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Effects of transport conditions on the stability and sensory quality of wines

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ABSTRACT

The quality of wine can be affected by several factors after bottling: temperature changes, shipment time, type and amount of mechanical stress (vibrations) and environmental conditions, such as light exposure and relative humidity. The effects of delivery using different packaging systems (boxes, bottles, containers) and the impacts of mode of shipment (car, truck, airplane and cargo ship) are reviewed, along with compositional markers, the reactions leading to off-odours and/or off-flavours and the approaches to monitoring transportation conditions (temperature, relative humidity and type and entity of vibration) and their impacts on the sensory profile of the wine. Temperature fluctuations are more prevalent during the transport of wine over land than by sea, and may lead to a decrease in the fresh, fruity and floral aromas of the wine and to premature aging due to the 'pump' effect (repeated expansion and contraction cycles). Trans-shipment phases should be reduced to a minimum, especially in hot climates. Vibrations, even for a short period of time (15 days), can alter the overall quality of the product.

KEYWORDS

wine transportation, chemical profile, sensory profile, quality, temperature changes

INTRODUCTION

After bottling, wine quality is influenced by several factors, such as light exposure (Arapitsas *et al.*, 2020; Fracassetti *et al.*, 2017), temperature fluctuations (Benítez *et al.*, 2006), vibrations (Chung *et al.*, 2008), contact with oxygen (Lopes *et al.*, 2006) and humidity. The shelf life of a wine essentially begins at bottling; from this moment the product is subjected to quality changes during storage and delivery (Hartley, 2008). The shipping method, the storage conditions and the packaging material are the most important factors to control in order to guarantee the shelf life of wine during transportation. Temperature has been found to be the key factor to impact the quality of wine (Ough, 1985; Francis *et al.*, 1994; Presa-Owens and Noble, 1997; Marquez *et al.*, 2012). Wine can be exposed to extreme temperatures during shipment and storage (4-44 °C), which can alter its physical, chemical, and sensory composition (Butzke *et al.*, 2012).

Temperature requirements (11-17°C for fine wines and 11-22 or 11-25 °C for commercial wines, respectively) and relative humidity requirements (55-80% for fine wines and >50% for commercial wines) are prescribed in certification schemes to ensure optimal wine storage management systems (WSMS); these requirements also include maximal daily and annual fluctuation ranges (HKQAA, 2019). However, it was not possible to find any scientific studies on the effects of humidity fluctuations during transport. Prolonged low relative humidity might reduce the sealing properties of cork stoppers due to cork contraction and consequent dry out, and it may cause and increase mechanical fragility, which will lead to the cork stopper crumbling when the bottle is opened. In contrast, an excess of humidity can cause the growth of mould on the surface of the wine bottle, particularly the cork stopper, leading to potential off-flavours and odours, which can contaminate the wine at opening; in addition, it could damage the wine label and reduce the traceability of the product (Jung and Schaefer, 2010).

A light-struck fault can develop in white wine bottled in flint glass just after 1–2 days of supermarket shelf life (Arapitsas *et al.*, 2020), whereas green bottles may secure the wine for at least 50 days of typical supermarket shelf conditions.

There are several reactions - each occurring at different rates inside the wine - which can impact its colour, aroma, flavour, and structure during transport (Benkwitz *et al.*, 2012; Coetzee and Du Toit, 2015). The ongoing reactions causing these microscopical changes can acquire exponential rates or accelerate at varying rates as a result of the effects of different types of environmental conditions, such as high temperatures (Scrimgeour *et al.*, 2015). It is therefore essential to ensure that the wine is properly conserved throughout the entire journey and storage. This review explores currently available information on the influence of environmental factors and transportation conditions of wine and provides recommendations for preventing detrimental quality risks when transporting or shipping wine either within or to a country. Innovative solutions for the wine market that address the problems encountered when exporting wine are discussed.

1. History of wine transportation

The transportation of wine began when it started to be produced using different grape varieties in different wine-growing regions, because it was one of the main beverages to provide a source of calories with hedonistic connotations. In ancient times, wine was transported in amphorae (Estreicher, 2002). These were used for many centuries before the introduction of other containers, such as wooden barrels and then glass bottles, which were more practical for the transportation and storage of wine. Over the years, Roman manufacturers constantly improved the design of amphorae for wine storage, with the aim of transporting a higher number during shipments. A larger clay container called *dolium* was also widely used throughout the Roman Empire for bigger shipments (Estreicher, 2002). Problems were encountered when transporting wine in larger amphorae over long distances for instance, it was almost impossible to completely seal the amphorae, which resulted in the high oxygenation of their content; therefore, their transportation over land was not efficient. For these reasons, clay containers were eventually abandoned in favour of wooden barrels (Estreicher, 2002). In the late nineteenth and early twentieth century, most of the wine was stored and transported in barrels as bulk containers. After this period, a rapid decrease in the use of barrels was observed due to the high cost attributed to their maintenance and were gradually replaced by other packaging materials such as metal cans, bags-in-boxes, tetra Pak and kegs for wine transportation (Work, 2014). In addition, the use of thick glass bottles became very widespread in the twentieth century, particularly for champagne wine, because they can withstand high pressures.

The heavy weight of glass bottles, and in turn wine crates, led to an increase in shipping costs, thus causing wine business operators to switch by shipping inexpensive wine in massive plastic bladders, also known as *flexitank* bags. The ability of *flexitank* bags to hold up to 24,000 liters helped to improve profit margins and the environment, and it increased the global wine trade (Accorsi *et al*., 2014). ISO-tanks containers and stainless-steel wine tanks are also widely used to transport wine on long journeys over land.

