Impact of different closures on intrinsic sensory wine quality and consumer preferences

By Paulo Lopes[1]*, Isabel Roseira[1], Miguel Cabral[1], Cédric Saucier[2], Philippe Darriet[2], Pierre-Louis Teissedre[2] and Denis Dubourdieu[2]
[1]Amorim & Irmãos, S.A., Research & Development, Rua de Meladas 380, 4536-902 Mozelos VFR, Portugal
[2]UMR1219 Oenologie, Faculté d'Oenologie - 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 were the standard by which wine was packaged, shipped, and presented to consumers. However, in the 1990s, the increasing awareness among consumers of problems associated with natural cork, such as 'cork taint', has encouraged wine producers to seek alternative closures, such as synthetic closures and screwcaps. 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 closures and screwcaps, respectively (Bates 2010). The wine industry still expresses some hesitation with alternative closures, due to the evidence that cork stoppers have the most appropriate properties to seal wine bottles, which contrasts with the less-than-ideal barrier properties of synthetic closures and screwcaps (Godden *et al.* 2005). Since the cork industry has enhanced its reliability in delivering untainted corks in recent years, the perception and status of cork stoppers has improved, which contributed to slowing the movement towards screwcaps and synthetic closures.

Aesthetic considerations and brand image are often among the major selling points for wines, which must be taken 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, to also influence wine producers' closure choice, although it is not clear how wine consumers perceive and value the environmental friendliness 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 Amorim R&D department on the barrier properties of different wine closures, especially in the determination of their oxygen transmission rates and evaluating its impact on the flavour, colour and sensory properties of wines post-bottling. The results contributed to elucidating the role of oxygen on wine development during the post-bottling period, and determining the importance of bottling and closure technologies for this phenomenon. Secondly, a brief summary is presented of recent studies about the importance of closures on wine extrinsic attributes, which highlights both the trade's and consumers' opinions, and attitudes toward closures and how this can affect their wine purchase decision.

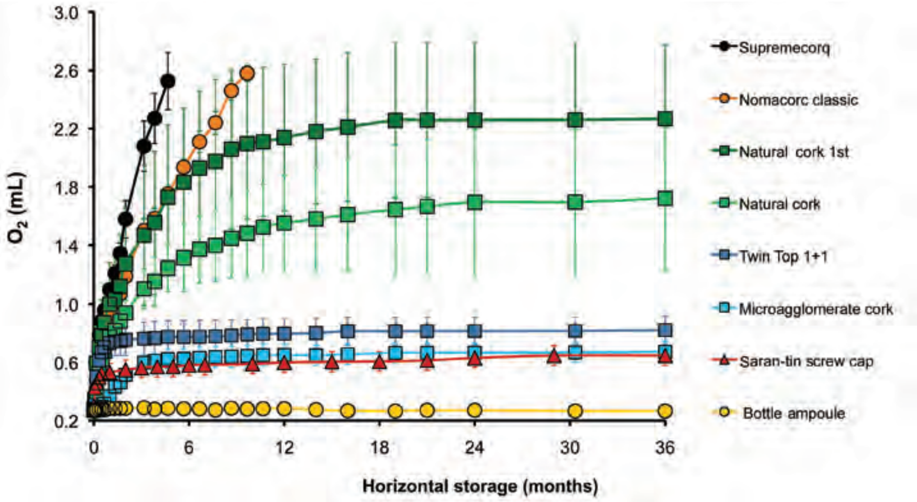

Figure 1. Kinetics of oxygen ingress through different closures into commercial bottles stored horizontally over 36 months. Error bars represent the standard deviation of four replicates.

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 flavours 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 analysed without compromising the closure seal) colourimetric method to measure oxygen ingress into wine bottles. This method infers oxygen ingress through closures by direct colourimetric scan of colourless wine bottles (375mL) containing indigo carmine solutions. The solutions gradually change colour 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, and the amount of oxygen contained in the closure; the effect of oxygen inserted at bottling was not, initially, 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 (0.1-0.4μL per day). In contrast, synthetic closures - Nomacorc classic and Supremecorq - exhibited the highest oxygen transmission (6μL and 13μL per day, respectively), reaching the limit of quantification of the method (2.5mL of oxygen) within 140 and 290 days, respectively. For natural corks, oxygen rates decreased over time (1.0-6.0μL per day), being totally residual after the first 12 months of storage (0.1-0.8μL per day). The apparent ingress of oxygen through saran tin screwcap was substantially higher during bottling than in the following storage period. This appeared to be due to the insertion of oxygen contained within the screwcap in the bottle headspace at the time of sealing. After bottling, the screwcaps allowed the ingress of consistent low amounts of oxygen (0.1-0.3μL per day) (Lopes *et al*. 2006).

