CATOLICA
ESCOLA SUPERIOR DE BIOTECNOLOGIA
PORTO

IS LIGHT WEIGHTING GLASS BOTTLES FOR WINE AN OPTION? A STUDY ON THE PORTUGUESE WINE MARKET AND CONSUMERS.

por

João Emanuel Sousa de Araújo Soares

Dezembro de 2019

CATÓLICA
ESCOLA SUPERIOR DE BIOTECNOLOGIA
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A REDUÇÃO DE PESO NAS GARRAFAS DE VIDRO PARA VINHO É UMA OPÇÃO? UM ESTUDO SOBRE O MERCADO PORTUGUÊS E OS SEUS CONSUMIDORES.

Tese apresentada à Escola Superior de Biotecnologia da Universidade Católica Portuguesa para obtenção do grau de Mestre em Engenharia Alimentar

por

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SUMÁRIO

Atualmente, no mercado de vinhos Português são usadas garrafas de vidro de uma grande diversidade de formas e pesos. Uma vez que o sistema de embalagem é um dos principais fatores responsáveis pela pegada de carbono do produto, a redução do seu impacto é uma medida importante para a sustentabilidade. Nesse contexto, este estudo foca a possibilidade de redução do peso da garrafa de vidro para vinho, numa perspetiva do consumidor. Foi feita uma caracterização de uma amostra de garrafas de vinho, no que diz respeito ao peso, capacidade e distribuição da espessura do vidro. Foram analisadas 315 garrafas de vinho tinto liso presentes no mercado quanto ao seu peso, forma e preço. Foi também realizado um estudo ao consumidor sobre as suas convicções quanto à garrafa de vinho e à sustentabilidade. Foi possível verificar que uma diferença de 100 g numa garrafa é tecnicamente possível graças a uma melhor distribuição do vidro e que apenas uma minoria dos consumidores conseguiu percecionar essa diferença. O peso das garrafas foi positivamente correlacionado com o preço do vinho. Verificou-se que os consumidores, apesar de também associarem uma garrafa mais pesada a um vinho *premium*, não dão importância a esse fator na escolha de um vinho. Os resultados do inquérito indicaram que os consumidores têm uma grande consciencialização quanto a algumas características da embalagem, como: não conter plástico, ser reciclável, reutilizável, biodegradável, conter material reciclado, e ter uma baixa pegada de carbono. No entanto, existe uma falta de conhecimento quando ao impacto da redução de peso da embalagem na redução da pegada de carbono.

Palavras-chave: Garrafa de vinho, Perceção de qualidade, Redução de peso, Sustentabilidade da embalagem

ABSTRACT

Currently, the Portuguese wine market has a great diversity of glass bottle shapes and weights. Since the packaging system is a major factor responsible for the product's carbon footprint, reducing its impact is an important measure towards sustainability. In this context, this study focuses on the possibility of light weighting glass bottles, in the consumer perspective. A characterization of bottle samples was made regarding their weight, capacity and glass thickness distribution. A sample of commercialized red wine bottles (315) were assessed regarding their weight, shape and wine price. A consumer survey was conducted on beliefs about the wine bottle and sustainability. Results showed that a difference of 100 g in wine bottles is technically possible by promoting a better glass distribution, and that only a minority of consumers could perceive that difference. The weight of the bottles was positively correlated with the price of the wine. Results indicate that although consumers associate a heavier bottle with a premium wine, they did not rely on weight as an important factor for their wine buying choice. Results from the survey showed that consumers have a high awareness regarding several packaging characteristics, such as: being plastic free, recyclable, reusable, biodegradable, made with recycled materials and having a low carbon footprint. However, there is a lack of knowledge about the impact of packaging light weighting on reducing the carbon footprint.

Keywords: Wine bottle, Quality perception, Light weighting, Packaging sustainability

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ABBREVIATIONS INDEX

B&B – Blow and blow

FEM – Finite element modeling

IS – Individual section

LCA – Life cycle assessment

NNPB – Narrow neck press and blow

SD – Standard deviation

SLS – Soda lime silica

1. INTRODUCTION

1.1. Wine glass bottle

Wine is one of the oldest man made beverages. In fact, archeological studies indicate that the first wine productions took place around 6000 BC and that large-scale production would already be a reality by the year 5200 BC (McGovern *et al.*, 2003).

Originally packed in clay containers, wine has gained popularity among the human race, making it one of the most widely consumed beverages to date, along with water and beer.

While humanity was refining its winemaking techniques, it was also developing its knowledge on the manufacture of glass. Glass is a material used since ancient times by humans, in the form of various objects, such as the early knifes made from obsidian. Documents dated from 658 BC reveal the world's first glass "recipe", a recipe whose basis has hardly changed to this day – sand, soda ash and limestone (Vetropack Group, 2019; Moorey, 1999).

With the development of glass manufacturing, wine bottles currently come in many different shapes and sizes and so specific terminology is utilized.

The bottle have different designations according to its shape – the main ones being the Bordeaux, Burgundy, Rhône, Port and Champagne type bottles (Figure 1) – which, as their name suggests, are strongly connected to specific type of wines and regions. As for capacity, many different bottle sizes can be found, however the most frequent are the 375 mL (half bottle), 750 mL (standard bottle) and the 1.5 L (Magnum bottle). Wine bottles with different colors and levels of opacity can also be found, namely amber, green and blue among others.

Figure 1 – Different shapes of commonly used wine bottles (left to right: Bordeaux, Burgundy, Rhône, Port and Champagne type bottle)

A glass bottle is composed of several parts, and the main terminology used is presented in Figure 2.

Figure 2 – Terminology of the different zones of a wine glass bottle

Apart from the wide range of sizes, colors and shapes possible for the glass bottle, other intrinsic properties such as its thermal resistance, inertia, barrier and recycling properties make glass one of the best packaging materials.

1.2. Glass bottle manufacturing

The three main components required for the manufacture of common glass are silica (0.70 to 0.75 w/w) – responsible for the glass structure; sodium carbonate (Na_2CO_3) (0.12 to 0.16 w/w) – used to reduce the melting temperature of glass – and calcium oxide (CaO) (0.1 to 0.15 w/w) which acts as a stabilizer. Other components are also used in smaller proportions such as aluminum and magnesium oxides to increase the hardness of glass, dyes and other production aid elements (Hasanuzzaman *et al*., 2015).

This type of glass is known as Soda Lime Silica Glass (SLS) and represents about 90% of the total glass production in the world. SLS applications are vast, but the bulk of its use is confined to the manufacture of float glass (used for example in windows) and containers, such as bottles, cups and other food utensils.

SLS glass has several advantages over other types of glass, the main ones being more economical and easier to work with. The melting temperature of pure silica is about 1713 °C. With the addition of sodium carbonate manufactures manage to decrease this temperature to values around 800 °C, depending on the amount used, which grants a significant reduction in the energy cost of the process. Another feature of this type of glass that allows it to distinguish itself from other packaging materials is its recyclability. Waste and recovered glass are called cullet, which can be used over and over as an input in the process, making glass infinitely recyclable while also reducing the need for new raw materials, decreasing the energy demand and the cost of manufacturing (Le Bourhis, 2014).

Other types of glass includes borosilicate glass (used in laboratory and kitchenware), organic glass (used in the production of optical lenses), metallic glass, optical fibers among others (Le Bourhis, 2014).

The productive process of glass differs depending on the type of glass and its final function. In the case of glass bottles, the plant is divided in two production zones: the hot end and the cold end.

The hot end begins with the furnace, where the raw materials melt. Temperature control is crucial in this stage, as temperature plays a vital role in the definition of the glass viscosity. The melting of the raw materials requires a large amount of energy, therefore the furnaces are constantly fed and are only cooled down for rebuilding. Even during repairing operations, furnaces are kept running.

After the melting of raw materials, two other operations take place within the furnace: the fining of glass and gob formation. Fining consists in the release of trapped gas bubbles in the molten glass. This is done through the inclusion of components that aid the dissolution of these bubbles, in order to prevent downstream defects in the glass (Verweij, 1983). The gob is a cylindrically shaped portion of molten glass that has the exact amount of material required to form an individual bottle. Gob formation takes place when a piston pushes out the molten glass through an orifice in the furnace, which is then cut by scissors blades. The gob falls to a distribution channel and enters the individual section (IS) machine, where the bottle is formed.

In the IS machine, two different processes of forming the bottle are possible. The most common is the "blow and blow" (B&B) process, in which the gob enters a first mold where is blown against its walls, forming the finish and the neck of the bottle. This first pre-form of the bottle is called the "parison". The parison then moves into a second mold where is again blown to obtain the final bottle shape. The other process is the "Narrow Neck Press and Blow" (NNPB), where the bottle is formed by pressing followed by blowing – the gob is compressed by a piston against the walls of the first mold, thereby distributing the glass and forming the parison. The parison is then transferred into the second mold where is blown to form the final bottle, as in the B&B method. Once its final shape is obtained, the bottle leaves the IS machine and follows the conveyers of the production line. While still on the hot end of the plant the bottle undergo a first surface treatment (≈500 °C), where is spray coated with a thin layer of a high hardness material, the most common being tin dioxide (SnO_2) or titanium dioxide (TiO_2). These coatings reduce the impact of contact forces on the bottle, making it stronger (Beerkens *et al.*, 2011; Le Bourhis, 2014; Laevsky, 2003; McKown, 2000). Organic coatings are currently being developed but are not yet widespread (Ng *et al*., 2017).

After the treatment the bottle enters a large tunnel where is reheated up to ≈560 °C and then slowly cooled down at a controlled rate, in a process known as annealing. This process allows

for the removal of residual stresses present in the bottle, an essential measure to improve glass mechanical resistance.

The cold end of the plant starts at the end of the annealing tunnel, where an organic coating is sprayed on the bottle external surface to protect the glass surface (McKown, 2000), before palletization and storage. It is also important to mention that several control measures of different parameters of bottle specifications take place on-line and in laboratory after sampling (Le Bourhis, 2014).

1.3. Consumers perception of glass bottles

The glass bottle is usually acknowledged by the consumer as a high quality packaging, associated to premium products due to its optical, preservative and protective properties, being the preferred choice for over 85% of European consumers (Bragg, 2018; Friends of Glass, 2017). It is recognized that glass will continue to be the dominant choice as a wine packaging material (Market Research Future, 2019). As such, it is of the outmost importance to reduce the environmental impact of its use.

Today's consumer shows an increasing concern about product sustainability (Olsen *et al.*, 2014), and packaging is no exception. Studies shows that the consumer correlates packaging as a major factor in the environmental impact of the product (Tobler *et al.*, 2011; Grönman *et al.*, 2013). The growing demand for more sustainable products is also noticeable in the wine industry (Gary *et al*., 2009), although it is not yet clear whether this demand also relates to a greater perception of product value (Sogari *et al.*, 2016). Still, consumers are willing to pay a premium price for wines produced through environmentally friendly practices (Barber *et al*, 2009; Forbes *et al,* 2009). However, much less studies have been reported regarding how consumer perceives wine packaging in what relates to packaging sustainability.

1.4. Sustainability

The main environmental impact of glass bottles relates to their manufacturing process, which requires a high amount of energy and fuel. Altogether, the glass packaging industry in the European Union in 2007 was responsible for the emission of 12.4 Mt of CO_2 and the consumption of 160.8 PJ of energy – 136 of which are a direct result of fuel combustion (Schmitz *et al.*, 2011). This consumption has been gradually reduced over the years, as a result

of an increased insulation, glass recycling (use of cullet as an input) and a higher process efficiency (e.g. the use of heat regenerators and an increasing higher percentage of hybrid furnaces i.e. the combined consumption of gas and electricity as fuel) (Le Bourhis, 2014; Zippe, 2011; Geueke *et al.*, 2018).

