DOSE RESPONSE FUNCTIONS, DIFFERENCE THRESHOLDS AND WEBER RATIOS FOR BACK-SWEETENED RED AND WHITE TABLE WINES

A Thesis in
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by
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ABSTRACT

Sweet wines predate biblical times and the popularity of sweet wines continues to flourish today. Traditionally, the key to creating a sweet wine has been to stop fermentation before the yeast consumes all the grapes’ sugars. However, alternative practices have been adopted to better meet market demand for these products. Back-sweetening has become a common practice in which a sweetener is added to wine after fermentation is complete, creating a sweet, high alcohol wine. However, because there is limited information available about back-sweetening, many wineries may be making uninformed decisions about their back-sweetening practices. The goals of this thesis were to investigate the dose response functions for sucrose on perceived sweetness in wine and to determine the difference thresholds, as well as the Weber Ratios of sucrose, when back-sweetening white and red table wines with varying acidity levels. While sucrose is traditionally used to back-sweeten wine, there is a growing demand for sweet wines for calorie conscious consumers. Thus, a secondary goal was to determine the dose response functions for aspartame on perceived sweetness, as well as the difference thresholds and Weber Ratios of aspartame while back-sweetening a neutral white and red wine without high acidity. Practically, the data collected indicates winemakers have substantial latitude in reducing the amount of sucrose they add to back-sweeten wines before consumers will notice, greater than 20%. In addition, data collected shows similar results using aspartame to back-sweeten wine and practically that significant changes would need to be made for consumers to perceive a difference in sweetness. Finally, data supports the assertion that simple water based model systems do not always generalize to complex beverages.
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Chapter 1

Literature Review

Introduction

Sweet wines have a long history, predating biblical times and recorded history. Over the years, consumption of sweet wine has fluctuated, but they continue to be a popular alcoholic beverage today (Pape, 2011). Traditionally, there are four main practices used to produce a sweet wine: 1.) using grapes that are picked after the regular harvest when the grape’s sugar is very high; 2.) using grapes which have been raisinated which will in turn concentrate the grape’s sugars; 3.) using grapes that have been frozen on the vine so that water can be separated from the juice which in turn concentrates the grape’s sugars; and 4.) using a grape that has been attacked by noble rot, a fungus which pulls water from the grape, simultaneously concentrating the sugars within the grape while imparting a characteristic sweet flavor (MacNeil, 2001). These wines can have sugar levels as high as 14% or more, varying upon their degree of fermentation (Berg, Fillipello, Hinreiner, & Webb, 1955). The key to creating a sweet wine in each of these four practices is to stop fermentation early and before the yeast consumes all the grapes’ sugars. When using this method however, wines are typically characterized by a lower alcohol content, which some consumers may find unappealing (Amerine & Joslyn, 1970).

Adaptively, the wine market continues to change and more pre- and post-harvest practices have been applied to meet consumer demands. Such practices include back-sweetening. While chaptalization is the addition of a sweetener before fermentation is
started or in the midst of fermentation, back-sweetening is typically done by taking a dry base wine, or a wine that has completed fermentation, and adding a sweetener to it resulting in a sweet wine (MacNeil, 2001). Typically sucrose is used, although honey and other sweetening agents have also been used historically (Baines & Seal, 2012). Characteristically, some of these wines can have the same percentage of sugar as they contain alcohol; upwards of 13% sucrose weight per volume or more (Amerine & Joslyn, 1970).

**History of Sweet Wines**

Wine is a unique commodity in many aspects. Grapes for winemaking have been cultivated in Egypt since 2500 BC and the Near East since 4000 BC. In these ancient times, wine was seen as a gift from the gods, used both as a sacrament and also an offering (Wansbrough, Sherlock, & Reeves, 2014). It was also used as a bartering tool for trade among communities and today it serves as a form of entertainment, as well as a means for pleasant experiences to be had by the consumer (Bisson, Waterhouse, Ebeler, Walker, & Lapsley, 2002).

Sweet wine was ubiquitous in early Mediterranean cultures. For centuries, members of the Jewish faith considered sweet wines to be a religious symbol and these wines have been included in various ceremonies. Within the Torah, sweet wine is praised: “It is medicine to all who drink it/It is heart’s joy, gladness, and great delight to its drinkers” (Wieder, 1970). In ancient Greece and other Mediterranean regions, dried grapes were used as rations and inhabitants would take them and ferment them, which
created a sweet wine. This wine was consumed frequently by ancient people and was often safer to drink than water locally sourced (Mencarelli & Tonutti, 2013).

Later, as colonies were established in South America, South Africa and Australia, Europeans found it difficult to transport their wines without spoiling during transit. To alleviate this, winemakers discovered that adding high levels of sugar, alcohol and/or musts allowed their wines to survive these long journeys (Mencarelli & Tonutti, 2013). Sucrose, like alcohol, has an inhibitory effect on the growth and fermentation of yeast, as well as the growth of spoilage organisms when at high concentrations, making for a more stable product. This relationship is described through “Delle units,” a measure of the inhibitory activity of the solution. Delle units are calculated through the formula: (a + 4.5 c), where ‘a’ is the percentage sugar (grams of sugar/100 ml) and ‘c’ is the volume percentage of alcohol; stability is typically seen at 75 to 85 Delle units (Kunkee & Amerine, 1968).

**Sweet Wine Market**

Since colonization, the popularity of sweet wines has fluctuated; however, a steady market of consumers has typically existed. Less than a century ago, sweet wines were revered among both experienced and inexperienced wine consumers, however today most sweet wine consumers are young and of low social status; and typically sweet wine consumers are considered inexperienced wine consumers (Pape, 2011). In 1951, dessert and fortified wines accounted for almost 90% of the California wine market share (Tourney, 2011). In 1974, Schutz and Ortega conducted a study among 52 Woodland,
California housewives. The outcome of the study revealed that women would consume sweet wines a “high” quantity in their homes as it was considered to be easy to store and a drink for woman (Schutz & Ortega, 1974). In 2000; however, dessert and fortified wines only accounted for 2% of the dollar value of California wines (Tourney, 2011). Remarkably however; today, wine companies are witnessing a phenomenon coined “Moscato madness.” This sweet, and often cheap, varietal saw a 33% growth in volume in the U.S. in 2012 and now accounts for 6% of the wine market (Forsyth, 2013).

During the 1990’s Australia saw shifts in the prices of sweet wines compared to the average wine. Researchers found that sweet wines commanded a 27.4% price premium compared to the average wine price in Australia which was hypothesized to be a factor of production costs as grapes used to make premium sweet wine tend to require more favorable grape growing conditions within Australia (Oczkowski, 1994).

Canada also saw shifts in the popularity of sweet wines. In the 1960’s the market shifted towards dry table wines with lower alcohol contents simultaneously reducing the popularity of sweet table wines and fortified wines (Hope-Ross, 2006). Similar trends existed in the United States; for example, in the 1970’s, many wineries saw a change in consumer preference resulting in a growing penchant for dry table and sparkling wines rather than sweet wines as previously preferred (Peters, 1984). Recently, ice wine, an extremely sweet wine created from naturally frozen grapes, has become a popular commodity within Canada and abroad. Between 2004 and 2005, domestic ice wine sales were close to 1 billion Canadian dollars and the export sales were close to 6.7 million Canadian dollars; the majority of sales coming from Taiwan, Singapore, the United States and Japan (Hope-Ross, 2006). Within the last five years, sweet wines have again
become of interest to wine consumers, especially those with a lower income and between the ages of 21 and 35 years (NRN, 2012).

Research conducted in other countries has revealed that certain demographic and socio economic segments have an interest in sweet wines. In a study conducted in Hungary, it was found that the majority of participants preferred Tokaji wine, a sweet wine compared to other wines available. Most participants who favored this sweet wine were young and of low socio economic wealth (Szakal, 2009). Similar results were found in other studies based in Budapest and the Dominican Republic. In a study conducted in Budapest, it was found that sweet wines were preferred over dry wines, especially among woman (Farkas, 2010). In a study done by Velikova et al. (2013) among 482 Dominican participants, it was found that nearly half consumed sweet wines. In addition, these sweet wine consumers spent on average 20.10 U.S. dollars on wine a month. Characteristically, the majority of these sweet wine consumers were young and of low socio economic status (Velikova, Murova, & Dodd, 2013).

Within Pennsylvania, a large market for sweet wines exists. In total there are 59 different wines sold within Pennsylvania State Wine and Spirits stores which fall into the “dessert, port, sherry, sweet” category out of 572 table wines offered for sale. The current value of domestic dessert, port, sherry and sweet wines is estimated at $19.3 million and imports are estimated at $7.4 million in Pennsylvania. On a per liter value, domestics have an average estimated price of $5.87 and imports at $21.87 (Sechrist, 2012). In addition, nearly 70% of Pennsylvania grown wine grapes are native varieties rather than Old World varieties; the majority of which are used to create the sweet wines for which Pennsylvania is recognized for (Dombrosky & Gajanan, 2013). As discussed
later within the chapter, a survey conducted among winemakers, winery owners, wine hobbyists and winery employees revealed that the majority of respondents’ wine production was sweet (above one gram per liter residual sugar).

Overall, a large market for sweet wines continues to exist. In Switzerland, wine consumers are demanding sweet wines. Many Swiss wineries have recently seen a large trend towards sweet wines and a decline in their local dry wine purchases, as imported wines are often cheaper and sweeter than those produced within the county (Laesslé, 2013). Chinese and Japanese wine consumers are also demanding sweet wines; currently some consumers even adulterate their wines with 7-Up and other sodas to make their wines sweeter (Anderson, 2003).