Main routes and sources of oxygen ingress into bottles

Using the colourimetric method, an experiment was conducted to elucidate the main routes of oxygen ingress through a synthetic closure, Nomacorc classic, a natural cork and a microagglomerate cork closure, into bottled wine (Lopes *et al*. 2007). These studies 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 atmospheric oxygen. Therefore, only oxygen contained 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 (see page 36).

For the synthetic closures, the normal (without any coverage) and those sealed with a polyurethane ring in the closure-glass interface did not differ significantly in oxygen level, reaching the limit of quantification of the colourimetric method after eight 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 indicates 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 seems to show the main source of oxygenation of wine bottles sealed with microagglomerate cork is the oxygen within the closure's internal structure, which is released into bottles essentially during the first months of storage. Atmospheric oxygen entering through the cork-glass interface or through the cork is negligible.

Natural cork stoppers were also unaffected by the presence of the polyurethane resin during 38 months of storage. Therefore, this data indicates that oxygen within natural cork diffuses out of the 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 a polyurethane ring in the

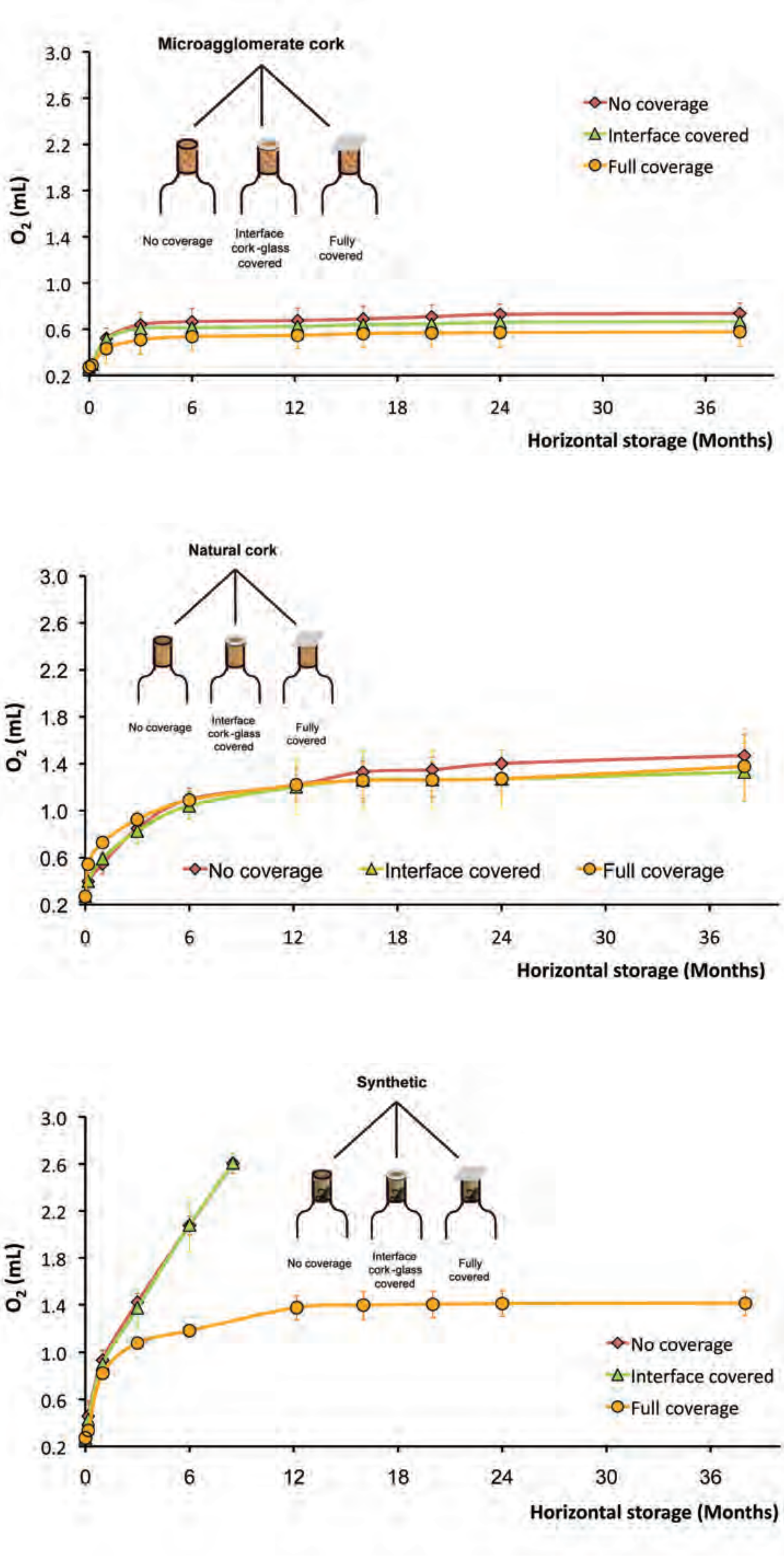

Figure 2. The effect of polyurethane varnish coverage of natural cork, microagglomerate and synthetic closure on the oxygen entry in wine bottles during 38 months' horizontal storage at 20 ± 1°C. Error bars represent the standard deviation of four replicates.

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 with oxygen transmission rates of closures

Recently, the colourimetric method was re-optimised in order to allow the calculation of not only the oxygen ingress rate through closures and oxygen contained in 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 the bottle due to the closure. Figure 3 represents the total amount of oxygen introduced into wine bottles sealed under different closures stored horizontally over a shelf-life scenario of 36 months. The data indicates that the oxygen introduced at bottling is the major source of oxygenation, representing, regardless the type of closure, around 1mL of oxygen (~2mg/L in a 750mL bottle, which can result in a decrease of sulfur dioxide levels by 10mg/L). Therefore, the amount of oxygen inserted at bottling represents around 60% of the total amount of oxygen after 36 months of storage in