IMPACT OF DIFFERENT CLOSURES ON INTRINSIC SENSORY WINE QUALITY AND CONSUMER PREFERENCES

Paulo Lopes[1]*, Isabel Roseira[1], Miguel Cabral[1], Cédric Saucier[2], Philippe Darriet[2], Pierre-Louis Teissedre[2], Denis Dubourdieu[2]

[1] Amorim & Irmãos, S.A., Research & Development, Rua de Meladas 380, 4536-902 Mozelos VFR – Portugal.

[2]UMR1219 Œnologie, Faculté d'Œnologie - ISVV, 210 Chemin de Leysotte, CS 50008, 33882 Villenave d'Ornon-France

*Corresponding Author. Email: pdl@net.sapo.pt

Introduction

For nearly 400 years natural cork stoppers have remained the standard by which wine was packaged, shipped, and presented to consumers. However, in the 1990s, the increasing awareness by consumers of problems associated with natural cork, such as “cork taint” has encouraged wine manufacturers to seek alternative closures such as synthetic closures and screw caps. Although, the market share has been eroded since the mid-1990s, cork stoppers still seal around 70% of the 18 billion wine bottles produced per year; while, 15 and 20% of bottled wines are sealed with synthetic and screw caps, respectively (Bates 2010). Wine industry still express some hesitation with alternative closures, caused by the evidences that cork stop ers have the most appropriate properties to seal wine bottles, which contrasts with the less-than-ideal barrier properties of synthetic closures and screw caps (Godden et al. 2005). Since the cork industry has enhanced its reliability in delivering untainted corks in the last years, perception and status of cork stoppers has improved, which contributed to reverse the movement towards screw caps and synthetic closures.

Aesthetic considerations and brand image are often among the major selling points for wines and must take into account to ensure consumer acceptance (Mueller and Lockshin, 2008). Although, closure choice is theoretically a technical decision based on its sealing properties, wine producers are also influenced by the players in the marketplace and consumers preferences. In addition, sustainability and environmental credentials associated with each closure seem, nowadays, also influence wine producer’s closure choice, although this is not clear how wine consumers perceive and value the environmental friendless of each closure.

This article aims, primarily, to resume the extensive work carried out by the Faculty of Enology of Bordeaux and also by the R&D Department of Amorim on the barrier properties of different wine closures, especially in the determination of their oxygen transmission rates and evaluate its impact on the flavor, color and sensory properties of wines during post-bottling. The results contributed to elucidate the role of oxygen on wine development during the post-bottling period and determine the importance of bottling and closure technologies for this phenomenon. Secondly a brief summary is presented regarding recent studies about the importance of closures on wine extrinsic attributes; highlighting the trade and consumer's opinions, and attitudes toward closures and how this can affect their wine purchase decision.

Barrier properties of wine closures

The primary function of a closure as a part of wine packaging is to ensure a good seal, preventing sensory deterioration of the wine, providing barriers to moisture, oxygen, carbon dioxide, and other gases as well as flavors and aromas (Risch 2009). Unlike the glass bottle, not all closures are impermeable materials, and their sealing properties can lead to mass transfer of various small molecules, such as oxygen (Lopes et al. 2007; Lopes et al. 2011).

Oxygen transmission rates of closures

Lopes et al. (2005) optimised a non-destructive (i.e. a single bottle can be analyzed without compromising the closure seal) colorimetric method to measure oxygen ingress into wine bottles. This method infers oxygen ingress through closures by direct colorimetric scan of colorless wine bottles (375 mL) containing indigo carmine solutions that gradually changes color from yellow to indigo as oxygen reacts with the reduced indigo carmine. The method was developed to allow the calculation of the oxygen ingress rate through closures but also the amount of oxygen entrapped in the closure; the effect of oxygen inserted at bottling was not, in a first moment, taken into account.

Figure 1 shows the kinetics of oxygen ingress through different closures into wine bottles stored horizontally over 36 months. It can be observed that only the control (bottle sealed by flame) was completely airtight, while other closures allowed oxygen transmission into bottles. Oxygen ingress through cylindrical closures was much more important in the first month than in the following months of storage. This latter period was extremely dependent on the oxygen barrier properties of each closure (Lopes et al. 2006). “Technical” cork stoppers (1+1 and microagglomerate) exhibited a low level of oxygen transmission (0.1 to 0.4 µL per day). In contrast, synthetic closures, Nomacorc classic and Supremecorq, exhibited the highest oxygen transmission (6 and 13 µL per day respectively), reaching limit of quantification of the method (2.5 mL of oxygen) within 140 and 290 days, respectively. For natural corks, oxygen rates decrease over time (1.0 to 6.0 µL per day), being totally residual after the first 12 months of storage (0.1 to 0.8 µL per day). The apparent ingress of oxygen through screw cap saran-tin was substantially higher during bottling than in the following storage period. This appeared to be due to the insertion of oxygen contained within the screw cap in bottle headspace at the time of sealing. After bottling, the screw caps allowed the ingress of consistent low amounts of oxygen (0.1 to 0.3 µL per day) (Lopes et al. 2006).