**Complexity of Wine**

The sensory properties, as well as chemical properties, of wine are quite complex. Wine is a combination of water; carbohydrates, specifically fructose, glucose, pectin, and pentoses; alcohols, such as ethanol, glycerol, methanol and higher alcohols; aldehyde; organic acids, typically malic, tartaric and citric acid; phenolics such as tannins and anthocyanins; nitrogenous compounds; aroma compounds; and trace minerals such as calcium, chloride and magnesium (Wansbrough et al., 2014). In addition, there are numerous steps within the process of winemaking: harvesting, crushing and de-stemming, juice preparation and fermentation; all of which serve to play a factor in the characteristics of the final product. In terms of sweetness, the various alcohols within the wine often contribute to a wine’s sweetness, as most are characteristically sweet.
themselves (Jackson, 2008), meaning that a “dry” wine, could still taste sweet to some because of the alcohol present. The residual sugar within the wine however, typically has the most effect on perceived sweetness (MacNeil, 2001).

**Regulations**

Winery regulations are established by laws in the Code of Federal Regulations, specifically in Subtitle E-Alcohol, Tobacco, and Certain Other Excise Taxes, Chapter 51-Distilled Spirits, Wines, and Beer of the Title 26 Internal Revenue Code, United States Code, 2011 Edition. The Code of Federal Regulations states that the added sucrose content of a finished wine may not exceed 21% on a weight per volume basis. Subtitle E further details this by stating that, for wines without high acidity, wineries are only allowed to back-sweeten with pure dry sugar or liquid sugar if the total solids do not exceed 12% of the weight of the final wine and the alcoholic content is below 14%. For high acid wines, this amount is increased, with the exact limit contingent on the amount of alcohol present. If the alcohol content is less than 14% (w/v), up to 21% (w/v) sugar may be used, while wines with more than 14% alcohol may have 17% sugar added (US Government, 2012).

**Survey Results**

To better understand back-sweetening and the popularity of sweet wines within Pennsylvania, a preliminary internet survey was conducted in 2014 among Pennsylvania winemakers, winery employees, winery owners and hobbyists. The survey was
distributed through an email contact list managed by the Pennsylvania State University Extension Enologist. In addition, several participants were recruited through word of mouth. All responses were anonymous and voluntary, with 46 participants choosing to take part. Data collection was approved by The Office of Research Protections at The Pennsylvania State University, University Park, PA (Protocol #37365).

From data collected, several outcomes became apparent. As might be expected, the majority of respondents indicated that they produced sweet wines and most indicated that over 50% of their wine production was characteristically sweet (above 1 g/L residual sugar). In terms of back-sweetening, it was found that 35 of the 46 participants currently back-sweeten their wine, six currently do not back-sweeten their wine, but have in the past and only five responded that they do not nor have they ever back-sweetened their wine. These results therefore suggest that a substantial portion of Pennsylvania wineries are using this technique to sweeten their wines.

In order to explore reasoning behind back-sweetening, participants who indicated that they currently back-sweeten were asked why they chose to back-sweeten their wines. Common responses included to “meet market demands,” “customer preferences and their demands,” “they want a high alcohol product and then will sweeten to taste,” “to balance out the acid,” and that it “gives the best flavor and palatability.”

Research conducted from the 1950’s to the 1970’s unanimously concluded that increased acidity interferes with the perception of sweetness, specifically that increased acidity within a wine depresses perceived sweetness; however, research is inconclusive on the role of sucrose on perceived sourness (Berg et al., 1955, Lundgren, 1976, Pangborn, 1964). Expanding on previous knowledge, Noordeloos et al. (1972) explored
the use of sugar to ameliorate sourness in wine among untrained wine consumers. Using treatments ranging from 0%-20% (w/v) sucrose additions, it was found at 1.2% acid, the highest level of acid tested, only 10.9% sucrose was needed (Noordeloos & Nagel, 1972). Results from this experiment suggest that some sucrose may be needed in wines with high acidity so to ameliorate the sourness of the wine; however, the amount required may not be as high as anecdotally believed by some winemakers.

**Popularity of Sweeteners**

Since the 1970’s, consumption of nutritive (e.g. caloric) sweeteners in the United States has steadily increased, as well as total calorie intake (USDA, 2002). Over the last 30 years, the average calorie intake has increased by 24.5%, resulting in the average daily calorie intake to be well over 3,500 calories (USDA, 2002). As illustrated in Table 1-1, per capita consumption of nutritive sweeteners such as cane and beet sugar, as well as corn syrup, has dramatically escalated, suggesting that U.S. consumers are indulging in more sweet beverages and foods. The outcome of back-sweetening wines may cause increased consumption of nutritive sweeteners and unnecessary calories for the consumer. Based off the standard caloric composition of sucrose, wineries are adding nearly 25 calories per serving, or four ounces of wine, for every 5% increase in sucrose back-sweetened into the wine (USDA, 2014).
Compared to other alcoholic beverages such as beer, wine is typically considered a low-carbohydrate alcohol product. Sweet wines however, typically have higher amounts of carbohydrates, either from the unfermented sugars or back-sweetening. In perspective, with a 1% addition of sucrose to a wine, wineries are adding 10 g of carbohydrates per liter of wine, making the wine substantially higher in carbohydrate content compared to dry wines (USDA, 2014).

The market for “skinny” alcohol products, or lower calorie alcohol products, has been growing over the last decade. In 2011, Bethenny Frankel released a line extension of her Skinnygirl Cocktails which now includes “skinny wines.” The Skinnygirl wine line includes a red blend, primarily Syrah, a white blend, primarily Chardonnay and Pinot Grigio, and a rose blend, which is a blend of Grenache and Syrah. Beam Global Spirits & Wine Inc. currently own the rights to the company and has stated that they hoped to capitalize on the established brand core and its consumers, which are generally health-conscious women between 30 and 39 years of age. As stated on the label, these three wines claim to be a 100 calories per five ounce serving and 12 percent alcohol (Taylor,
However, as illustrated in Figure 1-1, the average wine is not much higher in terms of calories per ounce compared to Skinnygirl wine (Ingraham, 2014).

Beam representatives claim that extra care is taken in processing to make their product “special” in today’s market and estimate sales to be near 200,000 cases annually which has many of Beam’s competitors releasing their own version of low-calorie wine (Taylor, 2012). “Skinny wines” and other low-calorie wines continue to enter the wine market; however, because of their characteristically dry profile, there is opportunity to introduce a low-calorie sweet wine (Orlin, 2012). Currently, many consumers are looking for alternatives to “dry and skinny” wines and many winemakers are looking to replace sucrose in a back-sweetening, through the use of a non-nutritive sweetener. In fact, in 2005 a patent was filed for a low-alcohol, low-calorie wine which would use non-nutritive sweeteners such as aspartame and sucralose to sweet the wine (Lawson, 2005).
The Freedonia Research Group estimates that the sales for non-nutritive sweeteners will grow 3% faster than the overall rate for food ingredients in the United States. Growth is largely driven by consumer demand for alternative low calorie sweeteners. Furthermore, U.S. consumers are not the only group of sweet consumers starting to demand alternatives to nutritive sweeteners, China accounts for 5-10% of the saccharin sales world-wide (Seewald, 2000). Seeing as China accounts for a large portion of the world population, this is staggering.

Currently there are numerous non-nutritive sweeteners approved for use in the U.S., including saccharin, aspartame, acesulfame-K, sucralose, tagatose, sugar alcohols...
and stevia. Unfortunately, many have undesirable side tastes, which many consumers find unappealing in many applications. Among consumers, aspartame is highly accepted because of its flavor profile and minimal side tastes, while some non-nutritive sweeteners carry bitter or offending side tastes and flavors (Shankar, Ahuja, & Sriram, 2013). This may be why it is one of the most popular non-nutritive sweeteners markets on the market (Hutchinson, Ho, & Ho, 1999). In addition, aspartame, under the name of NutraSweet®, has been approved for use as a sweetener in wine coolers (wines with less than 7% alcohol content). This has allowed diet conscious consumers the ability to enjoy a sweet, low-alcohol wine through this alternative (Sherrod, 1988).

While added calories concern consumers, wineries are unknowingly adding to their production costs by back-sweetening. According to the United States Department of Agriculture in 2012, sugar prices today range from 19.09 cents per pound to 22.14 cents with prices largely affected by availability, climate and other factors making them susceptible to dramatic price changes (Service, 2012). Hence, when wineries add 5 percent (w/v) sucrose to their product, the price increases nearly twenty cents per case of wine, assuming twelve, 750 mL bottles per case and if sugar prices remain stable. In a report published by the Washington State University, wineries are already spending on average $280.45 (based off a 2,000 cases/year winery) in costs on a case of wine, more than twenty dollars per bottle (Fickle, Folwell, Ball, & Clary, 2005). Aside from the cost of the sugar itself, wineries must account for increased labor cost due to this labor intensive processing step. According to the same Washington State University report, labor is the second highest variable cost and by adding a labor-intensive step, wineries
are adding to their already high production costs and possibly increasing the price of wine for consumers (Fickle et al., 2005).

Response to Sweeteners

Numerous direct scaling methods have been developed to measure the perceived intensity of a stimulus by participants. Direct scaling often provides quick measurements of the stimulus (Suppes & Zinnes, 1962). Direct scaling procedures can also be used to determine the relationship between a stimulus concentration, such as percent sucrose, and the strength of the perceived taste, such as sweetness (Stevens, 1969). Fundamental psychophysics is generally concerned with a group’s data and is practically described by a power function which is typically stable and characteristic of the sense (Ekman & Åkesson, 1965).

