCD). Compounds analysed include:

- Hydrogen sulfide
- Methanethiol
- Ethanethiol
- Dimethyl sulfide
- Carbon disulfide
- Diethyl sulfide
- Methyl thioacetate
- Dimethyl disulfide
- Ethyl thioacetate
- Diethyl disulfide

Closure OTR testing was performed using the AWRI's proprietary 'wet-OTR' method to ascertain OTR values non-destructively. This method utilises a customised non-reactive housing fitted with a PreSens Pst3 oxygen sensor. This is used to encase the area surrounding the closure, therefore creating a sealed reservoir of air external to the closure. The oxygen concentration within the housing is continually monitored at constant temperature (17°C). Measurements are used to calculate the rate of oxygen transmission through the samples. Three replicates of each closure were trialled for a period of 6 weeks, stored upright and in darkness at 17°C.

2.2.2 Sensory Evaluation

A panel of twelve assessors (ten females, two males) with an average age of 52 years (SD = 7.8) was convened to evaluate the white wines and a panel of ten assessors (one male, nine females) with an average age of 54 years (SD = 7.4) was convened to evaluate the red wines. All panellists were members of the external AWRI trained descriptive analysis panel and have extensive experience in wine sensory descriptive analysis.

The white wine set was assessed prior to the red wines and the same procedure was followed for both studies.

Assessors attended one training session to determine whether the attribute list previously used to evaluate the wines after 36 months in bottle still contained appropriate descriptors for rating in the formal sessions. During this session, the assessors evaluated all the wines from the study. Wines were assessed by appearance, aroma and palate. Aroma standards from previous timepoints were presented, discussed and recipes adjusted as needed. These standards were also available during the booth practice session and the formal assessment sessions.

Following the training session, tasters participated in a practice session in the sensory booths under the same conditions as those for the formal sessions. After the practice session, any terms which needed adjustment were discussed and the final list of terms determined. For the white wine formal sessions, this list was refined to include one appearance term, eleven aroma terms (ten defined and "Other") and eleven palate terms (ten defined and "Other"). For the red wine formal sessions, there was one appearance term, twelve aroma terms (eleven defined and one "Other"), and fourteen palate terms (thirteen defined and one "Other"). These attributes, definitions/synonyms and standards provided are shown in Table 2 and Table 3and 1b, which contain only the attributes included in the final attribute list.

Samples were presented to panellists in 30 mL aliquots in 3-digit-coded, covered, ISO standard wine glasses at 22–24 °C, in isolated booths under daytime lighting, with randomised presentation order, except in the practice sessions where there was a constant presentation order. All samples were expectorated. In practice booth sessions the assessors were presented with two trays of four wines per tray. In formal booth sessions of two hours' duration the assessors were presented with four trays of four wines per tray. The assessors were forced to have a 30-second rest between samples and a ten-minute rest between trays. During the ten-minute break assessors were requested to leave the booths. Formal evaluations were completed in one session for white and one session for red wine.

The four closure treatments were presented to assessors four times, in a modified Williams Latin Square incomplete random block design. A different bottle was used for each of the four presentation replicates to assess the possible variation within each closure type.

The intensity of each attribute was rated using an unstructured 15 cm line scale from 0 to 10, with indented anchor points of 'low' and 'high' placed at 10% and 90% respectively. Data was acquired using Compusense Cloud sensory evaluation software (Compusense Inc., Guelph, Canada).

Panel performance was assessed using Compusense software and with the SensomineR (sensominer.free.fr/) and FactomineR (factominer.free.fr/) packages. The performance assessment included analysis of variance for the effect of judge, wine and presentation replicate and their interactions, degree of agreement with the panel mean, degree of discrimination across samples and the residual standard deviation of each judge by attribute. The judges were found to be performing to an acceptable standard.

Analysis of variance (ANOVA) was carried out using Minitab 18 (Minitab Inc., Sydney, NSW). The effects of closure type, judge, closure replicate and their two-way interactions were assessed, treating judge as a random effect. Following ANOVA, Fisher's least significant difference (LSD) value was calculated (P=0.05).

Table 2: Attributes, definitions and reference standards evaluated by panellists in formal sessions for the white wine samples.

Attribute	Definition/Synonyms
Appearance	
Yellow Colour Intensity	Intensity of the colour yellow in the sample
Aroma	
Tropical fruit	Intensity of the aroma of tropical fruits; pineapple, melon and mango.
Passionfruit/Box Hedge	Intensity of the aroma of passionfruit and box hedge.
Stone fruit	Intensity of the aroma of stone fruits: peach, apricot, nectarine both fresh and dried.
Citrus	Intensity of the aroma of citrus fruits: lemon and lime.
Floral	Intensity of the aroma of flowers: white and orange blossoms.
Vegetal	Intensity of the aroma of various cooked vegetables such as asparagus and green beans, and vegetable water.
Drain	Intensity of the aroma of dirty drains (reductive aromas)
Flint	Intensity of the aroma of flint, wet stones and metals.
Sweaty/Cheesy	Intensity of the aroma of sweat and cheese.
Pungent	Intensity of the aroma and sensation of alcohol.
Palate	
Tropical fruit	Intensity of the flavour of tropical fruits: pineapple, melon and mango.
Stone fruit	Intensity of the flavour of stone fruits: peach, apricot and nectarine.
Citrus	Intensity of the flavour of citrus fruits: lemon and lime.
Sweet	Intensity of the taste of sucrose.
Viscosity	The perception of the body, weight or thickness of the wine in the mouth. Low=watery, thin mouth feel. High=oily, thick mouth feel.
Acid	Intensity of acid taste in the mouth including aftertaste.
Hotness	The intensity of alcohol hotness perceived in the mouth, after expectoration and the associated burning sensation. Low = warm; High = hot.
Astringency	The drying and mouth-puckering sensation in the mouth. Low=coating teeth; Medium=mouth coating & drying; High=puckering, lasting astringency.
Bitter	The intensity of bitter taste perceived in the mouth, or after expectoration.
Fruit AT	The lingering fruit flavour perceived in the mouth after expectorating.

All standards were added to 30 mL of 2017 Yalumba premium selection bag-in-box Unwooded Chardonnay (2L) unless otherwise noted

Table 3: Attributes, definitions and reference standards evaluated by panelists in formal sessions for the red wine samples.

Attribute	Definition/Synonyms
Appearance	
Opacity	The degree to which light is not allowed to pass through a sample (colour intensity)
Aroma	
Red fruits	Intensity of the aroma of red fruits and berries: raspberries, strawberries, cranberries and red
Dark fruits	Intensity of the aroma of dark fruits and berries: blackberries, plums, cherries, black currants and
Dried fruit	Intensity of the aroma of dried prunes, raisins, figs and jam.
Port/Bruised Apple	Intensity of the aroma of port wine and bruised apples.
Herbal	Intensity of the aroma of mint and eucalyptus
Spice	Intensity of the aromas of various sweet spices: cinnamon, cloves, mixed spice, cardamom and
Vanilla/Chocolate	Intensity of the aroma of vanilla and chocolate
Earthy	Intensity of the aroma of wet earth, organic matter, mushrooms, mud and dust
Woody	Intensity of the aroma of wood and pencil shavings
Drain	Intensity of the aroma of dirty drains
Pungent	Intensity of the aroma and effect of alcohol
Palate	
Red Fruit	Intensity of the flavour of red fruits and berries: raspberries, strawberries, cranberries and red confectionary
Dark Fruit	Intensity of the flavour of various dark fruits: blackberries, currants, plums, cherries and Ribena
Dried Fruit	Intensity of the flavour of dried prunes, raisins, figs and jam
Port/Bruised Apple	Intensity of the flavour of port wine and bruised apples
Stalky	Intensity of the flavour of green stalks and green beans
Earthy	Intensity of the flavour of wet earth, organic matter, mushrooms, mud and dust
Woody	Intensity of the flavour of wood and pencil shavings
Viscosity	The perception of the body, weight or thickness of the wine in the mouth. Low=watery, thin mouth feel. High=oily, thick mouth feel.
Acid	Intensity of acid taste in the mouth including aftertaste
Hotness	The intensity of alcohol hotness perceived in the mouth, after expectoration and the associated burning sensation. Low = warm; High = hot, burning.
Astringency	The drying and mouth-puckering sensation in the mouth. Low=coating teeth; Medium=mouth coating & drying; High=puckering, lasting astringency.
Bitter	The intensity of bitter taste perceived in the mouth, or after expectoration.
Fruit AT	The lingering fruit flavour perceived in the mouth after expectorating.

All standards were added to 30 mL of 2017 Yalumba premium selection bag-in-box Shiraz (2L) unless otherwise noted.

3. Results

The results are presented as follows:

- Basic chemical attributes
- Free and total SO_2 levels
- Wine colour
- Low molecular weight sulfides (LMWS)
- Oxygen Transmission Rate (OTR)
- Sensory analysis

3.1 Chemical analysis

3.1.1 Basic chemical attributes

Results are available in Appendix 1. For the basic chemical attributes there were no significant differences due to closure type, for either wine.

3.1.2 Free and Total SO_2 Levels

Free and total SO_2 trends for the white wine over 60 months' bottle ageing are presented below in Figure 1 to Figure 4, respectively. Complete data is provided in Appendix 2.

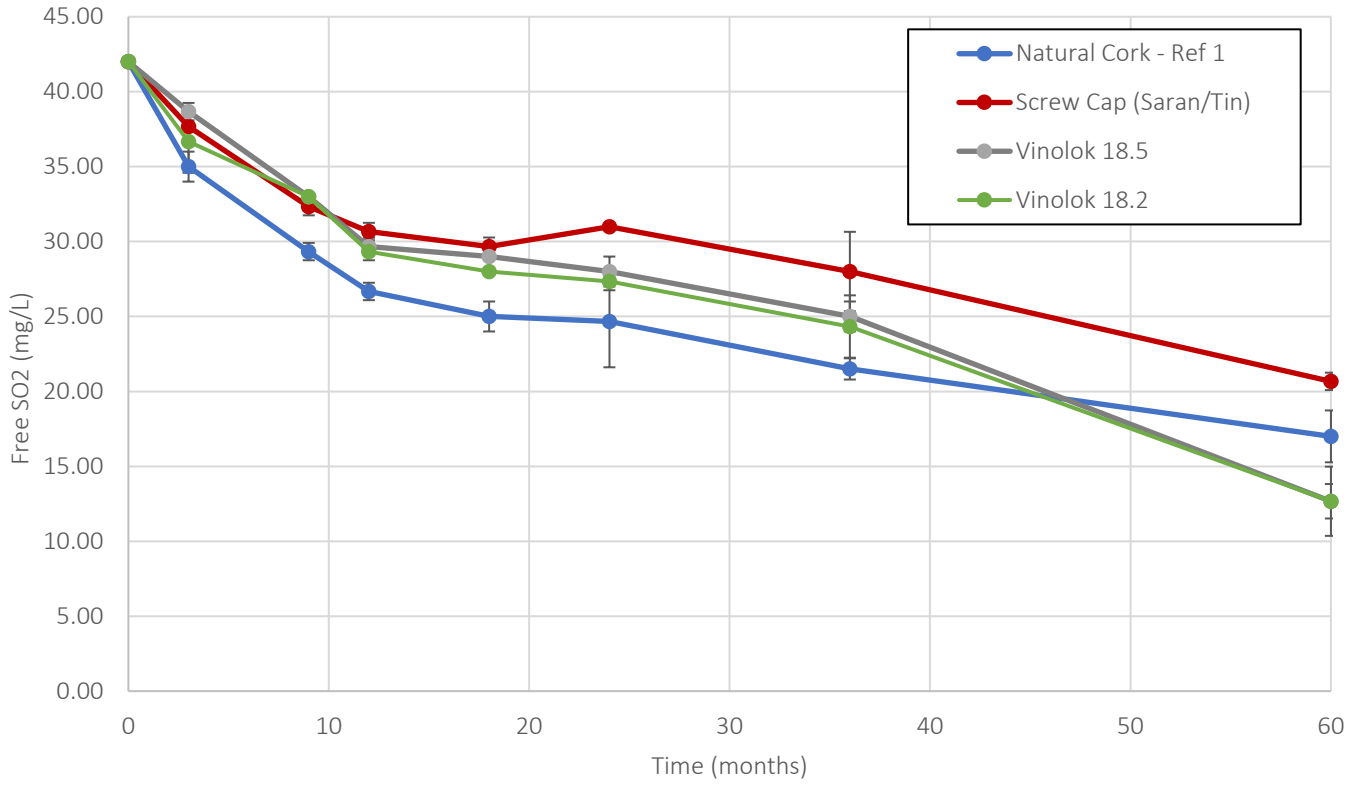


Figure 1: White wine free SO_2 trend over 60 months' post bottling. Error bars indicate standard deviation across replicates.

