beverages

Review

The Impact Packaging Type Has on the Flavor of Wine

Katherine A. Thompson-Witrick [1,*], Eric R. Pitts [1], John L. Nemenyi [2] and Drew Budner [3]

1 Food Science and Human Nutrition Department, University of Florida, Gainesville, FL 32611, USA; eric.pitts@ufl.edu
2 Agricultural and Biological Engineering Department, University of Florida, Gainesville, FL 32611, USA; nemenyi93@ufl.edu
3 Department of Chemistry, Coastal Carolina University, Conway, SC 29526, USA; dbudner@coastal.edu
* Correspondence: kthompsonwitrick@ufl.edu

Abstract: This is a literature review of the most commonly available wine packaging categories. This includes glass bottles, polyethylene terephthalate bottles (PET), bag-in-box (BIB), aluminum cans, and Tetra Pak. This review includes a description and history of each category. In addition, the market share and environmental impacts of each category are discussed. Special attention is paid to the reported impact on packaged wine flavor and aroma for each packaging type. Finally, the potential impacts on consumer preference are discussed. While glass is still the dominant packaging material within the wine industry and by consumer demand, economic and environmental concerns are driving the industry and consumers to investigate and adopt alternative packaging materials.

Keywords: wine packaging; flavor; sustainability; wine bottles; aluminum cans; consumer preference

check for updates

Citation: Thompson-Witrick, K.A.; Pitts, E.R.; Nemenyi, J.L.; Budner, D. The Impact Packaging Type Has on the Flavor of Wine. *Beverages* **2021**, *7*, 36. https://doi.org/10.3390/beverages7020036

Academic Editors: Stamatina Kallithraka and Matteo Marangon

Received: 28 April 2021
Accepted: 28 May 2021
Published: 7 June 2021

1. Introduction

Since the Neolithic era, humans have utilized the fermentation process as a means of extending the shelf life, increase the safety, as well as produce desirable flavors for foods and beverages [1,2]. Beer and wine have been around for tens of thousands of years. The discovery of wine is likely to have only been by accident when damaged grapes spontaneously fermented within a storage vessel. Farmers tried it and enjoyed the taste of the fermented product compared to the unfermented. The rest is history as they say [1]. Wine production is one of the oldest economic sectors in the world and presently is one of the most profitable agricultural products today [3,4]. The wine industry plays an important role in the global economy in terms of production and distribution [5]. In 2018, the International Organization of Vine and Wine (OIV) estimated that 292 million hectoliters of wine were produced worldwide. The international wine trade is estimated to be worth USD 36 billion (29.5 Euro) [6].

Wine packaging has drastically changed over the years from clay amphorae to single serving plastic bottles. The belief that only premium wine can be packaged in glass bottles with a natural cork has slowly been changing over the years [7,8]. Despite glass being an inert material, most consumers are not aging wine longer than a few months thus opening up the wine industry for alternative packaging [9]. As the industry adopts alternative packaging options, it is accepting the potential that the product packaging can have an impact on the consumer experience. The purpose of this literature review is to look how packaging type impacts wine flavor stability and flavor.

History of Wine Packaging

Several thousand years prior to the rise of the Roman Empire, winemakers from Mesopotamia and Egypt would store their wine in amphorae, clay flasks. These vessels played an important role in regard to the Ancient Greece and Roman's trading success, in that amphorae served in a similar manner to our modern-day shipping containers. Amphorae were used for far more than just storing wine but were used to store and transport oil, processed food items of the day, and household supplies. The markings on the outside of the container would indicate to the buyer what type of product was found within, which led them to be given the nickname "silent salesmen" [10]. Amphoras were also designed with temper evidence closures to prove to the consumer "truth in packaging" [11].

The first glass vessel was not produced until 1600 B.C.E. in Mesopotamia; however, these vessels were so delicate and too expensive for mass production. In 250 B.C.E. during the Babylonia Empire, glass became easier to produce but was still outside the realm for wine storage. It was not until the rise of the Roman Empire that glass products became more widely accessible to the common people [12,13]. It did not take long before people began to realize that glass is a great way to store wine, easily allowing long term storage in the bottle, and because of the inert properties of glass, there are no negative effects on the flavor of the wine. Glass bottle production remained relatively the same from the time of the Roman Empire until the 19th century when glass bottles were being produced by glass blowers [14]. These bottles were hand blown and would range in size, shape, and quality based upon the glass maker. Bottles could range anywhere from 700 to 800 mL. Due to the inconsistency in the size of the bottles, consumers were never truly aware of how much they were purchasing. It was not until the mid-19th century that glass blowing technology began to keep up to demand and provide a consistent size and shape as mass-produced product. The split mold process, developed in 1821, is what ultimately took glass manufacturing to the next level and quickly resulted in the decline of glass blowing. The split mold process allows for a number of different shapes to be mass produced utilizing a mold. For the production of consistent shapes and sizes, paper labels could be added to bottles. Semi-automation started taking place in 1887 by the Ashley Glass Company in Castleford, Yorkshire, in the United Kingdom. The semi-automated split mold process allowed the Ashely Glass Company to increase their production to over 200 bottles an hour, which was revolutionary at the time. It would take another 16 or so years, before glass manufacturing became fully automated in a process developed by American engineer named Michael Owens [8]. This highly efficient manufacturing has allowed a number of wine bottle styles to be developed and are named after the region or wine style for which they are primarily manufactured, such as Bordeaux, Burgundy, and the German Riesling [15,16].

2. Packaging Types

The most important function of food packaging is to protect and preserve the quality of the food or beverage stored within it [17]. The primary mission of the food's packaging is to provide a barrier against oxygen, carbon dioxide, moisture, light, and still be able to preserve the flavor and aroma of the product. Another requirement of the package is that should be inert with respect to flavor migration from the package to the product or sorption of flavors from the product to the package (flavor scalping) [7,17]. The current wine market has wine packaged in a wide range of materials including glass, a variety of plastics, aluminum, and even plastic covered paper (Tetra Pak). Table 1 summarizes the advantages and disadvantages of each packaging type discussed in this paper, along with size and recyclability.

Although the wine's package should protect and preserve the wine within, it also serves as a marketing tool. The wine bottle or package is a way to influence the customer's perception and ultimately the acceptance of the product [18]. Consumers eat with their eyes. Thus, the exterior package must be eye catching as well as provide information about the quality of the product within [19–21]. If the quality of the product does not meet the consumers expectation repeat purchasing may not occur. Surprisingly with wine, the package itself appears to have a greater influence over the consumer than other extrinsic cues like brand name recognizable, origin, and price [22]. Selecting which type of packaging to use can be difficult especially when taking into account processing constraints, consumer expectations, corrosion resistance, and environmental impact [23]. Although glass bottles are still the preferred method, there has been a growing demand for alternative wine packaging designs [24,25].

Table 1. A summary table for each of the packaging types discussed. This includes a short description of the key advantages and disadvantages of each packaging type, as well, as the common size and recyclability.

Packaging Type	Advantages	Disadvantages	Size	Recyclability
Glass	Traditional Inert superior gas and vapor barrier protection	Heavy Fragile Difficult to transport	Varies Common 750 mL	infinitely
PET	Light weight Strong Inexpensive to produce	Need to incorporate oxygen scavengers Higher potential for oxidation	Varies	infinitely
Bag-in-box	Larger volume Can be consumed over a period of time	More suspectable to oxygen permeation or SO_2 loss Potential for absorption of flavor compounds	Varies Common 3 to 5 L	limited
Aluminum cans	Light weight Ease of transport Resistant to oxidation Can be consumed directly from packaging	Low internal strength must be pressurized with N_2 More suspectable to flavor sculping and taint	Can vary 375 mL current regulated size	limited
TetraPak®	Light weight Easy to manufacture Flexible Highly stackable to improve transport and storage	Needs to incorporate both oxygen and light permeation Typically, a single use material	Varies 200 and 500 mL available	limited

2.1. Glass

Glass along with a natural cork is still one of the most popular ways to package wine today, because of its inertness and clarity [7,8]. Glass is made by combining silicon dioxide a relatively inexpensive quartz sand with sodium oxide in soda ash, calcium oxide and magnesium oxide in dolomite, and aluminum oxide in feldspar. Silicon dioxide and other ingredients first are mined. Once extracted from the earth, they are then placed into a gas burning kiln. After the bottles are formed, the interior of the bottles is chemically treated to make bottles nonporous [25,26]. Glass is still preferred for bottling of all different types of wine, because of its superior gas and vapor barrier protection, stability over time, transparency, and ability to be recycled. However, is it justifiable to store a short-lived product in such a long-lasting package [25,26]? Previous research has continued to reinforce that consumers associate glass wine bottles' shape, size, color, and closure with quality, while oddly shaped bottles and wine packaged in alternative packaging (bag-in-box, PET, cans, etc.) to be considered of lesser quality [27,28].

Glass wine bottles still have their place in the wine industry despite some of the disadvantages associated with them. As previously stated, wine bottles do have a superior gas and vapor barrier protection over other packaging types. This is important when it comes to aging wine. Glass bottles are better able to protect wine against oxygen permutation; in other words, glass allows less oxygen through the package than other packaging types. Although other packaging types may be lighter weight and more economical, they might not have the capability to preserve the quality of the wine like glass does. Hence why wines packaged in PET and other packaging types tend to have shorter lifespan [29].