Main routes and sources of oxygen ingress into bottles

Using above mentioned colorimetric method, an experiment was conducted to elucidate the main routes of oxygen ingress through a synthetic closure, Nomacorc classic, a natural cork and a microaagglomerate cork closure, into bottled wine (Lopes et al. 2007). These studies have used a polyurethane resin which is highly impermeable to oxygen, to cover different parts of the exposed surface of the closures in bottles. In addition, the fully covered bottles were also stored under argon atmosphere in order to prevent any contact with the atmospheric oxygen; therefore, only oxygen entrapped in closures, able to ingress into bottles, was measured. A schematic to illustrate the closure portions covered and storage conditions by the different treatments is given in **Figure 2**.

For the synthetic closures, the normal (without any coverage) and those sealed with polyurethane ring in the closure-glass interface did not differ significantly in oxygen level, reaching the limit of quantification of the colorimetric method after 8 months of storage. The synthetic closures fully covered and stored under argon allowed a significantly lower amount of oxygen ingress than the previous treatments, which essentially occurred during the first month of storage (**Figure 2**). The data clearly indicate that atmospheric oxygen essentially permeates throughout the synthetic closures.

The oxygen levels in bottles sealed with microagglomerate corks is seemingly unaffected by the presence of the polyurethane resin and storage under argon. This data seem to show the main source of oxygenation of wine bottles sealed with microagglomerate cork is the oxygen within closure's internal structure, which is released into bottles essentially during the first months of storage. Atmospheric oxygen entering throughout cork-glass interface or throughout cork is negligible.

Natural cork stoppers were also unaffected by the presence of the polyurethane resin during 38 months of storage. Therefore, this data indicate that oxygen within natural cork diffuses out of closure at decreasing rates through the first 12 months of storage. However, the levels of oxygen in bottles sealed without coverage were slightly higher, but statistically not significant, than those sealed with polyurethane ring in the closure-glass and fully covered stored bottles. This trend suggested that the cork–glass interface might be a residual secondary route for oxygen permeation, mainly after the first year of storage, but given the high variation within all treatments, this cannot be conclusively deduced.

Importance of oxygen inserted at bottling compared to oxygen transmission rates of closures

Recently, the colorimetric method was re-optimized in order to allow the calculation of not only the oxygen ingress rate through closures, oxygen entrapped into the closure, but also the amount of oxygen introduced at bottling. Using this method, the total oxygen entered into bottles during bottling (under vacuum -0.4 to -0.2 bar) and throughout storage was measured. The data allowed the development of non-linear models to predict the amount of oxygen entered at bottling and oxygen inserted into bottle due to the closure. In **figure 3** is represented the total oxygen amount introduced into wine bottles sealed under different closures stored horizontally over a self-life scenario of 36 months. The data indicate that the oxygen introduced at bottling is the major source of oxygenation, representing, regardless the type of closure, around 1 mL of oxygen (~2mg/L in 750 mL bottle, which can result in a decrease of sulphur dioxide levels by 10 mg/L). Therefore, the amount of oxygen inserted at bottling represent around 60% of the total amount of oxygen after 36 months of storage in bottles sealed with microagglomerate and natural corks; while oxygen entrapped in corks account to ~40%, being the remaining (in natural corks) due to the atmospheric entering through the closure/glass interface. Bottling contributes heavily to the total amount of oxygen into bottles sealed under screw caps saranex and saran-tin, representing respectively 60 and 85% of the total amount of oxygen over 36 months; the remaining corresponds to atmospheric oxygen that permeates throughout the different liners. In contrast, bottling only represents 16% of the total amount of oxygen in bottles sealed with Nomacorc over 36 months; while oxygen entrapped in closure and oxygen permeating throughout it accounts for 20% and 65%, respectively. These clearly shows that oxygen inserted at bottling are the most important source of oxygenation of bottles sealed under cork stoppers and screw caps, while for synthetic closures oxygen permeating throughout the closure is the major one, although its relative importance decreases with shorter shelf-life's.

Permeation of volatile compounds through closures

The barrier properties of closures are not exclusive to oxygen; other exogenous gases and volatile compounds seem to be able to permeate throughout some closures into bottled wines. This raised important questions about aerial wine contamination after bottling and which closures that can provide an effective seal to wine bottles. This field of research, relatively unexploited, was assessed by Lopes et al. (2011a). Wine model bottled solutions sealed microagglomerate, natural cork and synthetic, Nomacorc classic, closures were individually stored in a atmosphere with deuterium-labeled 2,4,6-trichloroanisole (d_5-TCA) (32 mg/dm^3 of air) used as exogenous aerial contaminant. During 36 months of storage, d_5-TCA was essentially retained in the outer portions of natural and microagglomerate, preventing the migration of this compound into bottled wine model solutions (**figure 4)**. This data indicate that cork stoppers are effective barriers to the transmission of exogenous aerial volatile compounds (Capone et al 2003). Conversely, d_5-TCA penetrated throughout synthetic closures and contaminated the wine (**figure 4)**. More recently, the authors have also shown that screw caps with permeable liners such as saranex can also allow the permeation of exogenous volatile compounds into bottles (Lopes et al. 2011b). Therefore, it can be deducted that closures favoring oxygen and air permeation through closures can also allow the ingress of other exogenous volatile compounds which under some storage conditions can negatively affect the intrinsic sensory properties of bottled wines. This aspect of closure performances is relatively unknown and uncommunicated to the wine industry, however, it seems to be critical once the primarily role of any wine packaging is to provide consistent and effective sealing qualities to ensure a perfect protection of bottled wines.