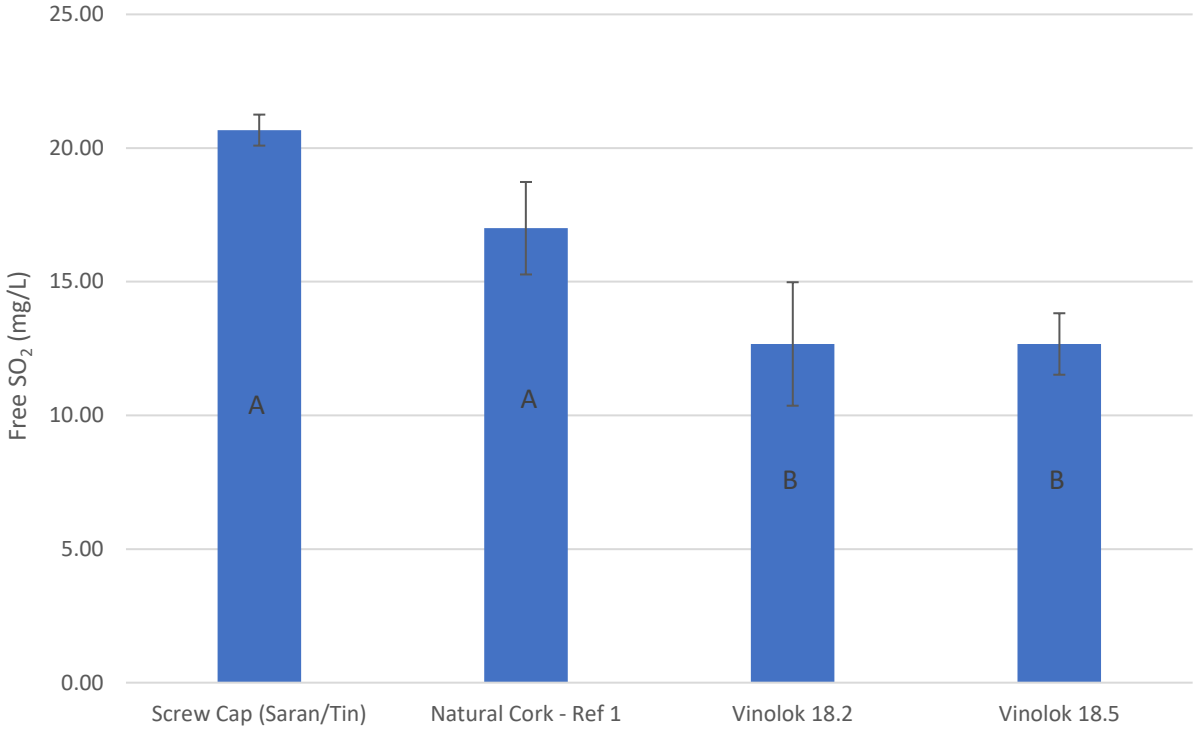


Figure 2: Free SO2 results at 60 months shown in descending order for the white wine. Error bars indicate standard deviation across replicates. Lettering denotes significant difference between closure variants (i.e. A vs. B: significantly different / AB: neither

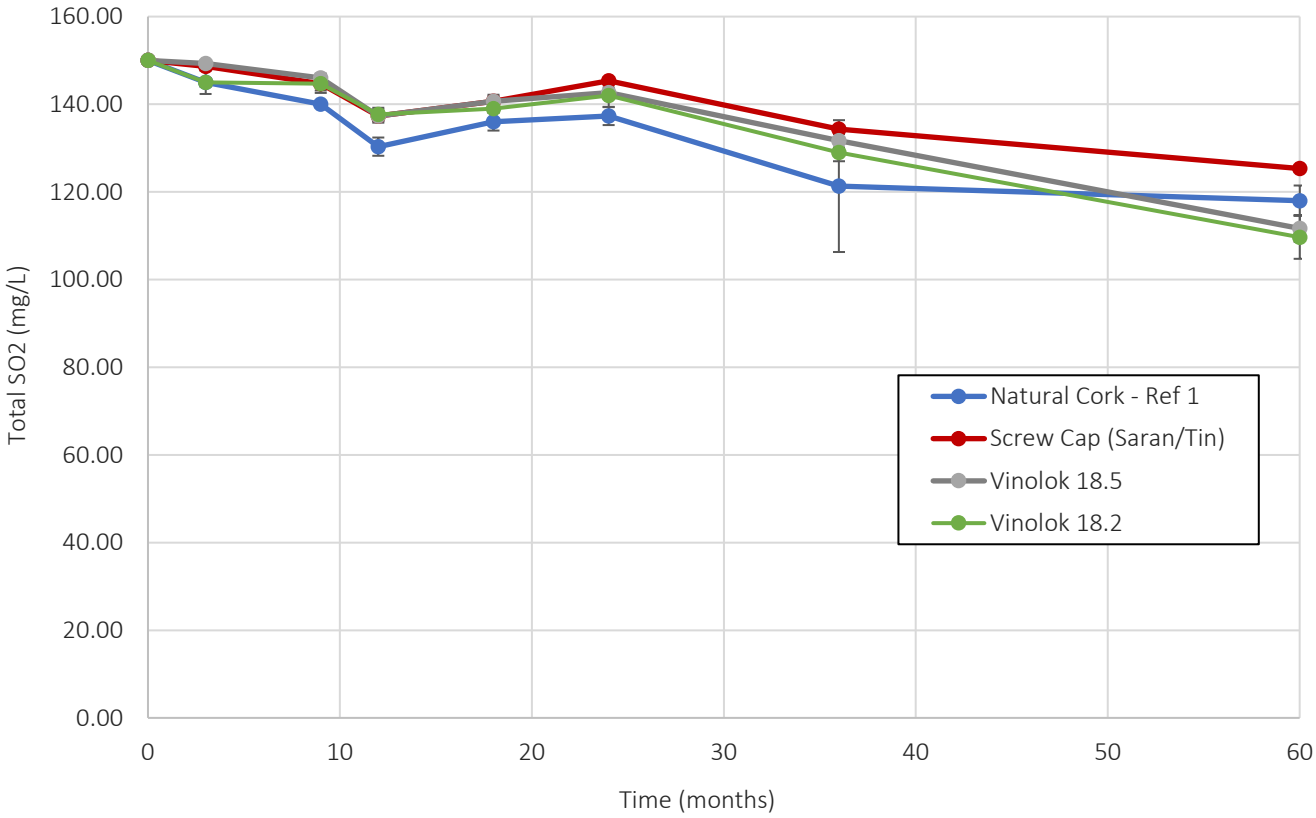


Figure 3: White wine total SO_2 trend over 60 months since bottling. Error bars indicate standard deviation across replicates.

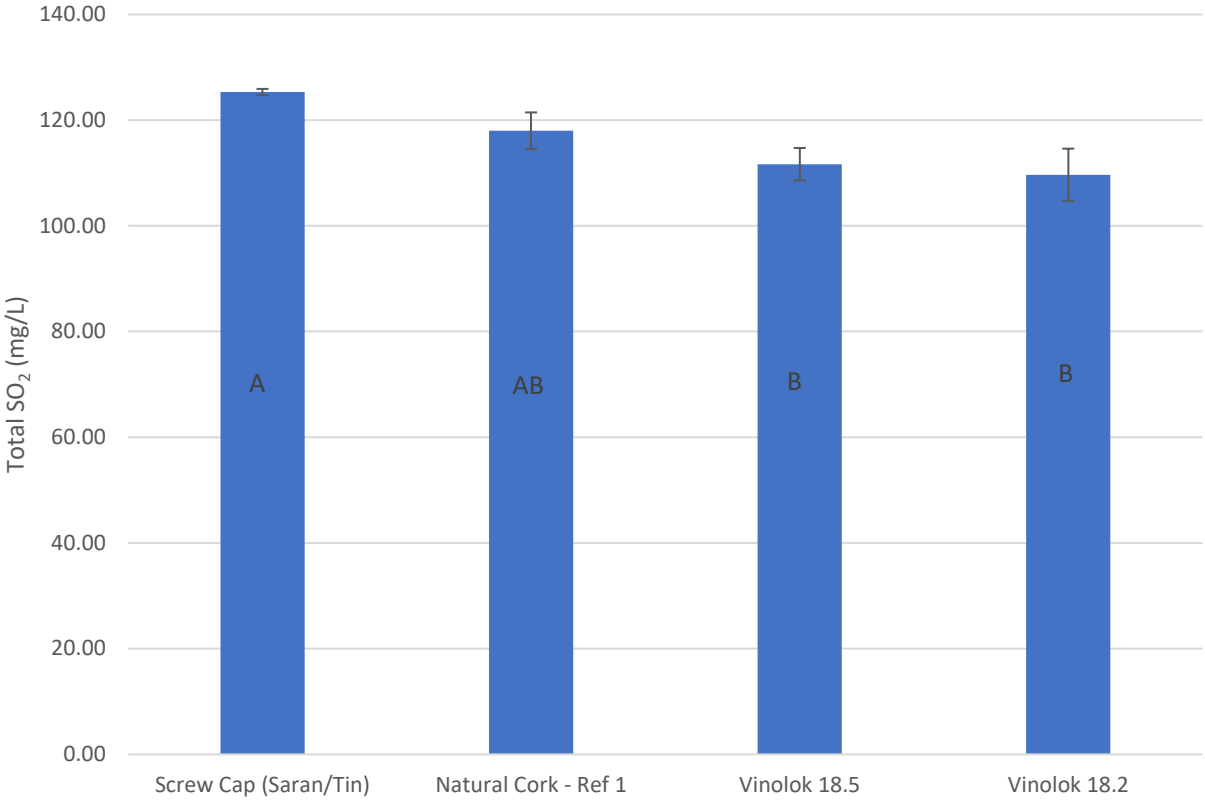


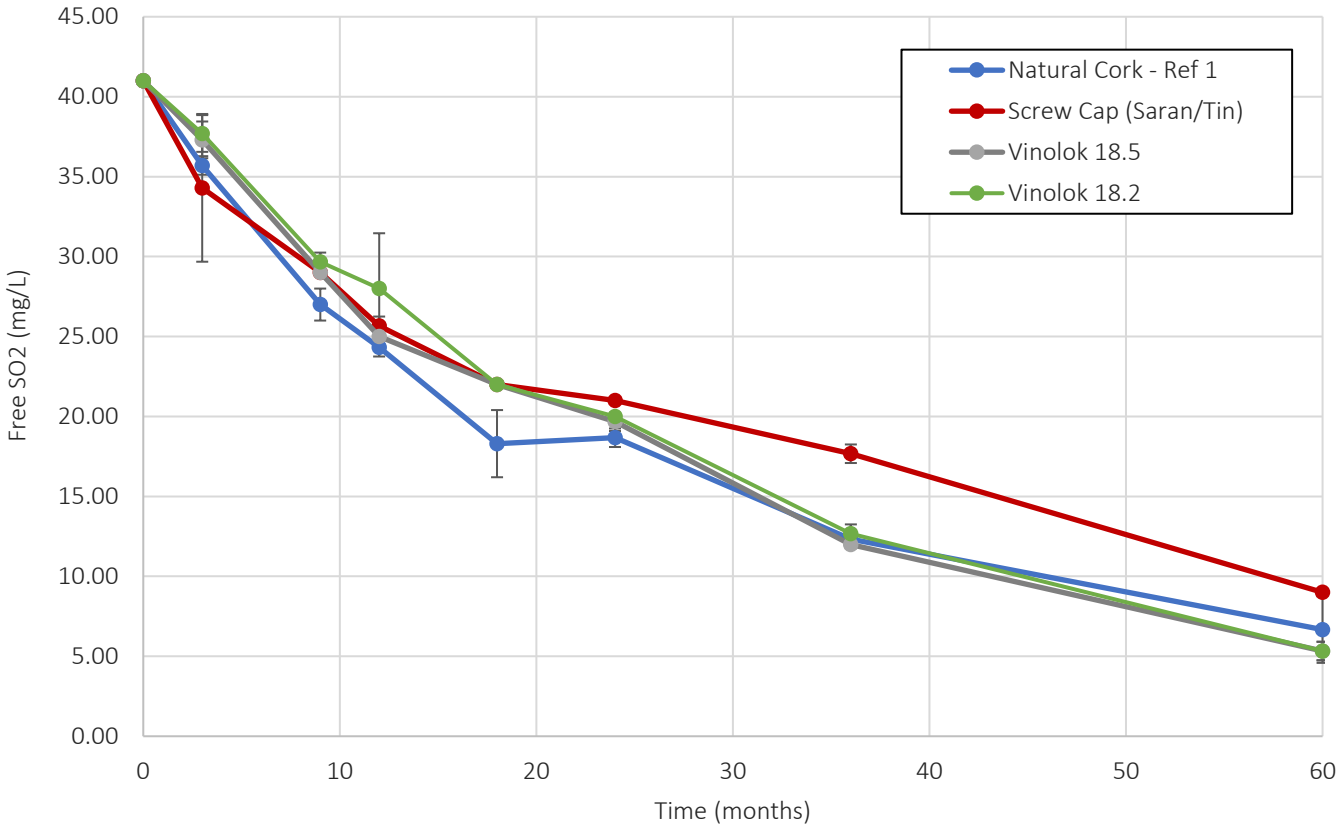
Figure 4: Total SO_2 results at 60 months bottling shown in descending order, for the white wine. Error bars indicate standard deviation across replicates. Lettering denotes significant difference between closure variants (i.e. A vs. B: significantly different / AB: neither significantly different to closures denoted with A or with B etc.)

As discussed at the 36-month timepoint, the variability seen for the cork samples was influenced by one replicate with free SO2 of 8 mg/L. This data was removed as an outlier considered to not truly reflect the results of the other two replicates analysed at the 36-month timepoint and this outlier has been excluded for future analysis as observed within the current graphics (Figure 1).

The trends observed with the white wine SO_2 data at the 60-month timepoint remain consistent with those observed over the duration of the trial for all closures with the exception of the natural cork product. The screw cap and two Vinolok samples have shown a modest, yet steady decline in free and total SO_2 values for the white wine since the 36-month time point (~7 – 10mg/L); however, the rate of the decline in free SO_2 of the natural cork samples is modest in comparison to the other closures (4-5mg/L).

Significant differences between closures at 60 months do exist, with white wine under the saran/tin closure significantly higher free and total SO_2. No significant differences are evident between the two Vinolok closures for free and total SO_2 in the white wine.

Free and total SO_2 trends for the red wine over the initial 60 months of the trial are presented below in Figure 5 and Figure 6, respectively. Complete data for the selected closure set is provided in Appendix 2.