2. Temperature and wine stability

Because it comprises a combination of several organic and inorganic components, wine is a complex matrix. The way end-consumers perceive the interactions of these components is linked to the concept of quality, defined as the combination of those features and characteristics of a product that satisfy consumer' needs (Henry *et al*., 2006). Therefore, any significant change in the composition of wine is considered to alter the quality (Charters and Pettigrew, 2006). In fact, if wine is stored at temperatures above 25 °C for an extended period of time, quality will be irreversibly affected (Ough, 1992). Also, if a temperature over 40 ºC is reached even for a shorter time, visual and sensory changes will be perceived (Ough, 1985). The browning of red and white wines has often been related to the aging of the product (Ibern-Gómez *et al*., 2000; Serra-Cayuela *et al*., 2013), and it is also known for being an indicator of a detrimental temperature effect (Berg and Akiyoshi, 1956). The physical state of the bottled wine can also be altered by temperature changes (e.g., pushed corks, leaking of wine, deposits and damaged labels), which can result in the customer deciding not to purchase it (Lam *et al*., 2013). Consumers expect to find clarity or absence of turbidity in quality wines. Turbidity (or light scattering) in wine is due to the presence of particles in suspension that block light rays, thus diffusing some of the light in different directions and creating what is called the Tyndall effect (Xu *et al*., 2019). This makes the wine seem opaque to various degrees. Particles in suspension, either veiled or dispersed in the liquid, will not only ruin the presentation of a wine, but they may also alter the wine flavour. No official guidelines are available regarding the turbidity of wines; however, the turbidity of 12 marketed red wines was found to range from 5.6 to 190 NTU in a previous study (Mutanen *et al*., 2007). Many factors can cause turbidity depending on temperature, such as protein instability, tannin and tartrate precipitations and *casse* (the French word for breakage); for example, some pigmented matter in red wines is soluble at normal temperatures, but at low temperatures (0 °C) it can precipitate causing turbidity in the wine. Therefore, it is advisable to eliminate part of the wine colloids by centrifugation or filtration before bottling. In addition, slow and gradual cooling leads to the formation of large bitartrate crystals (Ribéreau-Gayon *et al*., 2000). *Casse* has the effect of altering the appearance of a wine due to a loss of homogeneity in the colour and a formation of turbidity. It occurs when a wine is exposed to light, leading to the oxidation of bivalent (Fe^{2+}) to trivalent (Fe^{3+}) iron, which is highly insoluble in the presence of phosphates (e.g., iron (III) phosphate). In particular, high temperature and light can reduce cupric ions (Cu^{2+}) to cuprous ions (Cu^{+}), which in the presence of SO_2 can form insoluble cupric sulfite, which is also responsible for instability and haze formation (Ribéreau-Gayon *et al*., 2000).

Undesirable temperatures can lead to a substantial change in the aroma profile of a wine, and thus a substantial deterioration in quality (Scrimgeour *et al*., 2015; De Esteban *et al*., 2019). This change can occur by oxidation or reduction, and the concentration of some volatile compounds can increase or decrease, such as methyl butanol, a compound associated with off-odours when present at a high concentration in a wine (De Lerma *et al*., 2012; Fariña *et al*., 2015). For example, the presence of amyl alcohols reinforces the in-mouth structure of the alcoholic beverage, but at temperatures above 26 °C they increase in concentration (Ough *et al*., 1966); an excess of these compounds (> 400 mg/L) is associated with a poor quality product and unpleasant odors (Rapp and Versini, 1995).

3. Effects of temperature and vibration during shipment

Several studies on wine transport have proven that temperature fluctuations are the most detrimental factor for wine quality during its shipment, because they can lead to irreversible changes in the chemical and sensory profiles of the product, as well as an acceleration in the aging process (Meyer, 2002; Robinson *et al*., 2010; Marquez *et al*., 2012; Lam *et al*., 2013; Du Toit and Piquet, 2014). Wine bottles have little protection from temperature variations during transport in containers, thus potentially affecting quality (Hartley, 2008). Temperature fluctuation can be prevented by transporting wine in either insulated or refrigerated containers; the latter are also known as *reefers*, and they allow humidity and temperature to be controlled. Both options add significant costs to a container shipment, which are reflected in the final price of the bottle; therefore, unfortunately, only a limited proportion of wine shipments use temperature-controlled or insulated containers. Getahun *et al*. (2017) showed the efficiency of airflow and heat transfer in *reefers* when shipping fruit products. They developed an airflow model packaging system to monitor the temperature and airflow inside the reefer during the shipment of apple fruits. Non-uniform airflow and highly heterogeneous cooling were observed in the packaging boxes due to the absence of a vent-hole in the bottom side of the package; it is therefore essential that airflow be taken into account in the design of packaging boxes for transporting goods inside *reefers*, and for winemakers, food business operators and exporters to know the temperature fluctuations that their goods are exposed to during shipments and the vulnerability of the product itself. Meyer (2002) performed a study on temperature variations during wine shipments and their effect on wine quality. Results showed that the quality of wines exposed at high temperature changed irreversibly. It is common for wines to be submitted to extreme temperatures of up to 44 °C (Butzke *et al*., 2012) - often with significant fluctuations - when they are transported. MacCawley (2014) also showed that wines being transported overseas can undergo high variations in temperature (from -10 °C to 67 °C) in a shipping container; this can include a steady increase in temperature affecting wines shipped from winter temperatures to equator temperatures and further on to summer temperatures. The most extreme shipping temperatures are experienced during the trans-shipment phase, since relay ports are often located close to the equator. While the wine is resting in the trans-shipment phase, it is generally unprotected and therefore subjected to extreme diurnal temperature fluctuations. Research carried out by Butzke *et al*. (2012) comprises one of the most comprehensive documentations of temperature monitoring during wine transport within the USA. They recorded 26 individual shipments, containing a total of 47 recording devices, which departed from winery warehouses in California for 13 different destinations within the USA. They measured ethyl carbamate in the wine, a carcinogenic compound (Schlatter and Lutz, 1990) produced from urea and ethanol, and showed that the reaction accelerated at high storage temperatures. They also showed that temperature could fluctuate by as much as 21 °C in one day, which significantly impacted wine quality due to the expansion and contraction in volume of the wine. Between 20 and 40 °C, wine can thermally expand by up to 0.8 % of its volume, or 0.3 mL for each degree Celsius in extreme cases, such as in wines with high residual sugar. The repeated expansion and contraction of a wine subjected to daily fluctuations can cause significant changes to it: air is expelled from the bottle as the wine warms, possibly to the point of cork movement, and then air is drawn into the bottle as the wine cools, especially if the cork is compromised; this phenomenon is known as the "pump effect". This effect increases the risk of oxidation of the wine, as well as a change in vapour pressure and carbon dioxide solubility (MacCawley, 2014).