Impact of oxygen dissolved at bottling and transmitted through closures on the composition and sensory properties of a Sauvignon Blanc

There have been several studies assessing the influence of oxygen barrier properties of different closures on wine development after bottling (Godden et al. 2001; Skouroumounis et al. 2005, Lopes et al. 2009, Ugliano et al. 2009). Given their relatively high oxygen permeability, synthetic closures promote the wine development towards oxidation faster than the other closures. In contrast, reduced off-flavors have been reported to happen more frequently in wines sealed under screw caps, which is argued to be related to their very low oxygen permeability compared to other closures (Skouroumounis et al. 2005, Lopes et al. 2009, Ugliano et al. 2009). However, some authors consider that reductive off-flavors are only an expression of winemaking procedures and wine chemical composition; appropriate corrective action in the winery or vineyard should eliminate the problem (Godden et al. 2005).

Volatile sulfur compounds are often being responsible for reduced “off-flavor” characters, but also for typifying scents of some varietal wines such Sauvignon Blanc. Long chain polyfunctional thiols such as 3-Mercatohexanol (3MH) and 4-mercapto-4-methyl-2-pentanone (4MMP) display a remarkable effect on the typical box-tree and tropical fruit aroma of wines. In contrast, short-chain thiols, sulfides, disulfides, thioesters and heterocyclic compounds can spoil the wines with unpleasant aromas of onion, garlic, cooked cabbage, rotten eggs, rubber or putrefaction. These reactions can be regulated by the oxygen, which after bottling it is dependent of the operation itself but also from the barrier properties of closures. The Faculty of Enology of Bordeaux conducted between 2005 and 2008 a 24 months Sauvignon Blanc trial to assess the effect of the oxygen dissolved at bottling and the specific oxygen barrier properties of closures on its aromatic composition, color and sensory properties (Lopes et al. 2009). A 2004 unoaked Sauvignon Blanc wine free of any fault was bottled with eight sealing systems. The wine was then stored over 24 months under cellar conditions. Various chemical, colorimetric and sensory tests were carried out at 48 hours, 2, 12 and 24 months, analyzing five replicate per type of closure at each time point.

Figure 5 present the 24 month sensory and compositional analysis results for 8 different sealing technologies in the trial on a principal component analysis (PCA). This technique facilitates the visualization of the differences and similarities between wines sealed under different closures. Wine compositional parameters and sensory attributes at 24 months, dissolved oxygen at bottling and oxygen transfer rates of closures variables that display a strong relationship with each other, are clustered close together in **figure 5**. The wines plotted far from the origin were highest in those variables situated in close proximity.

The results showed that a poor oxygen management at bottling and the different closures generated a Sauvignon Blanc wine with different compositional and sensory properties after 24 months of storage. The bottle ampoule (hermetic system) and screw cap saran-tin were primarily separated by its high concentrations of antioxidant (ascorbic acid and sulfur dioxide), low color development and highest in pleasant 3MH, 4MMP. These wines were sensory rated high in freshness and aromatic intensity, but also in reductive characters which was associated with high levels of hydrogen sulfide (H_2S). The wines rated with the highest fruit intensity developed under natural cork but also with screw cap saranex, which was able to mitigate reduced like aromas, i.e. levels of H_2S presented by screw cap in wines, were not high enough to spoil the wine. In contrast, wines with oxidized characters developed under synthetic closures situated in the bottom left quadrant, where the wines presented the highest OD 420 nm, b*, c* and sotolon concentration. The microagglomerate cork was further discriminated on the basis of its oxygen content at bottling. Both agglomerate and colmated corks were close to the origin, presenting intermediary levels of chemical compounds and balanced sensory attributes.

The Sauvignon Blanc wine style evolution is consistent with the different oxygen content at bottling, but also with the different oxygen transfer rates of closures. Wines displaying the highest oxidized characters, high color development (high OD 420 nm, C*, b*) and high concentration of oxidative compounds such as sotolon (spicy nutty aromas) are consistent with those either submitted to high oxygenation at bottling and/or those sealed under closures with high oxygen transmission rates (OTR). Closures with low OTR such as natural cork, colmated and screw cap saranex generated high fresh tropical fruit wines with a relatively balanced concentration of varietal thiols, antioxidant compounds and color development. Under hermetic conditions or with very low OTR, wines presented high levels of H_2S, which were responsible for the strong reductive, “rotten egg” and “putrefaction” characters detected in wines sealed in bottle ampoule and screw cap saran-tin.

This study, together, with the results of previous research, indicate that the combination of bottling conditions and oxygen transfer rates of different closures have a significant effect on compositional and sensory properties of wines during post-bottling. The different style evolution generated by different closures was significant and probably strong enough to have an impact on the consumer's liking of this wine. Recently O'Brien et al. (2009) have shown that differences in sensory properties of a Semillon wine generated by different closures and detected by panelist experts were strong enough to be perceived by the Australian consumers and impact their enjoyment and liking of the product. From this study, it become clear that specific consumers segments react negatively to the presence of TCA, oxidation and mainly to the presence of reductive charterers. These results emphasize the importance of the oxygen management at bottling but also the barrier properties of closures. These variables can optimize wine intrinsic sensory properties and therefore, maximize the consumer preferences. However, wine is a credence good, consumers cannot ascertain their sensory intrinsic properties during purchase. Therefore, the consumer relies on wine extrinsic cues such as packaging to obtain credible information related to the quality of the product (Lockshin and Hall, 2003).