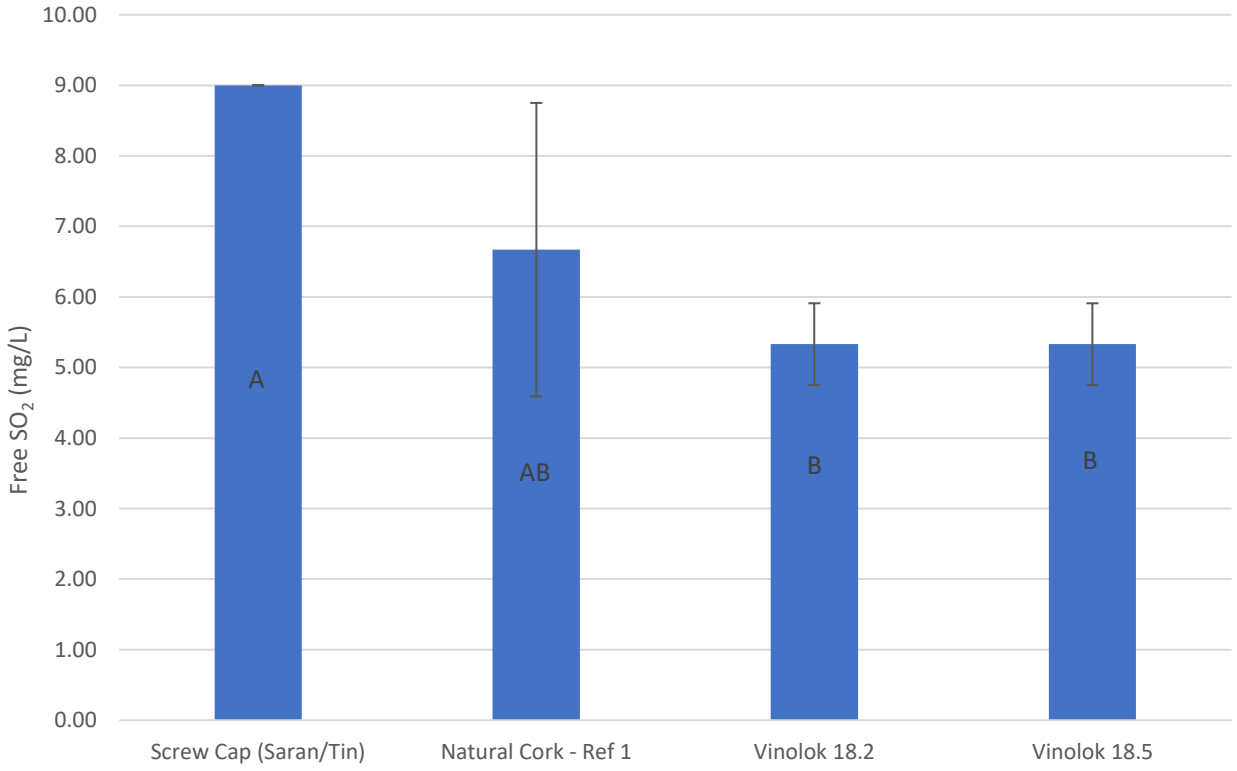


Figure 5a: Red wine free SO_2 trend over 60 months since bottling & 5b (bottom) – Free SO_2 results at 60 months bottling shown in descending order. Error bars indicate standard deviation across replicates. Lettering denotes significant difference between closure variants (i.e. A vs. B: significantly different / AB: neither significantly different to closures denoted with A or with B etc.)

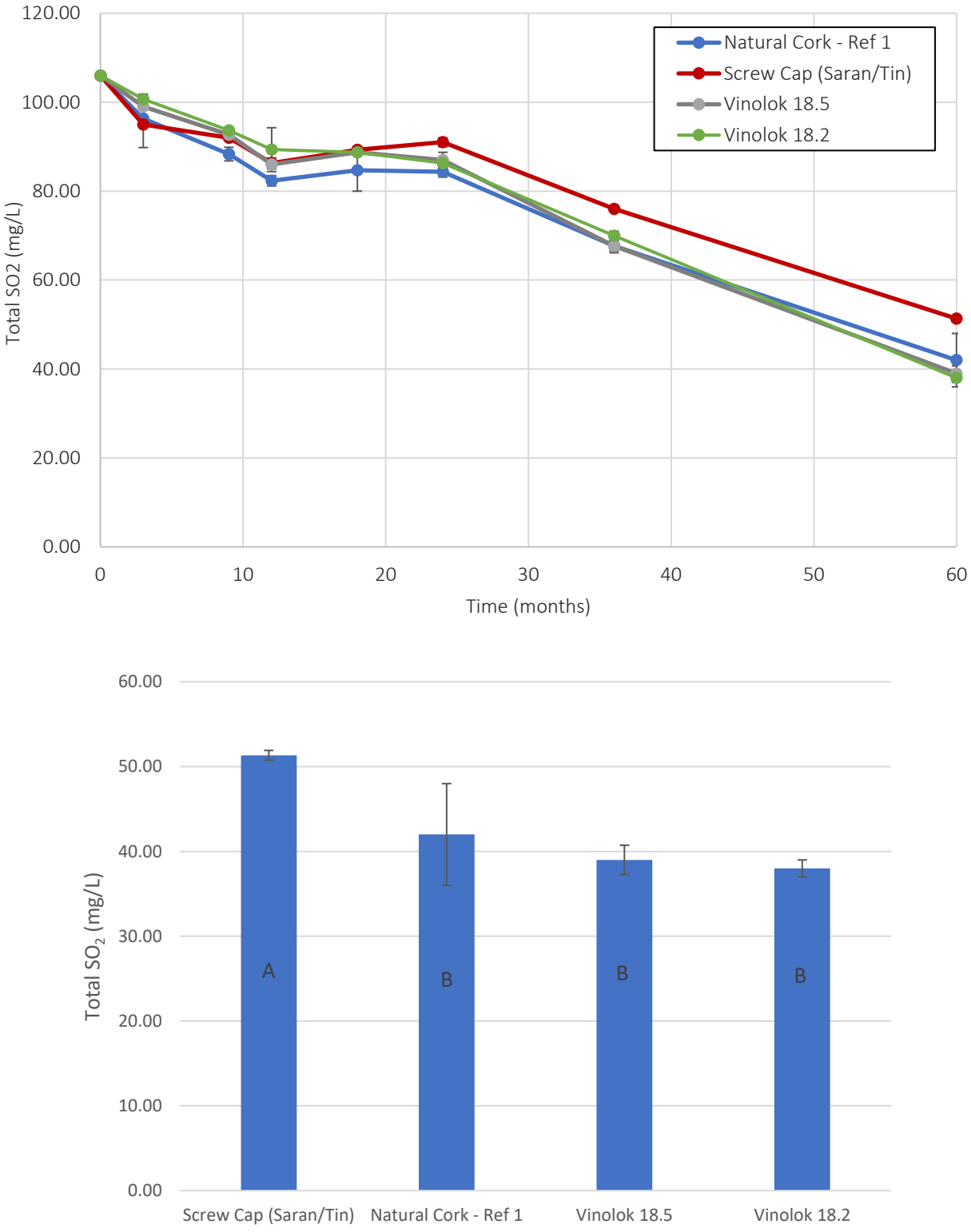


Figure 6a: Red wine total SO_2 trend over 60 months since bottling & 6b (bottom) – Total SO_2 results at 60 months bottling shown in descending order. Error bars indicate standard deviation across replicates. Lettering denotes significant difference between closure variants (i.e. A vs. B: significantly different / AB: neither significantly different to closures denoted with A or with B etc.)

For the red wine samples, SO_2 concentrations under the screw cap are significantly higher than under both Vinolok closures. No significant differences are present in the red wine between the two Vinolok closures and the natural cork. There exists a greater level of variability in results for the natural cork samples which suggests a greater variability in the oxygen ingress of the closure impacting upon SO_2 concentrations.

The free SO_2 levels for the red wine sealed by all closures has fallen under 10mg/L which is regarded as an indication that the wine is nearing the end of its shelf-life.

3.1.3 Wine Colour

The differences in the red wine colour parameters at 60-months' post bottling remain relatively small, as seen throughout the trial. Separation, albeit small, exists between the screw cap and the Vinolok closures. The wine under the screw cap is significantly different to both Vinolok closures for free anthocyanins and pigmented tannin, whilst only significantly different to the Vinolok 18.2 closure for total pigment and colour density.

Figure 7a and Figure 7b detail free anthocyanins and pigmented tannin levels under the different closures. Appendix 3 provides a summary of all red wine colour data up to and including the 60-month analysis point.

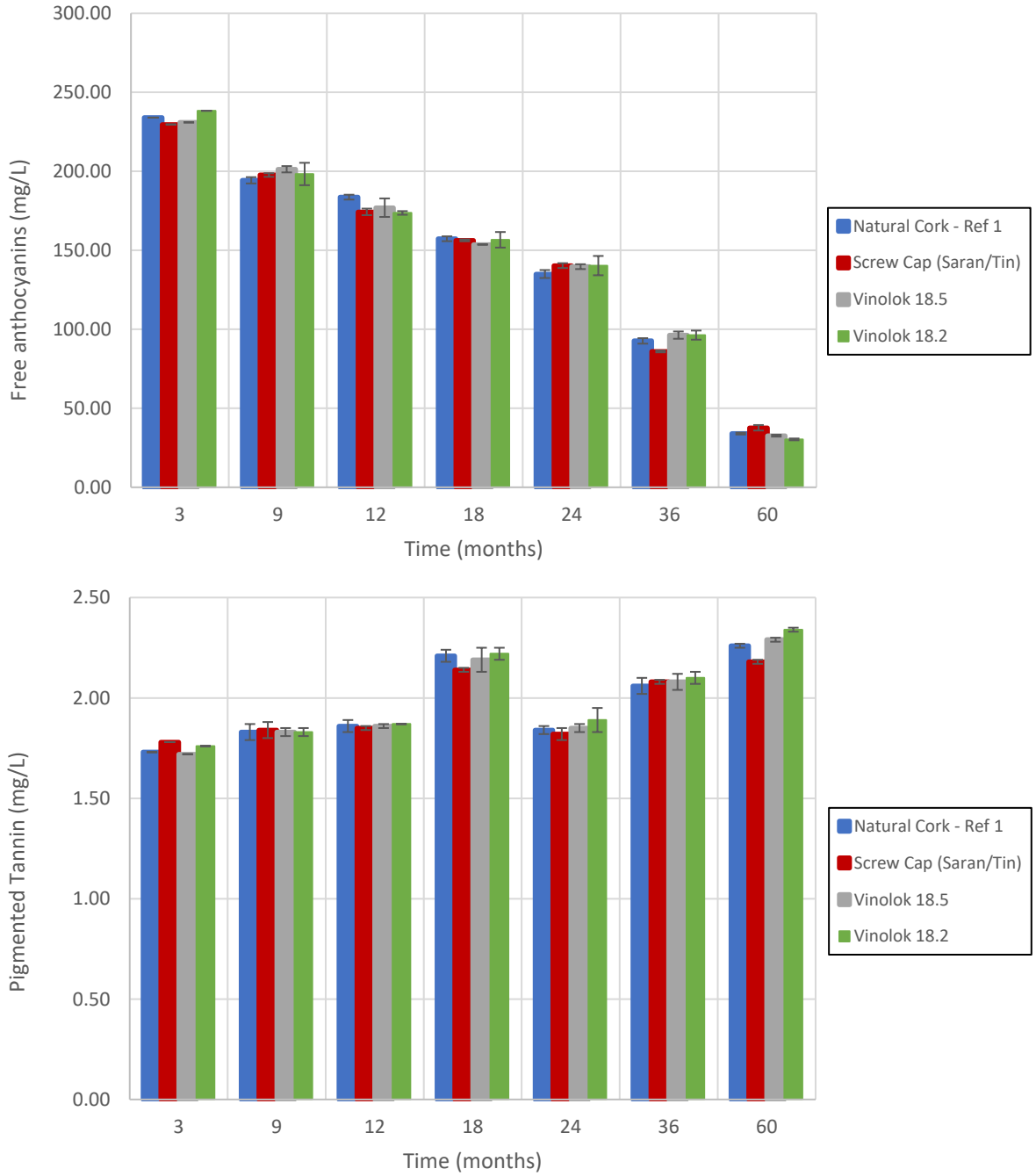


Figure 7a: Red wine colour (Free Anthocyanin) trend over 60 months since bottling, & Figure 7b: Red wine colour (Pigmented Tannin) trend over 60 months since bottling

Differences in optical density measurements at 420nm (browning indicator) and 520nm has led to colour density under the screw cap closure being significantly lower than all other closures; this is in line with expectations, given the relatively low OTR determined for the screw-cap.

There are very few differences in colour attributes for the white wine, due to closure impact, at the 60-month time point. However, small yet apparent differences and separation under different closures continue to exist for optical density measured at 420nm (browning) as seen at the 36-month time point. Significant differences exist between the wine under saran/tin and all other closures, with the other wines showing a greater degree of browning than under the screw cap. The optical density 420nm results are presented in Figure 8 below. Appendix 4 provides a summary of all white wine colour data up to and including the 36-month analysis point. For the optical density measures at 280nm (flavonoids) and 320nm (hydroxycinnimates), there exists small, albeit significant differences between closures, with natural cork sealed wine showing significantly higher absorbances at these wavelengths, compared to all other closures. There are no significant differences between the two Vinolok closures for either parameter.

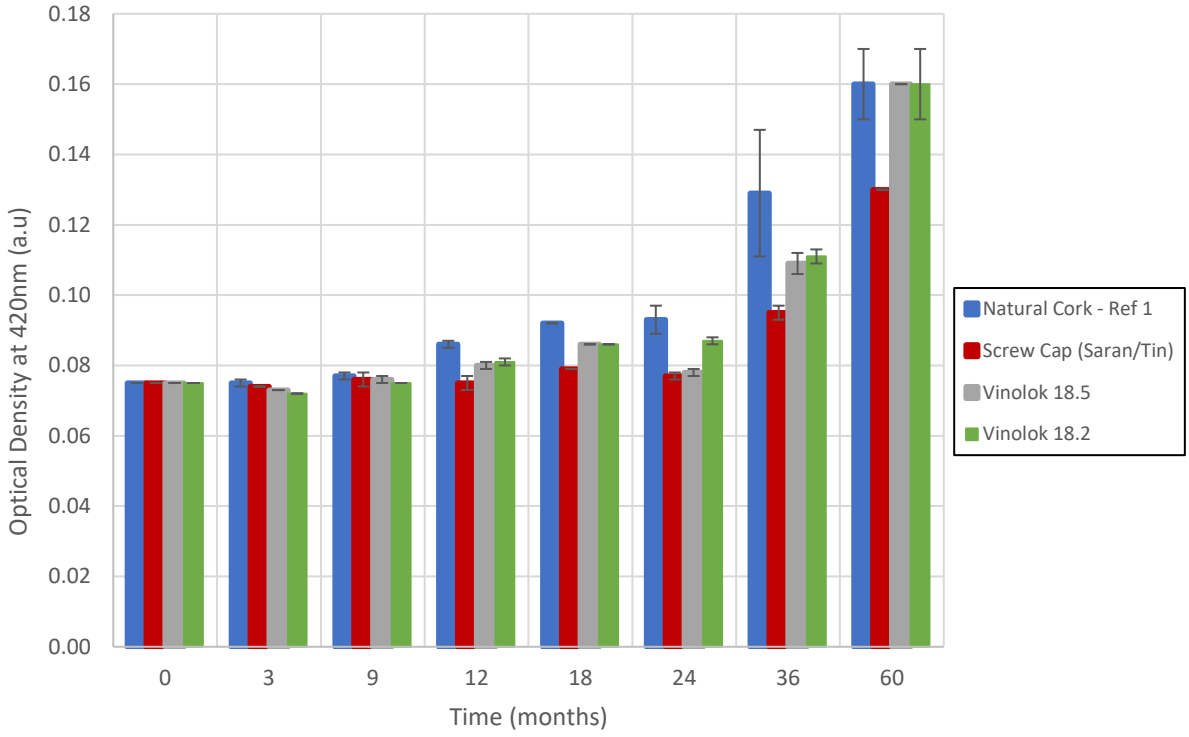


Figure 8: OD420 trend over 60 months since bottling in white wine

3.1.4 Low Molecular Weight Sulfides (LMWS)

Several LMWS compounds were detected within the wine samples, including dimethyl sulfide (DMS), carbon disulfide (CS_2), hydrogen sulfide (H_2S) and methanethiol (MeSH) Both white and red wines contained DMS present at levels greater than the sensory perception threshold under all closures, whereas the red wine contained H_2S concentrations bordering on or just above the upper limit of the threshold levels for all samples.