Truth is that the glass industry has been adopting a circular economy for decades, as the commercialization of returnable tare bottles is one of the clearest examples (FEVE, 2016). For non-returnable packages, recycling is possible through cullet incorporation. The recyclability rate of glass packaging in the European Union is currently at 74%, leaving still a large margin for improvement. In Portugal this rate sits at 58%, and is considerably lower than the European average (FEVE, 2018; Geueke *et al.*, 2018). When questioned, a major worldwide container manufacturer claimed they use all available cullet and that the low rate of recycling is explained by the exportation of a large fraction of bottled goods. Still, an old consumer study indicated that glass is perceived as the most environment friendly packaging material. However, unlike all other materials where smaller packages are associated to higher impact on the environment, for glass bottles, size did not seem to influence this perception (Van Dam, 1996). More recent studies on this topic were not found in the literature.

In the case of wine, several life cycle assessments (LCA) studies concluded that, of all the winemaking chain steps, packaging is what most contributes to increase the product's environmental impact, particularly thanks to the large CO_2 emissions required for the bottle production (Martins *et al.,* 2018; Benedetto, 2013; Neto *et al*, 2013; Point *et al.*, 2012; Petti *et al.,* 2006; Sogari *et al.*, 2016). One of the suggested improvement measures for the reduction of this impact is the use of lighter glass bottles (Martins *et al.,* 2018).

1.5. Light weighting of glass bottles

Despite its high recyclability and all its other intrinsic properties, glass has two major problems: its weight and brittleness. Since two of the main reasons for glass bottles breakage are the presence of microcracks on the surface and the low thickness of their wall (Le Bourhis, 2014), one of the industry approach to reduce brittleness is the increase of the weight of the bottles, in order to achieve thicker walls, and thus trusting that the thin spots and the microcracks had enough glass support to prevent bottle failure (Hartley, 2008).

Nowadays is possible to achieve a better control in the glass distribution through the bottle, without the need to change the bottle design, allowing for a lighter bottle to be manufactured.

This process optimization is achievable thanks to technology developments, which allows for greater control of the entire bottle shaping, namely the temperature and viscosity of the glass and the reduction in time of the operation. Furthermore, software such as Finite Element Modeling (FEM) allows the analysis of the bottle behavior regarding different parameters, including impact resistance. Based on this analysis it is possible to detect glass stress accumulation points and thus create a lighter bottle without significantly decreasing its resistance (Le Bourhis, 2014; Laevsky, 2003).

Another possible approach for light weighing of glass bottles, is the NNPB process that ensures a tighter control of the glass distribution and therefore offers the possibility of obtaining 15 to 30% lighter bottles (Sarwar and Armitage, 2003). However, most wine bottles are still manufactured through the B&B process, because of restrictions on the application of the NNPB regarding specific designs requirements for bottles, such as the punt and dimension profiles of the finish and neck (Figure 2). While the first maybe a marketing requirement, the latter is imposed by the closure system standardization – CETIE standards. B&B process does not guarantee uniform glass distribution, especially at radial level, even despite of all above advances in the forming line. This leads to fluctuation of the weight of the final bottle within the same batch.

All these measures allow for production gains through the use of less raw materials, less energy requirements and increased line speeds (HEYE International, 2014; Emhart Glass, 2015). Unlike plastic, glass bottles are transported in their final form and given that over 40% of these bottles travel more than 300 km to reach their destination (FEVE, 2019), the weight reduction of such bottles is an important measure of decreasing the environmental impact of both the bottle and the product contained within. Hence, the use of lighter glass bottles is of interest, not only for spending less resources but also for decreasing both monetary and energy costs of transport. This is particularly relevant when dealing with consumer issues that attributes increasing importance to sustainability (Bemporad *et al*., 2012) and who, prior to its consumption, sees packaging as an integral part of the product while considering it as a waste afterwards (Olsson and Larsson, 2009; Lindh *et al.*, 2015).

1.6. Issues regarding glass bottles light weighting

Lighter bottles are commonly regarded as being less resistant to mechanical stresses and more prone to breakage then heavier ones. However, a study done by Wrap (Hartley, 2008) concluded

that “the weight of a wine bottle is not necessarily a good indicator as to its strength”. Moreover, Jaime *et al.* (2002) research showed that lighter bottles made from the NNPB process, having a more uniform thickness distribution, actually had better performance than its corresponding heavier B&B made counterparts, with improvement of around 33% on impact strength and 50% on vertical load resistance.

However, the influence that the weight of the bottle may have on the consumer’s perception of quality of the wine itself, must also be taken into account. According to Piqueras-Fiszman and Spence (2012), Spanish consumers without a strong knowledge of wine generally associated a higher weight of a bottle with a higher quality and/or price of the wine. Likewise, wine companies are doubtful over lighter bottles, as they could jeopardize their product market value, not just by the reduced weight of the bottle but for its shape as well, since NNPB bottles have slumped shoulders and a very short punt depth. Nevertheless, in another food sectors, some companies like Coca Cola uses lightweight containers to spread out a positive environment message (Hartley, 2008).

1.7. Objectives

The objectives of the present work were to: (1) characterize B&B glass bottles from the Portuguese wine market regarding weight, capacity and wall thickness distribution; (2) verify if there is a correlation between the weight of the bottle and the wine price, and if the region of origin and bottle shape could affect this correlation; (3) explore the Portuguese consumers beliefs on the relationship between the weight of the bottle and the price and quality of the wine; (4) investigate if the consumer perceives bottle light weighting as a measure towards sustainability. Objectives 1 and 2 were addressed by experimental determinations in samples collected in a wine bottler and in a major retailer. An on-line consumer questionnaire was developed and run to address objectives 3 and 4.

2. MATERIALS AND METHODS

2.1. Characterization of B&B process made bottles

2.1.1. Weight and capacity at filling level

In order to verify if the bottles made by the B&B process are consistent in terms of weight and capacity, measurements were conducted in a sample of bottles supplied to a wine bottling plant. According to the sampling plan in the company, fifty samples of two references of bottles were taken randomly from a full pallet for weight and capacity determination. This protocol is supposed to ensure the collection of bottles from all production molds in the glass producer.

The references were 750 mL bottles (a conic Burgundy and a Bordeaux bottle) both produced by B&B method. The weight was measured with a common calibrated digital laboratory scale. The capacity was determined by the filling method: the bottles were filled with water (the volume was corrected to the bottle filling level using a vacuum pump) and weighted. The water temperature was noted at the beginning and the end of the measurements and its average density was calculated. The capacity of the bottles were calculated based on the difference of the filled and empty weight of the bottle divided by the water density.

2.1.2. Wall thickness

Three Bordeaux type bottles of commercialized wines, from different manufacturers, were selected to evaluate the variability within the bottle of its wall thickness. The bottles were selected because were visually similar (to the eye of common consumer) although with significantly different weights (Figure 3). The bottles weight was measured in a common calibrated digital laboratory scale. The bottles were then cut in longitudinal direction, along their seam, and a short dimensional characterization was performed. The following measures were taken: total height of the bottle, height of the punt and wall thickness at contact points between bottles in a filling operation (*i.e.* shoulder, body and heel). These measurements was taken from opposite sides of the bottle in the same radial plane, using a caliper (Mitutoyo, Japan).

Figure 3 – Visually similar bottles identified in the study with different weights (Bottle A – 405 g, Bottle B – 458 g, Bottle C – 555 g)

2.2. Analysis of current bottles in the Portuguese wine market

With the objective of characterizing the weight of the 750 mL wine bottles in the Portuguese wine market, sampling was performed in a large retailer and the weight of the bottle, shape, type of wine and region and standard price, were recorded. Only Portuguese wines were considered. Different wines (315) of 3 major wine regions of the country were sampled. As this study is focused on light weighting of wine bottles and internal pressure was not been taken as a factor, only non-carbonated red wines were studied. Table 1 presents a summary of the wines considered for this study.

The bottle weight (filled bottles) was determined in a common calibrated digital scale. For a small set of bottles, the average weight of wine was determined as the difference between the total weight of the full and closed bottle and the weight of the empty bottle. This average weight of the wine (plus cork and labels) was determined to be 746 g. This average value was used to determine the bottle weight of all samples that were weighed full to prevent wine waste, in order to estimate the empty bottle weight. Specifications data sheets from several bottle manufacturers showed an average tolerance of 10 mL for bottle capacity and 15 g for bottle weight. These differences were neglected in the above assumptions.

Table 1 – Number and characteristics of the wines (region, price and bottle shape) taken in consideration in this study

	Alentejo	Dão	Douro	Total
Price (€)				
< 5	76	20	33	129
5-10	60	13	45	118
10-15	16	5	20	41
> 15	15	1	11	27
Bottle shape				
Bordeaux	132	2	83	217
Conic Bordeaux	25	-	13	38
Burgundy	10	30	13	53
Conic Burgundy	-	7	-	7
Total	167	39	109	315

2.2.1. Statistical analysis of results for current bottles in the market

Pearson's correlation tests between the weight of the bottle and the price of the wine were performed with overall data and separately by region and bottle shape. The criteria for the strength of the correlation coefficient was based on the recommendations from Quinnipiac University for political science studies (Akoglu, 2018).

It was also conducted an ANOVA on the same factors above, where differences were considered significant at $p \leq 0.05$. The software used for the statistical treatment of data was SPSS Statistics 25 (IBM, NY, USA).

2.3. Consumer questionnaire

An internet-based questionnaire was developed to assess the Portuguese consumer's knowledge and beliefs on wine, glass bottles and sustainability. A draft questionnaire was pre-tested by representative consumers to ensure full understanding of the questions. Based on this pre-test, the questions were then refined into the final version. The survey was developed using Qualtrics

(SAP SE, Germany). Social media groups as well as the Corporate University email served as vehicles for its dissemination. It can be estimated that the number of persons reached by this method was about 3000.

The questionnaire was divided in several theme blocks, as is represented in the scheme of Figure 4. The complete questionnaire can be consulted in Appendix A, together with more detailed presentation of results.

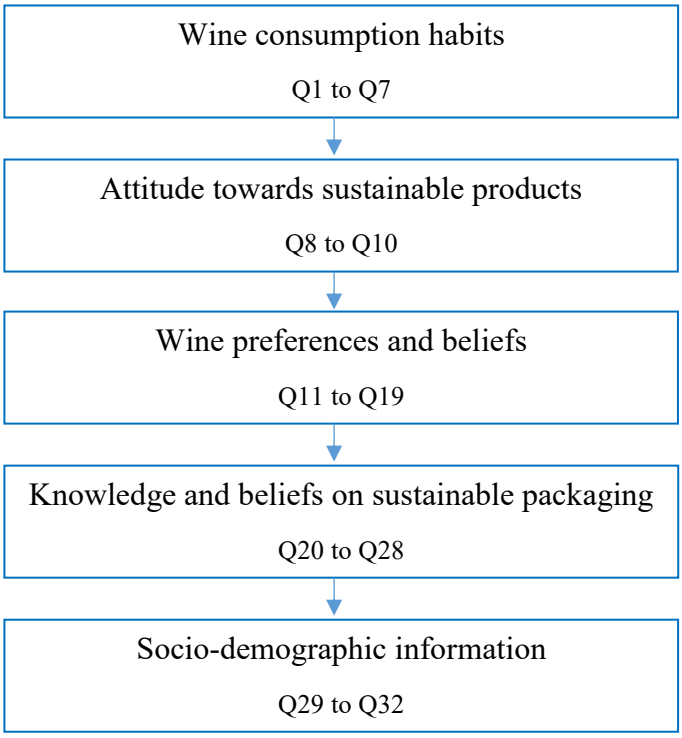

Figure 4 – Scheme of the online questionnaire

A total of 300 people answered the questionnaire in full extent, but only 271 were considered for further analysis. Respondents who had answered to both questions as not having wine consumption habits and not having bought a wine bottle in the past month were discarded. This ensures a data set corresponding to wine consumers and occasional wine buyers (who had the intention of potential consumption or who bought the wine to offer), allowing the insight of the opinion of different types of wine buyers.