bottles sealed with microagglomerate and natural corks, while oxygen contained in corks account for ~40%, being the remaining amount (in natural corks) due to the atmospheric oxygen entering through the closure-glass interface. Bottling contributes heavily to the total amount of oxygen entering bottles sealed under both saranex and saran tin screwcaps, representing, respectively, 60% and 85% of the total amount of oxygen over 36 months. The remaining amount 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 contained in-closure and oxygen permeating throughout it accounts for 20% and 65%, respectively. These figures clearly show that oxygen inserted at bottling is the most important source of oxygenation of bottles sealed under cork stoppers and screwcaps, while for synthetic closures oxygen permeating throughout the closure is the major one, although its relative importance decreases with shorter shelf-lives.

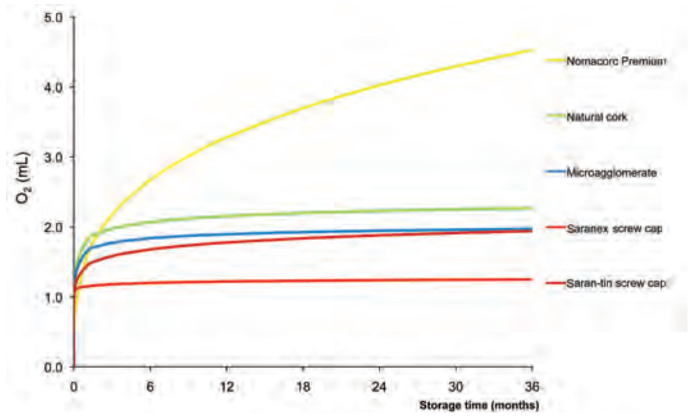

Figure 3. Total oxygen introduced into wine bottles sealed with different closures stored horizontally over 36 months. The values include the oxygen inserted at bottling (under vacuum -0.4 to -0.2 bar); oxygen within closure and released into bottles; and oxygen inserted through permeable closure over time.

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 can provide an effective seal to wine bottles. This relatively unexploited field of research was assessed by Lopes *et al.* (2011a). Wine-model bottled solutions sealed with microagglomerate, natural cork and synthetic Nomacorc classic closures were individually stored in an atmosphere with deuterium-labelled 2,4,6-trichloroanisole (d_5-TCA) (32mg/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 closures, preventing the migration of this compound into bottled wine-model solutions (Figure 4, see page 38). This data indicates 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, see page 38). More recently, the authors have also shown that screwcaps 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 favouring oxygen and air permeation 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 to the wine industry, however, it seems to be critical, given the primary role of wine packaging is to provide consistent and effective sealing qualities to ensure the 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's development towards oxidation faster than the other closures. In contrast, reductive off-flavours have been reported to happen more frequently in wines sealed under screwcap, which is argued to be related to their low oxygen permeability compared with other closures (Skouroumounis *et al.* 2005, Lopes *et al.* 2009, Ugliano