At the 60-month time point, significant differences were observed for three of the detected LMWS compounds in the red wine; CS_2, DMS and MeSH. The levels present under all closures for CS_2 were well below the sensory perception threshold (38µg/L). MeSH and DMS concentrations increased significantly (> 100%) under all closures since the 36month time point, with concentrations for DMS well above the sensory perception threshold, while MeSH concentations are at or above the upper limit of the sensory perception threshold for this compound.

Figure 9 shows the development of DMS in red wine over 60 months in bottle. A clear separation has developed between the natural cork and the other closures despite all increasing significantly. The wine under the natural cork closure exhibited DMS levels significantly below those seen under the other closures. Figure 10 shows the development of MeSH in red wine over 60 months in bottle. The concentrations present under all closures remains around or above the sensory perception threshold for this compound; however, levels remain relatively low comparative to those typically seen in commercial wines (0-11 µg/L). Significant differences exist between the screw cap and all other closures, with the wine under the screw cap closure exhibiting the highest concentration of MeSH. For all LMWS compounds detected in the red wine samples, there were no significant differences detected between those samples sealed with the Vinolok 18.2mm and 18.5mm closure.

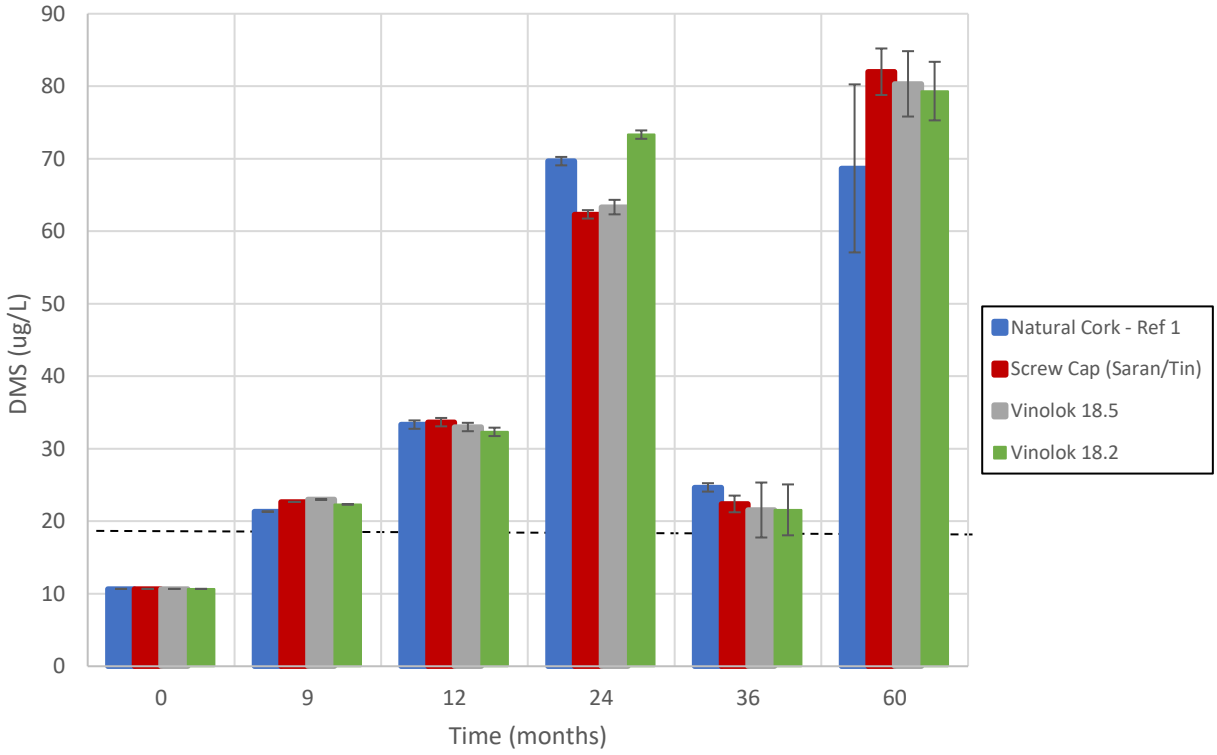


Figure 9: LMWS (Dimethyl Sulfide) analysis up to 60-months post bottling in red wine samples. The shaded area represents the aroma threshold for dimethyl sulfide (25 µg/L)

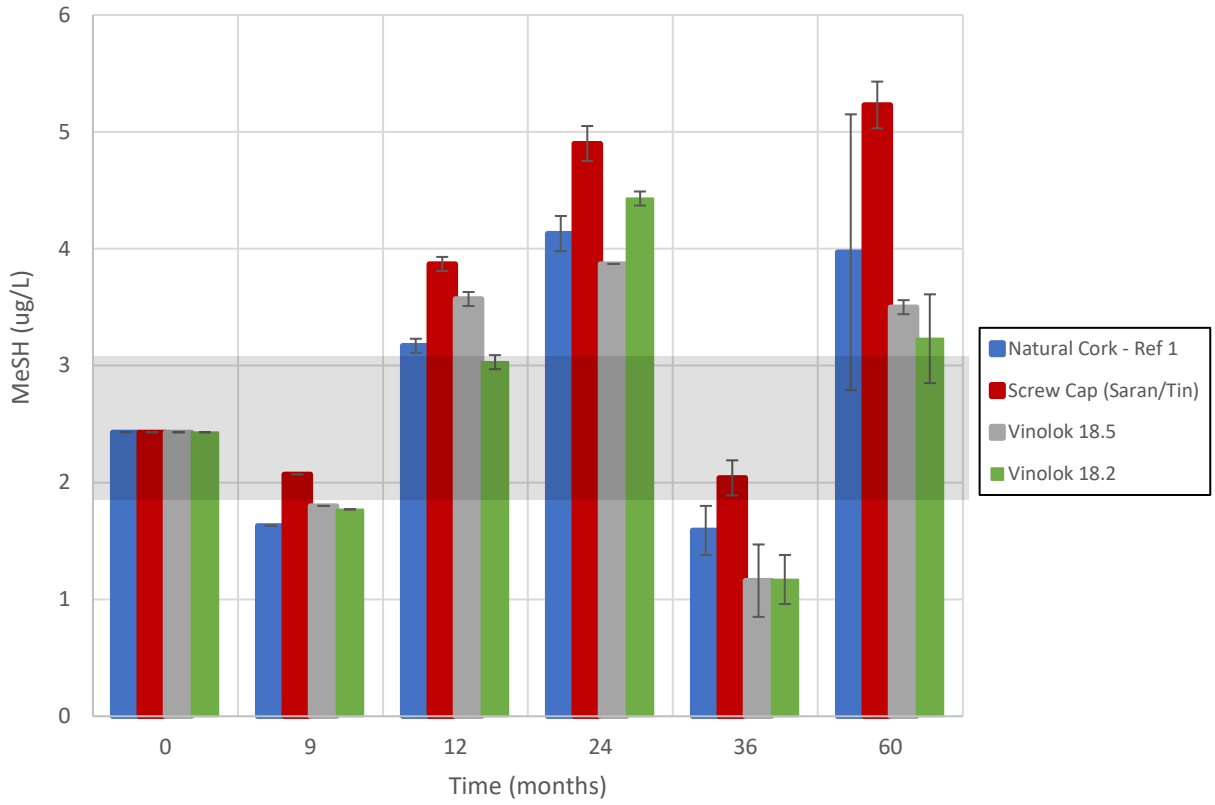


Figure 10: LMWS (Methanethiol) analysis up to 60-months post bottling in red wine samples. The shaded area represents the aroma threshold for methanethiol (1.8 – 3.1 µg/L)

Two LMWS compounds were detected within the white wine samples (MeSH and DMS); however only MeSH showed significant differences between closures. DMS concentrations showed a 200 – 300% increase under all closures comparative to the 36-month concentrations with all values well above the sensory perception threshold of 25µg/L. No significant differences existed for the DMS concentrations due to closure type, due to large variance among the data.

Figure 11 shows the DMS trend for the white wine under the four closures up to and including 60 months in bottle.

Figure 12 shows the MeSH trend for the white wine under the four closures up to and including 60 months in bottle. Levels of MeSH have increased under all closures across the twenty-four months since the previous testing point. The extent of the increase was lowest for the Vinolok 18.2 sample (~2.5 µg/L),. All concentrations were above the upper limit of the sensory perception threshold, with the wine under screw cap exhibiting the highest concentration; significantly higher than that under the Vinolok 18.2 closure.

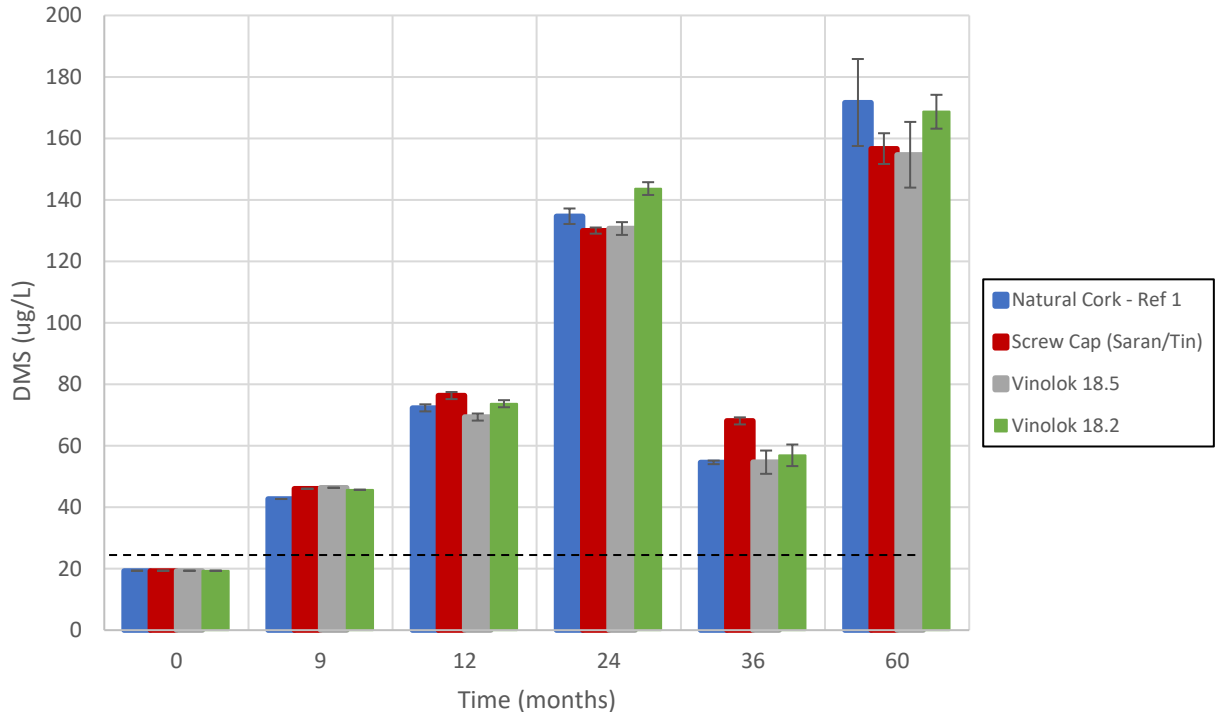


Figure 11: LMWS (Dimethyl Sulfide) analysis up to 60-months post bottling in white wine samples. The shaded area represents the aroma threshold for dimethyl sulfide (25 µg/L)

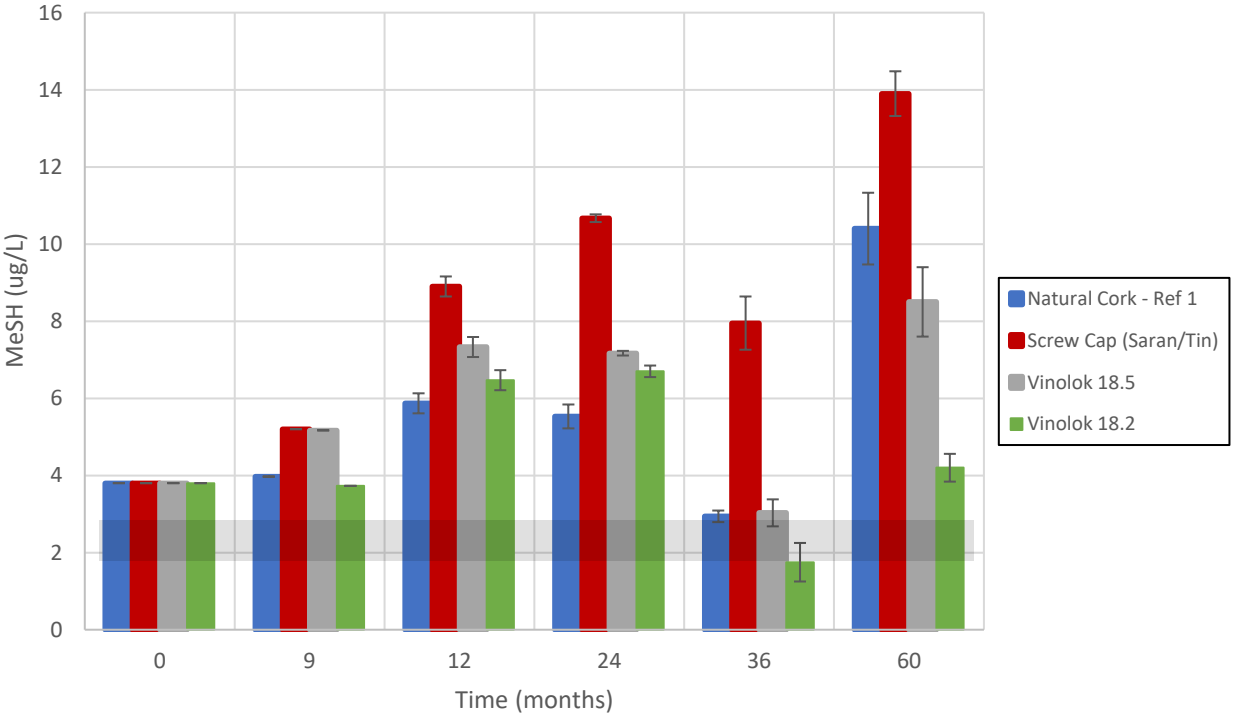


Figure 12: LMWS (Methanethiol) analysis up to 60-months post bottling in white wine samples. The shaded area represents the aroma threshold for methanethiol (1.8 – 3.1 µg/L)

Detailed raw data for the LMWS compounds detected in each wine can be found in Appendix 5 and Appendix 6. Within Appendix 6 there is a table summarising each of the detected LMWS compounds along with their odour descriptor, aroma detection threshold and typical range as found within Australian commercial wines.