Magnitude estimation, which is based off of the magnitude of the ratio between a standard and other samples, has been conducted by sensory scientists since the 1950’s (Stevens, 1956). The General Labeled Magnitude Scale which measures from 0 (no sensation) to 100 (strongest imaginable sensation of any kind) is also used frequently (Bartoshuk, Fast, & Snyder, 2005). In addition, Spectrum Descriptive Analysis provides detailed separation and perceived intensities for products and is conducted using a highly trained panel (Munoz & Civille, 1992). A method of category (interval) scaling may also be used. In Moskowitz et al. (1974) categories such as 1 = “no sweetness” and category 9 = “extreme sweetness” were successfully used (Moskowitz, Kluter, Westerling, & Jacobs, 1974).
The relationship between concentration and perceived intensity can be illustrated through the creation of a dose-response function. Previous investigations into sweetness found that rated sweetness increased systematically based on a function of concentration; while pleasantness of that sweet taste tended to rise and peak, then often decreased (Moskowitz et al., 1974). Dubois et al. (1991) used Spectrum Descriptive Analysis to evaluate the dose-response of various nutritive and non-nutritive sweeteners. A linear dose response was shown for the bulk sweeteners, although the authors noted this was likely an artifact caused by panel training (DuBois et al., 1991). More recent data by Antenucci (2014) suggests this is not the case, as other scaling methods result in a sigmoidal dose-response function.

**Mixture Suppression**

The phenomenon of mixture suppression may also play an important role in such a complex system such as wine. Mixture suppression is said to occur when the perceived intensity of two tastes within a mixture is perceived to be less than it would be if they were not together, or unmixed at the same concentration (Lawless & Heymann, 1998). Schifferstein and Frijters (1991) found that the presence of different sweeteners depressed the perceived sourness of citric acid within a solution (Schifferstein & Frijters, 1991). Similarly, Bonnans and Noble (1984) found sucrose and aspartame to suppress sourness in a model solution (Bonnans & Noble, 1984).

However, previous research in wine systems has been somewhat inconclusive. Varying results found during the expansive phase of psychophysical functions, or at low
concentrations, are inconclusive about the effect of binary mixtures of sweet tasting compounds with other basic tastes qualities such as sour, salty, bitter and savory or umami (Agrawal & Karban, 1997; Keast & Breslin, 2003; Prescott, Ripandelli, & Wakeling, 2001). When two characteristically different compounds (e.g. bitter and sweet) are mixed, the interaction may be monotonic (enhancement or suppression) or show an asymmetrical intensity shift (Keast & Breslin, 2003). Zamora et al. (2006) concluded that sourness and sweetness appeared to be less noticeable when in wine compared to water. In addition, these researchers found results to be dependent on the wine mixture due to the effects of numerous attributes such as: fructose, pH, acidity and alcohol content (Zamora, Goldner, & Galmarini, 2006). In 2002, Martin et al., found that sucrose had a suppressive effect on the perceived sourness of tartaric acid while the concentration of tartaric acid had little effect on the perceived sweetness intensity in a champagne (Martin, Minard, & Brun, 2002). As concluded by many researchers, there still remains a gap in this area of research (Martin et al., 2002).

Difference thresholds and Weber Ratios

Psychophysics is the study of the relationship between a stimulus and the sensory response to that stimulus (Woodworth & Schlosberg, 1954). Typically, there are four categories in which psychophysical models fall into: absolute thresholds, difference thresholds, scaling sensation above threshold and tradeoff relationship (Lawless, 2013). Absolute threshold is the minimal amount needed of a stimulus to be detected by the observer. A difference threshold is the smallest amount by which two sensory stimuli
can significantly differ in order for the item being evaluated to be perceived as different. Difference thresholds can be expressed as “just noticeable difference” (JND) values or Weber Ratios. A Weber Ratio describes the relationship between the difference threshold and the change in stimulus concentration relative to previous concentrations. These values can be determined using a variety of methods (Lawless, 2013). Frequently, methods used involve a direct comparison between two or more samples. Typically, this is a comparison between a sample containing the substance of interest and one without it. While this can be calculated through a simple paired comparison test, other difference testing methods can be used (Burgard & Kuznicki, 1990).

In 1954, Berg et al. determined the difference threshold of sucrose in various model wine solutions using a triangular test method, involving 12-16 people participants. Each evaluation typically included sugar levels of: 0, 1, 5, and 10 g/100 mL of model wine. In this study, investigators found that acid had little effect on the difference thresholds; however, the presence of tannins actually increased the difference threshold values (Berg et al., 1955).

Difference thresholds for sucrose in water and orange juice were determined by Lundgren et al. (1964) using the method of constant stimuli. Within pairs, one sample was always a control and the other sample was a treatment sample. Pairs were presented in a counterbalanced, randomized order within subjects and replicates. They determined that the JND of sucrose in water 0.38 and the Weber Ratio were 0.077 when using a 5% standard concentration of sucrose in water as the control, which was significantly different from that found using orange juice. In orange juice, the JND was found to be 1.07, while the Weber Ratio was found to be 0.29 (Lundgren, Pangborn, Barylko-
Pikielna, & Daget, 1976). These data suggest that simple model systems such as water do not translate into complex models such as orange juice.

In 1964, Pangborn et al. also looked at the relationships between sucrose, tartaric acid and caffeine in white table wine using a paired-comparison, forced-choice method presented in a randomized order and sought to determine the effect of sucrose on the discrimination of acidity. Unfortunately, the highest level of sucrose tested was 6.4% (w/v) (Pangborn, Ough, & Chrisp, 1964), which is significantly lower than that allowed by regulation in wine (US Government, 2012). As well, this study was done by a small, trained panel, not by wine consumers, and sought to determine the difference thresholds of tartaric acid and its effects on sweetness rather than sucrose and its effect on sweetness (Pangborn et al., 1964).

Following this, Noble et al. (1984) determined the difference threshold of glycerol, a simple sugar alcohol, in white wine. Using a paired comparison randomized design, they were able to determine the difference threshold of glycerol to be 5.2 g/L within white wine (Noble & Bursick, 1984). Berg et al. (1955) had previously completed a similar study with glycerol in white wine; however, a triangular test was used. The difference threshold of glycerol in white wine in this study was found to be nearly double that found by Noble and Bursick, suggesting that published values for thresholds in the literature can vary substantially based on the methods used (Berg et al., 1955; Noble & Bursick, 1984).

Lastly, in the study done by Noble et al., they determined that the increase in the viscosity for a 5.2 g/L increase of glycerol was 0.037 milliPascal seconds (mPA s), but
the difference threshold for viscosity is 0.14 mPa s suggesting that viscosity has little effect on sweetness perception (Noble & Bursick, 1984).

Conclusions

Sweet wines have been a popular component of human diets for millennia, as consumption and production is believed to predate recorded history. While wine was previously used for trade purposes and hydration, wine drinkers today are often consuming sweet wines for the pleasure they provide. Wine is a perceptually complex product which is variable in the aroma, taste and oral sensations it evokes. While many aspects of wine making have been thoughtfully researched, there is a knowledge gap with respect to back-sweetening wine, as minimal prior research exists. Moreover, prior methods used to evaluate sucrose in wine were often dated and/or lacked power.

For years, winemakers have been back-sweetening their products for a variety of reasons. Previous research suggests increasing acid levels within the wine depresses sweetness; however, little is known about its effects at high levels of back-sweetening within a wine. In addition, while regulations on back-sweeting exist, little is known about the dosage effects, difference thresholds and Weber Ratios of sweeteners in wine.

Unfortunately with the addition of a nutritive sweetener, sweet wines have more calories than their dry siblings. There is a large market demand for “skinny products,” which claim to be low calorie alcohol options and cater to diet conscientious consumers. However, these products are typically dry, neglecting a large segment of sweet wine consumers, so other means to sweeten wine need to be explored. While many non-
nutritive sweeteners are not currently approved in wines for sale with alcohol contents above 7% alcohol by volume, aspartame may be an option as it was approved in the 1980’s for use in wine coolers and it has proven successful in numerous product matrixes (Sherrod, 1988). The addition of a non-nutritive sweetener, such as aspartame could prove to be a successful, popular option in the creation of sweet wines.

Adding a sweetener to a product generally results in an increase in perceived sweetness intensity; however, small increments in sweeteners within complex beverages may be insufficient to increase perceived sweetness significantly (Lundgren et al., 1976). Without thorough research, wineries may be making uninformed decisions about their back-sweetening practices. We therefore sought to fill this research gap.
Aims

1.) To estimate the dose response functions of sucrose on the perceived sweetness within red and white wines with varying acid levels.

2.) To estimate the dose response functions of aspartame on the perceived sweetness within red and white wines without high acidity.

3.) To determine the Just Noticeable Difference (JND) when back-sweetening wines with sucrose or aspartame by determining the difference thresholds and Weber Ratios for these back-sweetened wines.
Chapter 2

Measuring the sweetness dose response functions of sucrose additions to red and white table wines with and without high acidity

Introduction

In the second half of the 20th century, many winemakers preferred to produce dry wine styles that were able to command premium prices from wine enthusiasts in North America and Europe (Tourney, 2011). However, sweet wines have a long history prior to the recent dominance of dry wines. Moreover, focusing exclusively on dry wines neglects a large segment of casual wine drinkers who prefer sweeter wines, as well as ignoring emerging wine markets in Asia and elsewhere (Forsyth, 2013). Traditionally, sweet wines were made using juice with high sugar content so that substantial residual sugar remained when fermentation was stopped. Unfortunately, this practice typically results in a wine with a lower alcohol content, which some consumers may find unappealing. Accordingly, many wineries in the United States and abroad have instead chosen to back-sweeten wines by adding sucrose to a dry base wine, which results in a wine that is both sweet and higher in alcohol.

While many studies describe the relationship between stimulus concentration and sweetness in water (Antenucci, 2014; DuBois et al., 1991) very little exists in the wine literature. Many studies have also explored mixture suppression in water, where the perceived intensity of two tastes within a mixture is perceived less than it would be if they were not together, or unmixed at the same concentration. The relationship of acidity
and sucrose on perceived sweetness intensity in particular has been researched in several studies (Bonnans & Noble, 1993; Lawless & Heymann, 1998; Schifferstein & Frijters, 1991); however, research in wine systems has been somewhat inconclusive. Zamora et al. (2006) concluded that sourness and sweetness appear to be less noticeable when in wine compared to water which suggests one cannot generalize from simple model systems such as water to more complex systems such as wine. Furthermore, the research conducted concluded that results were highly dependent on the overall wine mixture as the effects of numerous attributes such as: fructose, pH, acidity and alcohol content, not just acid and sucrose (Zamora et al., 2006). In addition, while many studies have concluded that acid levels affect perceived sweetness, previous research was somewhat limited. In many of these older studies, participant numbers were low, the amount of sucrose was below maximum allowable additions set by wine regulations and the studies were not specifically designed to address the issue of back-sweetening (Berg et al., 1955; National & Records, 2002; Pangborn, Ough, & Chrisp, 1964).