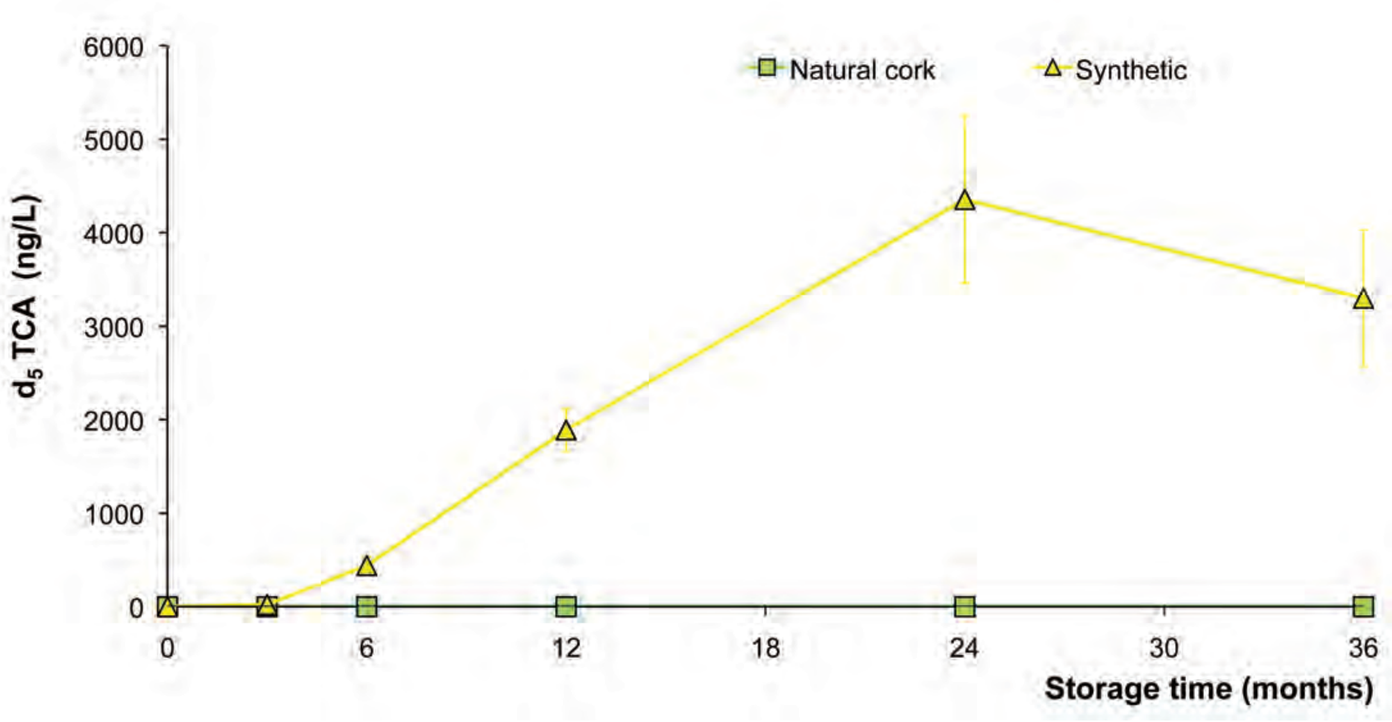

Figure 4. Levels of exogenous d_5-TCA in bottled wine-model solutions sealed with different closures during 36 months. Values per each analysis point and per closure are the means of five replicates.

et al. 2009). However, some authors consider that reductive off-flavours 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 held responsible for reduced 'off-flavour' characters, and also for typifying the 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 is independent of the operation itself, and also from the barrier properties of closures. Between 2005-2008, the Faculty of Enology of Bordeaux conducted a 24-month Sauvignon Blanc trial to assess the effect of oxygen dissolved at bottling and the specific oxygen barrier properties of closures on its aromatic composition, colour 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, colourimetric and sensory tests were carried out at 48 hours, and two, 12 and 24 months, analysing five replicates per type of closure at each time point.