3.1.5 Oxygen Transmission Rate

The results of the wet OTR analysis are shown in Figure 13. The graph compares data across three replicates of each of the four closure variants after sixty months in bottle. The complete data set for each trial variant is provided in Appendix 7.

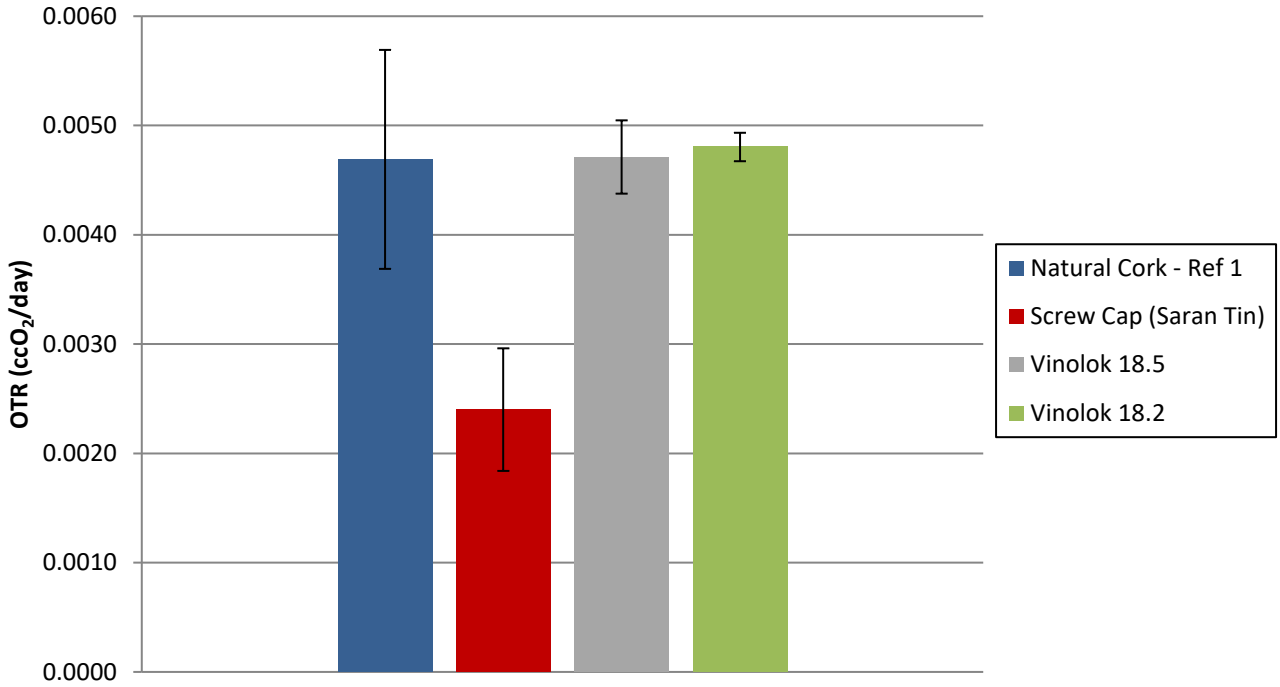


Figure 13: Wet OTR results for all four closures at 60-months post-bottling.

There are significant differences in the measured closure OTR values. The screw cap (Saran/tin) had the lowest OTR average value of 0.0024cc O_2 per day and is significantly lower than the other closures. The two Vinolok closures (18.2 and 18.5mm) were not significantly different with respect to OTR values, with the average difference between these closure sets negligible. The Vinolok closures and the natural cork closures presented near identical OTR averages across the three repetitions. There existed a greater degree of variability for the natural cork closure compared to the Vinolok samples. Please note that for the Vinolok 18.5 results, only results for two repetitions of the closure were recorded due to a sample processing error.

3.2 *Sensory analysis*

3.2.1 White Wine Sensory

From the ANOVA, seven attributes rated by the panel differed significantly (P<0.05) between the closures: *yellow colour intensity, tropical fruit aroma, stone fruit aroma, floral aroma, flint aroma, sweaty/cheesy aroma* and *pungency*. Significant (p<0.05) replicate by closure interaction effects were found for yellow colour intensity. Further inspection revealed that cork closures were most variable in yellow colour scores across the four replicates, while the screw-cap had low variability across replicates. The two Vinolok closures were intermediate in variability compared to the reference closures. Significant judge by closure interaction effects were found for some attributes indicating some concept alignment issues between some judges. Some variation is expected within sensory panels.

Table 4: F-ratiosand degrees of freedom (df) from the analysis of variance of the sensory data for the white wine sample set.

Attribute	Closure
Yellow	23.00***
Tropical fruit A	3.98*
Passionfruit/Box-hedge A	1.21
Stone fruit A	4.46*
Citrus A	0.78
Floral A	4.49**
Vegetal A	1.12
Drain A	0.60
Flint A	9.34***
Sweaty/Cheesy A	5.58**
Pungency	5.44**
Sweetness	1.80
Acidity	1.58
Astringency	0.49
Bitterness	1.37
Viscosity	0.95
Hotness	1.14
Tropical fruit F	0.33
Stone fruit F	1.20
Citrus F	2.14
Fruit Aftertaste	0.68
df	*3*

A: aroma, F: Flavour. †Significance levels are as follows: * *P*≤0.05; ** *P*≤0.01; *** *P*≤0.001; ǂ *P*≤0.10. df = degrees of freedom. J = Judge, Closure = Closure type, Rep = closure presentation replicate.

Table 4 shows the mean attribute values for the four closures. The white wine under the screwcap closure was significantly lower in *yellow colour intensity, tropical fruit aroma* and *stone fruit aroma* compared to all other closures. The wine under screwcap was also significantly lower in *floral aroma* compared to the Vinolok 18.2 closure. It also showed significantly (p<0.05) higher *flint* aroma (Figure 14) than under the other closures. The two Vinolok closures exhibited significantly lower ratings for *sweaty/cheesy aroma* compared to both the screw-cap and cork closures. The wine under the cork closure was higher in *pungency* compared to the Vinolok 18.2 closure, while the screwcap closure was significantly higher in this attribute than both Vinolok closures, although the magnitude of these differences was very small.

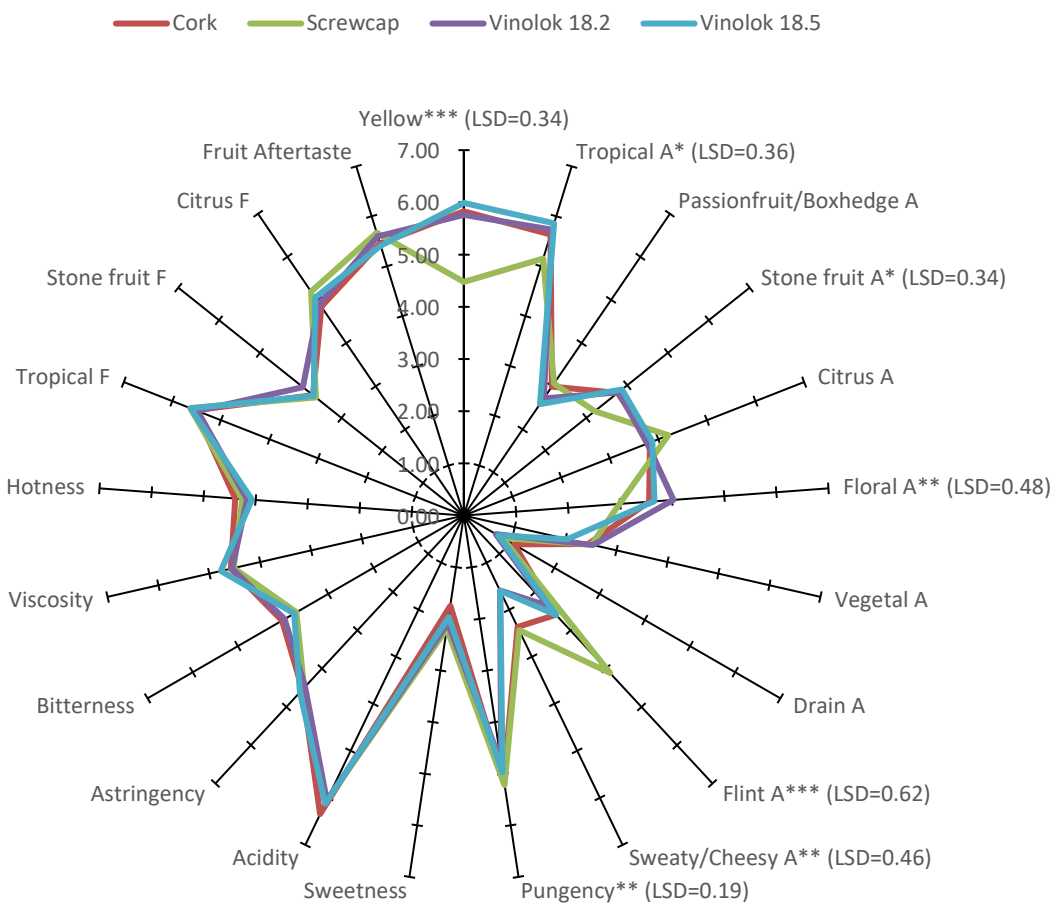


*Figure 14: Mean scores for all significant attributes for the white wine under the four different closures. LSD (5%) values included for significant attributes ($p < 0.05$). * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; ǂ $p < 0.10$.*

3.2.2 Red Wine Sensory

From the ANOVA, ten attributes rated by the panel differed significantly (P<0.05) between the closures: *opacity, dark fruit aroma, dried fruit aroma, port/bruised apple aroma, spices aroma, vanilla/chocolate aroma, drain aroma, viscosity, red fruit flavour* and *fruit aftertaste*. Astringency was close to significance (p<0.10). Significant (p<0.05) replicate by closure interaction effects were found for *opacity*. Further inspection revealed that cork closures were most variable in opacity scores across the four replicates. Significant judge by closure interaction effects were found for some attributes indicating some concept alignment issues between some judges. Some variation is expected within sensory panels.

Table 5: F-ratios and degrees of freedom (df) from the analysis of variance of the sensory data for the red wine sample set.

Attribute	Closure
Opacity	9.89***
Red Fruit A	2.00
Dark Fruit A	3.00*
Dried Fruit A	5.38**
Port/Bruised Apple A	6.16**
Herbal A	0.26
Spices A	5.64**
Vanilla/Choc A	3.58*
Earthy A	1.20
Woody A	0.17
Drain A	4.65*
Pungency	0.35
Acid	2.29
Hotness	0.98
Viscosity	4.43*
Astringency	2.34‡
Bitterness	1.13
Red Fruit F	4.22*
Dark Fruit F	1.76
Dried Fruit F	0.82
Port/Bruised Apple F	2.21
Stalky F	1.02
Earthy F	0.11
Woody F	0.28
Fruit Aftertaste	3.07*
df	*3*

A: aroma, F: Flavour. †Significance levels are as follows: * *P*≤0.05; ** *P*≤0.01; *** *P*≤0.001; ‡ *P*≤0.10. df = degrees of freedom. J = Judge, Closure = Closure type, Rep = closure presentation replicate.

The wine under screw-cap was rated significantly lower in *opacity, dark fruit aroma, dried fruit aroma, port/bruised apple aroma* and *spice aroma* compared to all other closures (Figure 15). The screw-cap wine was rated highest for *drain aroma* compared to all other closures. It was also rated significantly lower than under both Vinolok closures for *red fruit flavour* and lower for *fruit aftertaste* compared to the cork closure.

The wine under cork was rated significantly higher in *opacity, port/bruised apple aroma* and *viscosity,* and close to significant for *astringency* (p<0.10). The wine under Vinolok 18.2 was showed the highest *red fruit flavour* compared to the other closures.