Importance of closures on wine extrinsic attributes

Packaging extrinsic attributes such as closure, bottle color and shape, label type and color are generally considered as supporting, rather than dominant wine cues such as price, brand, variety, and country/region (Mueller and Lockshin 2008). Nevertheless, several studies have shown that the type of closure adds directly value to the look of the product and is considered by most consumers as a direct reflection of the quality of the wine, playing an important role during situational purchase decisions (Chaney 2000, Marin et al. 2007, Marin and Durham 2007, Barber et al. 2008). While synthetic corks and screw caps seem to be functional alternatives to cork stoppers, they create other problems, such as poor brand image. If a wine is selected for a wine list and the type of closure does happen to be a screw cap or synthetic, consumer is likely to assume that they have selected a lower quality wine, even if they have paid a premium for the bottle (Barber et al. 2008).

Several market studies have showed that wine consumers in countries such as Australia, France, U.K. and U.S., rated wine sealed with cork stoppers as the most preferred choice, mainly for special occasions, gift giving, and dinner parties (Bleibaum et al. 2005, Penn 2007). While French and Americans consumers always prefer wines sealed under cork regardless the situation use, Australians and U.K. consumers with a longer history of alternatives use, were less influenced by negative connotations of synthetic and screw caps.

Marin et al. (2007) reported that tasting the wine before purchase has a strong impact on consumers purchase decision regardless of the type of closure. Yet, consumer's ratings on wine quality decreased for wines sealed with screw caps, when the closure information is given. Furthermore, consumers expected to pay significantly less for wines sealed under screw cap, which indicates that closure type impacts in the expected price both directly and indirectly through consumer perception of quality (Marin and Durham 2007). Differences of consumer preferences towards closures reflects the prices of wine in market as it was observed in a hedonic price analysis of red wine scanner data from two U.S. Markets (Chicago and Tampa) showing that cork-sealed wine brands displayed a US$2.04 premium price over brands finished with alternative closures (Mueller and Szolnoki 2010).

Key messages

In summary, this paper shows, together with the results of other research, that wine matrix composition combined with bottling conditions and/or different closure barrier properties have a significant impact on the sensory intrinsic quality of wine presented to the consumers. Operations and closures technologies that promote high and continuous atmospheric air exposure, at bottling and throughout storage, accelerate the wine development towards oxidation, affecting negatively and irreversibly wine sensory properties. Therefore, maintain low levels oxygen exposure during wine storage life cycle is extremely important because storage conditions, self-life's and consumption moment cannot be fully controlled by the different players of the wine supply chain. A strict oxygen management before and at bottling, combined with the use of closure with low OTR and effective barrier properties, have an important contribution to the preservation of the varietal characters and kept the deleterious sulfides at residual levels. Differences on wine intrinsic sensory properties strongly impact consumer's preference and enjoyment of the product and therefore play an important role on a future re-purchase of wines. In addition, type of closure seems to be a relevant marketing tool as a part of wine extrinsic attributes, conveying visual, audible and tactile information to the consumer about a product. Numerous studies showed that cork is still ingrained in the minds of consumers as the status quo, while screw caps and synthetics introduce a cognitive dissonance, creating poor brand image and thus negative influence in the purchase and price.

References

Barber, N. and Almanza B.A. (2006), Influence of wine packaging on consumers' decision to purchase, Journal of Food Business Research **2006**, 9 (4), 83-98.

Barber, N., Meager, M. and Kolyesnikova . A new twist on tradition: sealing the experience to U.S. wine consumers". Journal of Culinary Science & Technology **2008,** 6 (4), 325-342.

Bates, J. A corking argument: special report wine closures. *The IWSR Drinks Record* **2010**, *June*, 27-29.

Bleibaum, R.N., Lattey, K.A. and Francis, I.L. (2005), "Conjoint research for consumer perception of wine closure options and their impact on purchase interest in the United States and Australia". Presented at 6th Pangborn Sensory Science Symposium, Harrogate, UK, available at: http://www.trag on.com/articles/2005PangbornWineClosures.pdf (accessed 22 January 2012).

Capone, D.; Skouroumounis, G.K.; Sefton, M.A. Permeation of 2,4,6-trichloroanisole through corks closures in wine bottles. *Aust. J. Grape Wine Res.* **2002**, 8, 196-199.

Chaney, I. M. (2000), "External Search Effort for Wine", International Journal of Wine Marketing, Vol. 12, pp. 5-21.

Godden, P.; Francis, L.; Field, J.; Gishen, M.; Coulter, A.; Valente, P.; Hoj, P.; Robinson, E. Wine bottle closures: physical characteristics and effect on composition and sensory properties of a Semillion wine. Performance up to 20 months post-bottling. *Aust. J. Grape and Wine Res.* **2001**, *7*, 62-105.

Godden, P.; Lattey, K.; Francis, L.; Gishen, M.; Cowey, G.; Holdstock, M.; Robinson, E.; Waters, E.; Skouroumounis, G.; Sefton, M.; Capone, D.; Kwiatkowski, M.; Field, J.; Coulter, A.; D'Costa, N.; Bramley, B. Towards offering wine to the consumer in optimal condition – the wine, the closures and other packaging variables. A review of AWRI research examining the changes that occur in wine after bottling. *Wine Ind. J.* **2005**, *20*, 20-30.