2.3.1. Description of the questions and scales used in the consumer questionnaire

Following, details on the specific questions considered in the present study are presented, as well as the correspondent data analysis and statistical treatment.

I) Q11 – Wine self-reported expertise

Respondents were asked to rate their knowledge on wine in a 7-point Likert scale anchored in the extremes with “Unacquainted” and “Expert”. Ratings from 1 to 3 were classified as “Low knowledge”, 4 to 5 as “Some Knowledge” and 6 to 7 as “High Knowledge”.

II) Q18 / Q19 – Beliefs regarding the relationship between the bottle weight and the wine price and quality

In order to access consumers beliefs on the relationship between the bottle weight and the wine price and quality respondents were asked to rate the two statements “More expensive wines come in” and “Higher quality wines come in” in a 7-point Likert scale anchored in the extremes with “Lighter bottles” and “Heavier bottles”.

III) Q14 – Important factors in the wine choice

Participants were asked to rate what factors were considered as the most important in their wine choice. The wine attributes “quality” and “previous experience” and attributes easily accessed by the consumer in a retail environment were chosen: price, region, grape variety, producer, bottle shape, bottle weight, label, alcoholic degree and environmental claims.

IV) Q20 / Q23 / Q24 / Q25 – Sustainability beliefs

In order to obtain a perspective of consumers’ beliefs and perceptions regarding sustainable packaging, the respondents were inquired on what they value the most in a sustainable package, by ranking several factors in a 7-point Likert scale anchored in the extremes with “Not at all important” and “Very important”. Items from sustainability scales (Gershoff and Frels, 2015; Haws *et al*., 2013; Steenis *et al.,* 2018) were used to provide insight about the consumers knowledge about the impact of bottle light weighting. Respondents were asked to rate the statements “A lighter bottle is more sustainable that a heavier one?”, “A lighter bottle contributes a lot for reducing the impact on the environment?” and “A lighter bottle deserves to be labeled as environmentally friendly?” in a 7-point Likert scale anchored in the extremes and middle point with “Completely (dis)agree” and “Neither agree or disagree”, respectively. In addition, participants were questioned about their opinion on what would contribute the most for increasing the sustainability of a glass wine bottle, having “increase of recycled material content” and “weight reduction” as options.

V) Q28 - Weight difference perception

To verify if the weight difference between bottles of similar shape could be perceived solely based on visual information, respondents were inquired if they could spot the weight difference between two of the visually similar bottles identified in **2.1.2.** (Figure 3). An image of the bottles B and C side by side was presented with the statement that there was a certain weight difference between them, with participants being asked to indicate what was the range of that weight difference, having 50 g, 100 g and "I can't tell" as options.

2.3.2. Statistical analysis of the consumer questionnaire

The statistical treatment of the questionnaire data was performed using SPSS Statistics 25 (IBM, NY, USA). One sample t-test with four (the middle point of the scale) as the test value, was carried out on each scale. Moreover, Pearson's correlation tests and ANOVA considering the consumer wine expertise as the fixed source of variation was run in all data. Tukey Post-Hoc test was conducted when significant differences were identified ($p \leq .05$). The criteria for the strength of the correlation coefficient was the same used in **2.2.1.**

3. RESULTS

3.1. Characterization of B&B process made bottles

3.1.1. Weight and capacity at filling level

Results for bottles capacity are presented in Figure 5 (Conic Burgundy Bottle) and Figure 6 (Bordeaux Bottle). The random sampling provided bottles, respectively from 10 and 17 different molds, which indicates a very good representative sample.

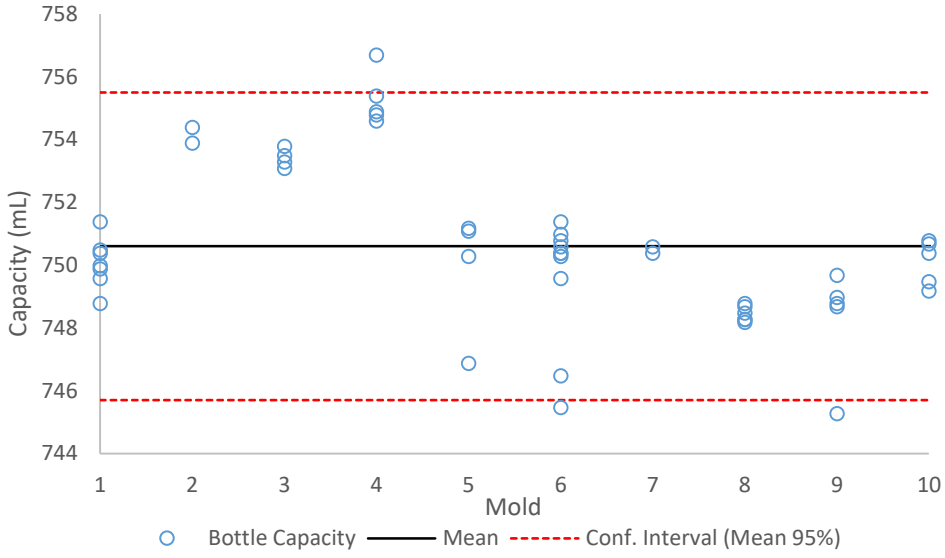

Figure 5 – Conic Burgundy bottles calculated capacity

Figure 5 shows a variability in the bottle capacity (M = 750.6 mL; σ^2 = 6.2 mL^2), even for bottles made in the same mold. Also, 40% of this bottles were under their labeled net content of 750 mL, but still within the tolerance range of 15 mL for 750 mL bottles, according to the European legislation (Council Directive 76/211/EEC, 1976). As for the weight of the bottles, there were a difference of 3.5 g between the lighter (513.7 g) and heavier (517.2 g) sample.

The Bordeaux bottles showed a much lower dispersion of their capacity (M = 752 mL; σ^2 = 0.7 mL^2) in comparison with the Burgundy ones. Only one bottle was under their labeled net content. The difference of weight between the lightest (408.4 g) and heaviest (413.8 g) bottle was 5.4 g, in the same order of magnitude.

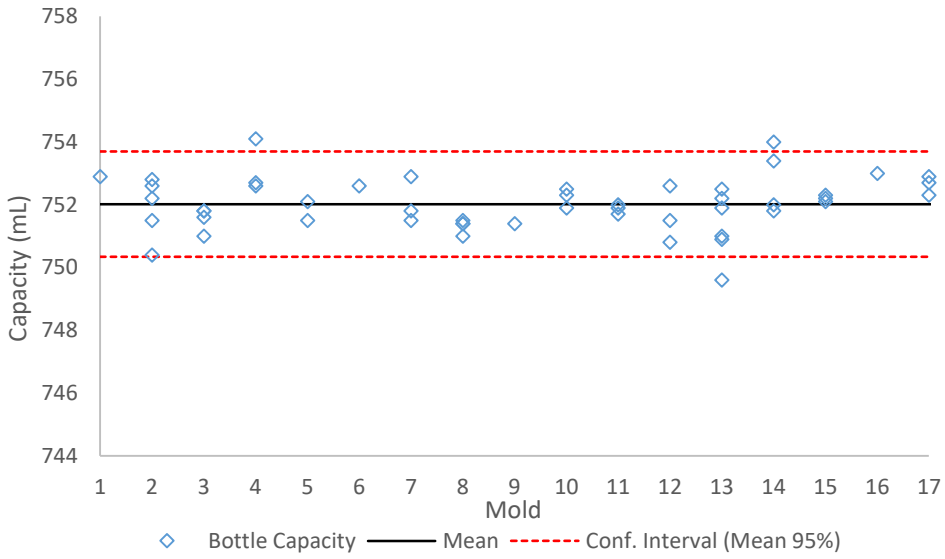

Figure 6 – Bordeaux bottles calculated capacity

3.1.2. Wall thickness

The bottles prepared for measurement of the wall thickness distribution are shown in Figure 7.

The dimensional study of the bottles revealed an increasing weight and punt height difference from bottle A to C, as presented in Table 2.

Table 2 – Dimensions of the identified visually similar bottles

	A	B	C
Weight (g)	405	458	555
Total height (cm)	31.5	32.36	32.5
Punt height (mm)	21	23.01	28.85

Figure 7 – Bottles A, B and C of increasing weight. Cut for wall thickness determination

Figure 8 shows the wall thickness variability in the shoulder, body and heel of the three bottles. Bottle A is the one with the thinnest walls (M = 2.13 mm; σ^2 = 0.18 mm^2) that, along with its lower total and punt heights explains why bottle A is the lightest bottle. All three bottles displayed the same neck and finish design. Bottle B displayed the lowest variability (M = 2.68 mm; σ^2 = 0.09 mm^2) while bottle C (M = 3.14 mm; σ^2 = 0.82 mm^2) presented thicker walls and the highest variability in the thickness throughout the bottle.

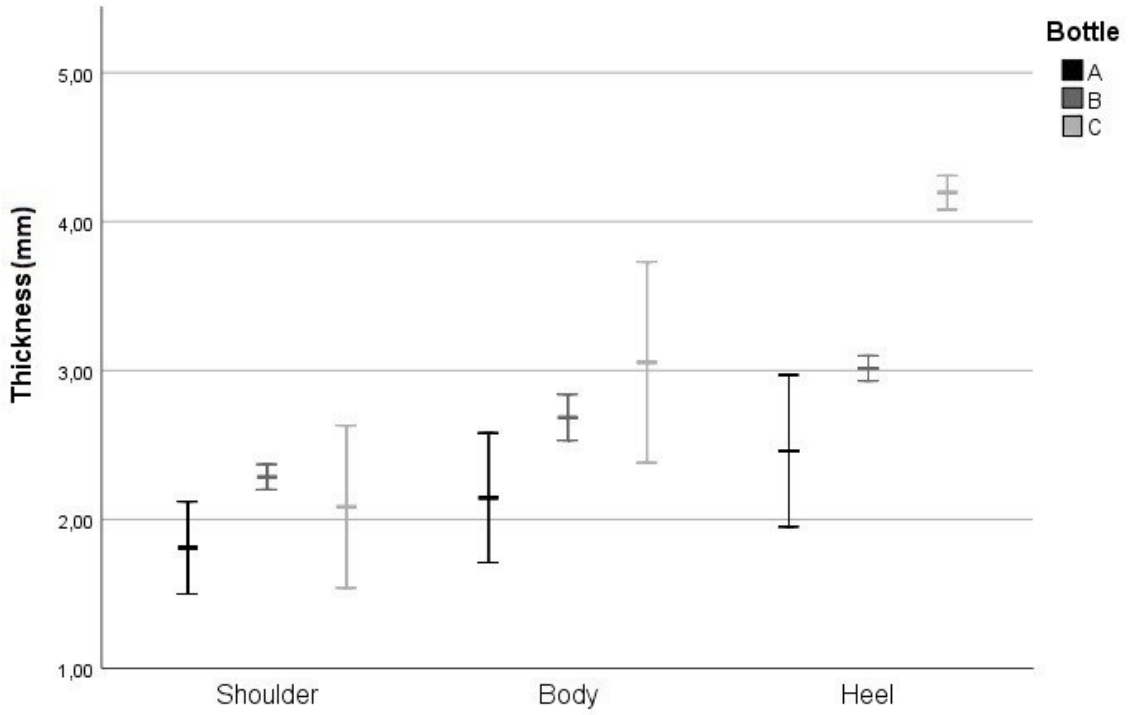

Figure 8 – Wall thickness in different contact points of bottles A, B and C

3.2. Analysis of current bottles in the market

In this section, the results for the samples from the retail shop, regarding bottle weight and price for different wines and bottle shapes, are presented.