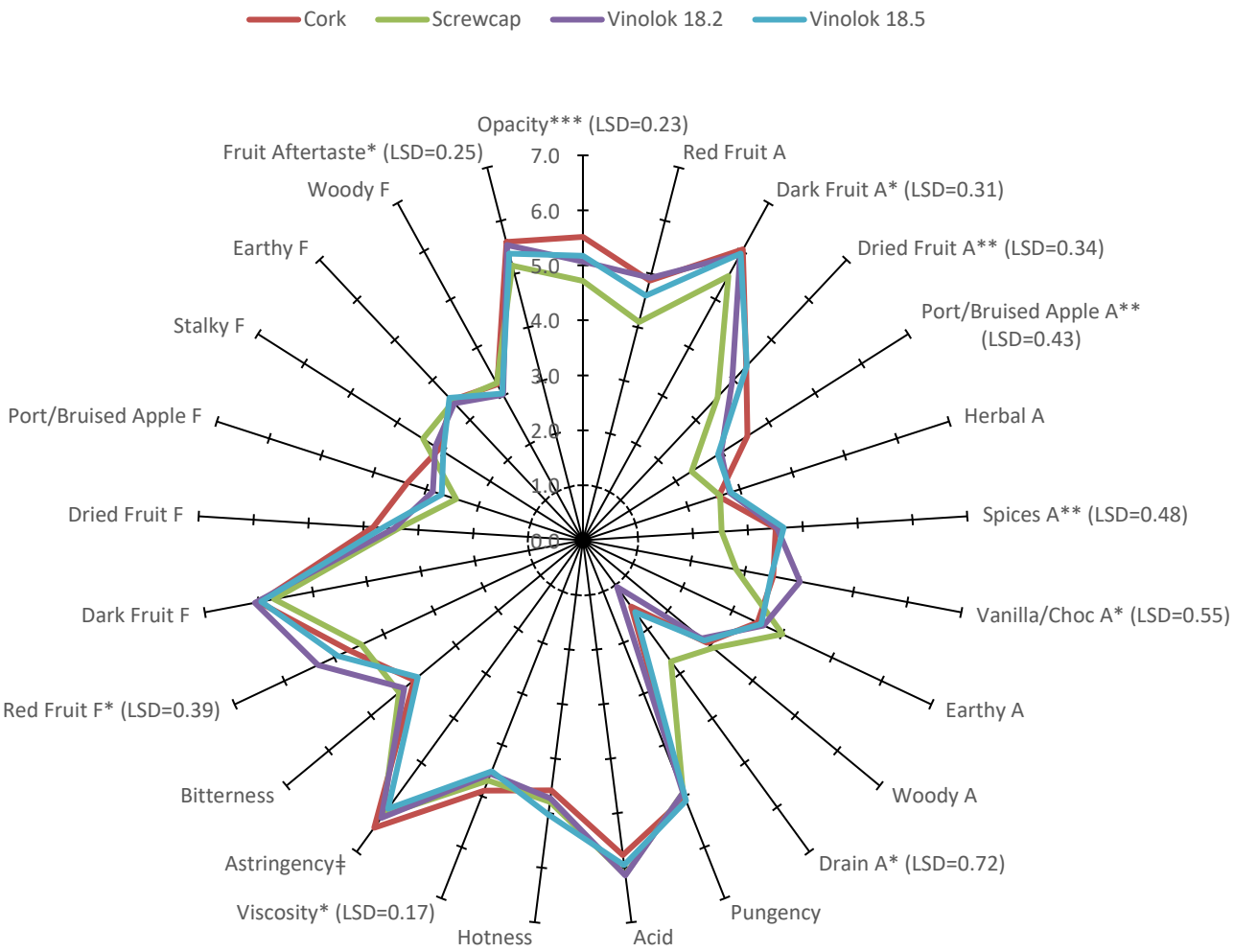


*Figure 15: Mean ratings for attributes for the four different closures. LSD values included for the attributes found to be significant across all samples. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; ǂ $p < 0.10$.*

4. Summary

Based on the results presented in this report, it can be summarised that:

- Significant differences exist for free and total SO_2 in the white wine samples, with concentrations under the saran/tin and natural cork closures higher relative to the Vinolok closures. For the red wine, free SO_2 concentrations under the screw cap were significantly higher than under both Vinolok closures. No significant differences are present between the two Vinolok closures and the natural cork; however there exists a greater level of variability in results for the natural cork samples.
- Differences in the red wine colour parameters at 60-months' post bottling remain relatively small, as seen throughout the trial. The wine under screw cap is significantly different to both Vinolok closures for free anthocyanins and pigmented tannin, whilst only significantly different to the Vinolok 18.2 closure for total pigment and colour density.
- Differences in LMWS compounds were present in both red and white wine varieties at the 60-month time point. Sensorially significant differences were observed for DMS and MeSH in the red wine due to closure type, but no significant differences were evident between the two Vinolok closures. MeSH concentrations were above sensory threshold in all wines and significantly different in the white wine due to closure type, with levels under the screw-cap being highest.
- There was no significant difference in OTR value between the two Vinolok closure closures after 60-months in bottle, with the screw-cap (tin/Saran) showing significantly lower OTR, as expected.
- The white wine under screw-cap was significantly lower in *floral aroma, yellow colour intensity, tropical fruit aroma* and *stone fruit aroma* compared to under the Vinolok 18.2 closure and higher in *flint* aroma. Furthermore, the two Vinolok closures had significantly lower ratings for *sweaty/cheesy aroma* compared to both the screw-cap and cork closures.
- The red wine under screw-cap was rated significantly lower in *opacity, dark fruit aroma, dried fruit aroma, port/bruised apple aroma* and *spice aroma* compared to all other closures , and highest in *drain* aroma, which is likely attributable to the higher concentration of MeSH present under the screw-cap closure. The wine under Vinolok 18.2 showed the highest *red fruit flavour* compared to the other closures.

Appendix 1: Basic Chemical Attributes

Red Wine														
Closure	% Alcohol		pH		Titratable Acidity @ pH 7.0		Titratable Acidity @ pH 8.2		Volatile Acidity as Acetic Acid		Glucose/Fructose		Specific Gravity	
	Average	StdDev	Average	StdDev	Average	StdDev	Average	StdDev	Average	StdDev	Average	StdDev	Average	StdDev
Natural Cork - Ref 1	13.40	0.00	3.61	0.01	5.57	0.06	6.17	0.06	0.37	0.01	4.10	0.10	1.00	0.00
Screw Cap (Saran/Tin)	13.40	0.00	3.60	0.00	5.50	0.00	6.13	0.06	0.36	0.01	4.10	0.00	1.00	0.00
Vinolok 18.2	13.40	0.00	3.60	0.01	5.50	0.00	6.13	0.06	0.36	0.00	4.00	1.00	1.00	0.00
Vinolok 18.5	13.40	0.00	3.60	0.01	5.50	0.00	6.10	0.00	0.35	0.01	4.13	0.06	1.00	0.00

White Wine														
Closure	% Alcohol		pH		Titratable Acidity @ pH 7.0		Titratable Acidity @ pH 8.2		Volatile Acidity as Acetic Acid		Glucose/Fructose		Specific Gravity	
	Average	StdDev	Average	StdDev	Average	StdDev	Average	StdDev	Average	StdDev	Average	StdDev	Average	StdDev
Natural Cork - Ref 1	12.23	0.06	3.35	0.01	5.80	0.00	6.23	0.06	0.28	0.01	5.63	0.06	0.99	0.00
Screw Cap (Saran/Tin)	12.27	0.06	3.36	0.01	5.80	0.00	6.20	0.00	0.27	0.01	5.60	0.10	0.99	0.00
Vinolok 18.2	12.17	0.06	3.35	0.01	5.73	0.06	6.13	0.06	0.27	0.00	5.57	0.06	0.99	0.00
Vinolok 18.5	12.23	0.06	3.36	0.00	5.80	0.00	6.20	0.00	0.27	0.01	5.57	0.06	0.99	0.00

Appendix 2: SO_2 Analysis Results

FREE SO2 RED WINE																
Closure	**0**		**3**		**9**		**12**		**18**		**24**		**36**		**60**	
	Avg.	**SD.**	**Avg.**	**SD.**	**Avg.**	**SD.**	**Avg.**	**SD.**	**Avg.**	**SD.**	**Avg.**	**SD.**	**Avg.**	**SD.**	**Avg.**	**SD.**
Natural Cork - Ref 1	41.00	-	35.70	0.58	27.00	1.00	24.33	0.58	18.30	2.10	18.67	0.58	12.33	0.58	6.67	2.08
Screw Cap (Saran/Tin)	41.00	-	34.30	4.62	29.00	0.00	25.67	0.58	22.00	0.00	21.00	0.00	17.67	0.58	9.00	0.00
Vinolok 18.2	41.00	-	37.70	1.15	29.67	0.58	28.00	3.46	22.00	0.00	20.00	0.00	12.67	0.58	5.33	0.58
Vinolok 18.5	41.00	-	37.30	1.15	29.00	0.00	25.00	0.00	22.00	0.00	19.67	0.58	12.00	0.00	5.33	0.58
Significance	No	-	No	-	Yes	-	Yes	-	Yes	-	Yes	-	Yes	-	Yes	-

FREE SO2 WHITE WINE																
Closure	**0 Month**		**3 Month**		**9 Month**		**12 Month**		**18 Month**		**24 Month**		**36 Month**		**60 Month**	
	Avg.	**SD.**	**Avg.**	**SD.**	**Avg.**	**SD.**	**Avg.**	**SD.**	**Avg.**	**SD.**	**Avg.**	**SD.**	**Avg.**	**SD.**	**Avg.**	**SD.**
Natural Cork - Ref 1	42.00	-	35.00	1.00	29.33	0.58	26.67	0.58	25.00	1.00	24.67	3.06	17.00	7.81	17.00	1.73
Screw Cap (Saran/Tin)	42.00	-	37.67	1.15	32.33	0.58	30.67	0.58	29.67	0.60	31.00	0.00	28.00	2.65	20.67	0.58
Vinolok 18.2	42.00	-	36.67	2.08	33.00	0.00	29.33	0.58	28.00	0.00	27.33	0.58	24.33	2.08	12.67	2.31
Vinolok 18.5	42.00	-	38.67	0.58	33.00	0.00	29.67	0.58	29.00	0.00	28.00	1.00	25.00	1.00	12.67	1.15
Significance	No	-	Yes	-	Yes	-	Yes	-	Yes	-	Yes	-	No	-	Yes	-

TOTAL SO2 RED WINE																
Closure	0 Month		3 Month		9 Month		12 Month		18 Month		24 Month		36 Month		60 Month	
	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.
Natural Cork - Ref 1	106.00	-	96.33	0.58	88.33	1.53	82.33	1.15	84.70	4.70	84.33	1.15	67.67	1.15	42.00	6.00
Screw Cap (Saran/Tin)	106.00	-	95.00	5.20	92.00	0.00	86.33	1.15	89.30	0.60	91.00	1.00	76.00	0.00	51.33	0.58
Vinolok 18.2	106.00	-	100.67	1.15	93.67	0.58	89.33	4.93	88.70	0.60	86.33	0.58	70.00	1.00	38.00	1.00
Vinolok 18.5	106.00	-	99.00	2.65	92.67	0.58	86.00	1.00	88.70	0.60	87.00	1.73	67.67	1.53	39.00	1.73
Significance	No	-	Yes	-	Yes	-	Yes	-	Yes	-	Yes	-	Yes	-	Yes	-

TOTAL SO2 WHITE WINE																
Closure	0 Month		3 Month		9 Month		12 Month		18 Month		24 Month		36 Month		60 Month	
	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.
Natural Cork - Ref 1	150.00	-	145.00	1.00	140.00	0.00	130.33	2.08	136.00	2.00	137.33	2.08	121.33	15.04	118.00	3.46
Screw Cap (Saran/Tin)	150.00	-	148.67	0.58	144.67	1.53	137.33	1.53	140.67	1.50	145.33	0.58	134.33	0.58	125.33	0.58
Vinolok 18.2	150.00	-	145.00	2.65	144.67	2.08	137.67	1.53	139.00	0.00	142.00	2.65	129.00	2.00	109.67	4.93
Vinolok 18.5	150.00	-	149.33	0.58	146.00	1.00	137.33	1.15	140.67	1.20	142.67	1.15	131.67	1.53	111.67	3.06
Significance	No	-	Yes	-	Yes	-	Yes	-	Yes	-	Yes	-	No	-	Yes	-

Appendix 2: Red Wine Colour Analysis Results

HUE RED WINE														
Closure	3 Month		9 Month		12 Month		18 Month		24 Month		36 Month		60 Month	
	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.
Natural Cork - Ref 1	0.66	0.01	0.68	0.01	0.69	0.01	0.550	0.000	0.79	0.01	0.86	0.01	1.03	0.01
Screw Cap (Saran/Tin)	0.65	0.00	0.68	0.00	0.68	0.01	0.543	0.006	0.78	0.00	0.82	0.01	1.01	0.01
Vinolok 18.2	0.64	0.01	0.68	0.00	0.69	0.01	0.540	0.000	0.78	0.00	0.85	0.01	1.03	0.00
Vinolok 18.5	0.65	0.00	0.68	0.00	0.68	0.01	0.540	0.000	0.78	0.00	0.85	0.01	1.02	0.01
Significance	No	-	No	-	No	-	No	-	No	-	No	-	No	-

COLOUR DENSITY RED WINE														
Closure	3 Month		9 Month		12 Month		18 Month		24 Month		36 Month		60 Month	
	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.
Natural Cork - Ref 1	7.63	0.12	7.30	0.10	6.97	0.06	9.83	0.06	7.20	0.00	7.07	0.12	6.70	0.10
Screw Cap (Saran/Tin)	7.43	0.06	7.27	0.12	6.87	0.12	9.77	0.12	7.10	0.00	6.63	0.06	6.50	0.00
Vinolok 18.2	7.43	0.06	7.33	0.06	7.00	0.17	9.90	0.00	7.10	0.26	7.27	0.15	6.73	0.06
Vinolok 18.5	7.43	0.06	7.20	0.10	6.90	0.10	9.83	0.06	7.10	0.00	7.13	0.06	6.70	0.10
Significance	Yes	-	No	-	No	-	No	-	No	-	Yes	-	Yes	-