For the past several decades, glass bottles have slowly been gaining weight and some wine writers have nicknamed these bottles the "bodybuilders", because of how thick the glass walls of the bottles are resulting in exorbitant weight gain. The reason for this is that people will often-times associate heavier bottles with higher quality wine. The wine bottle itself, has gained approximately a pound (454 g) [30]. Although glass wine bottles are 100% recyclable, it is more economical for wineries to bottle their wine in virgin glass than recycled bottles [31]. These are some downfalls to using glass over other packaging types such as glass shatters easily when dropped, can be heavy, and spatially inefficient. They also generate a huge carbon footprint through their manufacturing, transportation, and disposal. Glass also requires additional packaging to ensure the bottles are not damaged during transportation and delivery [32]. An average 750 mL glass bottle weighs 460 g, while a PET bottle weighs approximately 60 g [30]. However, there are a few traditional glass wine bottles that can weigh over a kilo empty.

2.2. Light Weight Glass

Light weight wine bottles are becoming more and more of a mainstay in supermarkets and liquor stores around the world [33]. Bottle manufacturers are starting to slim down their bottles making them greener and more economical without losing their sense of style or structural integrity [29,30]. Light weight glass does not necessarily mean weaker glass nor will result in a higher rate of failure due to the thinner walls [33]. Glass manufacturers have developed a new technique called "light weighting" this allows them to reduce the overall amount of glass required to manufacture a bottle. "Light weighting", as it is called, is done by reducing the amount of glass needed to make a bottle. They do this by reducing or eliminating the punt or the indention found on the bottom of a glass wine bottle [34]. Modern manufacturing techniques have the capability to thin the walls of the glass bottles but still maintain the same even glass distribution characteristics of traditional weight glass bottles [33,34]. Just by eliminating the punt in their manufacturing process, the amount of glass usage required to make a single glass bottle reduces by 14–16%. This decreases the amount of raw materials (sand and soda ash) needed to make the bottle itself, resulting in an overall cost savings of approximately 10% [29,34]. Light weight glass bottles are weighing in as little as 330 g in comparison to the average weight wine bottle at 460 g. These light weight bottles can hold both still and champagne style wines [30].

Light weight bottles can even be stronger than their traditional weight counterparts [33]. Like traditional glass bottles, light weight glass bottles are 100% recyclable and inert. Light weight bottles have lower transportation cost compared to heavier bottles, because more bottles can be loaded onto the truck [35]. Switching to lighter weight wine bottles results in a reduction of greenhouse gases as well [34].

2.3. Polyethylene Terephthalate (PET)

PET is the common name for polyethylene terephthalate, which belongs to the polyester family. PET is composed of ethylene glycol and terephthalic acid, which combined form a polymer chain [36]. The resulting PET material, can be extruded, cooled, and transformed into small pellets. The pellets are able to be heated thus allowing them to be easily extruded and molded into different shapes [36]. PET bottles can be manufactured as either single-layer or multi-layer. To improve upon the gas barrier properties of PET bottles, it is suggested that either 3-layer or 5-layer structure of PET/gas barrier resin/PET be used [37]. The transmission of gases through the packaging material is based upon the polymer crystalline structure [38]. PET bottles have been widely used for foods and beverages such as sodas, juice, and waters for several years [36,39]. Along with the CO_2 barrier properties, PET bottles also have the ability to protect sensitive products against sensory and nutritional deterioration caused by oxidation. The barrier properties of the PET can be improved with the addition of oxygen scavengers within the bottle [40].

Round lightweight PET bottles have been used to package wine for the past twenty years. In the past two years, Garçon Wines, a mail delivery wine service, partnered with Amcor to reinvent the PET bottle. Recycled flat PET (rPET) bottles are no longer round, but flat. These bottles are 87% lighter than traditional glass bottles as well as 100% recyclable. They are also 40% smaller allowing for twice as many bottles to fit on the pallet at one time. Unlike regular glass, these flat bottles are stackable and can save space on the retail shelf and at home. To ensure the consumer is still receiving the same 750 mL of wine, the bottles are taller than the average glass bottle. By packaging the wine in these taller PET bottles, the bottles, themselves are more distinguishable on retail shelves as well. The size of the bottles also make shipping to one's home easier, unlike traditional glass bottles that have to be left next to the front door. The packaging required to ships rPET bottles allow them to remain small enough to fit in a mail box or mail slot [41].

There are several advantages to using PET bottles over traditional glass. PET bottles are relatively inexpensive; they provide relatively good barrier protection against water, oxygen, and carbon dioxide; their lighter weight reduces environmental impact during transportation, and there is less loss of product due to damage during filling and storage [36,39,42]. When comparing the average weight of PET bottles to glass, PET bottles weigh only 60 g in comparison to glass at 460 g [42]. The decrease in weight can also reduce the shipping cost, which some have estimated could be reduced by approximately 30% [43]. It should also be mentioned that PET bottles can be recycled; however, unlike glass, they do have a limit. Over time, the structural integrity of the plastic will wear down requiring it to be made into something else [44]. PET bottles can also be manufactured in a number of different colors besides the traditional green, blue, brown, and clear glass bottles [41]. PET bottles come in several different sizes from single serving airplane bottles to over 1500 mL. Unlike glass bottles which require bulky cardboard boxes, PET bottles arrive on shrink wrapped trays [45]. Research conducted by an Australian wine bottle manufacturer discovered that for every 28 g (1 ounce) of glass made, approximately 0.6 ounces of CO_2 gas were generated [46]. Based upon the average wine bottle weighing 460 g (16.2 ounces), 9.74 ounces of CO_2 would be produced during manufacturing. In comparison, the EPA estimates that for every ounce of plastic produced an ounce of CO_2 is also produced. Thus, during the manufacturing of PET bottles, only 1.9 ounces of CO_2 are produced in comparison to the 9.74 ounces for a traditional glass wine bottle [29].

Of course, there are cons to each different packaging type, and PET bottles are no different. If glass wine bottles are considered high end luxury products, then PET bottles are considered cheap and of low quality. PET do protect the wine from oxygen; however, they are not perfect. Which is why manufacturers of PET bottles will combine barrier technology with oxygen scavengers. Although no research has shown that the chemicals used to create these types of bottles have caused or shown an increased health risk to humans, consumers are scared when they hear names of chemical compounds that they are unable to pronounce. Despite the combination of the barrier technology and the oxygen scavengers, PET bottles still allow more oxygen to transmit into the package than glass. The increase in oxygen transmission into the PET bottle ultimately shortens the shelf life of the wine [47].

2.4. Bag-in-Box

Wine packaging has continued to evolve throughout the years. Probably one of the most significant changes that have occurred in wine packaging is bag-in-box also known as boxed wine. The bag-in-box concept has been around since the 1950s. It was first proposed to be used by the dairy industry. It slowly gained popularity as a way to ship bulk milk. It was not until the 1970s in Australia that the first bag-in-box wine entered the market [8].

The bag-in-boxed package (see Figure 1) is a flexible, collapsible, welded double bag made of synthetic films, polypropylene (PP) valve, placed inside a rigid outer box or container with a spout attached for dispensing the contents of the container. The outer bag is made of polyester, which serves a higher barrier layer, while the inner bag is made up of either low density polyethylene (LDPE) or ethylene vinyl acetate (EVA) [7,8]. The wine pouches are filled under vacuum and back filled with nitrogen to remove the remaining oxygen found in the headspace. As wine is removed from the container through the valve, the pouch starts to collapse protecting the wine from oxygen [7]. This type of packaging is commonly used for medium quality table wine. The most common sizes available on the market are 3 and 5 L [48].

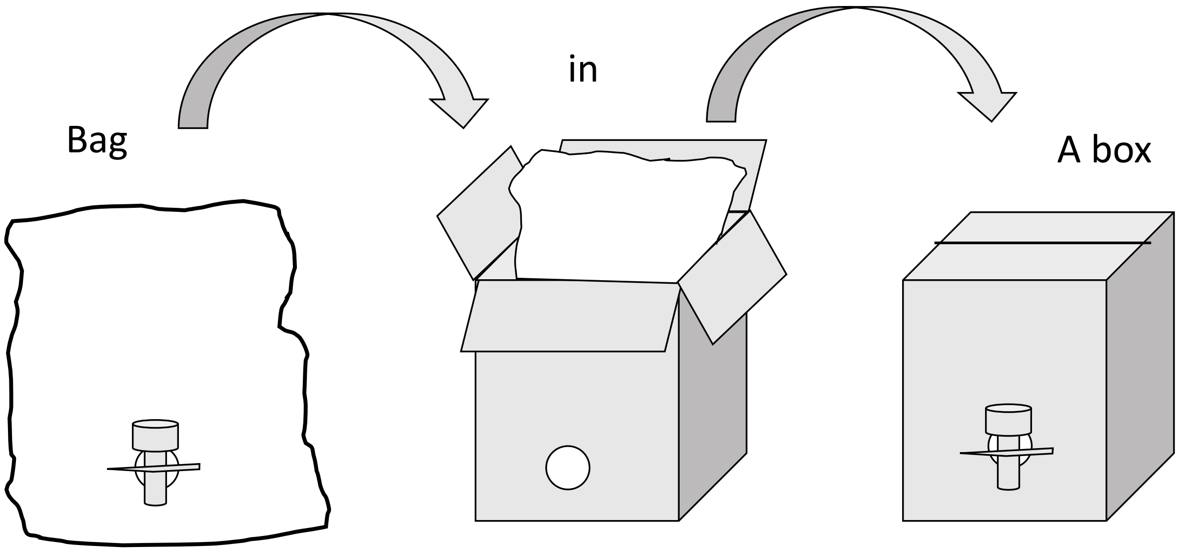

Figure 1. A schematic of a bag-in-box (BIB) design used by the packaging industry.