The bottle weight for all the samples is depicted in Figure 9.

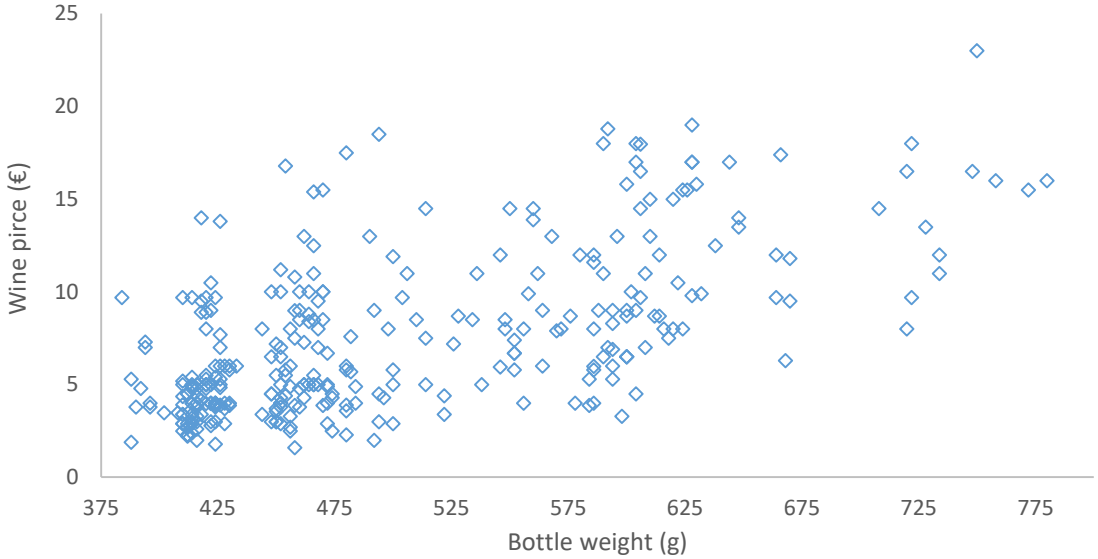

Figure 9 – Wine price and corresponding bottle weight of the studied samples

Results for correlation between weight of the wine bottles and price of the wine are presented in Table 3. The bottles weight was positively correlated with the wine price when all bottles were assessed together, with a Pearson's coefficient of 0.634 ($p < .001$), which represents a strong correlation. These results are in accordance to the findings of Piqueras-Fiszman and Spence (2012), who also detected positive correlations between the weight of bottles and the price of wine, for wines produced in Australia, France, Italy, South Africa and Spain. When taking in consideration the bottle shape and region, there was still a positive correlation except for the conic burgundy bottle shape, for which no correlation was found (probably due to the low number of samples).

Table 3 – Pearson's coefficient between weight and price, for wines divided by region and bottle shape

	r	p
Region		
Alentejo	.720*	< 0.001
Dão	.479*	0.002
Douro	.590*	< 0.001
Bottle shape		
Bordeaux	.668*	< 0.001
Conic Bordeaux	.478*	0.002
Burgundy	.453*	0.001
Conic Burgundy	.138	0.767

* Significant effect at $p < .01$

It can be assumed that the relationship between weight of the bottle and its price is stronger for Alentejo wines than for other regions and for wines filled in Bordeaux shape bottles than for other bottles shapes (although other regions and bottle shapes also have a strong correlation).

Table 4 shows the average weight and prices for the different regions and bottle shapes, as well as the weight difference between the heavier and lightest bottle. The ANOVA on the weight data showed significant differences between bottle shape ($p < .0001$), as the Bordeaux bottles

obtained the lower average weight (475 g) and the conic Bordeaux bottles were the heavier bottles (615 g). No significant differences between regions was found.

Table 4 – Average weight and price for wines from different regions and bottle shape and their corresponding difference between the lightest and heavier bottle in grams and percentage with respect to the heavier bottle

	Average weight (g)	Average price (€)	Maximum difference in weight (g)	(%)
Region				
Alentejo	502	7.12	386	49.5
Dão	518	6.35	282	42.1
Douro	498	8.57	286	42.7
Bottle shape				
Bordeaux	475	6.79	388	50.3
Conic Bordeaux	615	10.37	234	30.0
Burgundy	525	8.46	272	40.8
Conic Burgundy	560	8.05	160	23.9

Interestingly, for Douro region the wine bottled in the lightest bottle is actually more expensive then the wine sold in the heaviest bottle.

3.3. Consumer questionnaire

The socio-demographic characteristics of the consumer sample of respondents can be seen in Table 5. Geographical distribution is also shown in Figure 10.

Table 5 – Socio-demographic characteristics of the respondents taken in consideration in the data analysis

	Respondents	
	Number (n)	%
Gender		
Male	140	51.7
Female	131	48.3
Age (years)		
18-29	57	21.0
30-39	67	24.7
40-49	79	29.2
50-59	51	18.8
> 60	17	6.3
Income (€)		
< 600	23	8.5
600 – 1200	139	51.3
1300 - 1900	61	22.5
2000-2600	25	9.2
> 2600	23	8.5
Wine self-reported expertise		
Low knowledge	93	34.3
Some knowledge	128	47.2
High knowledge	50	18.5

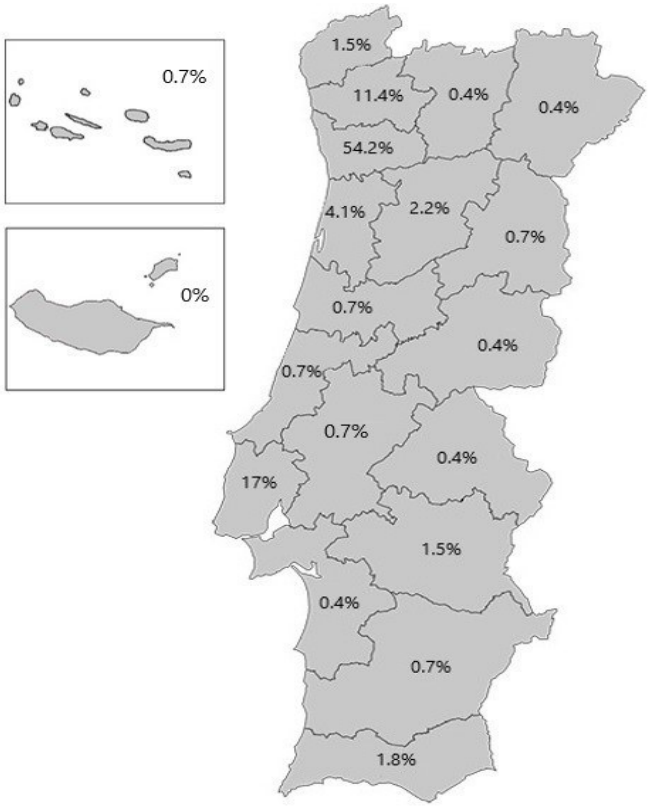

Figure 10 – Geographic distribution of the participants (%) of the online questionnaire who were considered in the data analysis

3.3.1. Beliefs between the relation of bottle weight and the wine price and quality

The mean scores and standard deviation (SD) of the participants rating for the statements relating the bottle weight and the wine price and quality are shown in Table 6.

Consumers wine expertise was positively correlated to their beliefs between the relation of the bottle weight and the wine price with a moderate correlation strength ($r = .321$; $p < .001$) and with wine quality with a weak correlation strength ($r = .278$; $p < .001$).

All the consumer groups' means were statistically different from the middle point of the scale ($p < .05$). Results from the Tuckey test show that consumers with low and some wine expertise have a significant different opinion as compared to consumers with high level of expertise. These latter associate more strongly a heavy bottle to both an expensive and a higher quality wine, than not expert consumers. These results differ from the ones obtained by Piqueras-Fiszman and Spence (2012), where the Spanish consumers with lower levels of knowledge in wine were the ones who scored the higher values for both attributes and the expert consumers scored lower values.

Table 6 – Mean scores (SD) of the ratings of consumers between bottle weight and the wine price and quality

Consumers reported expertise	Price	Quality
Low knowledge	4.5[a] (2.1)	4.5[a] (2.0)
Some knowledge	5.2[a] (1.6)	5.1[a] (1.6)
High knowledge	6.2[b] (1.5)	6.0[b] (1.6)
Overall	5.1 (1.9)	5.1 (1.8)

Superscripts of each column represent the groups that are significantly different, according to Tukey's Post-Hoc test ($p \leq .05$)

3.3.2. Importance of attributes in the wine's choice

The mean rates attributed by consumers for several factors in their choice of wine are presented in Table 7. Respondents gave the least importance to the weight of the bottle, closely followed by the bottle's shape (overall results). Interestingly, taking into consideration overall consumers, price was not one of the top 3 factors, unlike some other previous studies dealing with wine attributes (Speed, 1998; Gil and Sánchez, 1997; Chaney, 2000; Orth and Krka, 2002).

A weak correlation between the importance of the bottle weight in the choice of the wine and the beliefs of the relation between the bottle weight and both the wine price ($r = .248$; $p = .016$) and wine quality ($r = .251$; $p = .015$), was found only for the low knowledge group of consumers. No correlations were found for the other consumers groups. These results seems to indicate that, although consumers do associate a heavier bottle with both a higher quality and a more expensive wine, they do not rely on the bottle weight as a decisive factor in their choice of wine.

Table 7 – Mean values (SD) of respondents importance of factors when choosing a wine

	Overall	Low knowledge	Some knowledge	High knowledge
Quality	6.2 (1.1)	5.9 (1.2)	6.3 (1.0)	6.7 (.6)
Previous experience	6.2 (1.2)	6.1 (1.2)	6.7 (1.2)	6.2 (1.1)
Region	5.2 (1.8)	4.8 (1.9)	5.4 (1.5)	5.1 (2.1)
Price	5.1 (1.5)	5.4 (1.6)	5.1 (1.3)	4.8 (1.7)
Grape variety	4.5 (1.9)	3.6 (1.9)	4.8 (1.6)	5.2 (1.8)
Environmental claims	4.4 (1.8)	4.3 (1.9)	4.5 (1.5)	4.3 (2.1)
Alcoholic degree	4.3 (1.7)	4.5 (1.8)	4.2 (1.5)	4.0 (1.9)
Producer	4.3 (1.8)	3.7 (1.9)	4.4 (1.7)	5.0 (1.8)
Label	3.8 (1.9)	3.5 (1.9)	3.8 (1.8)	4.2 (2.0)
Bottle shape	2.8 (1.7)	2.5 (1.4)	2.8 (1.7)	3.1 (2.1)
Bottle weight	2.6 (1.7)	2.2 (1.4)	2.7 (1.7)	2.9 (2.0)

3.3.3. Beliefs on sustainable packaging

The consumers' responses on what they value the most in a sustainable package (having biodegradable, recyclable, reusable, made with recycled material, low carbon footprint, lightweight, low size, monomaterial structure and plastic free as factors) are presented in Figure 11. The responses concerning the consumer perception of the impact of bottle light weighting on sustainability ("A lighter bottle is more sustainable that a heavier one?", "A lighter bottle contributes a lot for reducing the impact on the environment?" and "A lighter bottle deserves to be labeled as environmentally friendly?") are shown in Figure 12.