Lockshin, L.; Hall, J. Consumer purchasing behaviour for wine: What we know and where we are going", paper presented at International Wine Marketing Colloquium, July, 2003, Adelaide, Australia.

Lopes, P.; Saucier, C.; Glories, Y. Nondestructive colorimetric method to determine the oxygen diffusion rate through closures used in winemaking. *J. Agric. Food Chem.* **2005**, *53*, 6967-6973.

Lopes, P.; Saucier, C.; Teissedre, P.L.; Glories, Y. Impact of storage position on oxygen ingress through different closures into wine bottles. *J. Agric. Food Chem.* **2006**, 54, 6741-6746.

Lopes, P.; Saucier, C.; Teissedre, P.L.; Glories, Y. Main routes of oxygen ingress through different closures into wine bottles. *J. Agric. Food Chem.* **2007**, 55, 5167-5170.

Lopes, P.; Silva, M.A.; Pons, A.; Tominaga, T.; Lavigne, V.; Saucier, C.; Darriet, P.; Teissedre, P.L.; Dubourdieu, D. Impact of oxygen dissolved at bottling and transmitted through closures on the composition and sensory properties of Sauvignon Blanc wine during bottle storage. *J. Agric. Food Chem.* **2009**, 57, 10261-10270.

Lopes, P.; Marques, J.; Lopes, T.; Lino, J.; Coelho, J.; Álves C.; Roseira, I.: Mendes, A.; Cabral, M. Permeation of d_5-2,4,6-trichloroanisol via vapor phase through different closures into Wine Bottles. *Am. J. Enol. Vitic*. **2011**, 62- 2.

Lopes, P.; Marques, J.; Pimenta, M.; Alves, C.; Roseira, I.; Mendes, A.; Cabral, M. Sealing effectiveness of different type of closures to volatile phenols and hanisoles. *In proceedings of the 34th World Congress of Vine and Wine OIV*, 20-27th June 2011, Porto-Portugal.

Marin, A.B.; Jorgensen, E.M.; Kennedy, J.A; Ferrier, J. Effects of bottle closure type on consumer perception of wine quality, American Journal of Enology and Viticulture*,* **2007**, 58 (2), 182-191.

Marin, A.B.; Durham, C. (2007), Effects of wine bottle closure type on consumer purchase intent and price expectation", American Journal of Enology and Viticulture **2007b**, 58 (2), 192-201.

Mueller, S.; Lockshin, L. How important is wine packaging for consumers: On the reliability of measuring attribute importance with direct verbal and indirect visual methods", paper presented at 4th International Conference of the Academy of Wine Business Research, Siena (It), 17-19th July 2010, 1-19.

Mueller, S.; Szolnoki, G. Wine packaging and labeling – do they impact market prices? A hedonic price analysis of US scanner data", paper presented at 5th International Academy of Wine Business Research Conference, 8-10 Feb 2010 Auckland (NZ), 1-7.

O'Brien, V.; Francis, L.; Osidacz, P. Packaging choices affect consumer enjoyment of wines. *Wine Industry J.* **2009**, 24(5), 24-28.

Pen, C., 2007. Independent consumer research on closures. April 2007, Wine Business Monthly. Available at: http://www.winebusiness.com/wbm/index.cfm?go=getArticle&dataId=47416 (accessed 27 January 2012).

Skouroumounis, G.K.; Kwiatkowski, M.J.; Francis, I.L.; Oakey, H.; Capone, D.; Duncan, B.; Sefton, M.A.; Waters, E.J. The impact of closure type and storage conditions on the composition, colour and flavour properties of a Riesling and a wooded Chardonnay wine during five years'storage. *Aust. J. Grape and Wine Res.* **2005**, 11, 369-384.

Risch, S. Food packaging history and innovations. *J. Agric. Food Chem.* **2009**, *57*, 8089-8092.

Ugliano, M.; Kwiatkowski, M.J.; Travis, B.; Francis, L.; Waters, E.J.; Herderich, M.J.; Pretorius, I.S. Post-bottling management of oxygen to reduce off-flavour formation and optimize wine style. *Wine Industry J.* **2009**, 24(5), 24-28.

Figure 1. Kinetics of oxygen ingress through different closures into commercial bottles stored horizontally over 36 months. Error bars represent the standard deviation of 4 replicates.

Figure 2. The effect of Polyurethane varnish coverage of natural cork, microagglomerate and synthetic closure on the oxygen entry in wine bottles during 38 months' storage horizontal at 20 ± 1 °C. Error bars represent the standard deviation of 4 replicates.

Figure 3. Total oxygen introduced into wine bottles sealed with different closures stored horizontally over three years. The values include the oxygen inserted at bottling (under vacuum -0.4 to -0.2 bar); oxygen within closure and released into bottles, and oxygen inserted through permeable closure over time.

Figure 4. Levels of exogenous d_5-TCA in bottled wine model solutions sealed with different closures during 36 months. Values per each analysis point and per closure are the means of 5 replicates.

Figure 5. Biplot of principal components analysis of the sensory and compositional attributes of a Sauvignon Blanc bottled wine sealed under 8 different sealing systems for 24 months of storage. The 8 wines are represented as larger symbols with the sensory and compositional variables represented by small orange and blue small circles, respectively. Compositional attributes: 3MH = 3-mercaptohexan-1-ol; 4MMP = 4-mercapto-4-methylpentan-2-one; H_2S = hydrogen sulfide; $[O_2]$ bottling = oxygen dissolved at bottling; Closure OTR = oxygen transfer rates.