Among winemakers, it is widely believed that adding sucrose decreases perceived sourness. In a study conducted among Pennsylvania wineries, many survey participants stated that they are back-sweetening to ameliorate sourness in their wine; however, previous research by Noordeloos and Nagel (1972) suggests the amount of sucrose needed to ameliorate sourness of wine, as a result of higher acidity, does not need to exceed 10.6% sucrose. Unfortunately, even with this knowledge, many wineries continue to back-sweeten upwards of 14% (w/v) sucrose or more, increasing the calorie content of the wine and adding to their production costs; both of which could be prevented if more information was available.
As sucrose concentrations are increased, there is an assumption that there will be an increase in perceived sweetness intensity. Historically, sucrose has been shown to elicit a linear function when intensity is plotted against concentration (DuBois et al., 1991). However, data on the effects of sucrose additions on the perceived sweetness of the wine among consumers is lacking and overall, a gap in the literature exists on the dosage effects of sucrose in wines at these high levels of back-sweetening. Here, we sought to determine the dose response functions of sucrose in a neutral red and white base wine with and without high acidity at levels within legal limits among sweet wine consumers using a direct scaling method.

**Materials and Methods**

**Participants**

Participants were prescreened to ensure that they qualified to participate. Screening criteria included: between the ages of 21 and 65 years, not pregnant or breastfeeding, non-smoker (had not smoked in the last 30 days), no known defects of smell or taste, no lip, cheek or tongue piercings, no history of choking or difficulty swallowing, no diagnosed history of being alcohol dependent or otherwise told by a health care provider to limit alcohol intake and no religious or moral objection to tasting alcohol. In addition, all participants indicated that they consumed red or white sweet wine (as appropriate) at least once every six months. Written informed consent was obtained from all participants. Participant ages were confirmed via government issued photographic identification by a Responsible Alcohol Management Program (RAMP).
certified employee of the Sensory Evaluation Center at the Pennsylvania State University. All procedures were approved by the Pennsylvania State University Institutional Review Board (protocol #44131).

In total, data was collected from 255 participants. In Experiment 1, without high acidity white wine, data were collected from 69 participants (5 men); in Experiment 2, without high acidity red wine, data were collected from 63 participants (18 men); in Experiment 3, high acid white wine, data were collected from 65 participants (13 men); and in Experiment 4, high acid red wine, data were collected from 58 participants (11 men).

**Stimuli**

Dry red and white viniferous base wines, Bandit Merlot and Bandit Pinot Grigio, were used for the “without high acidity” wines. Both wines were California bulk wines and sourced from the Pennsylvania Fine Wine and Good Spirits store. The base white wine, Bandit Pinot Grigio, was found to have a total sugar content of 13.07 grams per liter (6.05 g/L glucose, 7.01 g/L fructose) equivalent to 1.307 percent sugar at a dilution factor of ten using Vintessential Laboratories (Australia) Enzymatic Analysis Kit for the Determination of Glucose and Fructose in Grape Juice and Wine Kit and Genesys IOS UV-Vis Spectrophotometer. This wine was labeled to have an alcohol content of 12.8% by volume.

The base red wine, Bandit Merlot, was found to have a total sugar content of 5.94 grams per liter (2.95 g/L glucose, 2.99 g/L fructose) equivalent to 0.594 percent sugar at a dilution factor of 20 using the Vintessential Kit and Genesys IOS UV-Vis
Spectrophotometer. The Bandit Merlot was labeled to have an alcohol content of 13% by volume.

Titratable acidity was also measured to assure “without high acidity” and “high acid” status. Titratable acidity and pH were determined according to methods described in Zoecklein et al. (1990). Bandit Pinot Grigio, the without high acidity base white wine, was found to have 4.875 grams per liter titratable acidity, with an average pH of 3.41. Bandit Merlot, the without high acidity base red wine, was found to have 4.313 grams per liter titratable acidity, with an average pH of 3.75.

A white hybrid wine, Seyval Blanc, and a red vinifera wine, Merlot, were sourced from Mazza Vineyards, located in Erie, Pennsylvania, and used for the base high acid wines. Mazza provided specification sheets on the products and the titratable acidity and pH were confirmed by the researcher. The base high acid white wine, Mazza Seyval Blanc, was found to have a total sugar content of 0.16 grams per liter. The alcohol content of this white wine was found to be 14% by volume. The base high acid red wine, Mazza Merlot, was found to have no residual sugar and an alcohol content of 14% by volume. The titratable acidity of these samples was found to be 6.75 grams per liter for the Mazza Seyval Blanc and 5.25 grams per liter for the Mazza Merlot. These wines were classified as high acid wines, given their titratable acidity was greater than 5.00 grams per liter. In addition, the pH of the Mazza Seyval Blanc was found to be 3.35, while the pH of the Mazza Merlot was found to be 3.39.

Concentrations of sucrose were chosen for each experiment in pilot testing. The sucrose concentrations chosen for the without high acidity white wine experiment using Bandit Pinot Grigio were 0% (control), 4%, 8%, 10%, 12%, and 14% on a weight per
volume basis. The concentrations chosen for the without high acidity red wine experiment using Bandit Merlot were 0% (control), 4%, 8%, 12%, 16%, 18% sucrose (w/v). For the high acid experiments, using Mazza Seyval Blanc and Mazza Merlot, 0% (control), 4%, 8%, 16%, 20%, and 24% concentrations were used.

Participants were given 30 mL of each sample. All samples were capped with an odorless fitted “Pennsylvania Wine Extension” paper cap and labeled with a 3-digit blinding code. Samples were served at room temperature (69 ± 1 °F). Samples were made on the day of the experiment in a similar protocol to that described by Pangborn et al. (1964). It should be noted that sucrose hydrolysis, specifically when sucrose is hydrolyzed into glucose and fructose, may still be occurring at this point; however, low acid products expedite this process (Wilker, 1992).

**Design**

Participants were given 6 samples (5 treatments, 1 control) in a randomized, balanced design. A direct scaling method was used to collect perceived sweetness intensity ratings. Participants were instructed to rate the overall sweetness intensity of the sample on an unstructured line scale, which ranged from 0 (‘very weak’) to 100 (‘very strong’).

Recently, some have argued that Generalized Labeled Magnitude Scale (GLMS) is the ideal scale to use when measuring oral sensations (Bartoshuk et al., 2005). However, generalized scales are needed when making comparisons across people, not products, which was not the goal of the present study. In addition, sweetness intensity
has successfully been assessed using line scales in previous studies (Schiffman, Sattely-Miller, Graham, Booth, & Gibes, 2000).

Before rating the first sample, participants were instructed to rinse with reverse osmosis water, then swish the sample in their mouths for 5 seconds to evaluate the wine and spit it into the cup provided. There was a two-minute time delay between samples and participants were instructed to take additional time if the sensation continued to linger.

**Data Collection and Analysis**

Test sessions lasted approximately 30-40 minutes and each experiment took place on separate days in the Sensory Evaluation Center at the Pennsylvania State University, in isolated sensory testing booths under normal white lighting. All data was collected using computers equipped with Compusense Five, version 5.2 (Guelph, Ontario, Canada).

Mean scores for overall sweetness intensity were measured and an analysis of variance (ANOVA), followed by a Tukey’s Honestly Significant Different test at a 5% significance level. In addition, an independent sample t-test was performed on similar concentrations of back-sweetening between the high acid wines and wines without acidity to determine if there were significant differences in their sweetness intensity.
Results

Figure 2-1 illustrates the sucrose dose response function using white wine without high acidity. Means with like letters are not significantly different. Table 2-1, summarizes the analysis of variance (ANOVA) for this experiment. In this experiment, we observed a significant difference in the mean sweetness intensity between all white wine samples without high acidity and 0% and 4% (w/v) sugar additions. There was no significant difference in mean sweetness intensity between 8% and 10% (w/v) sugar additions, between 10% and 12% sugar additions and between 12% and 14% additions in this white wine (p>0.05).

Figure 2-2 illustrates the sucrose dose response function using red wine without high acidity. Means with like letters are not significantly different. Table 2-2, summarizes the analysis of variance (ANOVA) for this experiment. In this experiment, it was found that there was a significant difference in mean sweetness intensity between all red wine samples without high acidity and 0%, 4%, and 8% (w/v) sugar additions. There was no significant difference however, in mean sweetness intensity between 12%, 16% and 18% (w/v) sugar additions in red wine (p>0.05).

Using the high acid white wine, it was found that there was no significant difference in mean sweetness intensity between 20% and 24% (w/v) sucrose back-sweetened wines. In addition, there was no significant difference between 20% and 16% (w/v) back-sweetened wine samples. The sucrose dose response function determined using the high acid white wine is illustrated in Figure 2-3. Means with like letters are not
significantly different. Table 2-3, summarizes the analysis of variance (ANOVA) for this experiment.

Figure 2-4 illustrates the sucrose dose response function using red wine with high acidity. Means with like letters are not significantly different. Table 2-4 summarizes the analysis of variance (ANOVA) for this experiment. Again, there was no significant difference between 20% and 24% (w/v) sucrose wine samples. Nor were there any significant differences found in mean sweetness intensity between 20% and 16% (w/v) sucrose back-sweetened wine samples.