It should be noted that the physical strength of the bag is incredibly important. The bag itself must be able to withstand the stressors of transportation as well as subsequent storage time. During transportation, the bag itself is subjected to several different types of stress: (1) hydraulic shock (due to sudden acceleration/deacceleration) and (2) flexing (result of vibrations being transmitted through the wine causing the bag to flex). Due to the flexibility associated with this type of packaging material, it does experience fatigue, resulting in the appearance of a hole, causing it to fail. To overcome this issue, polymer films which have a high flexure resistance are used to increase the bond strength within the laminated webs, ensuring the bag and box volumes are close, along with a secondary bag used for cushion [8].

A major issue associated with packaging wine in bag-in-box is the decrease in shelf life when compared to traditional glass bottles [49]. In the 1970s, people in Australia were noticing that their bag-in-box wine started to taste oxidized as well as to have lower free SO_2 values only three months after packaging. Bag-in-box at that time had an approximate shelf life of about six-months. It was unclear if the decrease in shelf life was associated with the permeation of O_2 into the wine or permeation of SO_2 out of the wine. Researchers determined that the permeation of SO_2 out of the wine was negligible, but the true culprit that caused the wine to deteriorate was the O_2 into the wine. The oxygen was able to permeate through the valve and bag's seal. As a result of these findings, bag-in-box wines have greatly improved. They are currently being made with O_2-barrier for the bag, spout, and closure. Today's bag-in-box design consists of a single piece, flexible valve, which opens and closes when a lever is activated [8] keeping it fresh for two–three weeks after it has been opened [50].

Bag-in-box is still one of the most popular non-glass packaging types for wine holding about 5% of the market share [50,51]. Consumers are drawn to bag-in-box's 3 L size, which is equivalent to 4 standard sized bottles and can protect wine for several weeks once opened. Bag-in-box does come in smaller sizes 1.5 L and 500 mL Tetra Pak containers [50]. Bag-in-box accounts for more than 50% of all wine purchased in Australia, Sweden, and Norway, and in the United Kingdom and France, it accounts for 20% and for less than 18% within the United States [52].

2.5. Aluminum Cans

Commercial examples of canned wine date back to the 1930s, when cans were made out of tinplate steel [53]. However, wine being packaged today is placed in modern day aluminum cans, which has only been happening for the last two decades [54]. Cans are made of three different materials: (1) aluminum, (2) tin-coated steel (tinplate), and

(3) electrolytic chromium coated steel (ECCS) [55]. Bare aluminum metal is highly reactive and has the ability to form an incredibly (nanometer) thin passive layer of aluminum oxide when exposed to air or water [56]. The aluminum oxide passive layer has low reactivity, which is why aluminum foil and other aluminum-based products are considered relatively inert [57]. More often, aluminum cans have a thin (1–10 μm) polymer coating on the interior of the can to protect against the high reactivity of bare aluminum. Without the protective interior polymer layer, wine's acidic pH could cause the interior of the can to slowly corrode. The consumer is unaware of the interior protective layer's presence since it is invisible to the naked eye. The only way a consumer becomes aware of the interior protective layer is if the aluminum outer layer is etched away or by dissolving it away with a caustic solution [8,57]. Due to the interior liner of the can touching the wine, it is considered a food contact substance by the FDA and must meet their strict safety standards. Prior to 2015, can liners in the United States were made of bisphenol A (BPA) based epoxy resins. However, in May of 2015, the state of California passed Prop 65, requiring manufacturers to label their BPA based packaging materials. BPA-based products are suspected of being endocrine disruptors. Manufacturers are now using BPA-alternative can liners that exclude BPA epoxy, acrylics, and polymers [58].

Unlike carbonated beverages, still wine must be back flushed with N_2 to increase the internal pressure of the can otherwise the can could collapse on itself. The thin aluminum can has an inherently low internal strength; it relies on the pressure exerted by the beverage to keep it from collapsing. For wine packaged in cans to be successful it must meet these two requirements: (1) the nature and integrity of the enamel lining of the interior wall of the can and (2) minimal O_2 concentration within the can at time of filling [8]. O_2 concentrations should be as close to zero as possible to minimize oxidative reactions resulting in flavor deterioration [59]. This can be combated with the use of backflushing the can with N_2 at the time of filling [8].

There are advantages of packaging wine in cans such as (1) recyclable, (2) resistant to oxidation, (3) no risk of cork taint, (4) lighter than glass, (5) cost of manufacturing and shipping is cheaper than glass, (6) being able to drink directly from the can (7) will not shatter if dropped [50,54]. Canned wine is sold in a variety of sizes from 185 to 500 mL. However, Alcohol and Tobacco Tax and Trade Bureau (TTB) is proposing to eliminate the standards for wine packaging. Under the current standards, only certain sizes can be manufactured and sold individually such as 375 mL cans (2.5 glasses of wine). By changing these standards, this would allow wineries to package wine in 355 mL cans (standard beer can) as well as 250 mL cans individually, opening up new markets for the industry [60,61]. Due to wine having a higher alcohol content than beer, it could be beneficial that canned wine be served in smaller containers [54].

For years, canned wine has not been a category, as many felt it was a fad that would be short lived. However, due to the growth of this category over the last several years, it should now be considered a fully fledged category [54]. In less than a decade, wine sold in cans has jumped from USD 2 million in sales in 2012, to over USD 183.6 million for the same period ending in July 2020. That represents roughly 1.8 million cases of wine in the past year [60]. Canned wine only makes up about one-percent of the market; however, it is the fastest growing alternative wine packaged category on the market [50,61]. Canned wine is booming in all aspects from quality to sales, to the overall availability [60]. Canned wine is already a big hit at sporting events, concerts, theme parks, and other outdoor venues, where glass bottles are restricted [54,60]. Surprisingly, restaurants are catching on to canned wine as well [60].

While millennials initially drove growth within the canned wine category, others of all ages including traditional wine drinkers and even some beer drinkers are being drawn to canned wine. The availability of canned products has made wine somewhat more approachable and appealing to a wider audience including both younger and older drinkers. Oftentimes, wine is viewed as only being served at fancy dinner parties in fancy glasses; however, canned wine has defied that misconception and allowed people to experience wine anywhere such as at professional sporting events, cook outs and tailgating [54,60]. Originally, canned wine would see a spike in sales only during the spring and summer months when people would start to enjoy the outdoors; however, that is no longer the case. Sales have started to increase throughout the year [50].

2.6. Tetra Pak®

The idea of a tetrahedron-shaped, folded paper tube package for food and beverage products, later referred to as a Tetra Pak, has its origins dating back to 1944 [62]. Tetra Pak, originally a subsidiary of Åkerlund & Rausing, was established in Lund, Sweden, becoming its own company in 1951, and since then, the innovative package has expanded into many applications within the food and beverage industry making Tetra Pak the largest food packaging company in the world [63].

Tetra Pak are aseptic cartons made of multilayer packaging composed of three main, separate materials: paperboard, polyethylene polymers, and aluminum [64]. Paperboard is the primary material within the packaging. The paperboard provides stability, strength, and a smooth and ink receptive surface necessary for printing of labels. The polyethylene polymers protect the product and the packaging against moisture, both from the exterior moisture from the environment and interior moisture from the product. These polymer layers also provide a food safe layer between the product and packaging materials. The polymer layer also allows for the paperboard to stick to the aluminum foil layer, and it is this aluminum foil layer that protects the product against oxygen and light. This then prevents any photooxidative reactions from occurring [65]. Tetra Pak packaging comes in a variety of closure types, though the most common closure for wine packaged in Tetra Paks is a plastic screw top lid [66]. This plastic screw top lid has barbs on the underside of the lid that cut open the protective film and allows access to the product.

The use of Tetra Paks in the wine industry dates back to 2006 with the creation of the Tetra Pak "Prisma" [29]. The Tetra Pak "Prisma" was specifically developed for wine and provided the product with a flexible package where air could be squeezed out of the package, limiting oxidation and extending shelf life, as well as providing the product with an airtight seal with 100% UV protection. The Tetra Pak also provided the product with increased stackability when compared to more traditional wine packaging options such as glass bottles. These Tetra Paks also come in 200 and 500 mL sizes which increases the package size options and provides a single serving option for the product [66]. This single-serve option for wine packaging is becoming increasingly popular among consumers [67]. Some popular wine brands that utilize the single-serve Tetra Pak package for their product are French Rabbit, Fish Eye, and Yellow+Blue [68]. In addition to the "Parisma", Tetra Pak currently offers two additional product lines for wine packaging; the "Gemina" and the "Stelo" [69]. Tetra Pak packaging provides wine producers with an inexpensive alternative to traditional wine packaging such as glass with a Tetra Pak package costing only USD 10–25 ¢ to fill and produce [70]. Since Tetra Pak packaging is lighter than glass, the cost to ship the product is also reduced, and since the packaging is flexible, breakage is less likely to occur reducing loss of product and damage induced by breakage.