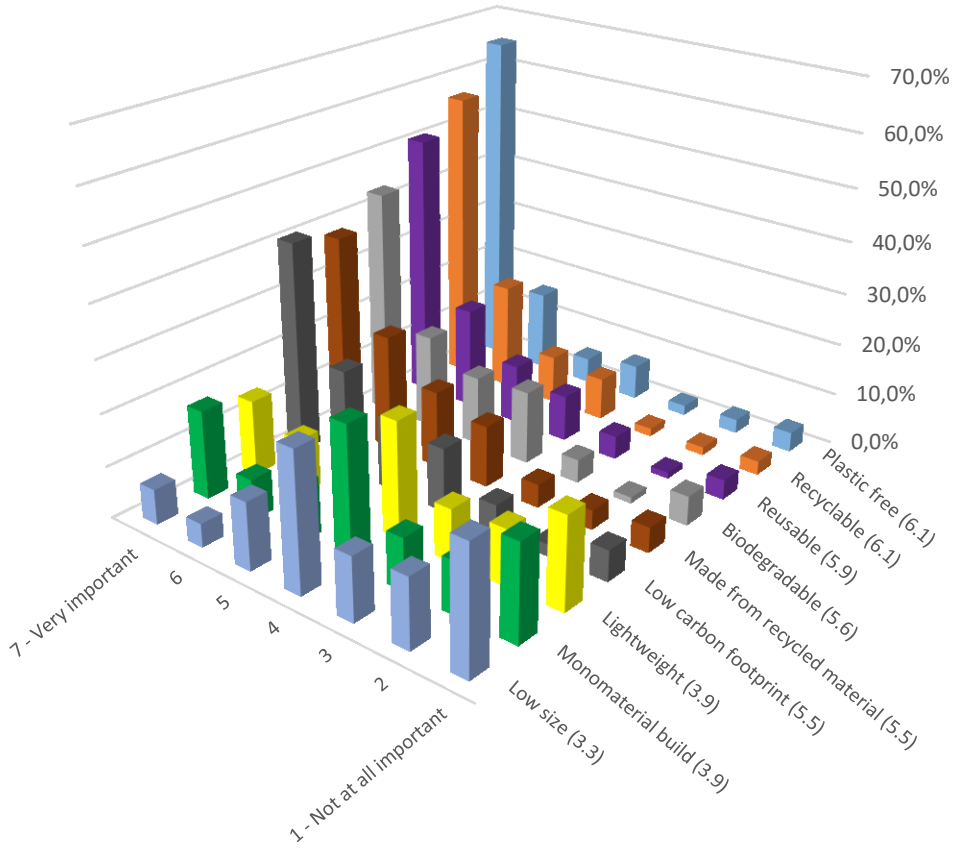

Figure 11 – Percentage of consumers' responses to what they value the most in a sustainable package and respective mean score of each factor

Several characteristics of packaging – namely it is plastic free, recyclable, reusable, biodegradable, made from recycled material and having low carbon footprint – showed an unimodal left skewed distribution, with a mean value higher than the middle point of the scale. These results show a high level of consumer awareness regarding the impact on sustainability of these factors, as over 30% of respondents attributed the highest level of importance for those characteristics. These may be due to the current trends on consumers increasing environmental concerns and needs for information. Those factors are between the most widespread sustainability-related subjects by the media.

However, consumers do not attribute much importance to the lightweight, monomaterial structure and size of the packaging. For these characteristics a more scattered distribution of attributed levels of importance and a mean value lower than the middle point of the scale were achieved.

These results are also a reflection of the lack of the consumer knowledge, namely about the bottle light weighting. About 50% of the survey sample of consumers does not have an established opinion (response: neither agree nor disagree) regarding the effects in the environment of this measure, while the other answers are rather equally scattered along the scale (Figure 12). Such lack of information results in a poor or wrong consumer perception on the impact of bottle light weighting has on benefits of sustainability.

Furthermore, as shown in Figure 13, when asked about the option that would contribute the most for the increase in sustainability of a glass wine bottle, 83% of the consumers choose the increase of recycled material over the weight reduction. In spite of increasing of recycled material being a good sustainability measure, as referenced in **1.4.** glass manufacturers use all available cullet in the market, leaving low room to improvement as glass constitution is concerned.

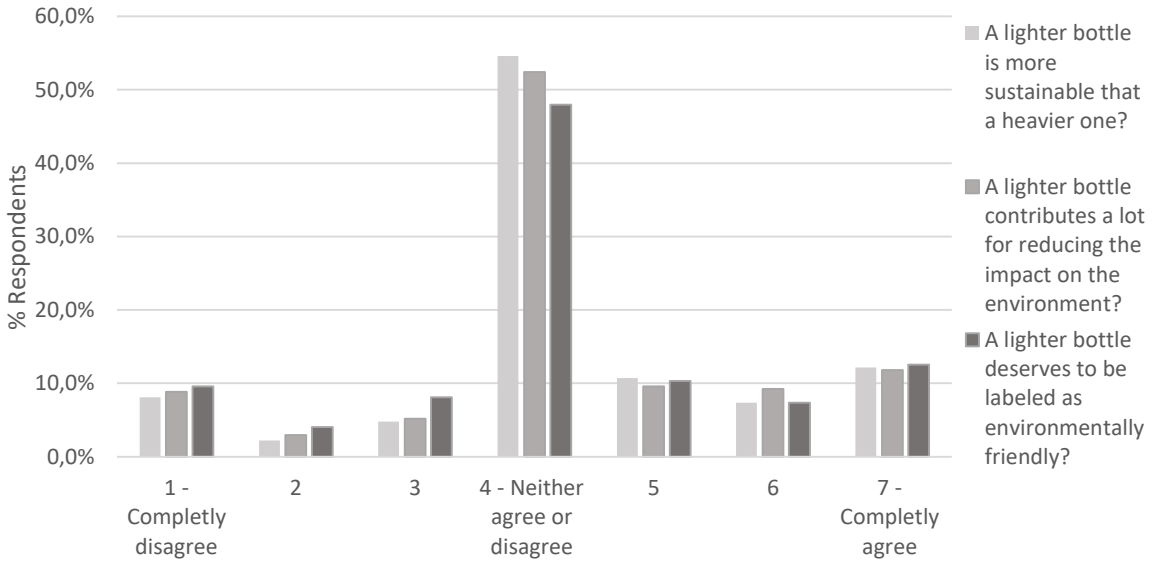

Figure 12 – Consumers answers to statements regarding their knowledge of the impact of bottle light weighting

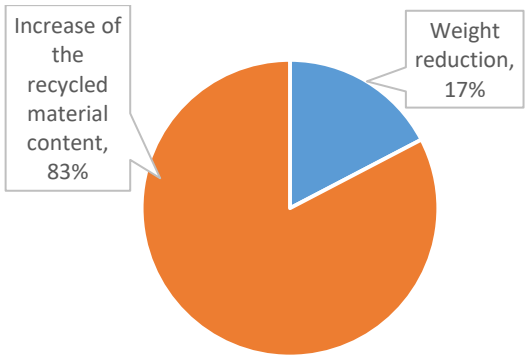

Figure 13 – Respondents beliefs on what of the two factors would contribute the most for the increase of a wine glass bottle sustainability

3.3.4. Weight difference perception

The consumers' answers to the question regarding the range of the weight difference between two bottles are presented in Figure 14.

Only 23% of the respondents indicated that there was around 100 g difference between the weights of the two bottles and 44% of the respondents could not tell the weight difference between the two bottles. This result suggests that for some types of bottles the weight reduction would not be noticed visually by the great majority of consumers. Moreover, this result may also be related to the consumer's lack of perception about the bottle weight reduction impact on sustainability, since most of them simply do not perceive it.

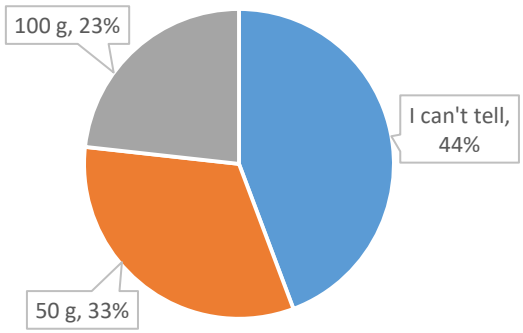

Figure 14 – Consumers' answers when asked what was the order of the weight difference between two visually similar bottles

4. CONCLUSIONS

4.1. General discussion

Results from this study indicated that capacity and weight of current bottles produced by the B&B process presented variability. Values for variance of capacity with a maximum of $\sigma^2 = 6.2$ mL^2 and a maximum difference of 5.4 g in weight, were found within batch for 750 ml bottles.

Three different wines packed in Bordeaux shaped bottles, with almost no perceptible differences to the naked eye were identified and characterized. Results found indicated a bottle weight difference in the order of 100 g between two bottles of roughly the same height. The lightest of the two bottles presented a 9 times more uniform distribution of the thickness of glass than the heaviest, and a punt depth almost 6 mm shorter. A weight reduction of 100 g is then possible by achieving a better distribution of the glass and reducing the depth of the punt without major impact to the visual appearance of the bottle. Only a minority (23%) of consumers were able to perceive such difference in weight.

When it comes to the current Portuguese wine market situation, the assessments on non-carbonated red wines glass bottles, showed a strong correlation ($r = .634$; $p < .001$) between the weight of the bottle and the price of the wine when all wine were assessed together, in good agreement with other studies. This seems to indicate a worldwide trend from winemakers to pack higher value wines in heavier containers. When taking in consideration the wine region and the bottle shape, positive correlations between weight of the bottle and price were also found with exception to the Conic Burgundy shaped bottles.

Interestingly, significant differences between bottles shapes weights were found with, on average, Bordeaux shaped bottles being the lightest ($M = 475$ g) and Conic Bordeaux bottles being the heaviest ($M = 615$ g). No significant differences between regions were found.

Results also showed that Portuguese consumers associate a heavier bottle with a wine with better quality ($r = .321$; $p < .001$) and higher price ($r = .278$; $p < .001$). However, and contrary to the beliefs of Spanish consumers studied by Piqueras-Fiszman and Spence (2012), the Portuguese consumers with a higher wine expertise are the ones who relate more strongly the bottle weight with the wine quality and price. Therefore consumer's beliefs seems to be different according to their socio-demographic characteristics, for different countries.

Despite this belief that consumers have, when asked about the importance of various wine characteristics that they can perceive in the moment of purchase, the weight of the bottle was the one that obtained the lowest average of importance (M = 2.6), with quality (M = 6.2), previous experience (M = 6.2) and region (M = 5.2) being the three main factors in the consumer's wine choice. Furthermore, a correlation between the importance of weight and both the beliefs between the relation of the bottle weight and the price (r = .248; p = .016) and quality (r = .251; p = .015) of the wine was only found for the low wine expertise consumer group. These findings seems to indicate that consumers do not rely on the bottle weight as a decisive factor in their wine buying choice.

Finally, results of consumer beliefs regarding packaging sustainability revealed that their three top concerns regarding packaging are: plastic free (M = 6.1), recyclable (M = 6.1) and reusable (M = 5.8). It also revealed their present low awareness on the importance of light weighting (M = 3.9). This is most probably related to the lack of knowledge about its environmental benefits, as about 50% of the consumer sample did not had an established opinion regarding the effects of this measure in the environment. Therefore, an investment from winemakers in lighter containers, together with an information campaign concerning this matter would be beneficial, with companies having a lot to gain in presenting a lighter bottle and remarking its environmental advantages.