A two-tailed independent sample t-test was run on the results collected from the equal sucrose additions between the high acid wines and wines without high acidity. There was no significant difference found between the back-sweetened low acidity and high acidity white wine (p>0.05) at 0%, 4% and 8% (w/v) sucrose levels, with p-values of 0.084, 0.062, and 0.94, respectively. Interestingly, there were significant differences (p<0.05) at 4% and 8% levels between the without high acidity red wine and the high acid red wine; however, there was no significant difference (p>0.05) at 0% and 16%. At 4% we had a p-value of 0.0094 and 0.0079 at 8%, while at 0% and 16% the p-value was 0.21 and 0.11 respectively.
**Figure 2-1:** Dose-response of sucrose on sweetness intensity in without high acidity white wine using sucrose
*Means followed by the same letter are not significantly different at p>0.05. Tukey’s honestly significant difference test was used to assess differences.

**Table 2-1: Analysis of Variance for without high acidity white wine**

<table>
<thead>
<tr>
<th>Analysis of Variance</th>
<th>Degrees of Freedom</th>
<th>Sum of Squares</th>
<th>Mean of Squares</th>
<th>F Value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Samples</td>
<td>5</td>
<td>84742.99</td>
<td>16948.599</td>
<td>56.50</td>
<td>0.00</td>
</tr>
<tr>
<td>Judges</td>
<td>68</td>
<td>125384.33</td>
<td>1843.89</td>
<td>6.15</td>
<td>0.00</td>
</tr>
<tr>
<td>Error</td>
<td>340</td>
<td>101995.384</td>
<td>299.99</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>413</td>
<td>312122.70</td>
<td>755.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Standard Error</strong></td>
<td><strong>2.09</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>(SEM)</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 2-2: Dose-response of sucrose on sweetness intensity in without high acidity red wine using sucrose

*Means followed by the same letter are not significantly different at p>0.05. Tukey’s honestly significant difference test was used to assess differences.

Table 2-2: Analysis of Variance for without high acidity red wine

<table>
<thead>
<tr>
<th>Analysis of Variance</th>
<th>Degrees of Freedom</th>
<th>Sum of Squares</th>
<th>Mean of Squares</th>
<th>F Value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Samples</td>
<td>5</td>
<td>127779.46</td>
<td>25555.89</td>
<td>80.13</td>
<td>0.00</td>
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<tr>
<td>Judges</td>
<td>62</td>
<td>117018.28</td>
<td>1887.39</td>
<td>5.92</td>
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<tr>
<td>Error</td>
<td>310</td>
<td>98864.83</td>
<td>318.92</td>
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<td></td>
</tr>
<tr>
<td>Total</td>
<td>377</td>
<td>343662.57</td>
<td>911.57</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Standard Error
(SEM) 2.25
Figure 2-3: Dose-response of sucrose on sweetness intensity in high acid white wine using sucrose
*Means followed by the same letter are not significantly different at p>0.05. Tukey's honestly significant difference test was used to assess differences.

Table 2-3: Analysis of Variance for high acid white wine

<table>
<thead>
<tr>
<th>Analysis of Variance</th>
<th>Degrees of Freedom</th>
<th>Sum of Squares</th>
<th>Mean of Squares</th>
<th>F Value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Samples</td>
<td>5</td>
<td>166063.12</td>
<td>33212.624</td>
<td>117.91</td>
<td>0.00</td>
</tr>
<tr>
<td>Judges</td>
<td>64</td>
<td>67828.93</td>
<td>1059.83</td>
<td>3.76</td>
<td>0.00</td>
</tr>
<tr>
<td>Error</td>
<td>320</td>
<td>90136.30</td>
<td>281.68</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>389</td>
<td>324028.34</td>
<td>832.98</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard Error</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(SEM)</td>
<td>2.08</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Figure 2-4:** Dose-response of sucrose on sweetness intensity in high acid red wine using sucrose. *Means followed by the same letter are not significantly different at p<0.05. Tukey’s honestly significant difference test was used to assess differences.*

**Table 2-4: Analysis of Variance for high acid red wine**

<table>
<thead>
<tr>
<th>Analysis of Variance</th>
<th>Degrees of Freedom</th>
<th>Sum of Squares</th>
<th>Mean of Squares</th>
<th>F Value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Samples</td>
<td>5</td>
<td>142069.50</td>
<td>28413.90</td>
<td>113.40</td>
<td>0.00</td>
</tr>
<tr>
<td>Judges</td>
<td>57</td>
<td>60130.00</td>
<td>1054.91</td>
<td>4.21</td>
<td>0.00</td>
</tr>
<tr>
<td>Error</td>
<td>285</td>
<td>71410.50</td>
<td>250.56</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>347</td>
<td>273610.00</td>
<td>788.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard Error</td>
<td>2.08</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(SEM)
Discussion

The present study successfully identified the concentrations at which adding additional sucrose did not further increase perceived sweetness intensity among wine consumers within several of the wines tested. As well, using a direct scaling method, we were able to quantify the mean sweetness intensity at these high levels of back-sweetening within the four wines tested.

In without high acidity white wine, at 10% (w/v) sucrose addition we no longer see the mean sweetness intensity increasing as significantly as it did between 0%, 4% and 8%. We see similar findings in without high acidity red wine. After 12% sucrose additions, there’s no significant differences found in mean sweetness intensity even as dosages continue to increase in both the wines without high acidity. In high acid white wine, we begin to see mean sweetness intensity flat line around 16% (w/v) sucrose additions, as it no longer increases significantly even as dosages increase. As illustrated, similar findings were also found in the high acid red wine tested.

When comparing without high acidity white and red wine to high acid white and red wine, no significant differences were found between similar sucrose dosages and the two whites tested. However, significant differences were noted between the without high acidity red wine and high acid wine tested. Numerous factors may have caused this significant difference, seeing as wine is a complex matrix composed of numerous carbohydrates, alcohols, organic acids and phenolics at varying levels and which are characteristically different between varietals and productions. Previous studies have found that tannin levels had an effect on sucrose thresholds (Berg et al., 1955) suggesting
that the presence and levels of tannins or other attributes of the wine may affect the perceived sweetness intensity rather than acid as suggested by other studies (Pangborn et al., 1964).

Practically, this information can help winemakers identify the point at which to stop back-sweetening. Within regulatory limits, it appears there may be substantial leeway to reduce the amount of sucrose added to wines before consumers can perceive a difference – this supposition is tested in later chapters. From data collected within these studies, it is suggested that at a certain point it is not beneficial to add sucrose to the wine as there is no longer a significant increase in perceived sweetness. Finally, findings suggest that there is little difference between high acid wines and wines without high acidity, suggesting that high acid wines do not require more sucrose to ameliorate the sourness of the wine, as previously suggested.
Chapter 3
Determining the difference thresholds and Weber Ratios of sucrose in red and white table wine

Introduction

Many small, independent wineries have limited access to resources, which can leave many of the important wine processing decisions about back-sweetening up to the winemaker or winery owner who may be unfamiliar with the nuances of taste psychophysics. With minimal information on back-sweetening available, many wineries may be making decisions based on assumptions and folklore rather than on theory and prior data.

Direct and indirect scaling methods are both capable of obtaining reasonable information about perceived differences, such as sweetness between stimuli. However, Lawless et al. (1984) found noticeable differences between methods when comparing the same products among identical groups. Suggestively, differences may exist because of attention being brought to a specific attribute in a direct task; which can be difficult to some (Lawless & Schlegel, 1984).

Historically, it has been found that simple model systems often do not translate into complex models such as wine. This has been demonstrated in a study conducted by Lundgren et al. (1976). In this study, it was determined, that the just noticeable difference was dramatically different in orange juice compared to water.
In 1964, Pangborn et al. explored relationships between sucrose, tartaric acid and caffeine in white table wine using a paired-comparison, forced-choice method presented in a randomized order and sought to determine the difference thresholds of tartaric acid and its effects on sweetness at steady sucrose levels (Pangborn et al., 1964). Later Noble and Bursick (1984) determined the difference threshold of glycerol, a simple sugar alcohol, in white wine. Using a paired comparison, randomized design, they were able to determine the difference threshold of glycerol to be 5.2 g/L for a white wine. Within this study, researchers also determined that the increase in the viscosity for a 5.2 g/L increase of glycerol was 0.037 milliPascal seconds (mPa s), but the difference threshold for viscosity is 0.14 mPa s suggesting that viscosity has little effect on sweetness perception (Noble & Bursick, 1984).

Determining difference thresholds and Weber Ratios allows researchers to determine the amount of a stimulus that would need to be altered for a consumer to perceive a difference. Having this information available for sucrose in wine may prove useful for winemakers who may be making uninformed decisions to determine the dosage changes they would need to make to reach their goal.

While previous work by Berg et. al (1955) found that acidity does not alter sucrose difference thresholds; within the conducted research, dosages were below those allowed by regulations; only 12-16 participants were used, which likely limits the power of the study; and, a possibly fatiguing triangular design was employed which may limit the reliability of the outcomes. Here, we sought to determine the difference thresholds and Weber Ratios for back-sweetening a high and low acid red and white table wine.
Materials and Methods

Participants

Participants were prescreened to ensure that they qualified to participate. Screening criteria included: between the ages of 21 and 65 years, not pregnant or breastfeeding, non-smoker (had not smoked in the last 30 days), no known defects of smell or taste, no lip, cheek or tongue piercings, no history of choking or difficulty swallowing, no diagnosed history of being alcohol dependent or otherwise told by a health care provider to limit alcohol intake and no religious or moral objection to tasting alcohol. In addition, all participants indicated that they consumed red or white sweet wine (as appropriate) at least once every six months. Written informed consent was obtained from all participants. Participant ages were confirmed via government issued photographic identification by a Responsible Alcohol Management Program (RAMP) certified employee of the Sensory Evaluation Center at the Pennsylvania State University. All procedures were approved by the Pennsylvania State University Institutional Review Board (protocol #44131).