Figure 1

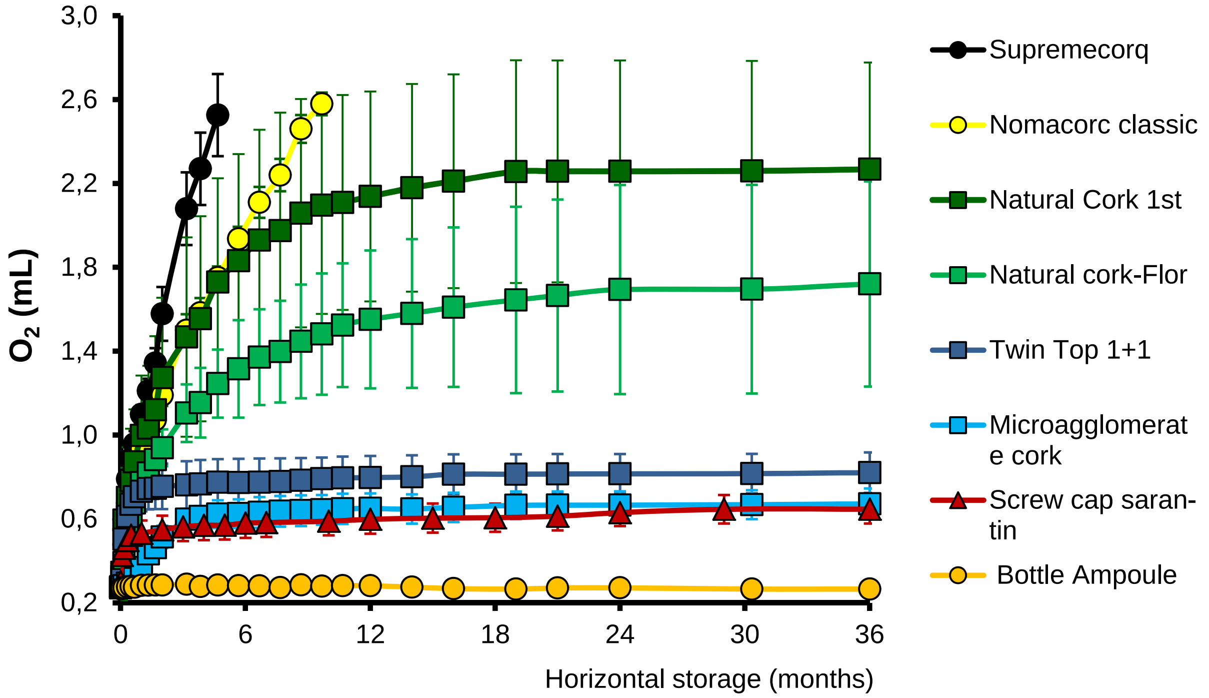
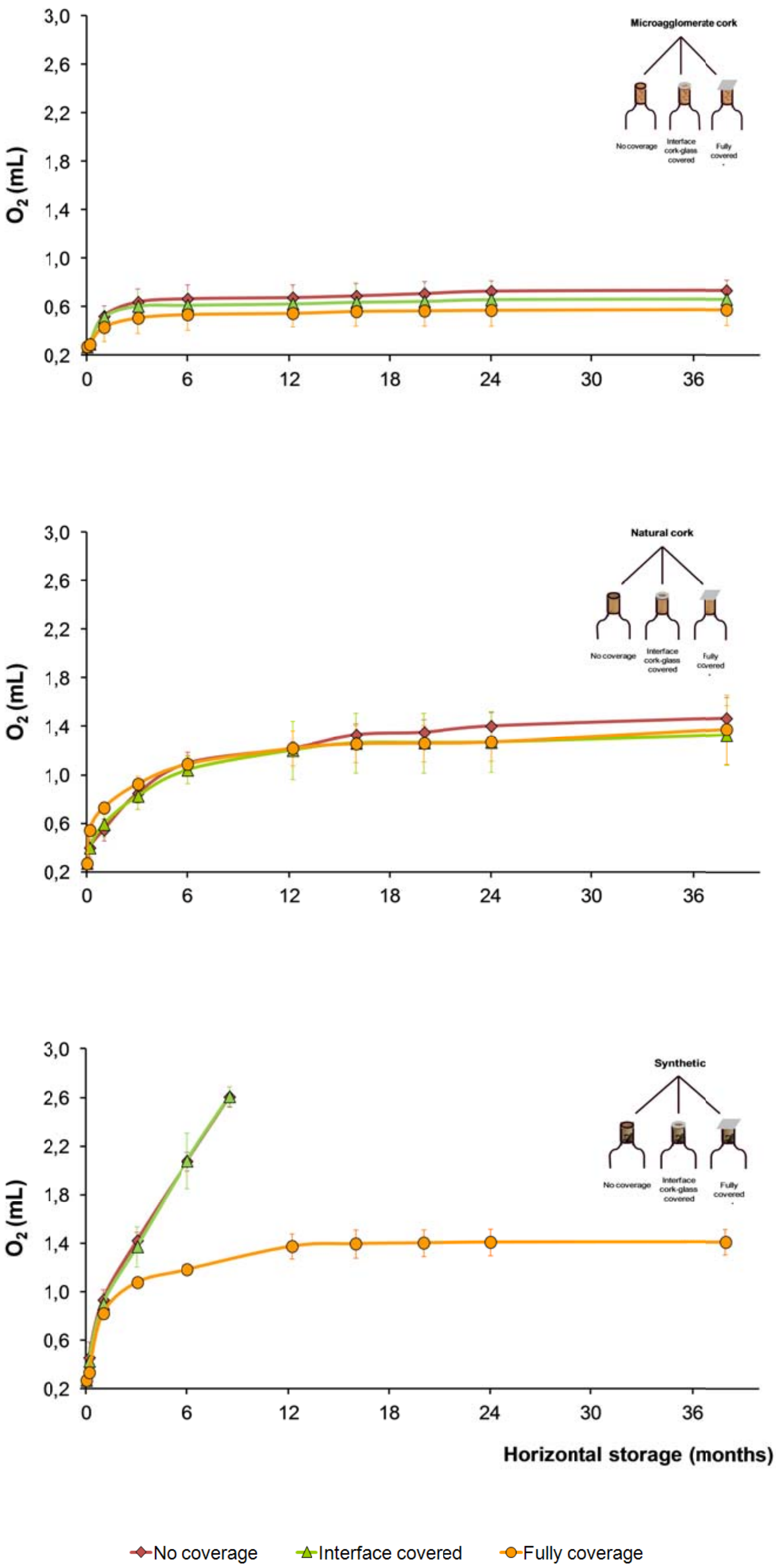