3. Sensory and Flavor

Wine like other fermented beverages is a complex product. Wine is primarily composed of water (80–85%), alcohols (ethanol being the major one 9–15%), and a variety of other minor components (3%) [71]. Minor components include organic acids, sugars, phenols, nitrogenous compounds, enzymes, vitamins, lipids, inorganic anions and cations, and other volatile compounds (esters, ketones, fusel alcohols, etc.) [72]. Wine flavor is a complex mixture of volatile compounds (alcohols–lower and fusel, esters, organic acids, aldehydes, phenols, lactones, sulfur containing compounds, methoxypyrazines, norisoprenoids, ketones, and terpenes) and a delicate balance of sweet (sugars), sour (organic acids), and bitterness/astringent (polyphenols) [7,72,73]. The flavor and aroma of the wine depends on the grape varietal(s) used, growing conditions (soil type, climate), and wine making practices (processing techniques, yeast strain, fermentation conditions) [74] wine aging, storage conditions among others [74]. Therefore, the consumer experience can be greatly affected by the packaging, transport, and storage conditions.

Wine aging can be divided into two phases: maturation (between fermentation and bottling) and bottling (aging within the bottle). During the aging process, the wine's composition is altered through a number of complex chemical reactions, and some chemical classes such as phenolics (anthocyanins, flavan-3-ols, flavonols, hydroxycinnamic acid) and volatile organic compounds (esters, fusel alcohols, aldehydes, ketones, acids, etc.) can result in noticeable changes to the sensory and physical characteristics of final product [75].

Micro-oxygenation of red wines during the aging process is acceptable at least to some extent to help improve the quality of the wine by removing unwanted aromas, color stabilization, and improvement in the mouth feel [76]. Oxidation is one parameter that can affect the shelf-life of a table wine. Oxidation of the wine depends on several factors: the wine's ability to resist oxidation and the level of exposure to oxygen. Oxidation can produce significant organoleptic changes in the color, aroma (less of freshness), and degradation of anthocyanins and can cause the wine to appear brown due to precipitates of condensed phenolic material [77–80], which is why it is important to monitor and manage the amount of oxygen that comes into contact with the wine during manufacturing, storage, and packaging [81,82].

One of the primary parameters that affect wine through the aging process is the transfer of gases through the packaging materials [82], hence why the type of packaging will have a considerable impact on the extent of wine oxidation and the loss of other sensory properties [80].

3.1. Sensory and Flavor of Wine from Glass

The packaging of wine is a material intensive process with bag-in-box, glass, and PET bottles [83]. Glass containers are traditionally utilized as the control when it comes to accelerated shelf-life studies for wine. Glass has a high impermeability to gases and vapors and stability over time. It is also preferred over other materials due to its historical use and transparency and to being easily recyclable [82]. Ghidossi et al. 2012 analyzed the impact different packaging (glass, monolayer PET (0.3 mm thickness), Multi-layer PET (0.4 thickness), and BIB) types have on the physical and chemical properties of white and red wine over an eighteen-month period [23]. Although there were clear differences at 6 and 18 months regarding the chemical and physical analysis of the white wine, it was apparent that the glass bottles were superior in terms of limiting gas transfer (O_2, CO_2), maintaining SO_2 content, and protecting color intensity and sauvignon character for white wine in comparison to the other packaging types. Glass was found to be superior to the other packaging designs in that it had the lowest concentration of oxidative flavor markers phenylacetaldehyde [84], methional [85], and sotolon [80,84] all of which were below their perception threshold levels [23].

Moreria et al. 2018 analyzed the sensory and volatile composition of white wines under different packaging conditions for a twelve-month period. Wines packaged in glass had significantly higher concentrations of 2-phenylethanol, 2-phenylethyl acetate, isoamyl acetate, ethyl butanoate, and ethyl hexanoate than BIB [86]. Similar results were observed by Mentana et al. when comparing glass to traditional PET bottles. Flavor compounds were better protected from oxidation and flavor deterioration in the glass bottle vs. PET. This was particularly evident for white wine [82].

3.2. Bag-in-Box

A major downside of this packaging type is that the polyolefinic (polyethylene, polypropylene) film comes in contact with the wine. Polyolefinic films have a strong capacity to absorb the volatile and semi-volatile compounds from the wine resulting in flavor deterioration. The film used for this type of packaging has a sorption rate for non-polar compounds due to the hydrophobic nature of the polyolefins [17]. Revi et al. 2014, conducted a study comparing the impact wines packaged in bag-in-box (low density polyethylene–LDPE and ethylene vinyl acetate–EVA) vs. traditional glass had on the enological parameters as well as the volatile and semi-volatile compounds over a six-month period. It was concluded that the packaging design did have an impact on the wine at the end of the six-month time period. Wine deterioration was most pronounced when stored in the bag-in-box pouches due to the sorption of flavor compounds into the polymeric packaging material. However, between the different types of pouches used the LDPE lined pouched had the highest potential for flavor sorption. It should be noted that when comparing sensory acceptability, consumers felt that after 90 days, the wine was unacceptable [7]. Moreira et al. 2016 found similar results as well with their study looking at the influence wine packaging and aging had on the volatile and sensory attributes of red wine [7,80]. Due to the higher permeability of the bag-in-box design, wine should be consumed rather quickly and not aged.

Moreria et al. 2018 repeated their original packaging experiment using white wine in lieu of red [86]. Moreria et al. (2018) found similar results to their original experiment in which wine packaging design does have a major impact on the chemical and sensory properties of wine. Bag-in-box in comparison to glass for white wines had the highest levels of oxidized aromas and a significant decrease in aromatic (2-phenylethanol, 2-phenylethyl acetate, isoamyl acetate, ethyl butanoate, ethyl hexanoate) compounds [86].

3.3. Sensory and Flavor of Wine from Aluminum Cans

Within canned beverages, there is a greater concern for sensory/flavor deterioration caused by degradation, scalping, or tainting than microbial spoilage [86].

Degradation is a chemical process that happens throughout the life span of the product ultimately resulting in the products loss of quality. Oxidative deterioration is one of the biggest causes of flavor degradation in wine. To slow down oxidative deterioration, wine makers add between 20–40 mg/L of free sulfur dioxide (SO_2) to their packaged wine. Oxidative aromas, colors, and other signs of deterioration start to become apparent when free SO_2 levels are below 10 mg/L [57].

Scalping occurs when VOCs migrate from the food product or beverage into the packaging material. Non-polar flavor and aroma compounds are affected the most because they have the capacity to be absorbed into the non-polar polymer packaging materials. Scalping has not been studied in canned wine products and leaves an area for future research. Scalping has been thoroughly studied in beer, strictly focusing on the aroma active non-polar hop compounds like limonene. Although, limonene is found in wine below detectable threshold levels, 1,1,6-trimethyldihydronaphthalene (TDN), rotundone, and 2,4,6-trichloroanisole (TCA aka "cork taint") are potential compounds that could be scalped by the can's lining during storage [57].

Tainting refers to introduction of off-flavors into the food or beverage products from packaging material. The most well-known example of tainting pertaining to wines is cork taint; however, it does not affect canned wines. Taint that is more likely to happen within canned products is the interaction between the impurities found on the can lining and the food product, resulting in off-flavor in the product [76]. These types of reactions are called "secondary taint", which can be much more difficult to predict and might be overlooked during simple model testing [57].

One issue associated with canned wine is the development of hydrogen sulfide (H_2S: rotten egg smell) after several months of storage. This issue has also been reported in canned hard ciders as well [57]. Hydrogen sulfide has a sensory threshold level of 1 ug/L (1 ppb) in wine, and oftentimes, this compound is a byproduct of yeast metabolism during the fermentation process [76]. Although the identification of hydrogen sulfide has not occurred in the literature pertaining to canned wines, it has occurred in multiple patents [87,88] as well as at conference proceedings. The issue is no one knows if their product will be affected. Some cans experience no detectable limits of hydrogen sulfide after a year of storage while others develop within a couple of months.

In recent blind tastings, more than a dozen canned wines scored between 85–90 points (Very good) on the Wine Spectator's 100-point scale [60].

3.4. Sensory and Flavor of Wine from Polyethylene Terephthalate (PET)

Mentana et al. 2009 conducted a study looking at the chemical and physical changes of Apulia table wine packaged in two different types of PET bottles (PET and Oxygen scavenging PET (OxSC-PET). The study looked at white and red wine over a six-month period. The flavor and aroma profile for red wines was analyzed following the completion of the storage period. The study concluded that there was a significant loss in a number of organic compounds including alcohols, acids, and esters for wines stored in PET bottles. Mentana et al. reported the loss of a number of these compounds to scalping by the PET bottle. However, OxSc-PET showed flavor scalping to a lesser extent than the regular PET bottle [82].