Jung *et al*. (2014) also monitored the effects of temperature, movements and vibrations on wines transported over longer distances within Europe (Portugal, France and Italy to Germany). Their results showed that transportation had an effect on the potential aging of wines, depending on the wine matrix. Movement and vibrations at high (40 °C) and varying temperatures during transport had negative effects on the quality of the wine, such as browning of the wine (especially visible in white wine) and sensory changes, with a reduction in the "fresh and fruity" notes in the transported wine samples compared to non-transported ones.

Several commercial wines have been studied under various shipping and storage conditions: storage at 20 °C and 40 °C, a daily cycle of between 20 °C and 40 °C, and travel in a car trunk in winter time (Robinson *et al*., 2010). The results showed that the wines stored at the higher temperature (40 °C) were found to be significantly different from those stored at the lower temperature (20 °C) in terms of aroma profile; specifically, tropical fruit and apple aromas were negatively correlated with rubber and diesel aromas according to the sensory analysis. For the wines stored at the higher temperature (40 °C), several modifications were observed: a higher concentration of norisoprenoids 1,1,6-trimethyl-1,2-dihydronaphthalene (TDN), vitispirane 1 and 2 and p-cymene, and a reduction in esters and acetates, as well as an acceleration in the aging process. As a result, wines stored at 40 °C were characterised by diesel, oxidized and rubber aromas, while those at lower temperatures maintained their citrus, floral and tropical fruit aromas.

Du Toit and Piquet (2014) evaluated the effects of constant and simulated shipping temperatures on the sensory composition of Chenin Blanc and

Sauvignon Blanc wines. Wine samples were stored at constant temperatures (-4 °C, 15 °C and 37 °C), as well as at varied temperatures over a period of 46 days. Wines exposed to elevated temperatures developed off-odours, such as over-aged, sulfur-like and a yellow colour, while those left at a cooler temperature of 15 °C retained tropical aromas. The effect of varying the temperatures did not lead to larger aroma differences in wines compared to those left at a constant lower temperature.

Stump (2017) monitored 71 commercial Swiss wines; three bottles of each wine were stored for seven days under different temperature conditions: (1) constant 15 ºC to reflect cellar storage conditions, (2) constant 40 ºC to reflect a hot environment, and (3) day/night temperature cycle (15 - 40 ºC alternating every 12 hours) to simulate transcontinental shipping conditions. A loss of the anthocyanin content was reported in all the red wines and those exposed to an extreme temperature (40 ºC) suffered the greatest loss, as well as a high visual increase in degree of turbidity.

Walther *et al*. (2018) also monitored the temperature of Chardonnay wines during bulk shipments from Australia to Germany, and they found that temperatures ranged from 4 to 47 °C inside the containers. A decrease in SO_2 content and an increase in the intensity of the yellowness of the wines exposed to higher temperatures was observed, as well as a decrease in some volatile compounds (ethyl decanoate, ethyl dodecanoate and phenylethyl acetate). In addition, an increase in diethyl malate, diethyl succinate, decanoic acid, and dodecanoic acid in wines transported on container ships was found, as compared to wines transported by air. The sensory analysis showed an increase in the honey attribute and a decrease in freshness when temperatures were above 25 °C.

Studies on temperature and humidity of wine during shipment conducted by Leinberger (2006) and Marquez *et al*. (2012) showed that temperature fluctuations are more prevalent during the transport of wine by land than by sea. The daily temperature cycles associated with transport by sea were negligible compared to land transport, which showed an extreme daily temperature of 57 °C.

The impacts of shipping conditions both at sea and at port on two dry, white wines of different vintages were investigated by Crandles (2016). The wine samples were subjected to three temperature programmes: control conditions (15 °C), linear increase (15 °C steadily increasing to 45 °C), and diurnal fluctuation (15 °C/40 °C) in both movement and non-movement conditions. The diurnal and linear programmes resulted in similar oxygen transfer in the bottles, which was different to that of the control. The results of the chemical analysis showed significant differences for tartaric acid, free sulfur dioxide, total sulfur dioxide and percent cork weight loss after eight months of storage between the different treatments (diurnal non-movement treatment compared to linear non-movement and control treatments, and diurnal movement and control treatments). It was possible to differentiate the varieties of the wines in the descriptive sensory analysis, but not to distinguish them according to experimental treatment after one month of storage.

Zhao *et al*. (2018) also evaluated the influence of excessive ambient temperature (40 °C for 14 days) and vibration (150 rpm for 15 days) on the sensory and chemical profiles of wine. Their results showed that the elevated temperature changed the organoleptic properties of the wine by significantly reducing the concentrations of volatile compounds, such as isoamyl acetate, ethyl butanoate, ethyl-2-methylbutanoate, ethyl hexanoate, ethyl octanoate, β-damascenone and linalool, which are all compounds responsible for the fruity and floral aroma notes in wine as shown by Peinado *et al*. (2004). The sensory analysis confirmed a decrease in fruity and floral aromas in wine samples subjected to high temperature. Conversely, no significant differences were found in the effect of vibration on the chemical and sensory profiles of the wines. Finally, Atkin and Cholette (2017) interviewed wine supply chain professionals and American wine producers in order to gain an insight into how they perceived temperature fluctuations during wine delivery. About 65 % of the interviewees estimated that 1 to 2 % of their wines suffered from excess temperature during transportation, and only 16 % of respondents thought that adequate temperatures were maintained during the journey to the retailer.