4.2. Limitations and further research

To conclude, the main limitations in this study were noted and future research possibilities were addressed.

The present study did not focus on carbonated wines. These wines have specific requirements regarding bottle resistance to internal pressure. Therefore, results cannot be applied to those wines and further research would be needed.

Although many companies use the same bottles for red, rosé and white wines, an investigation on the weight difference between different color wines would also be of interest.

Finally, further research on the consumer beliefs on the bottle weight is advisable. Mueller *et al*. (2010) proposes multi-media and graphic displays studies instead of direct attribute measurements. To assess the impact of the bottle weight on the wine quality perception by the consumer, a hedonic test could be set. A sample of consumers would taste a specific wine in bottles of different weights, where the consumers serve the wine themselves and would have

no knowledge that the wine is the same in all bottles. This could be done in a laboratory or in a normal consumption environment. Furthermore, results of two different groups of consumers, in which one of them received information on the impact of light weighting in environment indicators in previous sessions, thus mimicking the effect of an information campaign, and another group that did not receive any information, in such test could be compared. This would be a major follow up of this work, as the impact of an information campaign regarding this matter could then be assessed.

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APPENDIX

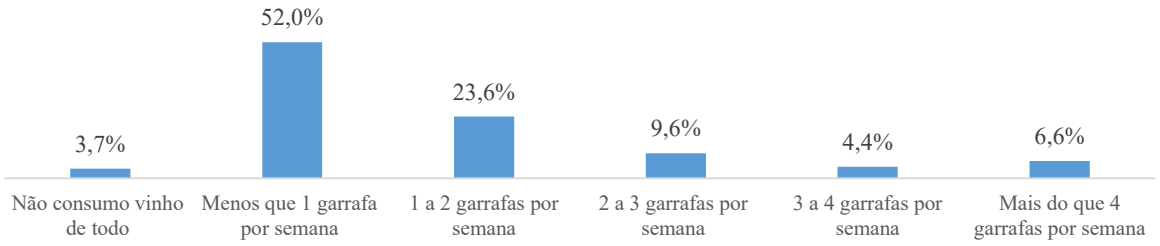
APPENDIX A – CONSUMER QUESTIONNAIRE

Q1. Costuma fazer as compras para a casa?

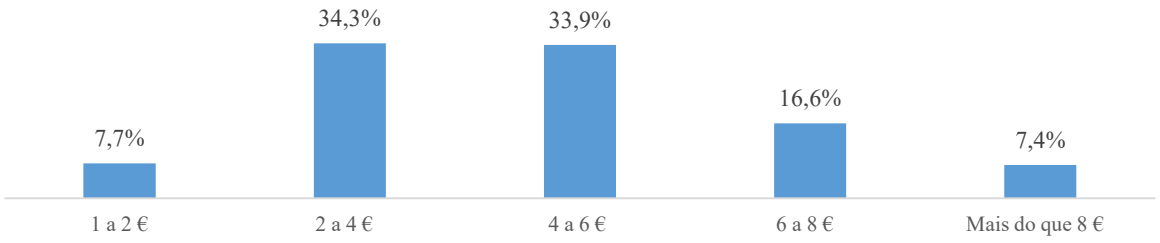
Q2. Comprou uma garrafa de vidro de vinho na passada semana?

Q3. Comprou uma garrafa de vidro de vinho no último mês?

Q4. Qual é a sua frequência de consumo de vinho?

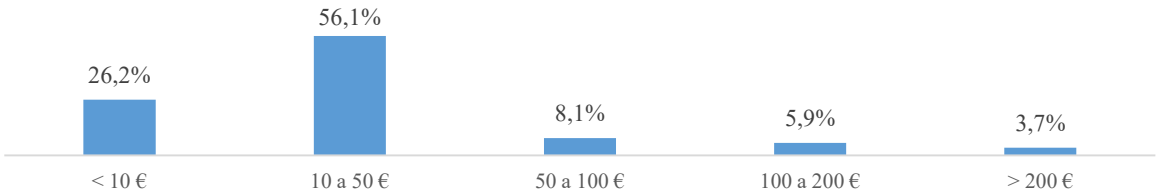


Q5. Qual é o valor médio que dá por uma garrafa de vinho para o seu autoconsumo regular?



Q6. Qual é o valor mínimo que dá por uma garrafa de vinho para o seu autoconsumo regular?

Q7. Qual é o valor máximo que já deu por uma garrafa de vinho para uma ocasião especial (oferta, celebração, etc)?

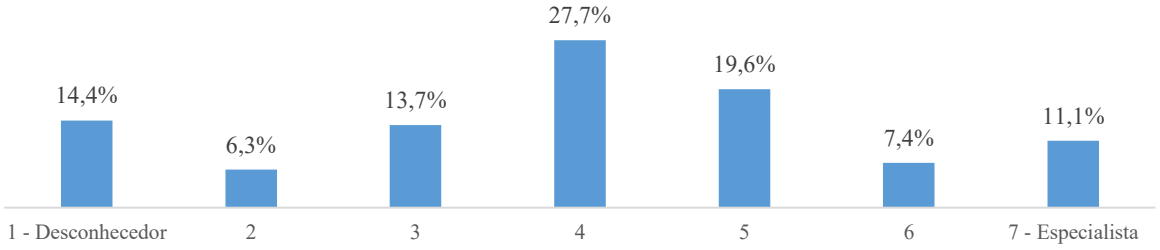


Q8. Costuma optar por produtos sustentáveis?

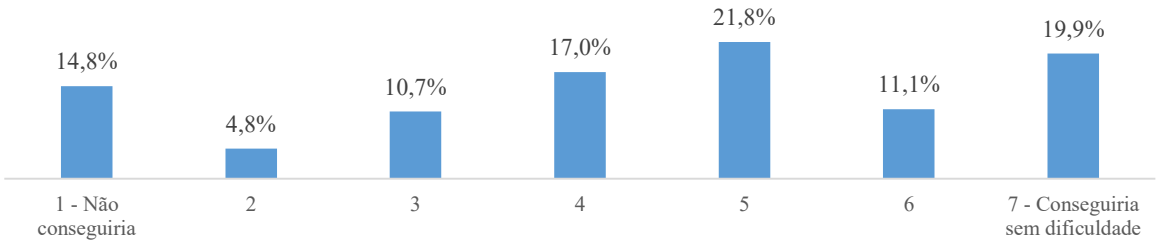
Q9. Acha que as alegações de sustentabilidade de um produto conferem-lhe um valor acrescentado?

Q10. Estaria disposto a pagar mais por um vinho mais sustentável?

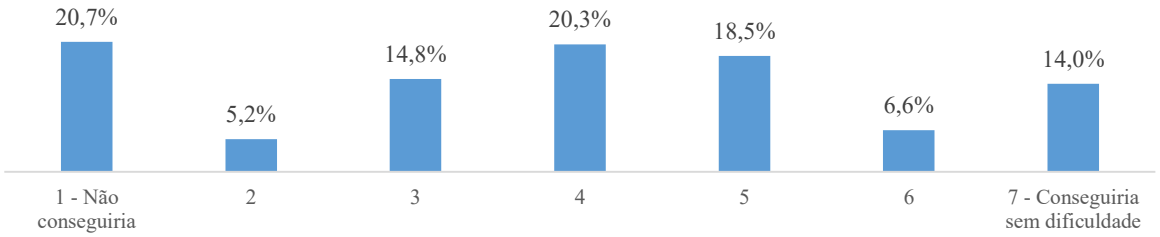
Q11. Como se classifica em relação aos seus conhecimentos sobre o vinho?



Q12. Considera que seria capaz de distinguir entre um vinho de elevada qualidade e um vinho comum numa prova sem saber qual o vinho que estava a provar?

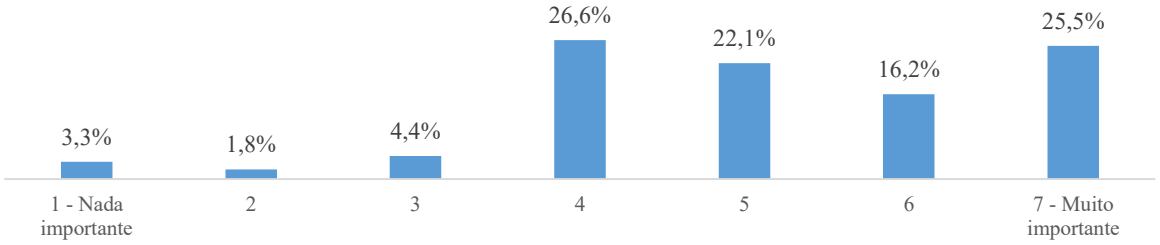


Q13. Considera que seria capaz de distinguir entre um vinho mais económico e um vinho mais caro numa prova sem saber qual o vinho que estava a provar?

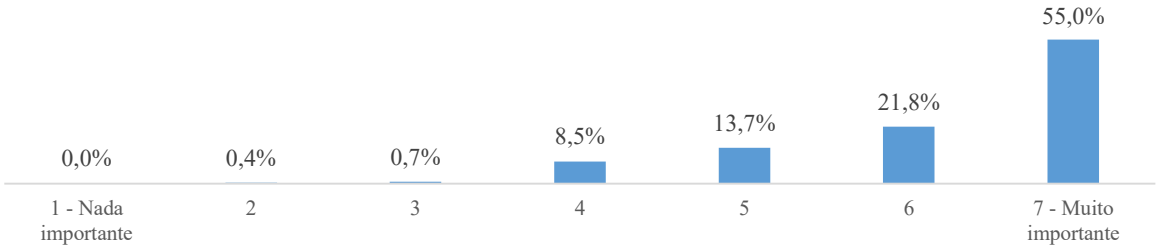


Q14. Qual a importância dos seguintes fatores na sua escolha de um vinho?