Ghidossi et al. 2012 analyzed the impact different packaging (glass, monolayer PET (0.3 mm thickness), Multi-layer PET (0.4 thickness), and BIB) types have on the physical and chemical properties of white and red wine over an eighteen-month period. Results from this study showed that PET bottles primarily the PET-monolayer had the highest degree of oxidation especially in the white wine [23]. Phenylacetaldehyde [84], methional [85], and sotolon [84,85] are three well known compounds associated with oxidation of white wine during storage. Ghidossi (2012) during their study showed that the PET monolayer (185 and 750 mL) bottles had increased concentrations of all three compounds due to increased oxygen levels found within the package over the eighteen-month period. All three compounds, phenylacetaldehyde, methional, and sotolon, had concentrations above their perception threshold levels 2 ug/L, 25 ug/L, and 2 ug/L. The presence of these compounds clearly impacts the overall flavor profile of white wine [23]. It is relatively common for the flavor compounds of white wines to age rapidly and develop sensory defects. Conversely, this study found no sensory differences within the red wine for the different packaging types over the eighteen-month study period.

4. Sustainability and Environmental Impact

As the world's population continues to increase and the accessibility of readily available raw, natural resources continues to decrease, the question that arises is how to provide for this growing population while maintaining and growing the quality of life [89]? There are many facets that go into this dilemma from global food sustainability [90] to the production and use of natural resources in our daily lives [91]. Wine and wine production are not immune to this dilemma. On top of the environmental costs and investments that go into growing the grapes and producing the wine, wine packaging also has challenges that impact the environment and effect sustainability. There are many different types of wine package options, and each one provides their own unique sustainability benefits and challenges.

Starting with the most popular category of wine packaging, glass, the material, as a whole, is generally considered sustainable and an environmentally sound packaging choice [89]. The initial production of new glass imposes a major impact to the environment, mainly from the energy costs and the issues surrounding the mining of the raw glass building material, silica. However, glass is infinitely recyclable, and as long as the used glass is being recycled, there is little need for the production of new glass [92]. There is a 60% reduction in energy costs when recycling glass over the production of new glass [93]. There is an extensive cost in the sorting of the types of glass received for recycling.

Glass wine bottles come in a variety of colors. The colors of a wine bottle are oftentimes varietal specific and can either be chosen because of the protective properties of the glass, such as the use of dark or amber colored glass to protect oxidation of the wine from light, or in culturally traditional bottle colors, such as light green, blue, or clear, based on the varietal needs or specifications [94]. Glass color is achieved by adding additives to the silica base of the glass [95]. These additives change the chemical makeup of the glass and thus pose certain intricacies in processing the glass while recycling [93,95].

Although a minority packaging format for wine, aluminum cans provide an environmentally sustainable packaging alternative [96]. Currently only making up about 10% of the wine market, the use of single-served, aluminum cans for wine is growing [28]. In recent years, the use of aluminum cans in the wine industry has seen an increase of 58% and is the fastest growing alternative wine packaging [97]. Not only do aluminum cans provide some added benefits to wine storage such as light and oxygen protection [98], but there are some environmental benefits from using aluminum cans as well [99]. Like glass, aluminum is also infinitely recyclable, so as long as aluminum is being recycled, the aluminum can be reused and made into a new product, such as a beverage can, without any degradation to the molecular integrity of the aluminum. Recycling aluminum saves about 95% of the energy used to produce aluminum from raw materials [100]. The amount of greenhouse gas and CO_2 produced while packaging 100 gallons of wine in cans is about 175 kg [101] in comparison to the 200–230 kg produced for packaging the same amount of wine into glass bottles [29].

Despite the relative ease of recycling and producing aluminum cans and the environmental and product quality protective nature of the can, aluminum cans are used in many different industries such as soft drinks and beer [102]. This competition for aluminum cans, coupled with international tax and trade disagreements, has caused an aluminum can shortage which has in turn caused the price of aluminum to rise [103]. Despite this, the use of cans as beverage packaging, including the wine market, continues to grow [28,104,105].

Plastics are another alternative wine packaging material that hold a minority share of the market, but it is these plastics that are used in multiple forms of packaging. Besides the PET plastic bottles used for wine, the bag from the bag-in-box form of wine packaging and the polymers used in the formation of Tetra Paks are also made of plastics. Unlike the glass and aluminum cans, the majority of plastics, although they can be recycled, degrade over time and have a finite ability to be recycled [106]. There are seven major types of plastics used in packaging, and they each have their own unique chemical properties. These unique chemical properties mean that handling and the methods of recycling these different types of plastics are aligned to the specific type of plastic. Plastics are derived from oil and are not considered sustainable packaging material options [107]. It is estimated that 80% of all plastic produced is produced for single use with only 8.7% of the plastic waste being recycled [108,109]. It is also estimated that 60–80% of marine pollution is due to plastics.

The degradation of plastics over time caused microplastic contamination of the environment, especially aquatic ecosystems [110]. This has led to the use of alternative packaging materials other than plastic [111] or the use and development of plant-based or biodegradable plastics [112]. For example, this environment and sustainable issue was important to the wine company Bota Box. The company chose to use plant-based and post-consumer packaging materials for their product which they claim reduces waste by 85% over traditional wine packaging [113]. It is estimated that 80–90 kg of CO_2 is produced in the production of plastics used in the wine industry [29].

Another packaging materials used in the wine industry are cardboard and other plant-fiber-based packing materials. These are typically used in conjunction with other packaging materials such as a bag as in the bag-in-box package with the box being made of cardboard or the paperboard layers of the Tetra Pak. This is not to mention the macro packaging such as cardboard wine boxes that hold wine packages such as bottles or cans. Cardboard and paperboard are important packaging materials within the wine industry making up the majority of the secondary and tertiary forms of packaging [114]. These fiberboard packaging materials are a vital part of the shipping and storage of wine and provide a protective and stable yet affordable package for bulk wine [115].

Although cardboard and paperboard are recyclable, the fibers that make up the boards do degrade over time and paper products are not infinitely recyclable [116]. Despite this, paper products such as cardboard and paperboard are made from plant products and are biodegradable, which makes these packaging materials sustainable materials [117].

Finally, although Tetra Paks are made of recyclable materials and some recycling facilities are capable of recycling the container, the layers of aluminum foil and paperboard are laminated together with polymers which make the separation of the individual pieces almost impossible for the average recycling center, thus making these types of packages non-recyclable [64,118,119]. For this reason, many Tetra Paks are thrown in the garbage and are not recycled. As current recycling infrastructure stands, these should not be considered sustainable forms of packaging. That said, the production of Tetra Paks uses 92% less material in the package compared to traditional wine packages like glass, and it uses 54% less energy to create the package, emitting 80% fewer greenhouse gases in its production [29].

5. Attitudes toward Purchasing Alternative Wine Packaging Designs

There has been a significant increase in the consumption of wine in the past several decades. Annual consumption for wine in the United States is roughly around 13.4 L (2.95 gals). The increase in consumption is a direct result of the number of wineries that have opened, wine brands, labels, bottle shapes and colors, style of closures, and regional designations [120]. Since 2009, there has been a 50% increase in the total number of wineries in the United States, with each state having at least one winery. The total number of wineries within the United States is approximately 11,053 [121]. The majority of legal drinking adults in the United States say they prefer beer (36%) over wine (30%) and distilled spirts (29%) based on a 2020 survey [122].

Purchasing a bottle of wine can oftentimes be a very difficult process for most consumers. Particularly since the quality of the product cannot be accessed until after consumption. The marketing of a wine package consists of several cues (bottles shapes, color, closure, and label design), which all interface with the consumers experience, knowledge about wine, and self-confidence, and the occasion and/or reason for purchasing wine will influence purchasing decisions [123]. Experienced wine consumers who know what they want will purchase wine based on past experiences and packaging cues, while inexperienced buyers will place more emphasis on the information obtained by reading the wine label [124]. Barber and Almanza (2007) conducted a study to look at how influential the wine packaging was on purchasing intent. It was determined that wine package had a greater influence on the purchasing intent for the consumer than other marketing cues [124].

As consumers become more aware of how their actions impact the environment around them, consumers are starting to make more environmental conscious decisions regarding their everyday lives [125]. As the wine industry becomes more and more competitive, global marketers are having to find ways to separate themselves from their competitors. Nevertheless, with the choices of wines numbering into the thousands, selecting a particular wine comes down to how the wine is perceived and brand success. Wine promoters who are more environmentally conscious are trying to provide more information to consumers to help increase their knowledge and change their attitudes in the hope of them purchasing more environment friendly wines [126–128]. A possible way of attracting environmentally conscious consumers who are interested in protecting the environment and reducing their ecological footprint would be to utilize selective marketing techniques geared toward these individuals [129,130].

Wineries large and small are trying to implement sustainable viticulture and winemaking practices to lessen their impact on the environment [131]. Barber (2012) found that environmentally conscious consumers were more willing to pay more for environmentally friendly wines [131]. Ferrara et al. 2020 conducted a study to look at people's willingness to purchase alternative packaging types for wine, and 91% of respondents were not willing to consider other packaging alternatives mainly due to their view of them being inferior to glass [132]. Although Barber (2012) found consumers were willing to pay more for environmentally friendly wines, it does not necessarily translate into actual purchasing of those products [123].