The conditions at which wine is subjected during shipment and storage can play an important role in the reduction of its quality due to temperature changes, bottle movement and associated oxygen uptake. Wines can suffer from several chemical, organoleptic and physical defects when exposed to poor shipping and storage conditions, including the development of notes associated with oxidation, reduction of fruity aromas, reduction of carbon dioxide, colour changes, cork ejection, leakage and even broken packaging (Meyer, 2002). The effect of vibration on commercial red wine during storage in bottles was evaluated by Chung *et al*. (2008): an increase in total acidity was observed in the wines subjected to high levels of vibration (20 cm/s^2), and an accelerated decrease in organic acids, tannins and refractive index was observed in wines undergoing higher levels of vibration than at lower levels (1.0 or 5.0 or 10 cm/s^2). Finally, wines undergoing higher levels of vibration had lower propanol and isoamyl alcohol content. This indicates that minimizing the movement of a wine assists in retaining higher levels of alcohol and overall wine aroma. Doyon *et al*. (2005) have shown that storage duration and temperature affect oxygen permeation more than mechanical movement does. Butzke *et al*. (2012) have shown that transportation can cause a bottle aging effect on wine of between 1 and 18 months more than that on wine stored at cellar temperatures. Some studies performed on beers (Paternoster *et al*., 2017), which evaluated the performance of different beer packaging when subjected to vibration and in terms of thermal insulation, showed that cardboard combined with plastic foil was the best beer packaging regarding vibration damping and thermal insulation during transportation. These findings may also be applicable to wine transportation. It was also shown that the combined effect of temperature and vibration on beer resulted in a rapid decrease in oxygen, as well as a significant increase in total aldehyde, such as 2-methylpropanal, 2-methylbutanal and furfural (Paternoster *et al*., 2019; Jaskula-Goiris *et al*., 2019). Reich-Weiser *et al*. (2010) performed a comparative study on the total greenhouse gas (GHG) emitted during the transportation of wine by train and truck. The GHG emissions were found to be lower by train than by truck. Therefore, selecting GHG efficient modes of wine transport can contribute to reducing the global wine trade's GHG emissions.

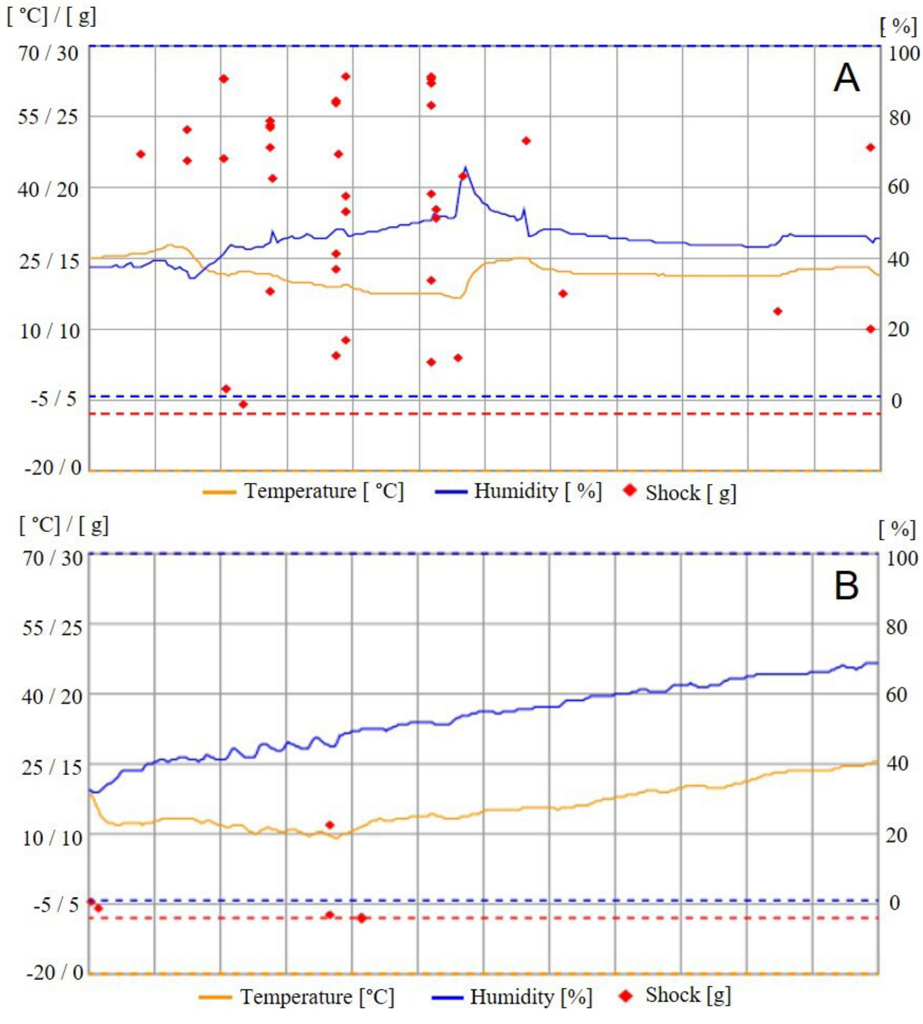

FIGURE 1. Transportation of grappa samples. A: transport within Italy by truck (in April); B: transport from Italy to Mexico by sea (in December).