A total of 252 individuals were tested. In Experiment 1, without high acidity white wine, data was collected from 62 participants (11 men); in Experiment 2, without high acidity red wine, data was collected from 64 participants (12 men); in Experiment 3, high acid white wine, data was collected from 63 participants (10 men); and in Experiment 4, high acid red wine, data was collected from 63 participants (9 men).
Design

A method of constant stimuli using a series of 2-Alternative Force Choice (2-AFC) tests was used. In these 2-AFC studies, participants were given a control and a treatment and asked to indicate which sample was sweeter within the pair. Participants received a total of six pairs in each test. Pairs were presented with treatments in an increasing concentration series, but within a pair, the position of the control and the treatment (first or second) was counterbalanced.

Before beginning, participants were instructed to rinse with reverse osmosis water. They were then instructed to take a sip of the sample, swish it around their mouths for 5-seconds, spit into the cup provided and rinse between samples. This evaluation step was repeated for the other sample in the pair, then participants were instructed to select the sample which they perceived to be sweeter. After which, there was a two minute time delay between pair during which participants were instructed to rinse with water and to take additional time if any sensation continued to linger.

Stimuli

Bulk dry red and white viniferous California base wines, Bandit Merlot and Bandit Pinot Grigio, were again used for the “without high acidity” wines. Again, Bandit Pinot Grigio had 6.05 g/L glucose, 7.01 g/L fructose, a titratable acidity of 4.875 g/L, a pH of 3.41 and an alcohol content of 12% by volume. The dry base red wine, Bandit Merlot, was again also used. This wine had 2.95g/L glucose, 2.99 g/L fructose, a titratable acidity of 4.313 g/L, a pH of 3.75 and an alcohol content of 13% by volume.
Mazza Seyval Blanc and Mazza Merlot from Erie, Pennsylvania were again used as the high acid wines. Mazza Seyval Blanc had a total sugar content of 0.16 g/L, a titratable acidity of 6.75 g/L, a pH of 3.35 and an alcohol content of 14% by volume. Mazza Merlot had a total sugar content of 0.00 g/L, a titratable acidity of 5.75 g/L, a pH of 3.39 and an alcohol content of 14% by volume.

Dosages for the method of constant stimuli were based on direct scaling results described in the prior chapter. For the without high acidity white wine experiment, 13% (w/v) sucrose was chosen as the constant stimulus (control) and the treatments were 9%, 10.5%, 12%, 15.5% and 17% sucrose in wine. For the without high acidity red wine experiment, 11% (w/v) sucrose was chosen as the constant stimulus (control) and the treatments were 7%, 9%, 10%, 12%, 13% and 15% sucrose in wine. For the high acid white wine and red wine experiments, 16% (w/v) sucrose was chosen as the control and the treatments were 12%, 14%, 15%, 18%, 19% and 20% sucrose in wine.

Participants were given 30 mL of each sample. All samples were capped with an odorless fitted “Pennsylvania Wine Extension” paper cap and labeled with a 3-digit blinding code and samples were served at room temperature (69 ± 1 °F). Samples were made on the day of the experiment in a similar protocol to that described by Pangborn et al. (1964).

Data Collection and Analysis

Test sessions lasted approximately 30-40 minutes and each experiment took place on separate days in the Sensory Evaluation Center at the Pennsylvania State University, in isolated sensory testing booths under normal white lighting. All data was collected
using computers equipped with Compusense Five, version 5.2 (Guelph, Ontario, Canada).

The proportion indicating treatment was sweeter than control were transformed to z-scores using a conversation table (see Appendix-A) and plotted. Typically, the probability of a response as a function of the stimulus results in an s-shaped psychometric function. However by converting results into z-scores this relationship can be fit as a linear function (Lawless, 2013), simplifying calculations. After fitting a line to the z-score transformed proportions, the point of subjective equality, lower difference threshold, upper difference threshold and Weber Ratios were calculated using the regression equation. Plots and fits were obtained using DataGraph for OSX (Visual Data Tools, Inc, Chapel Hill, NC)

**Results**

Percent of “more sweet responses” at the different levels were converted to z-scores and are illustrated in Tables 3-1, 3-2, 3-3 and 3-4. The point of subjective equality (PSE) was determined by plotting the point at which 50% of participants (a z-score of 0) would choose the treatment as equally sweet. The lower difference limen (LDL) was determined by subtracting the PSE from the point at which 25% of participants would choose the treatment as equally sweet (a z-score of -0.67). The upper difference limen (UDL) was determined by subtracting the point at which 75% of participants would choose the treatment as equally sweet (a z-score of +0.67). These values were then averaged to determine the overall difference limen, or difference threshold.
The Weber Ratio, or Weber fraction, $k$, can mathematically be determined by the following equation:

$$\frac{\Delta I}{I} = k,$$

where $\Delta I$ is the change in intensity required to result in a Just Noticeable Difference, and $I$ is the stimulus intensity of the control. Difference thresholds and the Weber Ratios for the four wines tested are summarized in Table 3-1.

Figure 3-1: Z-score transformed proportion of ‘more sweet’ responses versus control, 13%
Figure 3-2: Z-score transformed proportion of ‘more sweet’ responses versus control, 11%

Figure 3-3: Z-score transformed proportion of ‘more sweet’ responses versus control, 16%
Figure 3-4: Z-score transformed proportion of ‘more sweet’ responses versus control, 16%

Table 3-1: Summary of difference thresholds and Weber Ratios for sucrose in red and white wines with and without high acidity

<table>
<thead>
<tr>
<th>Wine</th>
<th>Difference Threshold</th>
<th>Concentration of Reference</th>
<th>Weber Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without high acidity white</td>
<td>3.65%</td>
<td>13%</td>
<td>0.28</td>
</tr>
<tr>
<td>High acid white</td>
<td>5.2%</td>
<td>16%</td>
<td>0.33</td>
</tr>
<tr>
<td>Without high acidity red</td>
<td>3.2%</td>
<td>9%</td>
<td>0.35</td>
</tr>
<tr>
<td>High acid red</td>
<td>3.65%</td>
<td>16%</td>
<td>0.23</td>
</tr>
</tbody>
</table>
Discussion

These four experiments identified the sucrose difference thresholds and Weber values for the four wines tested. Based on this, it was determined that winemakers have substantial latitude in reducing the amount the back-sweeten before consumers will perceive a difference. As summarized in the right column of Table 3-1, sucrose dosing would need to be increased or decreased by ~25% relative to the previous concentration for consumers to perceive a difference, which translates to a change of 32 to 52 grams per liter of wine (3.2 to 5.2 % w/v sucrose). Notably, acidity seems to have little effect on calculated difference thresholds and Weber Ratios, although this should be confirmed subsequently given the rather large differences seen in Weber Ratios between the without high acidity red wine (0.35) and the high acid red wine (0.23). Factors beyond acid level, such as tannins or other wine attributes within the wine may be relevant (Berg et al., 1955). Additional work looking at various other components of wine is warranted.
Chapter 4

Measuring the dosage effects of aspartame additions to red and white table wines

Introduction

Obesity is a recognized epidemic in the United State (CDC, 2013) and with the substantial interest in low calorie foods, wine consumers are seeking lower calorie wine options so they can still enjoy the beverage without unnecessary calories or guilt. Currently, there is a large market for “skinny” wines, or lower calorie wines; however, these items are typically dry and may not be a preferred option for sweet wine drinkers. Non-nutritive sweeteners have been used as alternatives to nutritive sweeteners such as sucrose, to elicit a sweet flavor in various food products without the added calories found in mono- and disaccharides. Proving to be a suitable alternative used in various food matrices, consumption of low-calorie sweeteners has increased nearly 6% annually (Sylvetsky, Welsh, Brown, & Vos, 2012).

Aspartame is a dipeptide of two amino acids: L-phenylanine, the methyl ester and L-aspartic acid and has been an approved food ingredient for nearly 40 years in various food matrices (Stegink, 1984) including beverages, dairy product toppings, chewing gum and other food products as a calorie-conscious alternative to sucrose (Hutchinson et al., 1999). Among consumers, aspartame is highly accepted because of its flavor profile and minimal side tastes while still eliciting a sweet taste similar to sucrose (Shankar et al., 2013) and it remains one of the most popular non-nutritive sweeteners available in the market (Hutchinson et al., 1999).
Aspartame, under the name NutraSweet®, has already been approved for use as a sweetener in wine coolers; however, there is no known published research on the dosage effects of aspartame on perceived sweetness intensity in a complex system such as wine. Currently, the market for wine coolers is rather low, suggesting that some consumers may find them unappealing on a “buzz per calorie” basis, as they contain less than 7% alcohol and numerous calories (USDA, 2014). I therefore sought to determine the dose response of aspartame on sweetness intensity in a neutral red and white table wine with alcohol contents above 7% using a direct scaling method among sweet wine consumers.

Materials and Methods

Participants

Participants were prescreened to ensure that they qualified to participate. Screening criteria included: between the ages of 21 and 65 years, not pregnant or breastfeeding, non-smoker (had not smoked in the last 30 days), no known defects of smell or taste, no lip, cheek or tongue piercings, no history of choking or difficulty swallowing, no diagnosed history of being alcohol dependent or otherwise told by a health care provider to limit alcohol intake and no religious or moral objection to tasting alcohol. In addition, all participants indicated that they consumed red or white sweet wine (as appropriate) at least once every six months and were not sensitive to phenylalanine. Written informed consent was obtained from all participants. Participant ages were confirmed via government issued photographic identification by a Responsible
Alcohol Management Program (RAMP) certified employee of the Sensory Evaluation Center at the Pennsylvania State University. All procedures were approved by the Pennsylvania State University Institutional Review Board (protocol #44131).

Data was collected from 122 Participants total. In Experiment 1, using without high acidity white wine, data was collected from 69 participants (9 men). In Experiment 2, using without high acidity red wine, data was collected from 53 participants (11 men).