6. Conclusions

The question comes down to whether bottles are outdated. Nowadays, with so many different types of packaging (BIB, PET, OxSC-PET, cans, TetraPak®, glass) and closure (screw cap, natural and synthetic corks) options available, winemakers and producers are able to select the type of packaging that will best fit their needs and allow them to stand out in a competitive market. Glass is still one of the most commonly used packaging types for wine worldwide and will likely never go away. Wine like other fermented beverages is a complex product, composed of a number of different chemical classes of volatile and semi-volatile compounds that are continuously changing throughout the maturation and storage life span of the product. However, a number of studies have looked at the impact wine packaging type has on the chemical and sensory attributes during the aging process of wine. It has been confirmed by numerous studies that glass is still superior to other packaging types despite its environmental impact.

Author Contributions: K.A.T.-W. worked on the conception of the idea, preparing the manuscript and editing the manuscript. E.R.P. helped in writing the manuscript along with editing the manuscript. J.L.N. worked on preparing the manuscript. D.B. worked on the figure and table for the manuscript as well as editing the manuscript in preparation for submitting it. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Chambers, P.; Pretorius, I.; Chambers, P.J.; Pretorius, I.S. Fermenting knowledge: The history of winemaking, science and yeast research. *EMBO Rep.* **2010**, *11*, 914–920. [CrossRef] [PubMed]
2. Sicard, D.; Legras, J.-L. Bread, beer and wine: Yeast domestication in the Saccharomyces sensu stricto complex. *C. R. Biol.* **2011**, *334*, 229–236. [CrossRef]
3. Navarro, A.; Puig, R.; Fullana-I-Palmer, P. Product vs. corporate carbon footprint: Some methodological issues. A case study and review on the wine sector. *Sci. Total Environ.* **2017**, *581–582*, 722–733. [CrossRef] [PubMed]
4. Devesa-Rey, R.; Vecino, X.; Varela-Alende, J.; Barral, M.T.; Cruz, J.; Moldes, A. Valorization of winery waste vs. the costs of not recycling. *Waste Manag.* **2011**, *31*, 2327–2335. [CrossRef] [PubMed]
5. Marras, S.; Masia, S.; Duce, P.; Spano, D.; Sirca, C. Carbon footprint assessment on a mature vineyard. *Agric. For. Meteorol.* **2015**, *214–215*, 350–356. [CrossRef]
6. The International Organization of Vine and Wine (OIV). Available online: http://www.oiv.int/public/medias/6782/oiv-2019-statistical-report-on-worldvitiviniculture.pdf (accessed on 16 November 2020).
7. Revi, M.; Badeka, A.; Kontakos, S.; Kontominas, M. Effect of packaging material on enological parameters and volatile compounds of dry white wine. *Food Chem.* **2014**, *152*, 331–339. [CrossRef]
8. Robertson, G.L. *Food Packaging Principles and Practice*, 2nd ed.; CRC Press: Boca Raton, FL, USA, 2006.
9. Roux, P.; Gérand, Y. *Comparative Life Cycle Assessment of the NOVINPAK® PET/RPET Bottle and Traditional Glass Bottle Including Vine Growing and Vine Making*; Irstea: Montpellier, France, 2014.
10. Twede, D. The packaging technology and science of ancient transport amphoras. *Packag. Technol. Sci.* **2002**, *15*, 181–195. [CrossRef]
11. Lockhart, H.E. A paradigm for packaging. *Packag. Technol. Sci.* **1997**, *10*, 237–252. [CrossRef]
12. McGovern, P.E.; Fleming, S.J.; Katz, S.H. *The Origins and Ancient History of Wine*; Gordon and Breach Publishers: Philadelphia, PA, USA, 1995.
13. Mass, J.L.; Wypyski, M.T.; Stone, R.E. Evidence for the Metallurgical Origins of Glass at Two Ancient Egyptian Glass Factories. *MRS Bull.* **2001**, *26*, 38–43. [CrossRef]
14. Island of Glass. *MRS Bull.* **1997**, *22*, 54. [CrossRef]
15. Lindsey, B. Bottle Typing/Diagnostic Shapes: Food Bottles & Canning Jars. Available online: http://www.sha.org/bottle/food.htm (accessed on 29 June 2020).
16. Estreicher, S.K. From Fermentation to Transportation: Materials in the History of Wine. *MRS Bull.* **2002**, *27*, 991–994. [CrossRef]

17. Sajilata, M.; Savitha, K.; Singhal, R.; Kanetkar, V. Scalping of Flavors in Packaged Foods. *Compr. Rev. Food Sci. Food Saf.* **2006**, *6*, 17–35. [CrossRef]
18. Imram, N. The role of visual cues in consumer perception and acceptance of a food product. *Nutr. Food Sci.* **1999**, *99*, 224–230. [CrossRef]
19. Deliza, R.; MacFie, H. The generation of sensory expectation by external cues and its effect on sensory perception and hedonic ratings: A review. *J. Sens. Stud.* **1996**, *11*, 103–128. [CrossRef]
20. Stefani, G.; Romano, D.; Cavicchi, A. Consumer expectations, liking and willingness to pay for specialty foods: Do sensory characteristics tell the whole story? *Food Qual. Prefer.* **2006**, *17*, 53–62. [CrossRef]
21. Lange, C.; Martin, C.; Chabanet, C.; Combris, P.; Issanchou, S. Impact of the information provided to consumers on their willingness to pay for Champagne: Comparison with hedonic scores. *Food Qual. Prefer.* **2002**, *13*, 597–608. [CrossRef]
22. Mueller, S.; Lockshin, L. How Important Is Wine Packaging for Consumers? On the Reliability of Measuring Attribute Importance with Direct Verbal Versus Indirect Visual Methods. Ph.D. Thesis, Academy of Wine Business Research, Sonoma, CA, USA, 2008.
23. Ghidossi, R.; Poupot, C.; Thibon, C.; Pons, A.; Darriet, P.; Riquier, L.; De Revel, G.; Peuchot, M.M. The influence of packaging on wine conservation. *Food Control* **2012**, *23*, 302–311. [CrossRef]
24. Charters, S.; Pettigrew, S. The dimensions of wine quality. *Food Qual. Prefer.* **2007**, *18*, 997–1007. [CrossRef]
25. Athens, K. Bottler caters to regional wineries. *Sustain. Ind. Jan.* **2009**.
26. Colman, T.; Päster, P. Red, White, and 'Green': The Cost of Greenhouse Gas Emissions in the Global Wine Trade. *J. Wine Res.* **2009**, *20*, 15–26. [CrossRef]
27. Jennings, D.; Wood, C. Wine: Achieving Competitive Advantage Through Design. *Int. J. Wine Mark.* **1994**, *6*, 49–61. [CrossRef]
28. Williams, H.A.; Williams, R.; Bauman, M. Growth of the Wine-in-Can Market. Available online: https://www.depts.ttu.edu/hs/texaswine/docs/Wine_in_Can_Industry_Report.pdf (accessed on 29 October 2020).
29. Thompson, K. Wine Packaging Alternatives Not All Good Wine Comes in Glass Bottles. Available online: https://www.iopp.org/files/public/ThompsonKatherineVT.pdf (accessed on 1 October 2020).
30. Robinson, J. Red, White, and Green. Available online: https://www.jancisrobinson.com/articles/red-white-and-green (accessed on 30 November 2020).
31. De Gianna, A. *Production of High-Quality Red Wines from Native Vines through the Management of Viticultural, Technological, Aging, and Packaging Variables*; Universita di Foggia: Foggia, Italy, 2016; p. 279.
32. Steckenborn, E. Why the Future of Wine Packaging is Recycled PET. Available online: https://www.beveragedaily.com/Article/2020/03/06/Why-the-future-of-wine-packaging-is-recycled-PET# (accessed on 11 November 2020).
33. WRAP. Case Study Lightweight Wine Bottles: Less Is More. Available online: http://www.wrap.org.uk/sites/files/wrap/GlassRight%20Wine%20lightweighing%20-%20web%20version.pdf (accessed on 17 November 2020).
34. Gannon, S. *How Light Can You Get? Economy Dictates that Bottles Decrease in Weight and Price*; Wine Communications Group: Sonoma, CA, USA, 2009.
35. Stevens, R. Lightweight Bottles: The Lighter the Better? Available online: https://signetbranding.com/news/lightweight-bottles-the-lighter-the-better/ (accessed on 17 November 2020).
36. Shirakura, A.; Nakaya, M.; Koga, Y.; Kodama, H.; Hasebe, T.; Suzuki, T. Diamond-like carbon films for PET bottles and medical applications. *Thin Solid Films* **2006**, *494*, 84–91. [CrossRef]
37. Van Bree, I.; De Meulenaer, B.; Samapundo, S.; Vermeulen, A.; Ragaert, P.; Maes, K.; De Baets, B.; Devlieghere, F. Predicting the headspace oxygen level due to oxygen permeation across multilayer polymer packaging materials: A practical software simulation tool. *Innov. Food Sci. Emerg. Technol.* **2010**, *11*, 511–519. [CrossRef]
38. Liu, R.Y.F.; Hu, Y.S.; Schiraldi, D.A.; Hiltner, A.; Baer, E. Crystallinity and oxygen transport properties of PET bottle walls. *J. Appl. Polym. Sci.* **2004**, *94*, 671–677. [CrossRef]
39. Dombre, C.; Rigou, P.; Wirth, J.; Chalier, P. Aromatic evolution of wine packed in virgin and recycled PET bottles. *Food Chem.* **2015**, *176*, 376–387. [CrossRef]
40. Ros-Chumillas, M.; Belissario, Y.; Iguaz, A.; López, A. Quality and shelf life of orange juice aseptically packaged in PET bottles. *J. Food Eng.* **2007**, *79*, 234–242. [CrossRef]
41. Rick, L. *Sustainably Optimized Flat Wine Bottles Enter US*; Packaging Digest: Oak Brook, IL, USA, 2020.
42. Wine Glass or Plastic Bottles? Available online: https://medium.com/@GarconWines/wine-in-glass-or-plastic-bottles-376d3c1dfd11 (accessed on 12 November 2020).
43. Baude, C.K. *A Preliminary Analysis of PET Barrier Technologies and Mechanical Performance Related to a 3L PET Wine Bottle, in Department of Packaging Science*; Rochester Institute of Technology: New York, NY, USA, 2008; p. 49.
44. Amcor Unveils Modern PET Bottle Concepts and Collaboration with Garçon Wines at Unified Wine and Grape Symposium. Available online: https://wineindustryadvisor.com/2020/02/05/amcor-unveils-modern-pet-bottle-concepts (accessed on 12 November 2020).
45. Firstenfeld, J. *The Changing Landscape of Wine Bottles*; Wine Communications Group: Sonoma, CA, USA, 2016.
46. Robinson, J. Carbon Footprints, Wine and the Consumer. Available online: https://www.jancisrobinson.com/articles/carbon-footprints-wine-and-consumer (accessed on 9 November 2020).
47. Wine Packaging: The Pros and Cons of PET Bottles. Available online: https://www.packaginginnovation.com/packaging-materials/wine-packaging-the-pros-cons-of-pet-bottles/ (accessed on 12 November 2020).