A study on the effect of transportation temperature and vibration on the quality of a winery product was also performed by our research group. Boxes containing bottles of *grappa* (an Italian distillate, obtained from fermented or semi-fermented grape pomace) were shipped from Italy to Mexico; the temperature, relative humidity and shock/acceleration were measured using a data logger (Testo 184 G1, West Chester, U.S.). The same experiment was carried out on *grappa* bottles transported by truck within Italy, but in a different season, to compare the variability of temperature, humidity and shock between transport by land and sea. A maximum temperature of 27 °C and a minimum of 17 °C (in April) were recorded outside of the *grappa* bottles (i.e., inside the cardboard boxes) for land transportation (Figure 1A). Maximum humidity was 67 % and minimum humidity 36 %, and a maximum shock of 28 g was observed (g, Gal or Galileo is the unit of acceleration used in gravimetry and is defined as 1 cm/s^2). Regarding the overseas transport (Figure 1B), a maximum temperature of 25 °C and a minimum of 10 °C were recorded (in December). Relative humidity ranged from 31 to 70 %, whereas the mechanical shock ranged from 4 to 11 g. Land transportation thus generated a high number of shocks between the bottles. These preliminary results confirm the studies carried out by Leinberger (2006) and Marquez *et al*. (2012), who stated that temperature fluctuations during wine transport are more prevalent in land transport than sea transport.

A summary of all the published studies on the effect of transportation conditions on the quality of wine is presented in Table 1.

5. Devices for temperature monitoring

Stump (2017) monitored the ambient temperature and humidity of wine samples using data loggers (HAX0-8, LogTag Recorders Limited, Auckland, New Zealand) every 30 minutes over a three-week period, after which the logged information was downloaded. Meanwhile, Robinson *et al*. (2010) monitored temperature (with TG-3080, Omni Instruments, Arroyo Grande, CA) every 10 minutes over a three-week period, after which the logged information was collected. Jung *et al*. (2014) used a data logger (EL-USB-2, Lascar Electronics) to monitor the temperature of wines shipped from Germany to Japan, determine fluctuations during shipment and then to simulate those temperatures in their work on the evolution of wines during shipment. Butzke *et al*. (2012) used Dickson SP100 dual-channel data loggers (Dickson, Addison, IL) to monitor the temperature of wines every 15 minutes during commercial shipments. Finally, Biccario *et al*. (2014) proposed the Wireless Sensor Network (WSN) system as an effective solution to monitor the temperature, humidity and light exposition of food products during transportation.

FINAL REMARKS AND FUTURE PERSPECTIVES

Published studies have shown that elevated temperatures during wine storage or transportation can irreversibly change the chemical and sensory profiles of the product, as well as define the acceleration in the aging process. Furthermore, the continued vibration of wine during storage and transport has a negative effect on its organoleptic properties. Temperature and vibration are therefore key factors which need to be monitored during the transportation or storage of wine.

Browning most commonly occurs in wines that have been exposed to elevated storage and transport temperatures, occurring much faster in white wines than in red ones; in addition, significant changes in the sensory profile of the wines occur, with a reduction in “fresh and fruity” aromas and the development of undesirable attributes. In terms of the chemical profile of wines stored and transported under high temperatures, a remarkable decrease in esters and acetates has been observed (compounds responsible for fruity and floral aromas in wine), as well as a decrease in SO_2 content and anthocyanin concentration. The results of the visual evaluation also showed a high increase in degree of turbidity in the red wines.

The published data also shows that temperature fluctuations are more prevalent during the transport of wine over land than by sea. Furthermore, strong vibration has a negative impact on wine, with a decrease in organic acids and tannins and an acceleration in the browning process, while a combination of temperature and vibration results in a rapid decrease in oxygen and an increase in total aldehydes. All the collected data highlight the importance of controlling temperature and vibrations during the shipment of wine in order to maintain its fresh, fruity and floral aromas and to prevent premature aging. This is useful information for the post-winery handling of winery products. Most wines are delivered far and wide (even overseas) in response to high consumer demand; therefore, their transport from the production area to the wholesalers and retailers must be controlled to minimize any degradation

TABLE 1. Summary of studies on the effect of temperature and vibration on wine quality during shipment.

Temperature and vibration effects on wine quality during shipment	Temperature/vibration	References
Wines exposed to temperatures above 25 °C for an extended period of time (21 days) showed an irreversible deterioration in quality, whereas those exposed to temperatures over 40 ºC, even for a short time, showed visual and sensory changes.	Constant (28 °C, 32 °C, 38 °C, 43 °C, and 47 °C)	Ough (1992); Ough (1985)
Wine bottles have little protection from temperature variation during transport in containers; insulation and refrigerated containers can be used to prevent temperature fluctuation.	-	Hartley (2008)
Poor shipping and storage conditions of wines resulted in development of oxidized notes, reduction in fruity aromas and in carbon dioxide, colour changes, cork ejection, leakage and broken packaging. When using convection during wine shipment on long journeys 95 % of the temperature was transferred.	-4 °C; 30 °C; 43 °C	Meyer (2002)
The most extreme shipping temperatures are experienced during the trans-shipment phase, since relay ports are often located close to the equator. While the wine is resting in the trans-shipment phase, it is generally unprotected and therefore subject to extreme diurnal temperature fluctuations.	Between -10 °C and 67 °C	MacCawley (2014)
The concentration of ethyl carbamate, a toxic compound produced from urea and ethanol, is higher in wines exposed to high shipping and storage temperatures. The heat exposure of wine bottles during transport may be compared to a period of conventional cellar ageing of 18 months.	24 °C; 44 °C; diurnal fluctuation (4-2 °C)	Butzke *et al*. (2012)
Transportation had an effect on the potential aging of wines depending on the wine matrix. Furthermore, movement and vibrations at high temperature during transport had negative effects on quality, such as browning of the wine and sensory changes, with a reduction in “fresh and fruity” notes in the transported wine samples compared to non-transported samples.	Constant 15 °C; and varying from -9 °C to 40 °C	Jung *et al*. (2014)
Wines subjected to elevated temperatures (40 °C) were significantly different in terms of aroma profile. Specifically, tropical fruit and apple aromas were negatively correlated with rubber and diesel aromas, whereas a high concentration of norisoprenoids 1,1,6-trimethyl-1,2-dihydronaphthalene (TDN), vitispirane 1 and 2 and p-cymene were observed, as well as a reduction in esters and acetates and an acceleration in the aging process. Wines in the highest temperatures also had diesel, oxidized and rubber aromas, while those at lower temperatures maintained their citrus, floral and tropical fruit aromas.	Constant (20 °C, 40 °C) and diurnal cycle between 20 °C and 40 °C	Robinson *et al*. (2010)