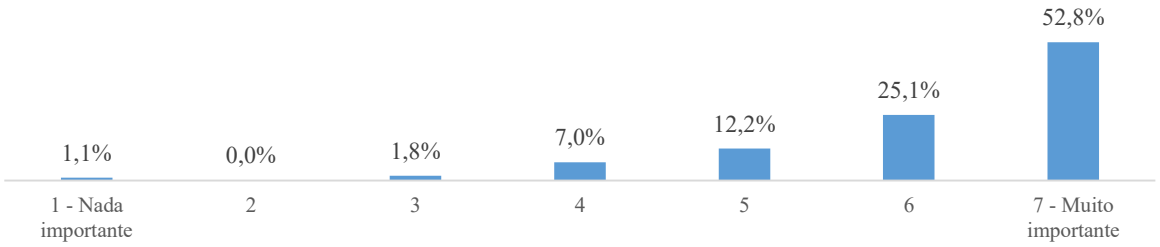
Q14.1. Preço



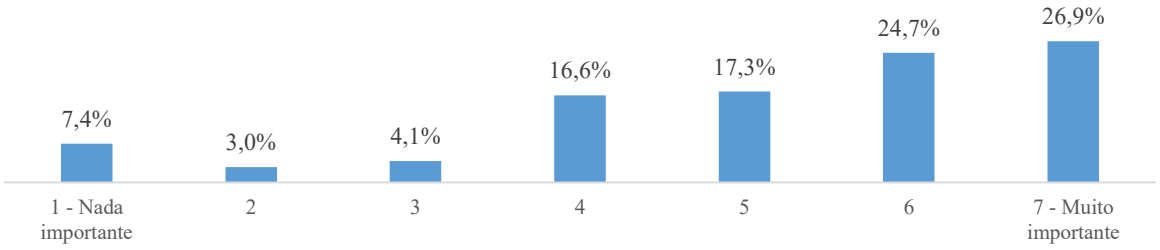
Q14.2. Qualidade



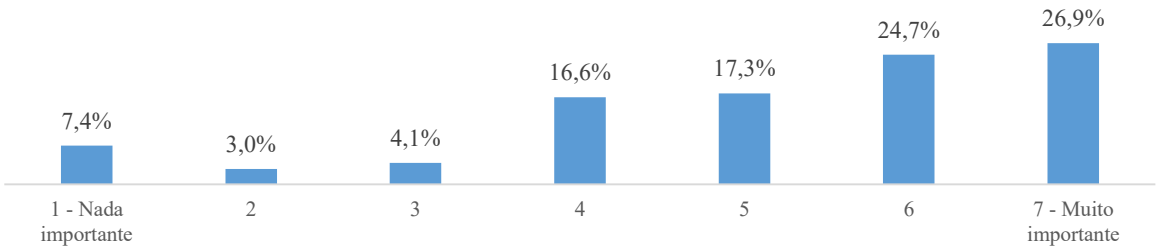
Q14.3. Experiência anterior com esse vinho



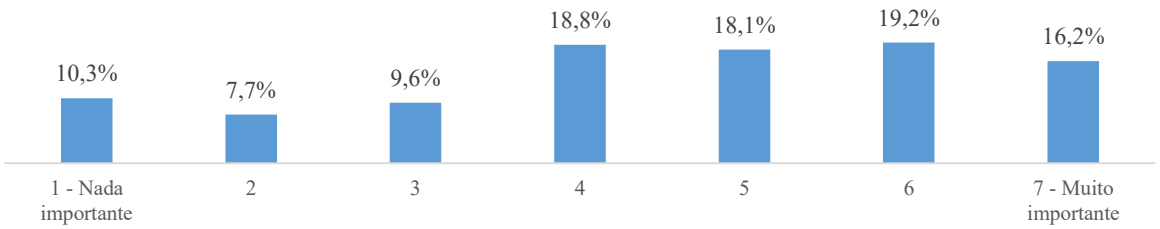
Q14.4. Região



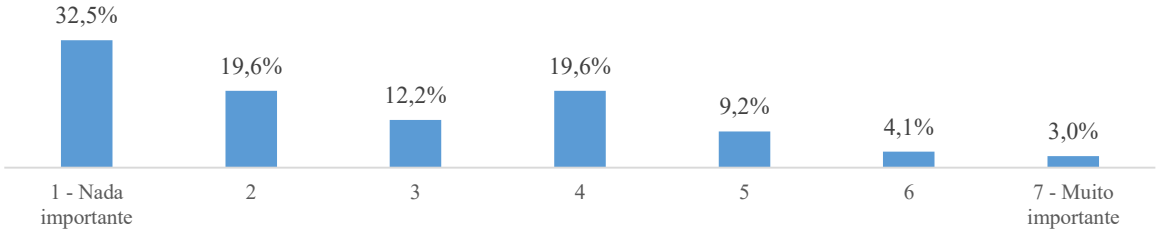
Q14.5. Castas



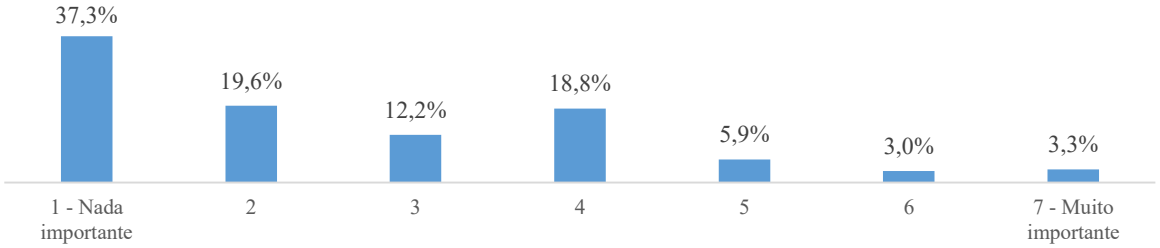
Q14.6. Produtor



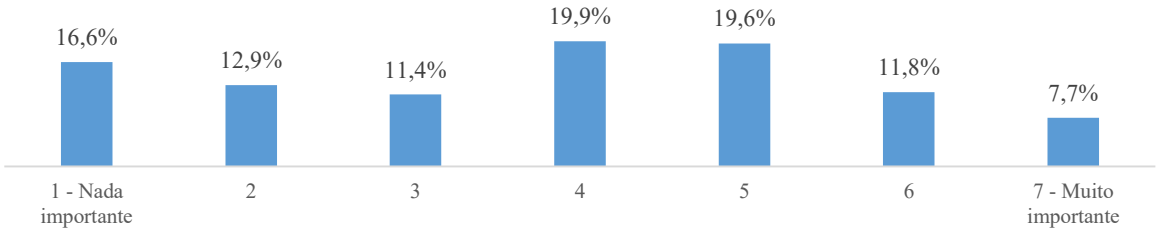
Q14.7. Forma da garrafa



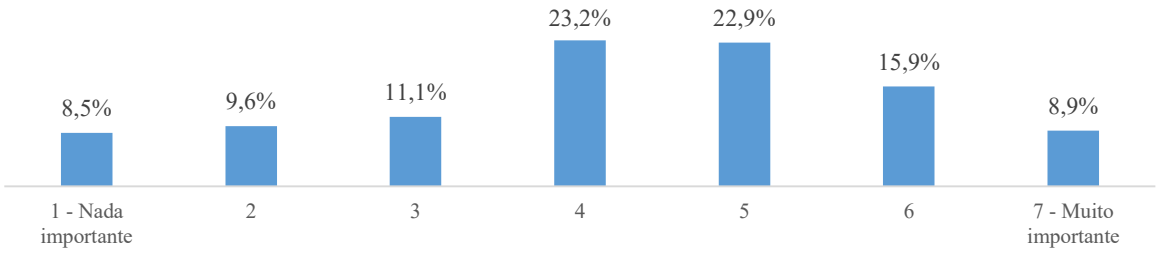
Q14.8. Peso da garrafa



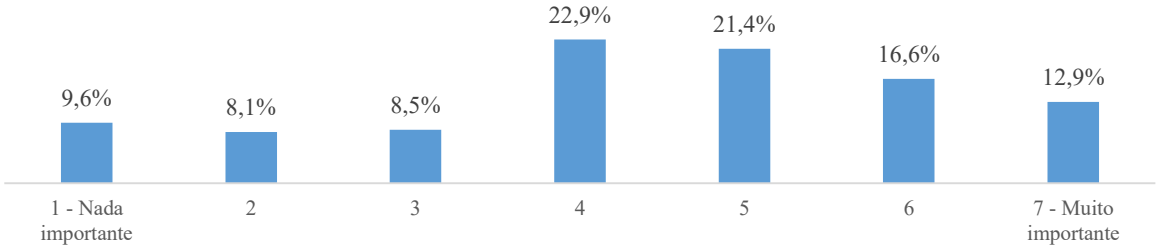
Q14.9. Rótulo



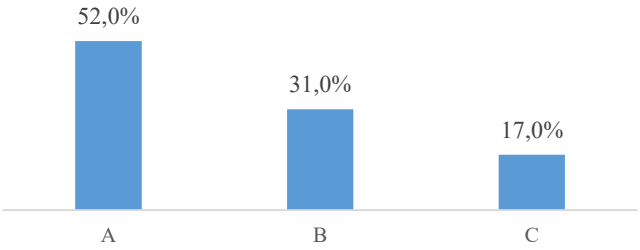
Q14.10. Teor de álcool



Q14.11. Alegações ambientais



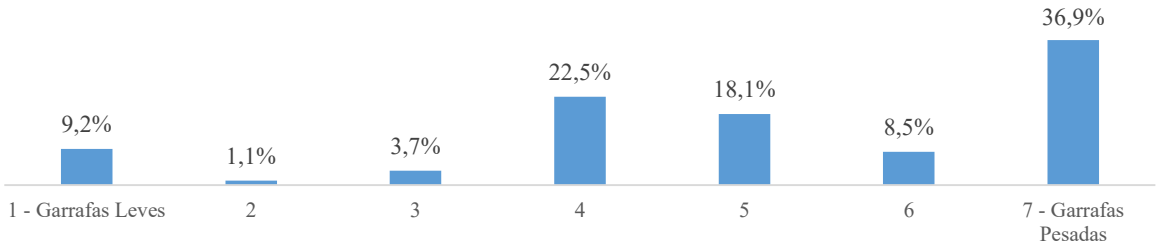
Q15. Qual destas garrafas prefere?



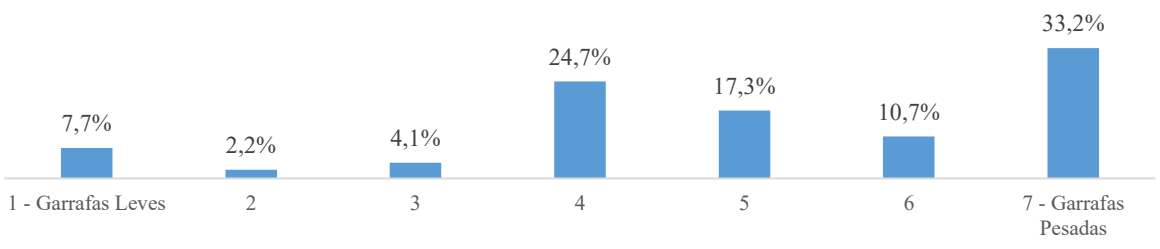
Q16. Costuma ler o rótulo e o contra-rótulo antes de comprar uma garrafa de vinho?

Q17. Considera a informação apresentada no rótulo e contra-rótulo relevante na decisão de compra?

Q18. Vinhos mais caros são engarrafados em?

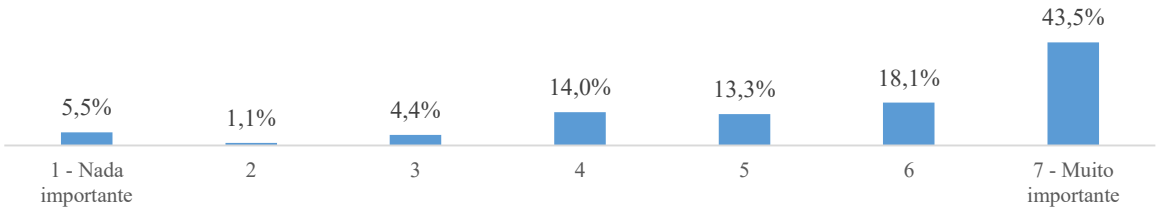


Q19. Vinhos de melhor qualidade são engarrafados em?

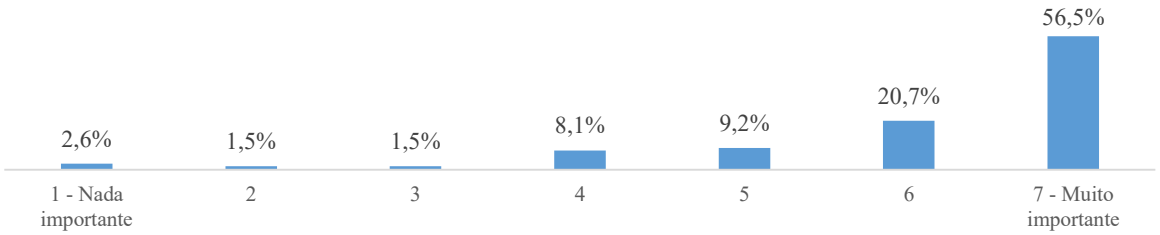


Q20. O que valoriza mais numa embalagem sustentável?