Figure 5 presents the 24-month sensory and compositional analysis results for eight different sealing technologies in the trial on a principal component analysis (PCA). This technique facilitates the visualisation 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

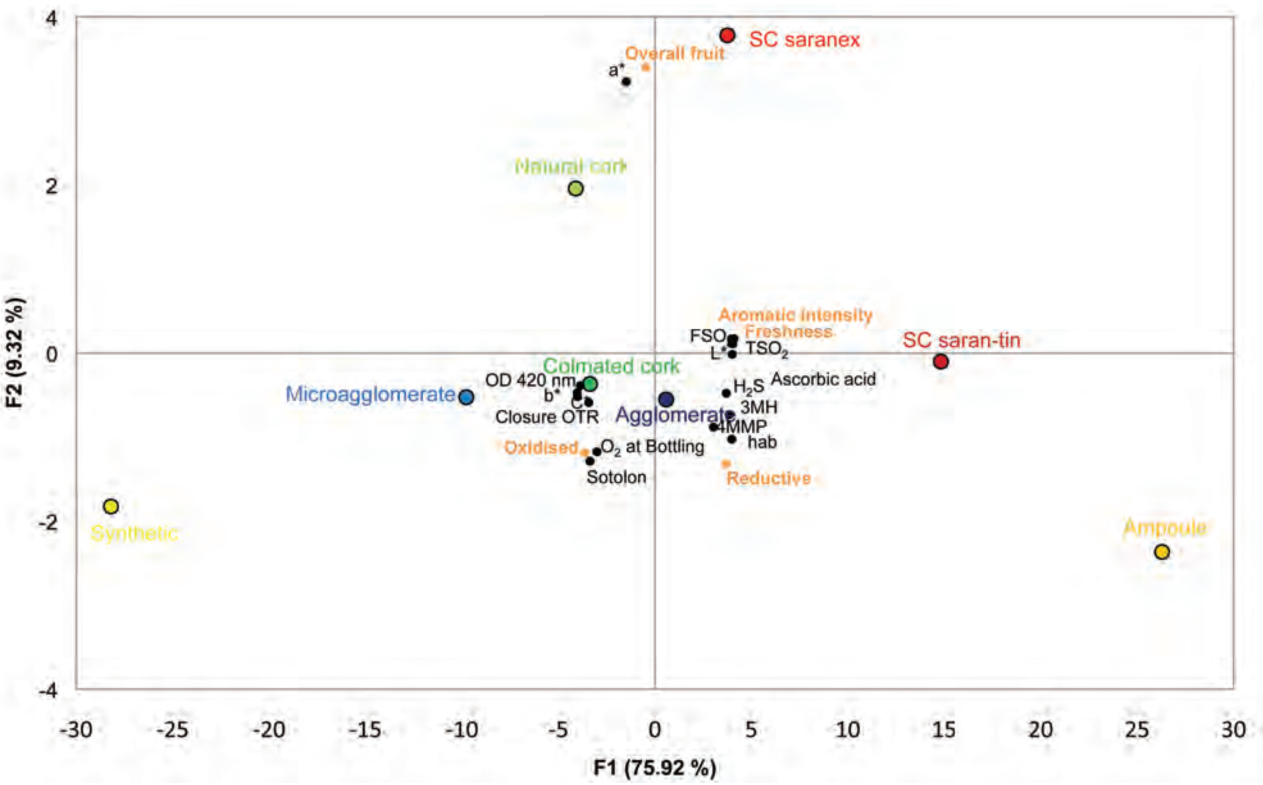

Figure 5. Bi-plot of principal components analysis of the sensory and compositional attributes of a Sauvignon Blanc bottled wine sealed under eight different sealing systems for 24 months of storage. The eight wines are represented as larger symbols, with the sensory and compositional variables represented 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.

rates of closure 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 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 saran tin screwcap were primarily separated by the high concentrations of antioxidant (ascorbic acid and sulfur dioxide) and low colour development. The wine was also highest in pleasant 3MH, 4MMP. These wines rated high in sensory 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 saranex screwcap, which was able to mitigate reduced-like aromas, i.e., levels of H_2S presented by screwcap in wines, which were not high enough to spoil the wine. In contrast, wines with oxidised characters developed under synthetic closures presented in the bottom left quadrant, where the wines showed the highest OD 420nm, 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, and with the different oxygen transfer rates of closures. Wines displaying the highest oxidised characters, high colour development (high OD 420nm, 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 or those sealed under closures with high oxygen transmission rates (OTR). Closures with low OTR, such as natural cork, colmated and saranex screwcap, generated fresh tropical fruit wines with a relatively balanced concentration of varietal thiols, antioxidant compounds and colour 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 saran tin screwcap.