CHEMICAL AGE 1 RED WINE														
Closure	3 Month		9 Month		12 Month		18 Month		24 Month		36 Month		60 Month	
	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.
Natural Cork - Ref 1	0.37	0.02	0.43	0.01	0.46	0.01	0.35	0.01	0.46	0.01	0.54	0.01	0.68	0.01
Screw Cap (Saran/Tin)	0.39	0.01	0.43	0.01	0.45	0.01	0.34	0.00	0.46	0.01	0.57	0.00	0.68	0.01
Vinolok 18.2	0.39	0.01	0.42	0.00	0.45	0.01	0.34	0.01	0.47	0.02	0.53	0.01	0.70	0.02
Vinolok 18.5	0.39	0.01	0.43	0.01	0.45	0.01	0.34	0.01	0.48	0.01	0.54	0.00	0.69	0.01
Significance	No	-	No	-	No	-	No	-	No	-	Yes	-	No	-

CHEMICAL AGE 2 RED WINE														
Closure	3 Month		9 Month		12 Month		18 Month		24 Month		36 Month		60 Month	
	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.
Natural Cork - Ref 1	0.12	0.00	0.14	0.01	0.15	0.00	0.19	0.00	0.19	0.01	0.26	0.01	0.41	0.01
Screw Cap (Saran/Tin)	0.12	0.01	0.14	0.00	0.16	0.00	0.19	0.00	0.18	0.00	0.27	0.00	0.39	0.00
Vinolok 18.2	0.12	0.00	0.14	0.00	0.16	0.00	0.19	0.01	0.18	0.01	0.25	0.00	0.43	0.01
Vinolok 18.5	0.12	0.00	0.14	0.00	0.16	0.01	0.19	0.00	0.18	0.01	0.25	0.00	0.42	0.00
Significance	No	-	No	-	No	-	No	-	No	-	Yes	-	Yes	-

FREE ANTHOCYANINS RED WINE														
Closure	3 Month		9 Month		12 Month		18 Month		24 Month		36 Month		60 Month	
	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.
Natural Cork - Ref 1	234.00	2.00	194.33	1.53	183.67	1.53	157.33	2.52	135.00	1.73	92.67	0.58	34.00	2.65
Screw Cap (Saran/Tin)	229.67	1.15	197.67	2.08	174.33	0.58	156.33	1.53	140.33	0.58	86.00	1.73	37.67	0.58
Vinolok 18.2	238.33	7.09	198.33	1.15	173.67	4.93	156.67	6.11	140.33	2.89	96.33	0.58	30.33	2.08
Vinolok 18.5	231.00	2.00	201.33	5.86	177.00	0.00	153.67	1.53	139.67	2.31	96.33	0.58	32.67	0.58
Significance	No	-	No	-	Yes	-	Yes	-	No	-	Yes	-	Yes	-

TOTAL PHENOLICS RED WINE														
Closure	3 Month		9 Month		12 Month		18 Month		24 Month		36 Month		60 Month	
	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.
Natural Cork - Ref 1	46.67	0.58	44.67	0.58	45.00	0.00	47.00	0.00	44.67	0.58	44.00	0.00	43.33	0.58
Screw Cap (Saran/Tin)	46.00	0.00	45.00	0.00	43.67	0.58	47.00	0.00	44.67	0.58	43.33	0.58	43.00	0.00
Vinolok 18.2	47.00	1.00	45.00	0.00	44.00	2.00	47.33	1.53	45.00	0.00	44.67	0.58	43.00	0.00
Vinolok 18.5	46.00	0.00	45.67	1.15	44.00	0.00	46.67	0.58	45.00	1.00	44.33	0.58	43.00	0.00
Significance	No	-	No	-	No	-	No	-	No	-	No	-	No	-

TOTAL PIGMENT RED WINE														
Closure	3 Month		9 Month		12 Month		18 Month		24 Month		36 Month		60 Month	
	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.
Natural Cork - Ref 1	14.58	0.15	12.77	0.09	12.28	0.10	11.54	0.12	9.81	0.05	8.07	0.03	5.45	0.05
Screw Cap (Saran/Tin)	14.46	0.06	12.94	0.11	11.79	0.02	11.38	0.08	10.04	0.05	7.75	0.08	5.51	0.02
Vinolok 18.2	14.83	0.40	12.96	0.06	11.82	0.29	11.53	0.36	10.16	0.10	8.32	0.03	5.41	0.02
Vinolok 18.5	14.42	0.11	13.12	0.28	11.96	0.08	11.34	0.10	10.07	0.13	8.28	0.01	5.45	0.04
Significance	No	-	No	-	Yes	-	Yes	-	Yes	-	Yes	-	Yes	-

PIGMENTED TANNIN RED WINE														
Closure	3 Month		9 Month		12 Month		18 Month		24 Month		36 Month		60 Month	
	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.
Natural Cork - Ref 1	1.73	0.04	1.83	0.03	1.86	0.03	2.21	0.02	1.84	0.04	2.06	0.01	2.26	0.05
Screw Cap (Saran/Tin)	1.78	0.04	1.84	0.01	1.85	0.01	2.14	0.03	1.82	0.01	2.08	0.01	2.18	0.01
Vinolok 18.2	1.76	0.02	1.83	0.00	1.87	0.03	2.22	0.06	1.89	0.03	2.10	0.01	2.34	0.06
Vinolok 18.5	1.72	0.02	1.83	0.01	1.86	0.06	2.19	0.02	1.85	0.04	2.08	0.01	2.29	0.01
Significance	No	-	No	-	No	-	No	-	No	-	Yes	-	Yes	-

TANNIN RED WINE														
Closure	3 Month		9 Month		12 Month		18 Month		24 Month		36 Month		60 Month	
	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.
Natural Cork - Ref 1	0.66	0.01	0.68	0.01	0.69	0.01	0.55	0.00	0.79	0.01	1.02	0.01	1.08	0.02
Screw Cap (Saran/Tin)	0.65	0.00	0.68	0.00	0.68	0.01	0.54	0.01	0.78	0.00	1.00	0.02	1.04	0.02
Vinolok 18.2	0.64	0.01	0.68	0.00	0.69	0.01	0.54	0.00	0.78	0.00	1.04	0.01	1.06	0.02
Vinolok 18.5	0.65	0.00	0.68	0.00	0.68	0.01	0.54	0.00	0.78	0.00	1.03	0.01	1.06	0.00
Significance	No	-	No	-	No	-	No	-	No	-	Yes	-	No	-

Appendix 3: White Wine Colour Analysis Results

OPTICAL DENSITY AT 280nm WHITE WINE																
Closure	0 Month		3 Month		9 Month		12 Month		18 Month		24 Month		36 Month		60 Month	
	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.
Natural Cork - Ref 1	7.54	0.00	7.46	0.01	7.67	0.06	7.65	0.01	6.91	0.06	7.87	0.08	8.19	0.13	9.00	0.06
Screw Cap (Saran/Tin)	7.54	0.00	7.42	0.00	7.61	0.23	7.59	0.03	6.91	0.18	7.66	0.01	7.94	0.07	8.77	0.06
Vinolok 18.2	7.54	0.00	7.18	0.00	7.50	0.04	7.55	0.03	6.66	0.01	7.65	0.06	7.81	0.07	8.52	0.08
Vinolok 18.5	7.54	0.00	7.33	0.00	7.63	0.13	7.63	0.03	7.24	0.17	7.58	0.05	7.95	0.04	8.66	0.04
Significance			Yes	-	Yes	-	Yes	-	Yes	-	Yes	-	Yes	-	Yes	-

OPTICAL DENSITY AT 320nm WHITE WINE																
Closure	0 Month		3 Month		9 Month		12 Month		18 Month		24 Month		36 Month		60 Month	
	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.
Natural Cork - Ref 1	4.55	0.00	4.57	0.00	4.74	0.05	4.74	0.00	4.07	0.11	4.76	0.08	4.87	0.12	5.07	0.03
Screw Cap (Saran/Tin)	4.55	0.00	4.54	0.00	4.71	0.20	4.70	0.02	4.07	0.15	4.63	0.01	4.72	0.05	4.96	0.05
Vinolok 18.2	4.55	0.00	4.41	0.00	4.68	0.06	4.70	0.02	3.92	0.01	4.66	0.04	4.70	0.07	4.87	0.05
Vinolok 18.5	4.55	0.00	4.44	0.00	4.69	0.11	4.71	0.03	4.31	0.14	4.44	0.01	4.73	0.03	4.87	0.02
Significance			Yes	-	Yes	-	No	-	Yes	-	Yes	-	No	-	Yes	-

OPTICAL DENSITY AT 420nm WHITE WINE																
Closure	0 Month		3 Month		9 Month		12 Month		18 Month		24 Month		36 Month		60 Month	
	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.	Avg.	SD.
Natural Cork - Ref 1	0.08	0.00	0.08	0.00	0.08	0.00	0.09	0.00	0.09	0.00	0.09	0.00	0.13	0.02	0.16	0.01
Screw Cap (Saran/Tin)	0.08	0.00	0.07	0.00	0.08	0.00	0.08	0.00	0.08	0.00	0.08	0.00	0.10	0.00	0.13	0.00
Vinolok 18.2	0.08	0.00	0.07	0.00	0.08	0.00	0.08	0.00	0.09	0.00	0.09	0.00	0.11	0.00	0.16	0.01
Vinolok 18.5	0.08	0.00	0.07	0.00	0.08	0.00	0.08	0.00	0.09	0.00	0.08	0.00	0.11	0.00	0.16	0.00
Significance			Yes	-	Yes	-	Yes	-	Yes	-	Yes	-	Yes	-	Yes	-

Appendix 5: Low Molecular Weight Sulfide Results: Red Wine

Closure	Carbon disulfide (µg/L)											
	0 month		9 month		12 month		24 month		36 month		60 month	
	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD
Natural Cork – Ref 1	1.73	0.06	3.37	0.70	3.57	1.16	6.97	1.59	2.53	0.71	5.53	0.96
Screw Cap (Saran/Tin)	1.73	0.06	3.50	0.30	4.03	0.12	7.13	0.38	2.69	0.20	7.83	0.51
Vinolok 18.2	1.73	0.06	3.63	0.35	3.03	0.64	5.30	0.56	1.57	0.14	3.27	0.25
Vinolok 18.5	1.73	0.06	2.93	0.32	2.80	1.10	4.50	0.52	1.44	0.10	3.73	0.06
Significance	No	-	Yes	-	Yes	-	Yes	-	Yes	-	Yes	-

Closure	Dimethyl Sulfide (µg/L)											
	0 month		9 month		12 month		24 month		36 month		60 month	
	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD
Natural Cork – Ref 1	10.67	0.58	21.33	0.58	33.33	0.58	69.67	11.59	24.67	10.11	68.67	3.21
Screw Cap (Saran/Tin)	10.67	0.58	22.67	0.58	33.67	1.15	62.33	3.21	22.39	1.55	82.00	1.00
Vinolok 18.2	10.67	0.58	22.33	0.58	32.33	3.51	73.33	4.04	21.57	2.00	79.33	2.08
Vinolok 18.5	10.67	0.58	23.00	1.00	33.00	3.79	63.33	4.51	21.55	1.73	80.33	1.15
Significance	No	-	Yes	-	Yes	-	No	-	No	-	Yes	-

Closure	Hydrogen Sulfide (µg/L)											
	0 month		9 month		12 month		24 month		36 month		60 month	
	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD
Natural Cork – Ref 1	2.73	0.12	0.90	0.17	2.57	0.12	2.30	0.44	1.55	0.12	3.20	-
Screw Cap (Saran/Tin)	2.73	0.12	1.67	0.25	2.23	0.29	2.47	0.29	2.15	0.27	3.40	0.10
Vinolok 18.2	2.73	0.12	1.57	0.15	2.77	0.25	2.57	0.21	1.68	0.19	<LOQ	-
Vinolok 18.5	2.73	0.12	1.27	0.06	4.50	1.48	1.90	0.30	1.62	0.27	3.00	-
Significance	No	-	Yes	-	Yes	-	No	-	Yes	-	Yes	-

Closure	Methanethiol (µg/L)											
	0 month		9 month		12 month		24 month		36 month		60 month	
	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD
Natural Cork – Ref 1	2.43	0.06	1.63	0.15	3.17	0.21	4.13	1.18	1.59	0.66	3.97	0.67
Screw Cap (Saran/Tin)	2.43	0.06	2.07	0.15	3.87	0.15	4.90	0.20	2.04	0.24	5.23	0.21
Vinolok 18.2	2.43	0.06	1.77	0.06	3.03	0.21	4.43	0.38	1.17	0.10	3.23	0.06
Vinolok 18.5	2.43	0.06	1.8	0.00	3.57	0.31	3.87	0.06	1.16	0.08	3.50	0.10
Significance	No	-	Yes	-	Yes	-	No	-	No	-	Yes	-

Appendix 6: Low Molecular Weight Sulfide Results: White Wine

Closure	Dimethyl Sulfide (µg/L)											
	0 month		9 month		12 month		24 month		36 month		60 month	
	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD
Natural Cork – Ref 1	19.33	1.15	42.67	2.52	72.33	0.58	134.67	14.15	54.59	0.44	171.67	13.20
Screw Cap (Saran/Tin)	19.33	1.15	46.00	1.00	76.33	1.15	130.00	5.00	68.08	1.02	156.67	43.98
Vinolok 18.2	19.33	1.15	45.67	2.08	73.67	3.51	143.67	5.51	56.89	0.53	168.67	8.14
Vinolok 18.5	19.33	1.15	46.33	2.08	69.33	3.79	130.67	10.69	54.65	0.28	154.67	49.80
Significance	No	-	Yes	-	Yes	-	No	-	Yes	-	No	-

Closure	Methanethiol (µg/L)											
	0 month		9 month		12 month		24 month		36 month		60 month	
	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD
Natural Cork – Ref 1	3.8	0.26	3.97	0.31	5.87	0.15	5.53	0.93	2.94	1.23	10.40	1.44
Screw Cap (Saran/Tin)	3.8	0.26	5.2	0.10	8.90	0.69	10.67	0.58	7.95	1.13	13.90	3.64
Vinolok 18.2	3.8	0.26	3.73	0.15	6.47	0.50	6.70	0.36	1.75	0.16	4.20	0.53
Vinolok 18.5	3.8	0.26	5.17	0.06	7.33	0.35	7.17	0.90	3.03	0.22	8.50	5.22
Significance	No	-	Yes	-	Yes	-	Yes	-	Yes	-	Yes	-

Low molecular weight sulfide compounds and their respective sensory thresholds.