Wines exposed to elevated temperatures developed off-odours, such as over-aged and sulfur-like, and a yellow colour, while those left at a cooler temperature retained their tropical aromas.	Constant (-4 °C, 15 °C and 37 °C) and variable temperatures	Du Toit and Piquet (2014)
A reduction in anthocyanin content was observed in all the red wines, especially those exposed to extreme temperature of 40 ºC, as well as a high visual increase in the degree of turbidity.	Constant (15 ºC, 40 ºC) and diurnal cycle (15 ºC - 40 ºC)	Stump (2017)
A decrease in SO_2 content and an increase in yellow colour were observed in wines exposed to higher temperatures, as well as a decrease in some volatile compounds, such as ethyl decanoate, ethyl dodecanoate and phenylethyl acetate. Diethyl malate and diethyl succinate, decanoic acid, and dodecanoic acid was found to increase more in wines transported on container ships than those transported by air. A sensory analysis also showed an increase in the honey attribute and a decrease in freshness when temperatures were above 25 °C.	From 4 to 47 °C	Walther *et al*. (2018)
Temperature fluctuations are more prevalent during the transport of wine by land than by sea.	1 ºC to 50 ºC	Leinberger (2006), Marquez *et al*. (2012)
Differences were found in term of tartaric acid, free sulfur dioxide, total sulfur dioxide and percent cork weight loss between the samples, and after a period of 8 months storage, the diurnal non-movement wines were different from the linear non-movement and control treatments, as well as diurnal movement and control.	Constant 15 ºC, linear increase from 15 ºC to 45 ºC and diurnal cycle (15 ºC - 40 ºC)	Crandles (2016)
Elevated temperatures had an impact on the organoleptic properties of wine by significantly reducing the concentrations of volatile compounds, such as isoamyl acetate, ethyl butanoate, ethyl 2-methylbutanoate, ethyl hexanoate, ethyl octanoate, β-damascenone, and linalool; whereas the sensory analysis revealed a decrease in fruity and floral aromas. No significant differences were found regarding the effect of vibration on wines.	40 °C for 14 days 150 rpm for 15 days	Zhao *et al*. (2018)
65 % of interviewed wine supply chain professionals and American wine producers estimated that 1 % to 2 % of their wines suffers from excess temperature during transportation, and only 16 % thought that adequate temperatures are maintained during the journey to the retailer.	-	Atkin and Cholette (2017)
Higher levels of vibration (20 cm/s^2) caused an increase in total acidity, a decrease in organic acids and tannins, and an acceleration in the browning process. A decrease in propanol and isoamyl alcohol content was observed in wines subjected to high levels of vibration than lower levels (1, 5 and 10 cm/s^2).	1, 5, 10 and 20 cm/s^2	Chung *et al*. (2008)

by using appropriate containers, shipping schedules and storage facilities. It seems to be less harmful to transport bulk wine over long distances than bottled wine. The use of refrigerated or dry containers is advisable, as well as choosing the most suitable time and route to ship the product. In addition, the use of a thermal insulation in the container should be considered. Unfortunately, these recommendations significantly increase the costs associated with shipping a container and consequently the final price of a bottle of wine. Trans-shipment phases should be kept to a minimum, because the operations involved cause the most damage to wine during its shipment. If unavoidable, it is recommended that the time spent during the trans-shipment phase be minimized (fast trans-shipment), especially when occurring in a port located near the equator. The time spent in the destination port should also be kept to a minimum to avoid extreme temperature exposure. Finally, heating and vibration can alter the overall quality of the wine and should therefore be avoided during its shipment and storage, even for a short period of time (15 days).

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REFERENCES

Accorsi, R., Manzini, R. & Ferrari, E., (2014). A comparison of shipping containers from technical, economic and environmental perspectives. *Transportation Research Part D: Transport and Environment,* 26, 52-59. https://doi.org/10.1016/j.trd.2013.10.009.

Arapitsas, P., Dalledonne, S., Scholz, M., Catapano, A., Carlin, S., & Mattivi, F. (2020). White wine light-strike fault: A comparison between flint and green glass bottles under the typical supermarket conditions. *Food Packaging and Shelf Life* 24, 100492. https://doi.org/10.1016/j.fpsl.2020.100492.

Atkin, T., & Cholette, S. (2017). Rough Seas Ahead: Quality Concerns for China-bound Wine Shipments. In the wine value chain in china, *Chandos Publishing,* (187-205). https://doi.org/10.1016/B978-0-08-100754-9.00012-X.

Benítez, P., Castro, R., Natera, R., & Barroso, C. G. (2006). Changes in the polyphenolic and volatile content of "Fino" Sherry wine exposed to high temperature and ultraviolet and visible radiation. *European Food Research and Technology*, 222(3), 302-309. https://doi.org/10.1007/s00217-005-0126-7.

Benkwitz, F., Tominaga, T., Kilmartin, P. A., Lund, C., Wohlers, M., & Nicolau, L. (2012). Identifying the chemical composition related to the distinct aroma characteristics of New Zealand Sauvignon blanc wines. *American Journal of Enology and Viticulture* 63(1), 62-72. https://doi.org/10.5344/ajev.2011.10074.

Berg, H. W., & Akiyoshi, M. (1956). Some factors involved in browning of white wines. *American Journal of Enology and Viticulture,* 7(1), 1-7.

Biccario, G. E., Annese, V. F., & de Vanuto, D. (2014). Wireless remote environmental monitoring and control of perishable goods in maritime transportation. TETHYS 2014 -Toward Emerging Technology for Harbour systems and Services, Bari, Italy.

Butzke, C. E., Vogt, E. E., & Chacón-Rodríguez, L. (2012). Effects of heat exposure on wine quality during transport and storage. *Journal of Wine Research,* 23(1), 15-25. https://doi.org/10.1080/09571264.2011.646254.