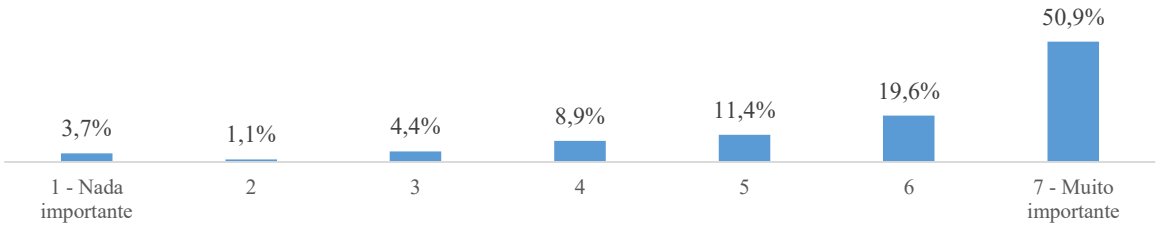
Q20.1. Ser biodegradável



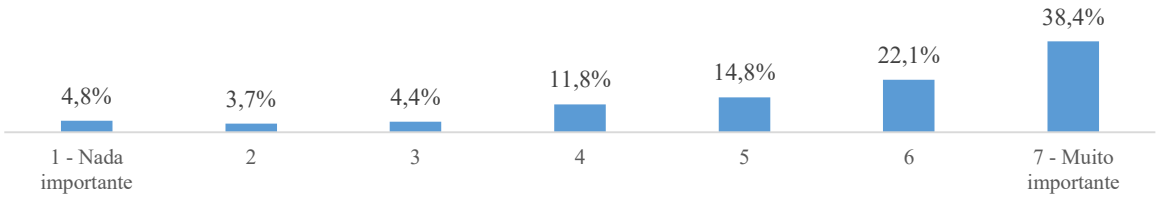
Q20.2. Ser reciclável



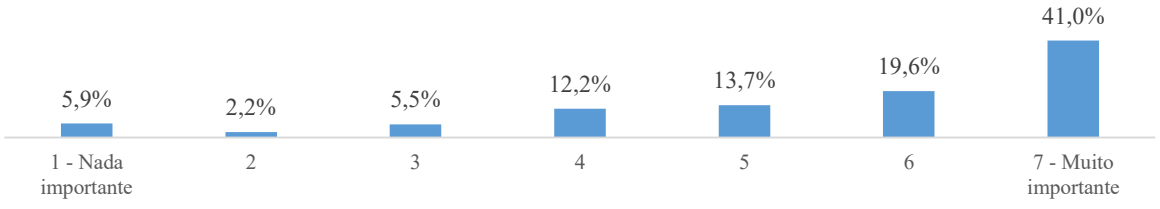
Q20.3. Ser reutilizável



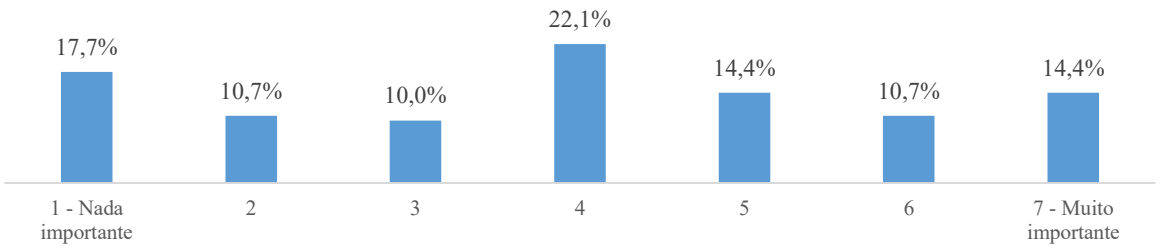
Q20.4. Ser produzida com material reciclado



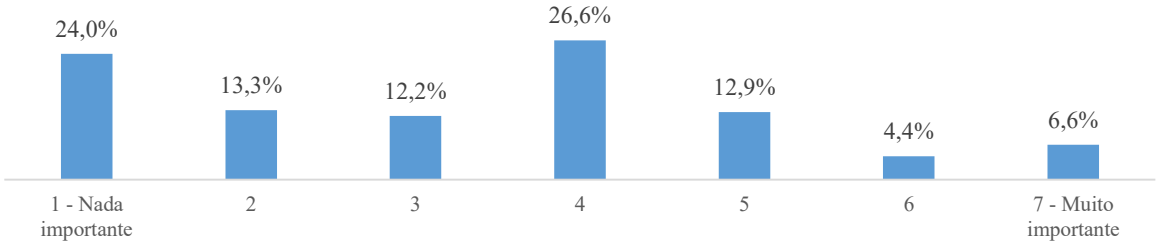
Q20.5. Ter uma baixa pegada de carbono



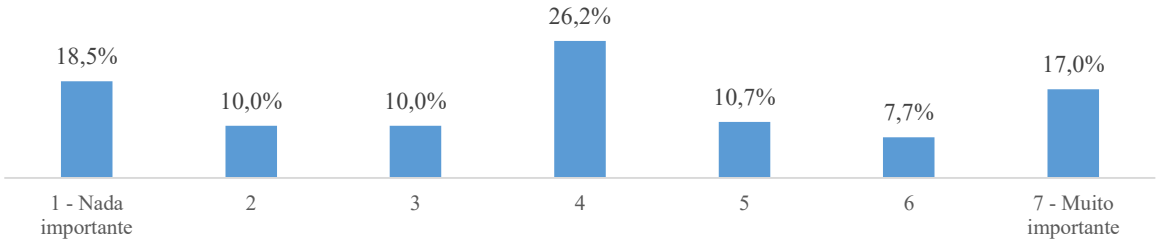
Q20.6. Ser leve



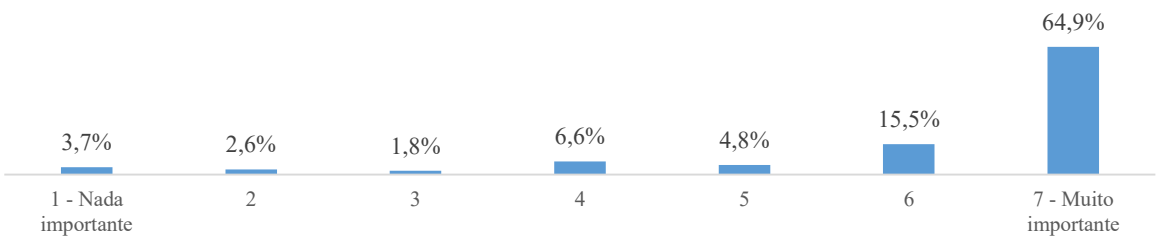
Q20.7. Ser pequena



Q20.8. Ser contituída por apenas um material



Q20.9. Não ser de plástico



Q21. Considera que o vinho é um produto sustentável?

Q22. Considera que a garrafa de vidro é uma embalagem sustentável?

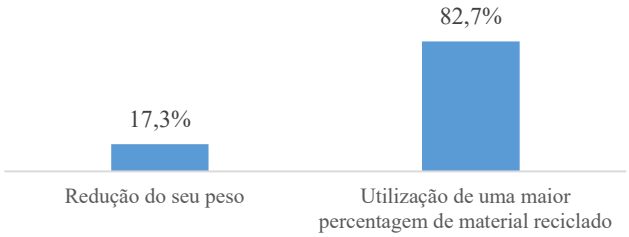
Q23. Uma garrafa de vidro mais leve é mais sustentável do que uma mais pesada?

Q24. Uma garrafa de vidro mais leve contribui bastante para melhorar o ambiente ?

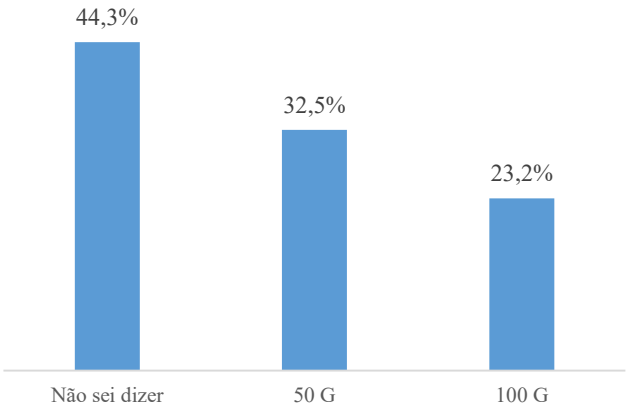
Q25. Uma garrafa de vidro mais leve merece ser rotulada de amiga do ambiente ?

Q26. Para um dado vinho, optaria por uma garrafa de vidro mais leve do que outra mais pesada, se pudesse escolher?

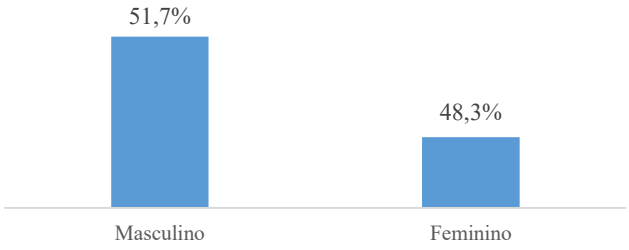
Q27. Qual das duas opções considera ser a que mais contribuí para o aumento de sustentabilidade de uma garrafa de vidro de vinho?



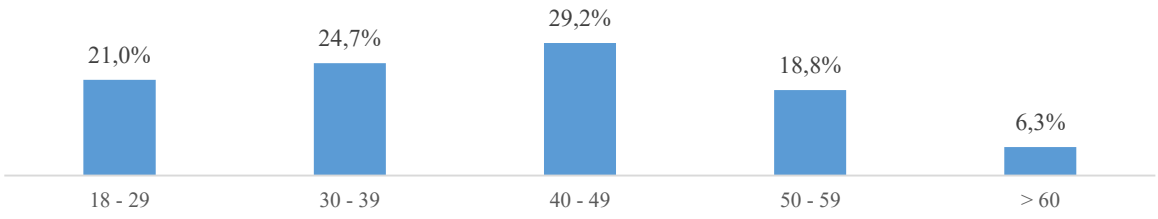
Q28. Estas garrafas têm um peso diferente. Consegue indicar a diferença? Acha que a diferença de peso entre elas é da ordem de:



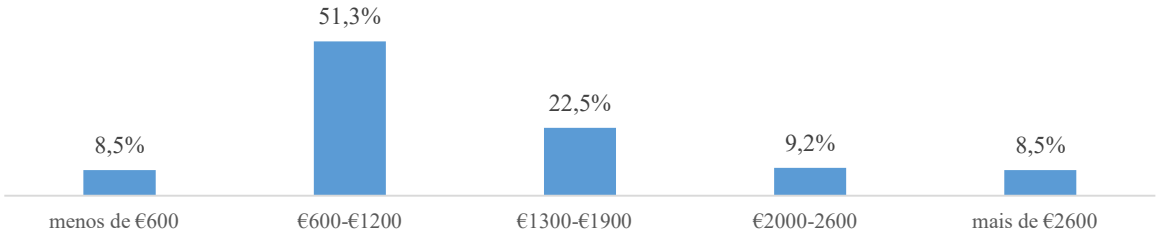
Q29. Género



Q30. Idade



Q31. Rendimento mensal



Q32. Distrito de residência