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. O'Brien *et al.* (2009) have shown that differences in sensory properties of a Semillon wine generated by different closures and detected by panellist experts, were strong enough to be perceived by Australian consumers and impact on their enjoyment and liking of the product. From this study, it becomes clear that specific consumer segments react negatively to the presence of TCA, oxidation and, mainly, to the presence of reductive characters. These results emphasise the importance of oxygen management at bottling, and the barrier properties of closures. These variables can optimise wine's intrinsic sensory properties and, therefore, maximise consumer preferences. However, wine is a credence product; consumers cannot ascertain its sensory intrinsic properties during purchase. Therefore, the consumer relies on wine's 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'S EXTRINSIC ATTRIBUTES

Extrinsic attributes of packaging, such as closure, bottle colour and shape, and label type and colour, 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 direct 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 screwcaps seem to be functional alternatives to cork stoppers, they create other problems, such as poor brand image. If a wine is selected from a wine list and the type of closure does happen to be a screwcap or synthetic, the consumer is likely to assume that he or she has selected a lower quality wine, even if he or she had paid a premium for the bottle (Barber *et al.* 2008).

Several market studies have shown that wine consumers in countries such as Australia, France, UK and US, 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 American consumers always prefer wines sealed under cork regardless of the situation use, Australians and UK consumers with a longer history of alternatives use, were less influenced by negative connotations of synthetic and screwcaps.

Marin *et al.* (2007) reported that tasting the wine before purchase has a strong impact on consumers' purchase decisions, regardless of the type of closure. Yet, consumers' ratings on wine quality decreased for wines sealed with screwcaps when the closure information was given. Furthermore, consumers expected to pay significantly less for wines sealed under screwcap, which indicates that closure type impacts on the expected price, both directly and indirectly, through consumer perception of quality (Marin and Durham 2007). Differences in consumer preferences towards closures reflect the prices of wine in-market. It was observed in a hedonic price analysis of red wine scanner data from two US markets (Chicago and Tampa) 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 different closure barrier properties have a significant impact on the sensory intrinsic quality of wine presented to consumers. Operations and closure technologies that promote high and continuous atmospheric air exposure, at bottling and throughout storage, accelerate the wine development towards oxidation, irreversibly negatively affecting wine sensory properties. Therefore, maintaining low levels of oxygen exposure during the wine storage lifecycle is extremely important, because storage conditions, shelf-lives and the moment of consumption cannot be fully controlled by the different players of the wine supply chain. Strict oxygen management before and at bottling, combined with the use of a closure with low OTR and effective barrier properties, have an important contribution to the preservation of the varietal characters and keep the deleterious sulfides at residual levels. Differences between wine's intrinsic sensory properties strongly influence consumers' preference and enjoyment of the product and, therefore, play an important role in the re-purchase of wines. In addition, the type of closure seems to be a relevant marketing tool as a part of wine's 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 many consumers as the status quo, while screwcaps and synthetics introduce a cognitive dissonance, creating poor brand image and, therefore, negatively influencing 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. 9(4):83-98.

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

Bates, J. (2010) 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.tragon.com/articles/2005PangbornWineClosures.pdf (accessed 22 January 2012).

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

Chaney, I.M. (2000) External search effort for wine. International Journal of Wine Marketing (12):5-21.

Godden, P.; Francis, L.; Field, J.; Gishen, M.; Coulter, A.; Valente, P.; Høj, P. and Robinson, E. (2001) 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. 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. and Bramley, B. (2005) 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 204:20-30.

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

Lopes, P.; Saucier, C. and Glories, Y. (2005) Non-destructive colourimetric method to determine the oxygen diffusion rate through closures used in winemaking. J. Agric. Food Chem. 53:6967-6973.

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

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

Lopes, P.; Silva, M.A.; Pons, A.; Tominaga, T.; Lavigne, V.; Saucier, C.; Darriet, P.; Teissedre, P.L. and Dubourdieu, D. (2009) 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. 57:10,261-10,270.

Lopes, P.; Marques, J.; Lopes, T.; Lino, J.; Coelho, J.; Álves C.; Roseira, I.: Mendes, A. and Cabral, M. (2011) Permeation of d5-2,4,6-trichloroanisol via vapor phase through different closures into Wine Bottles. Am. J. Enol. Vitic. (62):2.

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

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

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

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

Mueller, S. and Szolnoki, G. (2010) Wine packaging and labelling – 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 February 2010, Auckland (NZ). 1-7.

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

Pen, C. (2007) Independent consumer research on closures. 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. and Waters, E.J. (2005) 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. 11:369-384.

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

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

WVJ