Stimuli

Dry red and white bulk viniferous base wines from California, Bandit Merlot and Bandit Pinot Grigio, were again used for the “without high acidity” wines. Again, Bandit Pinot Grigio had 6.05 g/L glucose, 7.01 g/L fructose, a titratable acidity of 4.875 g/L, a pH of 3.41 and an alcohol content of 12% by volume. The dry base red wine, Bandit Merlot, had 2.95 g/L glucose, 2.99 g/L fructose, a titratable acidity of 4.313 g/L, a pH of 3.75 and an alcohol content of 13% by volume.

Concentrations of back-sweetened wine were chosen for each experiment from literature values (Antenucci, 2014) and confirmed in pilot testing. The concentrations of aspartame chosen for both the without high acidity wine experiments using Bandit Pinot Grigio and Bandit Merlot were 0 g/L (control), 0.2 g/L, 0.42 g/L, 0.9 g/L, 1.2 g/L and 2.0 g/L aspartame; in water, these concentrations are equisweet with 0%, 4%, 8%, 12%, 14% and 16% (w/v) sucrose based on equations presented in Antenucci, 2014.

Participants were given 30 mL of each sample. All samples were capped with a fitted paper “Pennsylvania Wine Extension” paper cap and labeled with a 3-digit blinding
code. Samples were served at room temperature (69 ± 1 °F). Samples were made on the day of the experiment in a similar protocol to that described above in Chapter 2.

**Design**

Participants were given 6 samples (5 treatments, 1 control) in a randomized, balanced design. A direct scaling method was used to collect perceived sweetness intensity ratings. Participants were instructed to rate the overall sweetness intensity of the sample on an unstructured line scale, which ranged from 0 (‘very weak’) to 100 (‘very strong’).

Before rating the first sample, participants were instructed to rinse with reverse osmosis water, then swish the sample in their mouths for 5 seconds to evaluate the wine and spit it into the cup provided. There was a two-minute time delay between samples and participants were instructed to take additional time if the sensation continued to linger.

**Data Collection and Analysis**

Sessions lasted approximately 30-40 minutes and each experiment took place on separate days. All evaluations took place in the Sensory Evaluation Center at the Pennsylvania State University, in individualized booths under normal white lighting. All data was collected using computers equipped with Compusense Five, version 5.2 (Guelph, Ontario, Canada).
Mean scores for overall sweetness intensity were measured and an analysis of variance (ANOVA), followed by a Tukey’s Honestly Significant Difference test was conducted at a 5% significance level.

Results

Figure 4-1 illustrates the aspartame dose response function using white wine without high acidity. Means with like letters are not significantly different. Table 4-1, summarizes the analysis of variance (ANOVA) for this experiment. There were no significant differences in mean sweetness intensity between 0.2 g/L and 0.42 g/L aspartame (p>0.05) within this wine. In addition, there was no significant difference in mean sweetness intensity between 0.9 g/L and 1.2 g/L aspartame within the wine (p>0.05).

Figure 4-2 illustrates the aspartame dose response function in red wine without high acidity. Means with like letters are not significantly different. Table 4-2, summarizes the analysis of variance (ANOVA) for this experiment. There was no significant difference in mean sweetness intensity between 2 g/L and 1.2 g/L aspartame (p>0.05). In addition, there was no significant difference in mean sweetness intensity between 1.2 g/L and 0.9 g/L aspartame (p>0.05).
Figure 4-1: Dose-response of aspartame on sweetness intensity in without high acidity white wine

*Means followed by the same letter are not significantly different at p>0.05. Tukey’s honestly significant difference test was used to assess differences.

Table 4-1: Analysis of Variance for without high acidity white wine using aspartame

<table>
<thead>
<tr>
<th>Analysis of Variance</th>
<th>Degrees of Freedom</th>
<th>Sum of Squares</th>
<th>Mean of Squares</th>
<th>F Value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Samples</td>
<td>5</td>
<td>132114.33</td>
<td>26422.87</td>
<td>85.24</td>
<td>0.00</td>
</tr>
<tr>
<td>Judges</td>
<td>68</td>
<td>71510.31</td>
<td>1051.62</td>
<td>3.39</td>
<td>0.00</td>
</tr>
<tr>
<td>Error</td>
<td>340</td>
<td>105398.71</td>
<td>310.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>413</td>
<td>309023.35</td>
<td>748.24</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard Error (SEM)</td>
<td>2.19</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 4-2: Dose-response of aspartame on sweetness intensity in without high acidity red wine
*Means followed by the same letter are not significantly different at p>0.05. Tukey's honestly significant difference test was used to assess differences.

Table 4-2: Analysis of Variance for without high acidity red wine using aspartame

<table>
<thead>
<tr>
<th>Analysis of Variance</th>
<th>Degrees of Freedom</th>
<th>Sum of Squares</th>
<th>Mean of Squares</th>
<th>F Value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Samples</td>
<td>5</td>
<td>104238.224</td>
<td>20847.65</td>
<td>61.46</td>
<td>0.00</td>
</tr>
<tr>
<td>Judges</td>
<td>52</td>
<td>62941.34</td>
<td>1210.41</td>
<td>3.47</td>
<td>0.00</td>
</tr>
<tr>
<td>Error</td>
<td>260</td>
<td>88190.73</td>
<td>339.20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>317</td>
<td>255370.30</td>
<td>805.59</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard Error (SEM)</td>
<td>2.53</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Discussion

Within this study, we have successfully found the points at which the wines tested are not perceived significantly sweeter by participants within the concentrations tested. As well, using a direct scaling method, we were able to quantify the mean sweetness intensity at these high levels of aspartame back-sweetening using the two wines tested. While the mean sweetness intensity score continues to increase within the white wine tested as shown by the significant difference in sweetness intensity between 0.9 g/L and 2.0 g/L additions, there were no significant differences seen between 0.9 g/L and 1.2 g/L aspartame using the without high acidity white wine. Within the red wine samples tested, we see that at 0.9 g/L aspartame additions, things begin to steadily flat line, as there is no significant difference in mean sweetness intensity between 0.9 g/L and 1.2 g/L, in addition to 1.2 g/L and 2.0 g/L aspartame additions in the wine. In without high acidity red wine, at 1.2 g/L aspartame addition we no longer see the mean sweetness intensity increasing as significantly as it did between 0, 0.2, and 0.42 g/L.

Based on our sucrose equivalence calculations, we also note that similar findings were found in this experiment, compared to those found using sucrose and described in Chapter 2. At 0.2 g/L aspartame in without high acidity red wine we found the mean sweetness intensity to be 36.90 using a 100 point scale. As previously noted, we based this off of lab data for 4% (w/v) sucrose, which when using sucrose in the without high acidity red wine was found to have a mean rating of 32.17. Similar results between sucrose and aspartame were also seen at the other various concentrations tested, suggesting that our chosen doses for aspartame were similar in sweetness to the doses chosen for sucrose within these two wines tested. This data also suggests that viscosity
has little effect on the perceived sweetness of the sample as aspartame does not affect perceived viscosity, unlike sucrose.

Practically, this information can help winemakers using aspartame identify the point at which to stop back-sweetening. It appears that larger doses of aspartame may need to be added to wines before consumers can perceive a difference, which is tested in later chapters. From the data collected within these studies, it may be also suggested that at a certain point it is not beneficial to add aspartame into the wine as there is no longer a significant increase in perceived sweetness.
Chapter 5

Determining the difference thresholds and Weber Ratios of aspartame in red and white table wine

Introduction

Currently, it is estimated that about 25% of Americans drink alcoholic beverages daily (CDC, 2013). Researchers also estimate that nearly 32% of people in the United States consume wine and 57% drink wine at least once a week or more (Thack, 2013). Further research estimates that 6% of females and 19% of males consume more than 300 calories daily from alcoholic beverages (Hellmich, 2012). While aspartame is not yet officially approved in wines for sale with alcohol contents above 7%; consumer demand and a needed change in the American diet, are driving companies to research calorie conscious options to the nutritive sweeteners used in other food products. While sucrose is typically used as the sweetening agent when back-sweetening, aspartame is a practical contender as a replacement for calorie dense sweeteners such as sucrose. Use of non-nutritive sweeteners has the potential to control caloric, carbohydrate and sugar intake which could potentially assist in weight loss. As well, replacement of sucrose with these non-nutritive sweeteners may result in reduced dental caries, management of diabetes and provide a cost effective alternative to nutritive sweeteners if other resources are limited (Cardello, Da Silva, & Damasio, 1999).

Aspartame is highly accepted among consumers and has successfully been used in wine coolers for over 20 years and suggestively a practical sweetener to use when back-
sweetening higher alcohol wines. On a weight per volume basis, aspartame is found to be more potent than sucrose (Cardello et al., 1999), suggesting that difference thresholds and Weber Ratios will vary from those found in complex systems such as wine when sucrose is used.

Although aspartame use is not regulated when making wine, it has potential to be used routinely as a back-sweetening agent by commercial winemakers. By determining difference thresholds and Weber Ratios for aspartame in wine at the present time this information can be readily available to a winery if they choose to use aspartame to sweeten their wines, with the added benefit of creating a lower calorie product. Determining difference thresholds and Weber Ratios allows researchers to determine the amount of a stimulus that would need to be altered for consumers to perceive a difference. Therefore determining the difference thresholds and Weber Ratios for back-sweetening red and white table wines, without high acidity was desired.

**Materials and Methods**

**Participants**

Participants were prescreened to ensure that they qualified to participate. Screening criteria included: between the ages of 21 and 65 years, not pregnant or breastfeeding, non-smoker (had not smoked in the last 30 days), no known defects of smell or taste, no lip, cheek or tongue piercings, no history of choking or difficulty swallowing, no diagnosed history of being alcohol dependent or otherwise told by a health care provider to limit alcohol intake and no religious or moral objection to tasting
alcohol. In addition, all participants indicated that they consumed red or white sweet wine (as appropriate) at least once every six months and were not sensitive to phenylalanine. Written informed consent was obtained from all participants. Participant ages were confirmed via government issued photographic identification by a Responsible Alcohol Management Program (RAMP) certified employee of the Sensory Evaluation Center at the Pennsylvania State University. All procedures were approved by the Pennsylvania State University Institutional Review Board (protocol #44131).