3,0
2,6
2,2
1,8
1,4
1,0
0,6
0,2
O2 (mL)
0
6
12
18
24
30
36
Horizontal storage (months)
Supremecorq
Nomacorc classic
Natural Cork 1st
Natural cork-Flor
Twin Top 1+1
Microagglomerat e cork
Screw cap saran-tin
Bottle Ampoule

Figure 2



Microagglomerate cork
No coverage
Interface cork-glass covered
Fully covered
Natural cork
Synthetic
O_2 (mL)
3,0
2,6
2,2
1,8
1,4
1,0
0,6
0,2
0
6
12
18
24
30
36
Horizontal storage (months)
No coverage
Interface covered
Fully coverage

Figure 3

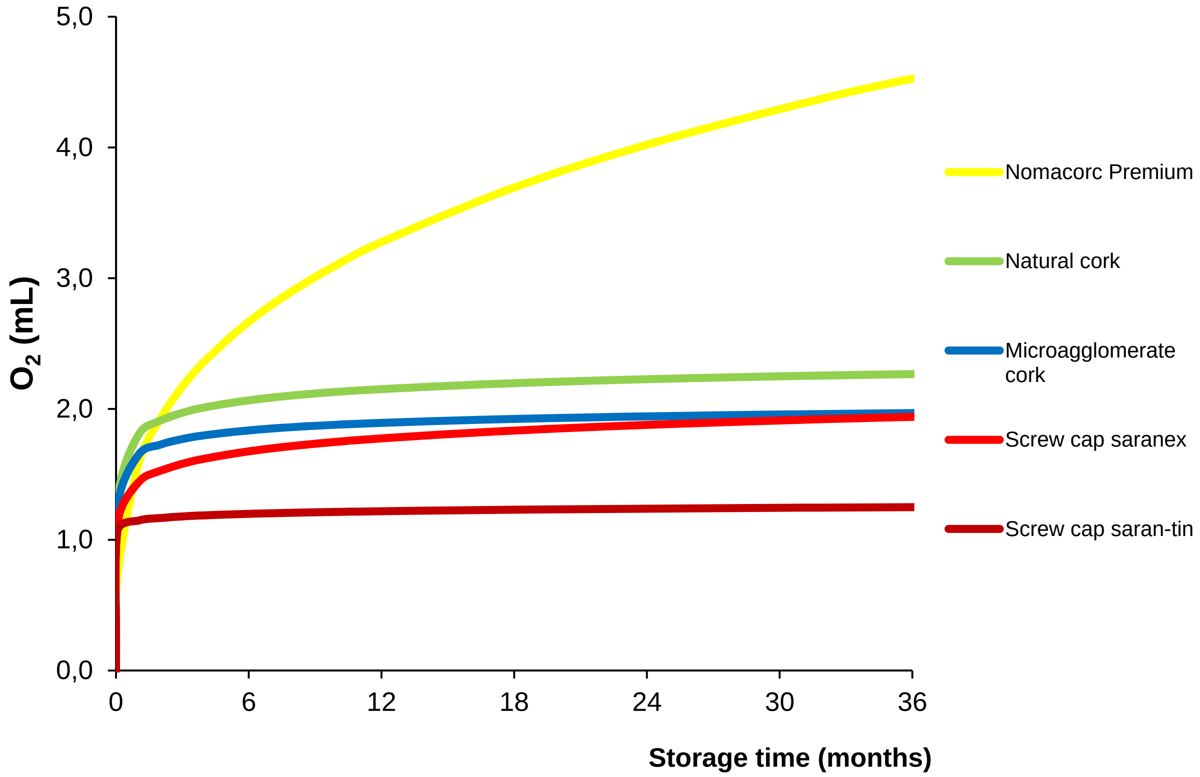


Figure 4

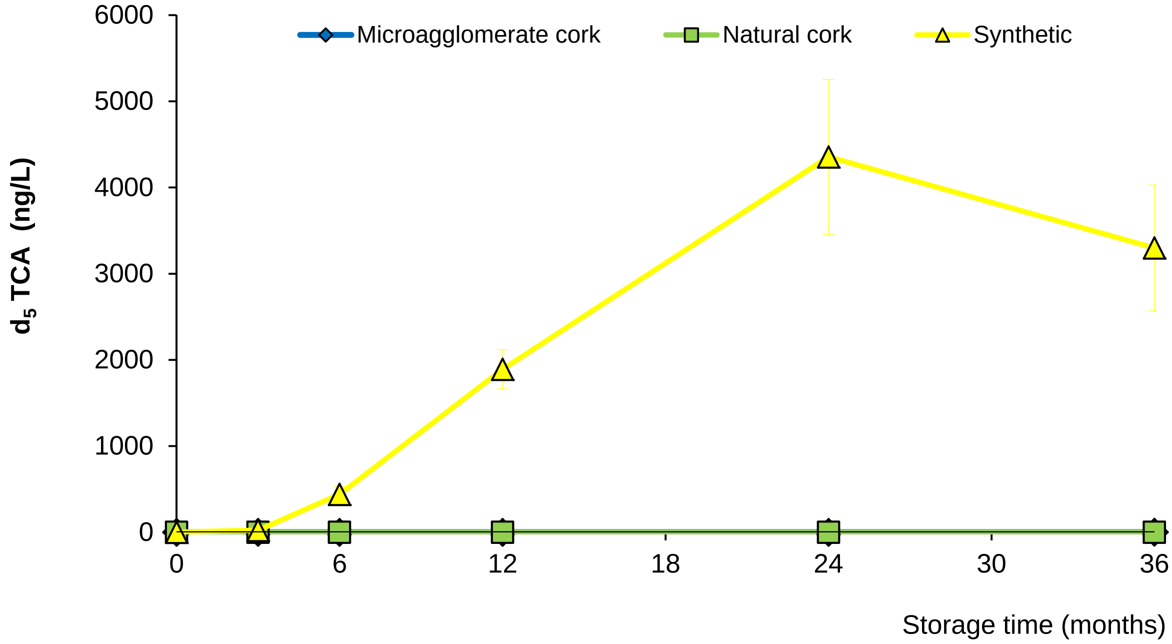
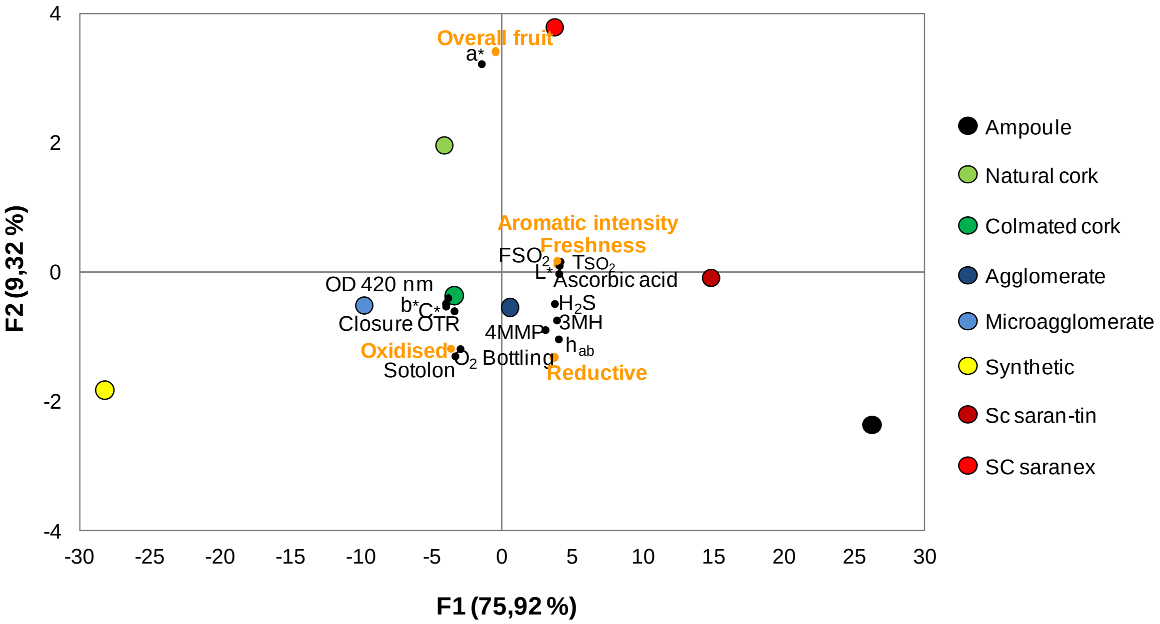


Figure 5



F2 (9,32 %)
F1 (75,92 %)
Overall fruit
a*
Aromatic intensity
Freshness
FSO2
TSO2
L*
Ascorbic acid
OD 420 nm
b*
C*
Closure OTR
H2S
3MH
4MMP
hab
Oxidised
O2 Bottling
Sotolon
Reductive
Ampoule
Natural cork
Colmated cork
Agglomerate
Microagglomerate
Synthetic
Sc saran-tin
SC saranex