Charters, S, Pettigrew, S. (2006) Conceptualizing product quality: the case of wine. *Marketing Theory*.6(4) 467-483. https://doi.org/10.1177/1470593106069932.

Chung, H., Son, J., Park, E., Kim, E., & Lim, S. (2008). Effect of Vibration and Storage on Some Physio-Chemical Properties of a Commercial Red Wine. *Journal of Food Composition and Analysis* 2: 655-9. https://doi.org/10.1016/j.jfca.2008.07.004.

Coetzee, C., & Du Toit, W. J. (2015). Sauvignon blanc wine: Contribution of ageing and oxygen on aromatic and non-aromatic compounds and sensory composition-A review. *South African Journal of Enology and Viticulture*, 36(3), 347-365.

Crandles, M. (2016). The effect of simulated transportation conditions on the chemical, physical and sensory profiles of Müller-Thurgau and Scheurebe wines. *Journal of Food Science and Engineering*, 6, 177-196. https://doi.org/10.17265/2159-5828/2016.04.001.

De Esteban, M. L. G., Ubeda, C., Heredia, F. J., Catania, A. A., Assof, M. V., Fanzone, M. L., & Jofre, V. P. (2019). Impact of closure type and storage temperature on chemical and sensory composition of Malbec wines (Mendoza, Argentina) during aging in bottle. *Food Research International*, 125, 108553. https://doi.org/10.1016/j.foodres.2019.108553.

De Lerma, N. L., Bellincontro, A., Mencarelli, F., Moreno, J., & Peinado, R. A. (2012). Use of electronic nose, validated by GC–MS, to establish the optimum off-vine dehydration time of wine grapes. *Food Chemistry* 130(2), 447-452. https://doi.org/10.1016/j.foodchem.2011.07.058.

Doyon, G., Clement, A. S., Ribereau, S., & Morin, G. (2005). Canadian Bag-in-Box Wine under Distribution Channel Abuse: Material Fatigue, Flexing Simulation and Total Closure/Spout Leakage Investigation. *Packaging Technology and Science* 18 (2) 97-106. https://doi.org/10.1002/pts.679.

Estreicher, S. K. (2002). From fermentation to transportation: Materials in the history of wine. *MRS*

Bulletin, 27(12), 991-994. https://doi.org/10.1557/mrs2002.309.

Fariña, L., Villar, V., Ares, G., Carrau, F., Dellacassa, E., & Boido, E. (2015). Volatile composition and aroma profile of Uruguayan Tannat wines. *Food Research International*, 69, 244-255. https://doi.org/10.1016/j.foodres.2014.12.029.

Fracassetti, D., Gabrielli, M., Encinas, J., Manara, M., Pellegrino, I., & Tirelli, A. (2017). Approaches to prevent the light-struck taste in white wine. *Australian Journal of Grape and Wine Research* 23(3), 329-333. https://doi.org/10.1111/ajgw.12295

Francis, I.L., Sefton, M.A., & Williams, P. (1994). The sensory effects of pre- or post-fermentation thermal processing on Chardonnay and Semillon wines. *American Journal of Enology and Viticulture*, 45, pp.243-251.

Getahun, S., Ambaw, A., Delele, M., Meyer, C. J., & Opara, U. L. (2017). Analysis of airflow and heat transfer inside fruit packed refrigerated shipping container: Part I–Model development and validation. *Journal of Food Engineering*, 203, 58-68. https://doi.org/10.1016/j.jfoodeng.2017.02.010.

Hartley, A. (2008). Bulk shipping of wine and its implications for product quality. Australian Wine Research Institute, 1-19.

Henry, P., Charters, S., & Pettigrew, S. (2006). Product involvement and the evaluation of wine quality. *Qualitative Market Research: An International Journal*. https://doi.org/10.1108/13522750610658810

HKQAA (2019), Wine storage management systems certifications: Hong Kong Quality Assurance Agency, http://hkqaa.org/cmsimg/WSMS/WSMS_Certification.pdf (accessed 9 April 2021)

Ibern-Gómez, M., Andrés-Lacueva, C., Lamuela-Raventós, R. M., Buxaderas, S., Singleton, V. L., & De La Torre-Boronat, M. C. (2000). Browning of cava (sparkling wine) during aging in contact with lees due to the phenolic composition. *American Journal of Enology and Viticulture*, 51(1), 29-36.

Jaskula-Goiris, B., De Causmaecker, B., De Rouck, G., Aerts, G., Paternoster, A., Braet, J., & De Cooman, L. (2019). Influence of transport and storage conditions on beer quality and flavour stability. *Journal of the Institute of Brewing*, 125(1), 60-68. https://doi.org/10.1002/jib.535.

Jung, R., Leyh, B., Patz, C. D., Rothermel, A., & Schuessler, C. (2014). Potential wine ageing during transportation. In *BIO Web of Conferences* 3. EDP Sciences. https://doi.org/10.1051/bioconf/20140302004.

Jung, R., & Schaefer, V. (2010). Reducing cork taint in wine. In Managing wine quality (pp. 388-417). Woodhead Publishing. https://doi.org/10.1533/9781845699987.388

Lam, H. Y., Choy, K. L., Ho, G. T., Kwong, C. K., & Lee, C. K. (2013). A real-time risk control and monitoring system for incident handling in wine storage. *Expert Systems with Applications*, 40(9), 3665-3678. https://doi.org/10.1016/j.eswa.2012.12.071.

Leinberger, D. (2006). Temperature and humidity in ocean containers, Technical Report, Xerox Corporation. Online version accessed. March 2009, http://www.ista.org/pages/resources/TempRH.php.

Lopes, P., Saucier, C., Teissedre, P.-L., & Glories, Y., (2006). Impact of storage position on oxygen ingress through different closures into wine bottles. *Journal of Agricultural and Food Chemistry*, 54, 18, 6741-6746. https://doi.org/10.1021/jf0614239.