A total of 133 participants were tested. In Experiment 1, without high acidity white wine, data was collected from 69 participants (11 men) and in Experiment 2, without high acidity red wine, data was collected from 64 participants (13 men).

**Design**

A method of constant stimuli using a series of 2-Alternative Force Choice (2-AFC) tests was used. In these 2-AFC studies, participants were given a control and a treatment and asked to indicate which one was sweeter within the pair. Participants received a total of six pairs in each test. Pairs were presented with treatments in an increasing concentration series, but within a pair, the position of the control and the treatment (first or second) was counterbalanced.

Before beginning, participants were instructed to rinse with reverse osmosis water. They were then instructed to take a sip of the sample, swish it around their mouths for 5-seconds, spit into the cup provided and rinse between samples. This evaluation step was repeated for the other sample in the pair, then participants were instructed to select the sample which they perceived to be sweeter. After which, there was a two minute time
delay between the pairs during which participants were instructed to rinse with water and to take additional time if the sample continued to linger.

**Stimuli**

Dry red and white California bulk viniferous base wines, Bandit Merlot and Bandit Pinot Grigio, were again used for the “without high acidity,” wines. Again, Bandit Pinot Grigio had 6.05 g/L glucose, 7.01 g/L fructose, a titratable acidity of 4.875 g/L, a pH of 3.41 and an alcohol content of 12% by volume. The dry base red wine, Bandit Merlot, was again also used. This wine had 2.95 g/L glucose, 2.99 g/L fructose, a titratable acidity of 4.313 g/L, a pH of 3.75 and an alcohol content of 13% by volume.

Mazza Seyval Blanc and Mazza Merlot were again used as the high acid wines. Mazza Seyval Blanc had a total sugar content of 0.16 g/L, a titratable acidity of 6.75 g/L, a pH of 3.35 and an alcohol content of 14% by volume. Mazza Merlot had no residual sugar, a titratable acidity of 5.75 g/L, a pH of 3.39 and an alcohol content of 14% by volume.

Dosages for the method of constant stimuli were based on direct scaling results described in the prior chapter. For the without high acidity white and red wine experiments, 0.75 g/L aspartame was chosen as the constant stimulus (control) and the treatments were 0.15 g/L, 0.31 g/L, 0.51 g/L, 0.9 g/L, 1.6 g/L and 3 g/L aspartame in each of the wines tested; in water, these concentrations are equisweet with 11% (control), 3%, 6%, 9%, 12%, 15% and 18% (w/v) sucrose.

Participants were given 30 mL of each sample. All samples were capped with an odorless fitted “Pennsylvania Wine Extension” paper cap and labeled with a 3-digit
blinding code. Samples were served at room temperature (69 ± 1 °F). Samples were made on the day of the experiment in a similar protocol to that described by Pangborn et al. (1964).

**Data Collection and Analysis**

Sessions lasted approximately 30-40 minutes and each experiment took place on separate days. All evaluations took place in the Sensory Evaluation Center at the Pennsylvania State University, in isolated sensory testing booths under normal white lighting. All data was collected using computers equipped with Compusense Five, version 5.2 (Guelph, Ontario, Canada).

The proportion indicating treatment was sweeter than control were transformed to z-scores using a conversation table (see Appendix A) and plotted. Typically, the probability of a response as a function of the stimulus results in an s-shaped psychometric function. However by converting results into z-scores the relationship is illustrated through a linear function (Lawless, 2013), simplifying calculations. After fitting a line to the z-score transformed proportions, the point of subjective equality, lower difference threshold, upper difference threshold and Weber Ratios were calculated using the regression equation. Plots and fits were obtained using DataGraph for OSX (Visual Data Tools, Inc., Chapel Hill, NC).
Results

Percent of “more sweet responses” at the different levels of aspartame additions were converted to z-scores and are illustrated in Tables 5-1 and 5-2. The point of subjective equality (PSE) was determined by plotting the point at which 50% of participants (a z-score of 0) would choose the treatment as equally sweet. The lower difference limen (LDL) was determined by subtracting the PSE from the point at which 25% of participants would choose the treatment as equally sweet (a z-score of -0.67). The upper difference limen (UDL) was determined by subtracting the point at which 75% of participants would choose the treatment as equally sweet (a z-score of +0.67). These values were then averaged to determine the overall difference limen, or difference threshold.

The Weber Ratio, or Weber fraction, k can mathematically be determined by the following equation:

\[
\frac{\Delta I}{I} = k,
\]

where \( \Delta I \) is the change in intensity required to result in a Just Noticeable Difference, and I is the stimulus intensity of the control. Difference thresholds and the Weber Ratios for the four wines tested are summarized in Table 5-1.
Table 5-1: Summary of difference limens and Weber Ratios for aspartame in red and white wines without high acidity

<table>
<thead>
<tr>
<th>Wine</th>
<th>Difference Threshold</th>
<th>Concentration of Reference</th>
<th>Weber Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without high acidity white</td>
<td>0.6 g/L</td>
<td>0.75 g/L</td>
<td>0.80</td>
</tr>
<tr>
<td>Without high acidity red</td>
<td>0.52 g/L</td>
<td>1.05 g/L</td>
<td>0.50</td>
</tr>
</tbody>
</table>

Figure 5-1: Z-score transformed proportion of ‘more sweet’ responses versus control, 0.75 g/L
Discussion

Results presented are suggestive for the difference thresholds and Weber Ratios for aspartame in the two wines tested. As was assumed, as a result of aspartame’s potency, the Weber Ratios determined on a weight per volume basis were dramatically higher than those found in sucrose. Present research can be used for future winemaking practices when a sweet, lower-calorie high-alcohol wine is demanded. As well, we note differences between the white wine and red wine tested, suggesting that different components between varietals, such as tannins and other wine constructs, may be affecting results. Results summarized in Table 5-1 suggest that aspartame levels would need to be altered by over ~50% for consumers to perceive a difference. As well, on a
gram per liter basis, only small amounts are needed to illicit significant changes in perceived sweetness in the tested wine models. Unfortunately, even when converted to z-scores, findings are not linearized, suggesting that the data should be interpreted cautiously. Only small additions of aspartame were added into the wine and if even a minor amount was left on the prepping equipment, there may be issues with dose estimates. Within future studies it is warranted to use a stock solution to reduce this risk. As well, looking at other components within the wine affecting perceived sweetness of the wine are warranted.
Chapter 6
Conclusions and Future Work

The present findings provide insight into psychophysical responses to sweet stimuli in a complex system, in addition to providing practical information on the perceived sweetness intensity and *Just Noticeable Differences* for sucrose and aspartame in red and white wines that can be applied to an industry setting, as well as future wine research.

I conclude that wineries have substantial leeway in reducing the amount they of sucrose back-sweeten before consumers will notice; which may prove to be beneficial to both consumers and the winery. In addition, based off the dose response functions obtained using both aspartame and sucrose, wineries and researchers can roughly estimate the aspartame quantities needed to replace sucrose and result in equally sweet wines. When using either sucrose or aspartame, winemakers are now presented practical estimates for back-sweetening that can ultimately be used to make important decisions about back-sweetening. This information can prove beneficial to winemakers who had very few resources on back-sweetening before.

Wine however, is a complex matrix composed of numerous carbohydrates, alcohols, organic acids, phenolics and other attributes at varying levels suggesting that there may be differences in results found using sucrose and aspartame. Further work looking into the effects of various constituents in wine and their effects on sucrose and aspartame difference thresholds, Weber Ratios and overall sweetness intensity is therefore suggested.
In addition, while we were able to conduct surveying among Pennsylvania winemakers, winery owners and winery employees, minimal research has been done in other states assessing the practice of back-sweetening among wineries. Further expansion of this research is therefore suggested.

Furthermore, possible experimental errors could have occurred. Sucrose hydrolysis may still have been occurring at the time of experiments, as samples were made the day of testing. In future studies, the researcher hopes to compare results obtained using product, or back-sweetened wine samples, made the day of the experiment and samples made three days before evaluations, so to determine if this phenomenon affects perceived sweetness. As well, aspartame is a potent sweetener, so if small amounts did not end up in the sample, it could have resulted in a decrease in perceived sweetness intensity at the estimated dosages. Therefore it is suggested in future studies using aspartame that a stock solution be used and samples be made by dilution.

As well, the use of aspartame in wine has yet to be commercialized. It is unknown to the researcher whether or not such products would be successful in the market. It is therefore suggested that studies be conducted looking at the consumer acceptability of aspartame back-sweetened wine.

Finally, while this research addresses some of the gaps in wine research in regards to back-sweetening, there still remains a multitude of opportunities to expand the knowledge and research available.
Forsyth, J. (2013). Consumer taste are changing—but wine has been slow to adapt. *Mintel*.


Appendix A: z-score Conversion Table

Table A-1: z-score conversion table. Table has been taken from [(H. T. Lawless, 2013)].

<table>
<thead>
<tr>
<th>Proportion</th>
<th>Z-score</th>
<th>Proportion</th>
<th>Z-score</th>
<th>Proportion</th>
<th>Z-score</th>
<th>Proportion</th>
<th>Z-score</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01</td>
<td>-2.33</td>
<td>0.26</td>
<td>-0.64</td>
<td>0.51</td>
<td>0.03</td>
<td>0.76</td>
<td>0.71</td>
</tr>
<tr>
<td>0.02</td>
<td>-2.05</td>
<td>0.27</td>
<td>-0.61</td>
<td>0.52</td>
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<td>0.77</td>
<td>0.74</td>
</tr>
<tr>
<td>0.03</td>
<td>-1.88</td>
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<td>-0.58</td>
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<td>0.08</td>
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<td>0.84</td>
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<td>-1.55</td>
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*Calculated in Excel.*