48. Kalkowski, J. *Brining Innovation to Bag-in-Box*; Packaging Digest: Oak Brook, IL, USA, 2014.
49. Fradique, S.; Hogg, T.; Pereira, J.; Pocas, M.F.F. Performance of Wine Bag-in-Box during Storage: Loss of Oxygen Barrier. *Ital. J. Food Sci.* **2011**, *23*, 11–16.
50. Weed, A. *Canned Wine Comes of Age*; Wine Spectator: New York, NY, USA, 2019.
51. Cooper, G. Wine Boxes and Cans Come of Age. Available online: https://www.nielsen.com/us/en/insights/article/2019/wine-boxes-and-cans-come-of-age/ (accessed on 26 October 2020).
52. Patterson, T. *How Good Is That Wine Bag, Really?* Wine Communications Group: Sonoma, CA, USA, 2010.
53. Pinney, T. *A History of Wine in America*, 2nd ed.; University of California Press: Oakland, CA, USA, 2005.
54. Williams, M. Is the Future of Wine in the Can? Available online: https://www.forbes.com/sites/michellewilliams/2019/08/28/is-the-future-of-wine-in-the-can/#3d8590b76cc3 (accessed on 26 October 2020).
55. Geueke, B. *FPF Dossier: Can Coatings*; Food Packaging: Zurich, Switzerland, 2016.
56. Vargel, C.; Jacques, M.; Schmidt, M.P. *Corrosion of Aluminium*; Science-Direct: Amsterdam, The Netherlands, 2004.
57. Allison, R.; Sacks, G.; Maslov-Bandic, L.; Montgomery, A.; Goddard, J. *The Chemistry of Canned Wines*; Cornell Viticulture and Enology: Ithaca, NY, USA, 2020; pp. 1–8.
58. Bomgardner, M. New epoxy could boot BPA from cans. *Chem. Eng. Glob. Enterp.* **2019**, *97*, 32–35. [CrossRef]
59. Pires, E.J.; Teixeira, J.A.; Brányik, T.; Vicente, A.A. Yeast: The soul of beer's aroma—A review of flavour-active esters and higher alcohols produced by the brewing yeast. *Appl. Microbiol. Biotechnol.* **2014**, *98*, 1937–1949. [CrossRef] [PubMed]
60. Weed, A. *Canned Wine Sales Are Bursting at the Seams*; Wine Spectator: New York, NY, USA, 2020.
61. McIntyre, D. *Once a Niche Product, Canned Wine Enters the Mainstream*; Washington Post: Washington, WA, USA, 2019.
62. IVA. Tetra Pak. Available online: https://www.iva.se/en/ (accessed on 15 April 2021).
63. Tetra Pak in Figures. Available online: https://www.tetrapak.com/about-tetra-pak/the-company/facts-figures (accessed on 15 April 2021).
64. Tetra Pak Packaging Material—Packed with Innovation. Available online: https://youtu.be/fR-esiS1Pn0 (accessed on 15 April 2021).
65. Packaging/Materials. Available online: https://www.tetrapak.com/packaging/materials (accessed on 20 November 2020).
66. Tetra Pak Prisma. Available online: https://www.tetrapak.com/en-us/solutions/packaging/packages/tetra-prisma-aseptic (accessed on 15 April 2021).
67. Acuti, D.; Mazzoli, V.; Grazzini, L.; Rinaldi, R. New patterns in wine consumption: The wine by the glass trend. *Br. Food J.* **2019**, *122*, 2655–2669. [CrossRef]
68. Ponstein, H.J.; Meyer-Aurich, A.; Prochnow, A. Greenhouse gas emissions and mitigation options for German wine production. *J. Clean. Prod.* **2019**, *212*, 800–809. [CrossRef]
69. Tetra Pak: Protects What's Good. Available online: https://www.tetrapak.com/en-us (accessed on 20 November 2020).
70. Gannon, S. *Pushing the Packaging Envelope—Alternative Formats and Closures Growing Fast in Volume Sales*; Wine Communications Group: Sonoma, CA, USA, 2009.
71. Jackson, R.S. *Wine Science: Principles and Applications*; Academic Press: London, UK, 2014.
72. Amerine, M.A.; Ough, C.S. Wine and Must Analysis M. A. Amerine and C. S. Ough Agricultural Experiment Station; University of California, Davis, CA John Wiley & Sons, New York/London/Sydney Toronto, 1974, 121 pp. *J. Chromatogr. Sci.* **1974**, *12*, 19A.
73. Moreno-Arribas, M.V.; Polo, M.C. *Wine Chemistry and Biochemistry*; Springer: New York, NY, USA, 2009.
74. Moreira, N.; Lopes, P.; Ferreira, H.; Cabral, M.; De Pinho, P.G. Sensory attributes and volatile composition of a dry white wine under different packing configurations. *J. Food Sci. Technol.* **2018**, *55*, 424–430. [CrossRef]
75. Guerrini, L.; Pantani, O.; Politi, S.; Angeloni, G.; Masella, P.; Calamai, L.; Parenti, A. Does bottle color protect red wine from photo-oxidation? *Packag. Technol. Sci.* **2019**, *32*, 259–265. [CrossRef]
76. Kilmartin, P. Understanding and controlling non-enzymatic wine oxidation. *Manag. Wine Qual.* **2010**, 432–458.
77. Benítez, P.; Castro, R.; Natera, R.; Barroso, C.G. Changes in the polyphenolic and volatile content of "Fino" Sherry wine exposed to high temperature and ultraviolet and visible radiation. *Eur. Food Res. Technol.* **2006**, *222*, 302. [CrossRef]
78. Cheynier, V.; Basire, N.; Rigaud, J. Mechanism of trans-caffeoyltartaric acid and catechin oxidation in model solutions containing grape polyphenoloxidase. *J. Agric. Food Chem.* **1989**, *37*, 1069–1071. [CrossRef]
79. Gómez, E.; Martínez, A.; Laencina, J. Prevention of oxidative browning during wine storage. *Food Res. Int.* **1995**, *28*, 213–217. [CrossRef]
80. Moreira, N.; Lopes, P.; Ferreira, H.; Cabral, M.; De Pinho, P.G. Influence of packaging and aging on the red wine volatile composition and sensory attributes. *Food Packag. Shelf Life* **2016**, *8*, 14–23. [CrossRef]
81. Vidal, J.-C.; Moutounet, M. Monitoring of oxygen in the gas and liquide phases of bottles of wine at bottling and during storage. *OENO One* **2006**, *40*, 35. [CrossRef]
82. Mentana, A.; Pati, S.; La Notte, E.; Del Nobile, M.A. Chemical changes in Apulia table wines as affected by plastic packages. *LWT* **2009**, *42*, 1360–1366. [CrossRef]
83. Eilert, S. New packaging technologies for the 21st century. *Meat Sci.* **2005**, *71*, 122–127. [CrossRef] [PubMed]
84. Ferreira, A.C.S.; Hogg, T.; De Pinho, P.G. Identification of Key Odorants Related to the Typical Aroma of Oxidation-Spoiled White Wines. *J. Agric. Food Chem.* **2003**, *51*, 1377–1381. [CrossRef]