MacCawley, A. (2014). *The International Wine Supply Chain: Challenges from Bottling to the Glass* (Doctoral dissertation, Georgia Institute of Technology).

Marquez, L., Dunstall, S., Bartholdi, J., & MacCawley, A. (2012). 'Cool or hot': A study of container temperatures in Australian wine shipments. *Australasian Journal of Regional Studies*, 18(3), 420.

Meyer, D., (2002). Final Report. A study of the impact of shipping/transportation conditions and practices on wine. *Wine Land (South Africa)* (1) 1-42.

Mutanen, J., Räty, J., Gornov, E., Lehtonen, P., Peiponen, K. E., & Jaaskelainen, T. (2007). Measurement of color, refractive index, and turbidity of red wines. *American Journal of Enology and Viticulture* 58(3), 387-392.

Ough, C. S., Guymon, J. F., & Crowell, E. A. (1966). Formation of higher alcohols during grape juice fermentations at various temperatures. *Journal of Food Science*, 31(4), 620-625. https://doi.org/10.1111/j.1365-2621.1966.tb01915.x.

Ough, C.S., (1985). Some Effects of Temperature and SO_2 on Wine During Simulated Transport or Storage. *American Journal of Enology and Viticulture*, 36(1), 18-22.

Ough, C.S., (1992). Winemaking basics. Binghamton, N.Y.: The Haworth Press, Inc., 242.

Paternoster, A., Jaskula-Goiris, B., De Causmaecker, B., Vanlanduit, S., Springael, J., Braet, J., & De Cooman, L. (2019). The interaction effect between vibrations and temperature simulating truck transport on the flavor stability of beer. *Journal of the Science of Food and Agriculture*, 99(5), 2165-2174. https://doi.org/10.1002/jsfa.9409.

Paternoster, A., Van Camp, J., Vanlanduit, S., Weeren, A., Springael, J., & Braet, J. (2017). The performance of beer packaging: Vibration damping and thermal insulation. *Food Packaging and Shelf Life*, 11, 91-97. https://doi.org/10.1016/j.fpsl.2017.01.004.

Peinado, R. A., Moreno, J., Bueno, J. E., Moreno, J. A., & Mauricio, J. C. (2004). Comparative study of aromatic compounds in two young white wines subjected to pre-fermentative cryomaceration. *Food*

Chemistry, 84(4), 585-590. https://doi.org/10.1016/S0308-8146(03)00282-6.

Presa-Owens, C. D. L., & Noble, A. C. (1997). Effect of storage at elevated temperatures on aroma of Chardonnay wines. *American Journal of Enology and Viticulture*, 48(3), 310-316.

Rapp, A., & Versini, G. (1995). Influence of nitrogen compounds in grapes on aroma compounds of wines. *Developments in Food Science* 37, 1659-1694. Elsevier. https://doi.org/10.1016/S0167-4501(06)80257-8.

Reich-Weiser, C., Paster, P., Erickson, C., & Dornfeld, D. (2010). The role of transportation on the GHG emissions of wine. *Journal of Wine Research* 21(2-3), 197-206. https://doi.org/10.1080/09571264.2010.530111

Ribéreau-Gayon, P., Glories, Y., Maujean, A., & Dubourdieu, D. (2000). The chemistry of wine stabilization and treatments, Handbook of Enology, 2nd Edition, ISBN: 978-0-470-01037-2.

Robinson, A. L., Mueller, M., Heymann, H., Ebeler, S. E., Boss, P. K., Solomon, P. S., & Trengove, R. D. (2010). Effect of simulated shipping conditions on sensory attributes and volatile composition of commercial white and red wines. *American Journal of Enology and Viticulture*, 61(3), 337-347.

Schlatter, J., & Lutz, W. K. (1990). The carcinogenic potential of ethyl carbamate (urethane): risk assessment at human dietary exposure levels. *Food and Chemical Toxicology*, 28(3), 205-211. https://doi.org/10.1016/0278-6915(90)90008-B.

Scrimgeour, N., Nordestgaard, S., Lloyd, N. D. R., & Wilkes, E. N. (2015). Exploring the effect of elevated storage temperature on wine composition. *Australian Journal of Grape and Wine Research*, 21, 713-722. https://doi.org/10.1111/ajgw.12196.

Serra-Cayuela, A., Aguilera-Curiel, M. A., Riu-Aumatell, M., Buxaderas, S., & López-Tamames, E. (2013). Browning during biological aging and commercial storage of Cava sparkling wine and the use of 5-HMF as a quality marker. *Food Research International*, 53(1), 226-231. https://doi.org/10.1016/j.foodres.2013.04.010

Stump, B. (2017). Impact of shipping and transporting conditions on Swiss wine. Master thesis report.

Du Toit, W. J., & Piquet, C. (2014). Effect of simulated shipping temperatures on the sensory composition of South African Chenin blanc and Sauvignon blanc wines. *South African Journal of Enology and Viticulture*, 35(2), 278-282.

Walther, A. K., Durner, D., & Fischer, U. (2018). Impact of temperature during bulk shipping on the chemical composition and sensory profile of a Chardonnay wine. *American Journal of Enology and Viticulture*, 69(3), 247-257. https://doi.org/10.5344/ajev.2018.17089.

Work, H.H. (2014). Wood, whiskey and wine: A history of barrels. Reaktion books, London, ISBN 9781780233567.

Xu, B. W., Shen, Y., Zhang, Q. A., Zhao, W. Q., & Yi, X. (2019). Effect of ultrasound irradiation on the particle size distribution and rheological properties of red wine. *CyTA-Journal of Food*, 17(1), 180-188. https://doi.org/10.1080/19476337.2019.1569167.

Zhao, P., Wang, H., & Li, H. (2018). Characterization of the effect of short-term high temperature and vibration on wine by quantitative descriptive analysis and solid phase micro-extraction gas chromatography-mass spectrometry. *Acta Alimentaria*, 47(2), 236-244. https://doi.org/10.1556/066.2017.0007.