Compound	Odour Descriptor	Aroma Threshold (µg/L)	Typical range (µg/L)
Hydrogen sulfide	Rotten egg, sewage like	1.1 – 1.6	0 – 370
Methanethiol	Rotten cabbage, burnt rubber, putrid	1.8 – 3.1	0 – 11
Dimethyl sulfide	Blackcurrant, cooked cabbage, asparagus, canned corn, molasses	25	0 – 980
Carbon disulfide	Sweet, ethereal, slight green, rubber, sulfidy, chokingly repulsive	>38	0 – 140
Methyl thioacetate	Sulfurous, cheesy, egg	50	0 – 115

Appendix 7: Wet OTR Results

Closure	Average	StDev
Vinolok 18.5	0.0047	0.0003
Vinolok 18.2	0.0048	0.0001
Natural Cork - Ref 1	0.0047	0.0010
Screw Cap (Saran Tin)	0.0024	0.0006

Appendix 8: Mean sensory ratings for white wines

Closure Type	Closure Replicate	Yellow	Tropical A	Passionfruit/Box-hedge A	Stone fruit A	Citrus A	Floral A	Vegetal A	Drain A	Flint A	Sweaty/Cheesy A	Pungency
Cork	R1	4.92	5.23	3.25	3.24	3.92	2.93	2.40	0.81	2.78	2.70	5.15
	R2	6.47	6.36	2.69	4.16	3.51	4.70	1.97	0.80	2.25	2.16	5.05
	R3	5.57	5.16	2.99	3.95	4.09	3.19	2.48	1.54	3.00	2.31	5.24
	R4	6.35	5.79	3.04	3.73	3.78	3.41	2.91	1.28	2.35	2.29	5.11
	Mean	5.83	5.63	2.99	3.77	3.83	3.56	2.44	1.11	2.59	2.36	5.14
	Standard Deviation	0.63	0.48	0.20	0.34	0.21	0.68	0.34	0.32	0.31	0.20	0.07
Screwcap	R1	4.47	4.64	2.81	3.14	4.70	2.77	2.42	0.66	4.21	1.79	5.31
	R2	4.34	5.61	2.79	3.10	4.13	3.09	2.47	0.79	4.05	2.26	5.17
	R3	4.43	5.26	3.86	3.38	4.10	3.26	2.67	0.79	3.79	2.74	5.51
	R4	4.68	5.08	2.78	3.20	3.89	2.83	2.47	1.16	4.40	2.96	4.90
	Mean	4.48	5.15	3.06	3.21	4.21	2.99	2.51	0.85	4.11	2.44	5.22
	Standard Deviation	0.12	0.35	0.46	0.11	0.30	0.20	0.10	0.19	0.22	0.45	0.22
Vinolok 18.2	R1	6.19	5.37	2.24	3.86	3.39	3.76	2.38	0.94	2.39	1.66	4.63
	R2	5.81	5.95	2.47	3.72	3.64	4.24	2.59	0.66	2.24	1.90	4.98
	R3	5.41	6.09	2.62	4.03	3.75	4.36	2.36	0.81	2.48	1.19	4.60
	R4	5.63	5.50	3.53	3.55	4.30	3.74	2.82	0.42	2.33	1.63	4.99
	Mean	5.76	5.73	2.72	3.79	3.77	4.02	2.54	0.71	2.36	1.59	4.80
	Standard Deviation	0.29	0.30	0.49	0.18	0.33	0.28	0.19	0.20	0.09	0.26	0.18
Vinolok 18.5	R1	6.16	5.55	3.06	3.50	4.01	3.14	2.05	0.84	2.09	1.84	4.88
	R2	5.54	6.40	2.67	3.90	3.62	3.77	1.50	0.90	2.59	1.49	4.88
	R3	6.17	5.78	2.53	4.27	4.08	4.25	1.81	0.91	2.72	1.58	4.96
	R4	6.09	5.70	2.09	3.82	3.80	3.47	2.74	0.40	3.00	1.49	5.20
	Mean	5.99	5.86	2.59	3.87	3.88	3.66	2.03	0.76	2.60	1.60	4.98
	Standard Deviation	0.26	0.32	0.35	0.28	0.18	0.41	0.46	0.21	0.33	0.14	0.13

Closure Type	Closure Replicate	Sweetness	Acidity	Astringency	Bitterness	Viscosity	Hotness	Tropical F	Stone fruit F	Citrus F	Fruit Aftertaste
Cork	R1	1.64	6.58	4.63	3.97	4.28	4.23	5.22	3.32	4.53	5.57
	R2	2.06	6.19	4.36	4.07	4.95	4.62	5.80	3.96	4.58	5.50
	R3	1.70	6.49	4.63	3.95	4.31	4.58	5.61	4.04	5.00	5.28
	R4	1.57	6.12	4.58	4.12	4.79	4.14	5.50	3.48	5.27	5.48
	Mean	1.75	6.35	4.55	4.03	4.58	4.39	5.53	3.70	4.85	5.46
	Standard Deviation	0.19	0.19	0.11	0.07	0.29	0.21	0.21	0.31	0.30	0.11
Screwcap	R1	2.48	6.35	4.59	3.54	4.08	4.03	5.22	3.34	5.10	5.47
	R2	1.97	5.90	4.22	3.91	4.57	4.33	5.85	3.57	5.26	5.71
	R3	1.92	6.06	4.68	3.93	4.76	4.61	5.82	3.81	5.20	5.78
	R4	2.40	6.01	4.51	3.46	4.70	4.06	5.64	3.79	5.23	5.71
	Mean	2.19	6.08	4.50	3.71	4.53	4.26	5.63	3.63	5.20	5.67
	Standard Deviation	0.25	0.17	0.17	0.21	0.27	0.24	0.25	0.19	0.06	0.12
Vinolok 18.2	R1	1.56	6.45	4.46	4.16	4.81	3.95	4.85	3.57	5.12	5.52
	R2	2.33	5.79	4.07	3.54	4.75	4.37	5.69	4.41	4.61	5.73
	R3	1.91	6.18	4.67	4.07	4.27	3.95	5.49	3.89	4.69	5.47
	R4	2.53	5.81	4.70	4.09	4.41	4.39	5.90	3.92	5.24	5.67
	Mean	2.08	6.06	4.47	3.96	4.56	4.17	5.48	3.95	4.92	5.60
	Standard Deviation	0.38	0.27	0.25	0.25	0.23	0.22	0.39	0.30	0.27	0.11
Vinolok 18.5	R1	1.88	6.29	4.47	3.70	4.78	3.87	5.53	3.53	4.60	5.16
	R2	2.15	6.07	4.53	4.01	4.81	4.07	5.62	3.65	5.01	5.21
	R3	1.69	6.04	5.04	4.03	4.77	4.37	5.94	3.86	5.33	5.63
	R4	2.13	6.10	4.43	3.28	4.73	3.98	5.40	3.68	5.26	5.63
	Mean	1.96	6.13	4.62	3.75	4.77	4.07	5.62	3.68	5.05	5.41
	Standard Deviation	0.19	0.10	0.25	0.31	0.03	0.19	0.20	0.12	0.29	0.22

Appendix 9: Mean sensory ratings for red wines

Closure Type	Closure Replicate	Opacity	Red Fruit A	Dark Fruit A	Dried Fruit A	Port/ Bruised Apple A	Herbal A	Spices A	Vanilla/ Choc A	Earthy A	Woody A	Drain A	Pungency
Cork	R1	4.96	4.59	5.94	3.68	3.04	2.71	3.82	3.34	4.23	2.76	1.15	5.16
	R2	5.83	5.96	6.23	4.37	3.79	3.21	3.80	4.09	3.10	2.91	1.49	4.94
	R3	6.05	3.91	5.83	4.86	4.48	1.66	2.95	2.69	3.54	2.84	1.97	5.04
	R4	5.24	5.04	6.14	4.43	2.86	2.79	3.47	3.95	3.16	3.17	1.34	4.99
	Mean	5.52	4.88	6.04	4.34	3.54	2.59	3.51	3.52	3.51	2.92	1.49	5.03
	Standard Deviation	0.44	0.74	0.16	0.42	0.65	0.57	0.35	0.55	0.45	0.15	0.30	0.08
Screwcap	R1	4.41	3.75	5.29	3.78	2.77	2.52	2.28	2.95	3.89	3.72	2.88	4.98
	R2	4.66	4.10	5.69	3.67	2.67	2.94	2.51	2.62	4.16	3.38	2.25	4.85
	R3	4.95	4.41	5.55	3.64	2.21	3.05	2.88	3.27	4.06	2.95	2.46	4.99
	R4	4.86	4.14	5.40	3.21	1.71	1.97	2.44	2.53	3.93	2.21	3.30	4.93
	Mean	4.72	4.10	5.48	3.57	2.34	2.62	2.53	2.84	4.01	3.07	2.72	4.94
	Standard Deviation	0.21	0.23	0.15	0.22	0.42	0.42	0.22	0.29	0.11	0.57	0.40	0.05
Vinolok 18.2	R1	5.23	4.76	6.80	4.83	3.73	2.93	4.32	4.49	3.27	3.45	0.59	5.14
	R2	5.43	4.88	5.66	3.60	2.81	3.18	3.29	3.46	3.85	2.96	1.50	4.67
	R3	4.71	4.80	5.07	3.78	2.44	2.26	2.56	4.26	3.90	2.42	1.22	4.93
	R4	4.90	5.28	6.19	3.61	2.91	2.84	3.97	3.85	3.52	2.35	0.87	4.99
	Mean	5.07	4.93	5.93	3.96	2.97	2.80	3.54	4.02	3.63	2.79	1.05	4.93
	Standard Deviation	0.28	0.21	0.64	0.51	0.47	0.34	0.67	0.39	0.25	0.44	0.35	0.17
Vinolok 18.5	R1	5.15	5.20	6.20	4.55	3.01	2.08	3.62	3.82	3.34	4.00	1.41	5.14
	R2	5.33	4.02	5.80	4.21	2.95	3.27	3.93	3.32	3.81	2.50	1.56	4.97
	R3	5.16	4.30	5.82	4.07	2.51	3.26	3.90	3.45	3.65	2.48	2.19	5.18
	R4	5.06	4.85	5.99	4.58	3.17	2.67	3.18	3.33	3.52	2.45	1.28	5.06
	Mean	5.18	4.59	5.95	4.35	2.91	2.82	3.66	3.48	3.58	2.86	1.61	5.09
	Standard Deviation	0.10	0.46	0.16	0.22	0.25	0.49	0.30	0.20	0.17	0.66	0.35	0.08

Closure Type	Closure Replicate	Acidity	Hotness	Viscosity	Astringency	Bitterness	Red Fruit F	Dark Fruit F	Dried Fruit F	Port/ Bruised Apple F	Stalky F	Earthy F	Woody F	Fruit After-taste
Cork	R1	6.21	4.60	4.21	6.35	4.26	4.35	6.28	3.65	3.81	3.70	3.45	3.25	5.50
	R2	5.99	4.69	5.09	6.39	4.26	5.51	5.93	3.64	3.17	2.89	3.43	3.54	5.88
	R3	5.24	4.55	5.17	6.69	3.72	3.81	5.61	3.97	3.93	2.70	3.94	3.27	5.43
	R4	5.63	4.48	5.11	6.41	3.70	5.11	6.16	4.04	2.54	3.12	3.14	2.91	5.61
	Mean	5.77	4.58	4.89	6.46	3.99	4.69	6.00	3.82	3.36	3.10	3.49	3.24	5.60
	Standard Deviation	0.37	0.08	0.40	0.13	0.28	0.66	0.26	0.18	0.56	0.38	0.28	0.23	0.17
Screwcap	R1	5.87	4.41	4.32	5.78	4.95	3.81	5.47	3.41	2.34	3.62	3.21	2.96	5.56
	R2	6.39	4.99	4.78	6.61	4.33	4.95	5.63	3.44	2.42	3.41	3.19	4.28	5.09
	R3	5.95	4.46	4.84	5.93	3.94	4.43	6.33	3.49	2.75	2.80	3.60	3.00	5.36
	R4	6.31	5.31	4.85	6.40	4.13	4.62	5.43	3.13	2.19	3.96	3.80	2.82	4.62
	Mean	6.13	4.80	4.70	6.18	4.34	4.45	5.72	3.37	2.43	3.45	3.45	3.26	5.16
	Standard Deviation	0.22	0.38	0.22	0.34	0.38	0.42	0.36	0.14	0.20	0.42	0.26	0.59	0.35
Vinolok 18.2	R1	6.09	4.48	4.55	6.00	4.47	5.16	6.25	3.58	2.30	3.73	3.55	3.55	5.52
	R2	6.18	4.87	4.31	6.44	4.11	4.94	6.30	3.48	3.07	2.86	3.54	3.15	5.48
	R3	6.18	4.69	4.94	6.48	4.21	5.13	5.65	3.46	3.24	2.89	3.59	3.29	5.39
	R4	6.13	4.87	4.47	6.03	4.07	6.07	6.10	3.27	2.89	3.25	2.98	2.09	5.78
	Mean	6.14	4.73	4.57	6.24	4.22	5.33	6.07	3.45	2.87	3.18	3.42	3.02	5.54
	Standard Deviation	0.04	0.16	0.23	0.22	0.15	0.44	0.26	0.11	0.35	0.35	0.25	0.56	0.14
Vinolok 18.5	R1	5.93	4.89	4.64	6.44	4.38	4.39	6.00	3.39	2.67	2.71	3.91	3.63	5.38
	R2	5.95	5.23	4.35	5.94	3.80	5.10	5.77	3.50	2.65	3.40	3.08	2.97	5.18
	R3	6.19	5.25	4.45	5.78	4.00	5.25	6.04	3.83	2.74	2.70	3.78	3.07	5.51
	R4	5.74	4.74	4.63	5.97	3.41	4.99	6.02	3.87	2.75	3.22	3.44	2.53	5.46
	Mean	5.95	5.03	4.51	6.03	3.90	4.93	5.96	3.65	2.70	3.01	3.55	3.05	5.38
	Standard Deviation	0.16	0.22	0.12	0.25	0.35	0.33	0.11	0.21	0.04	0.31	0.33	0.39	0.13