85. Escudero, A.; Cacho, J.; Ferreira, V. Isolation and identification of odorants generated in wine during its oxidation: A gas chromatography–olfactometric study. *Eur. Food Res. Technol.* **2000**, *211*, 105–110. [CrossRef]
86. Duncan, S.E.; Webster, J.B. Chapter 2 Sensory Impacts of Food–Packaging Interactions. In *Advances in Food and Nutrition Research*; Academic Press: London, UK, 2009; pp. 17–64.
87. Daiwa. *Metal Can for Canning Wine*; Daiwa Can: Tokyo, Japan, 2006.
88. Stokes, G.; Barics, S.J.A. Wine Packaged in Aluminum Containers. European Patent 2,767,583, 20 August 2014.
89. Brewer, M.F. Scarcity and Growth: The Economics of Natural Resource Availability. *Nat. Resour. J.* **1964**, *3*, 550–552.
90. Meneses, M.; Torres, C.; Castells, F. Sensitivity analysis in a life cycle assessment of an aged red wine production from Catalonia, Spain. *Sci. Total Environ.* **2016**, *562*, 571–579. [CrossRef]
91. Speirs, J.; McGlade, C.; Slade, R. Uncertainty in the availability of natural resources: Fossil fuels, critical metals and biomass. *Energy Policy* **2015**, *87*, 654–664. [CrossRef]
92. Vellini, M.; Savioli, M. Energy and environmental analysis of glass container production and recycling. *Energy* **2009**, *34*, 2137–2143. [CrossRef]
93. Isa, H. The need for waste management in the glass industries: A review. *Sci. Res. Essays* **2008**, *3*. [CrossRef]
94. Molloy, M. The Meaning behind Colored Wine Bottles. In CGT Blog, Chateau Grand Traverse. Available online: https://cgtwines.com/cgt-lifestyle/blog/ (accessed on 15 April 2021).
95. Chen, D.; Masui, H.; Akai, T.; Yazawa, T. Investigation on a recycling process of waste colored glass. In *Environmental Issues and Waste Management Technologies in the Ceramic and Nuclear Industries VIII*; Wiley: Hoboken, NJ, USA, 2012; p. 398.
96. Ankur, O.; Akriti, S.; Manvesh, S.; Seema, O. Food packaging–materials and sustainability—A review. *Agric. Rev.* **2015**, *36*, 241–245.
97. Dudlicek, J.E.D. Beyond the Bottle. *Progress. Groc.* **2018**, *97*, 16.
98. Berry, C. Should You Skip Canned Wine and Just Buy the Bottle? Available online: https://www.tasteofhome.com/article/canned-wine/ (accessed on 15 April 2021).
99. Rugani, B.; Vázquez-Rowe, I.; Benedetto, G.; Benetto, E. A comprehensive review of carbon footprint analysis as an extended environmental indicator in the wine sector. *J. Clean. Prod.* **2013**, *54*, 61–77. [CrossRef]
100. Schlesinger, M.E. *Aluminum Recycling*, 2nd ed.; CRC Press: Boca Raton, IL, USA, 2013; p. 282.
101. Onstad, E. Factbook: Aluminum Cans Get Boost from Anger over Plastic Pollution. Available online: https://www.reuters.com/article/us-environment-plastic-aluminium-factbox/factbox-aluminum-cans-get-boost-from-anger-over-plastic-pollution-idUSKBN1WW0KC (accessed on 15 April 2021).
102. Hosford, W.F.; Duncan, J.L. The Aluminum Beverage can. *Sci. Am.* **1994**, *271*, 48–53. [CrossRef]
103. Pitts, E.; Witrick, K. Brewery Packaging in a Post-COVID Economy within the United States. *Beverages* **2021**, *7*, 14. [CrossRef]
104. Squire, S. *Wine Packaging: The Future of Wine Packaging in an Enviro-Conscious World*; Winetitles Media: Broadview, Australia, 2019; pp. 79–81.
105. Kriel, G. Canned wines take off in the SA market. *Finweek* **2020**, *2020*, 10.
106. Shen, L.; Worrell, E. Chapter 13—Plastic Recycling. In *Handbook of Recycling*; Elsevier: Amsterdam, The Netherlands, 2014; pp. 179–190.
107. Geyer, R.; Jambeck, J.; Law, K.L. Production, use, and fate of all plastics ever made. *Sci. Adv.* **2017**, *3*, e1700782. [CrossRef] [PubMed]
108. Kibria, G. Presentation: Plastic Pollution- Sources, Global Production, Global "Hotspots", Impacts on Biodiversity & Seafood; Adsorption of Organic & Inorganic Chemicals, and Mitigation. *Pollut. Clim. Chang. Impacts* **2018**. [CrossRef]
109. United States Environmental Protection Agency. Plastics: Material-Specific Data. Available online: https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/plastics-material-specific-data (accessed on 15 April 2021).
110. Conkle, J.L.; Del Valle, C.D.B.; Turner, J.W. Are We Underestimating Microplastic Contamination in Aquatic Environments? *Environ. Manag.* **2018**, *61*, 1. [CrossRef]
111. Defruyt, S. Towards a New Plastic Economy. *Field Actions Sci. Rep.* **2019**, *19*, 78–81.
112. Marichelvam, M.K.; Jawaid, M.; Asim, M. Corn and Rice Starch-Based Bio-Plastics as Alternative Packaging Materials. *Fibers* **2019**, *7*, 32. [CrossRef]
113. Where Glass Cannot Go: Bota Box Launches Eco-Friendly Bag-In-Box Premium Wine Range. Available online: https://www.packaginginsights.com/news/where-glass-cannot-go-bota-box-launches-eco-friendly-bag-in-box-premium-wine-range.html (accessed on 15 April 2021).
114. Ferrara, C.; De Feo, G. Comparative life cycle assessment of alternative systems for wine packaging in Italy. *J. Clean. Prod.* **2020**, *259*, 120888. [CrossRef]
115. Garbowski, T.; Gajewski, T.; Grabski, J.K. Estimation of the Compressive Strength of Corrugated Cardboard Boxes with Various Perforations. *Energies* **2021**, *14*, 1095. [CrossRef]
116. McKinney, R.W.J. *Technology of Paper Recycling*; Blackie Academic & Professional: New York, NY, USA, 1994.
117. Otto, S.; Strenger, M.; Maier-Nöth, A.; Schmid, M. Food Packaging and Sustainability—Consumer Perception vs. Correlated Scientific Facts: A Review. *J. Clean. Prod.* **2021**, *298*, 126733. [CrossRef]
118. Zawadiak, J.; Wojciechowski, S.; Piotrowski, T.; Krypa, A. Tetra Pak Recycling—Current Trends and New Developments. *Am. J. Chem. Eng.* **2017**, *5*, 37. [CrossRef]

119. Ma, Y. Changing Tetra Pak: From Waste to Resource. *Sci. Prog.* **2018**, *101*, 161–170. [CrossRef]
120. *Wine Statistics: US Wine Consumption*; Wine Institute: San Francisco, CA, USA, 2018; p. 94105.
121. Statista. Total Number of Wineries in the United States from 2009–2021. Available online: https://www.statista.com/statistics/259353/number-of-wineries-in-the-us/ (accessed on 25 April 2021).
122. Brown, K. America's Favorite Drink over Time. Available online: https://vinepair.com/articles/americas-favorite-drinks-infographic/ (accessed on 28 April 2021).
123. Lockshin, L.; Corsi, A.M. Consumer behaviour for wine 2.0: A review since 2003 and future directions. *Wine Econ. Policy* **2012**, *1*, 2–23. [CrossRef]
124. Barber, N.; Almanza, B.A. Influence of Wine Packaging on Consumers' Decision to Purchase. *J. Foodserv. Bus. Res.* **2006**, *9*, 83–98. [CrossRef]
125. GFK. Americans Reach Environmental Turning Point: Companies Need to Catch Up. *Custom Research North America.* Available online: https://www.csrwire.com/press_releases/15416-americans-reach-environmental-turning-point-companies-need-to-catch-up-according-to-gfk-roper-green-gauge-r-study (accessed on 25 April 2021).
126. Peattie, K. *Environmental Marketing Management: Meeting the Green Challenge*; Financial Times Management: London, UK, 1995; p. 320.
127. Bazoche, P.; Deola, C.; Soler, G.L. An experimental study of wine consumers' willingness to pay for environmental characteristics. *AgEcon* **2008**. [CrossRef]
128. Arcury, T. Environmental Attitude and Environmental Knowledge. *Hum. Organ.* **1990**, *49*, 300–304. [CrossRef]
129. Dolnicar, S.; Leisch, F. Selective marketing for environmentally sustainable tourism. *Tour. Manag.* **2008**, *29*, 672–680. [CrossRef]
130. *Tourism Planning: An Integrated and Sustainable Development Approach*; Van Nostrand Reinhold: New York, NY, USA, 1991.
131. Barber, N. Consumers' Intention to Purchase Environmentally Friendly Wines: A Segmentation Approach. *Int. J. Hosp. Tour. Adm.* **2012**, *13*, 26–47. [CrossRef]
132. Ferrara, C.; Zigarelli, V.; De Feo, G. Attitudes of a sample of consumers towards more sustainable wine packaging alternatives. *J. Clean. Prod.* **2020**, *271*, 122581. [CrossRef]