SENSORY PERCEPTION OF TARTARIC, MALIC, & LACTIC ACIDS IN MODEL WINE

A Project Paper
Presented to the Faculty of the Graduate School
of Cornell University
In Partial Fulfillment of the Requirements for the Degree of
Master of Food Science in Agriculture and Life Sciences
Field of Food Sciences

by
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May 2022

ABSTRACT

The sensory characteristics of wine are driven in large part by its acidity. Acidity is typically perceived as sour, but its other sensory impacts are not as well documented. Many wine industry professionals believe that each acid has different aromas, but this has not been well studied. Here, we made up five hydroethanolic solutions of approximately equal pH and TA using tartaric acid, lactic acid, and/or malic acid, and presented them to a panel of wine professionals. Panelists were asked to evaluate the model wines for aroma characteristics, then rate the sourness of each on a magnitude scale. There was no consensus as to which acid was more sour, or if any acid had unique sensory characteristics. However, lactic acid, described in many wine sensory texts as having a yogurty aroma, was not perceived as different from the other acids. Future studies should focus on larger sample sizes, repeated trials, and higher acid concentrations.

BIOGRAPHICAL SKETCH

Brian Noack graduated from University of Miami with a B.S. in microbiology. He then went on to complete a J.D. from Indiana University - Bloomington. After working in the wine industry in Napa, Sonoma, and New Zealand, he began an MFS degree in enology at Cornell University in 2021. Upon graduating, he plans to pursue a winemaking position.

ACKNOWLEDGEMENTS

I would like to acknowledge and thank my advisor Anna Katharine Mansfield for all of her support and guidance; to Gavin Sacks for his unfailing patience in answering my endless questions; and to my wife Rebecca Oman, whose unwavering love and support made this possible.

INTRODUCTION

Acidity is generally considered to be the most important taste characteristic in dry wines (Amerine 1964). An acidic wine may taste excessively sour or tart, while a less low-acid wine may be perceived as flabby (Amerine 1964). Further, there is a pervasive and unsubstantiated belief in the wine industry that each acid has a specific taste. For example, malic acid is described as "green" and citric acid as "fresh" (Amerine 1965). While it is unclear where this belief began, the most likely explanation for its current popularity is confirmation bias, whereby individuals seek information that confirms their pre-existing hypotheses and disregard information that conflicts with their hypotheses. In other words, if an individual is tasting a white wine and believes that tartaric acid provides green apple aromas, the taster will be particularly sensitive to even the slightest hint of green apple. Given the integral nature of acidity to wine quality, there is surprisingly little consensus regarding the causation of acid perception or if there are other sensory characteristics beyond sourness. The theoretical causes of acid perception include pH, titratable acidity (TA), lipophilicity, molarity, number of carboxyl groups, buffer capacity, and anion concentration. Complicating matters further, acid perception is impacted by a variety of factors, including temperature, interactions with other components in the wine matrix (such as ethanol or sugar), differences in taste sensitivity between individuals, and the presence or absence of food (Fischer & Noble 1994, Waterhouse et al. 2016). Of particular importance in wine, ethanol substantially decreases sourness perception (Fischer & Noble 1994).

While the wine matrix contains numerous species of acids (Boulton 1980), malic acid, tartaric acid, and lactic acid are present in the highest molar concentrations and likely have the largest sensory impact (Boulton 1996). Of these, tartaric acid makes up a majority of the total acidity (Thorngate 1997). The ratios and concentrations of the acids in an individual grape vary widely based on variety, vintage, ripeness, and climate (Amerine 1964). The ratio of tartaric acid to malic acid is of particular importance, since tartaric acid buffers pH more effectively than the other acids (Amerine 1964). A unique feature of wine acidity is the imperfect correlation between pH and titratable acidity (TA), where pH and TA are generally inversely correlated but not always (Amerine 1964). This is likely a result of the exchange of hydrogen ions from the berry acids with metal cations from the vine (Boulton 1980; Waterhouse et al. 2016). Another important quality of acids in a wine matrix is that weak acids are only partially dissociated into protons and acid anions, while strong acids are almost entirely dissociated (Ganzevles & Kroeze 1987). Relatedly, acids are commonly categorized by how many carboxylic acid groups, and thus protons, they have to dissociate (Neta et al. 2009). For example, tartaric acid and malic acid are both diprotic acids (two carboxylic acid groups), while lactic acid is monoprotic (one carboxylic acid group) (Waterhouse et al. 2016).

The primary sensory characteristic of acid in wine is an increase in perceived sourness (Waterhouse et al. 2016), which is one of the primary tastes (DeSimone et al. 2001). Sourness is associated with a rejection response in human babies, and most animals and adults do not enjoy strongly sour solutions (DeSimone et al.

2001). The perception of taste begins when a substance is dissolved in saliva and passes into pores on the tongue, exposing the solution to taste buds located in papillae (Wolfe et al. 2019). Each taste bud contains a varying number of taste receptor cells arranged perpendicularly to the surface (Neta et al. 2007), each responding to a different type of molecule (Wolfe et al. 2019). Like all cells of the body, taste buds have an electrical potential difference between the two sides of the plasma membrane as a result of differences in ion concentrations inside the cell versus outside of the cell (Neta et al 2007). At rest, the inside of the cell has a negative charge (Neta et al 2007). Stimulation causes depolarization and eventually an internal positive charge (Neta et al 2007). Acidic conditions usually result in decreased intracellular pH, leading to sourness perception. This perception is mediated by Type III taste bud cells, which synapse with peripheral taste axons to send signals to the brain (Wolfe et al. 2019). This signal travels via cranial nerves VII, IX, and X to the medulla, thalamus, insular cortex, and eventually the orbitofrontal cortex where it becomes a conscious sensation (Wolfe et al. 2019). Interestingly, there is wide variation in taste bud density in the human population, which is a confounding factor in studying sourness perception (Thorngate 1997).

The quantity and composition of saliva also impact the perception of sourness (Norris et al. 1984). This is likely due to a combination of dilution, buffering, and/or neutralization (Norris et al. 1984). Acid species may alter the characteristics of saliva, as well (Norris et al. 1984). It has been demonstrated that decreasing pH in samples with equal TA results in increased salivary flow and sourness perception, suggesting that sourness perception may be similar to titration (Norris et al. 1984). This was also the case where pH was held steady and TA increased (Norris et al. 1984). This is likely due to the dissociation of acids to maintain equilibrium, as anions bind receptors (Norris et al. 1984). Some studies have found that tasters with higher saliva flow and pH consistently rated acid intensity higher than those with low saliva flow and pH (Norris et al. 1984). Although, other studies have been unable to replicate these results and have found no impact on intensity and salivary flow rate (Sowalsky et al. 1998). One possible explanation for this discrepancy is that some studies accounted for PROP supertasters, who are known to be sensitive to sourness, while other studies did not (Sowalsky et al. 1998). An increase in salivary flow also results in an increase in protein and bicarbonate content, buffer capacity, and pH (Sowalsky et al. 1998).

There are two general categories of theories relating to how acidic stimuli provoke the perception of sourness: (a) acidic stimuli penetrate into the cell; and, (b) acidic stimuli interact with the extracellular surface (Neta et al. 2007). It is not known whether this signal is triggered by a change in extracellular pH, intracellular pH, or both (Desimone et al. 2001). And, it also may be the case that both theories are involved, given that both undissociated acids and dissociated protons interact with the cell membrane (Desimone et al. 2001) and weak fully protonated organic acids have the ability to pass through the membrane and then dissociate intracellularly (Taylor 1927). This transmembrane diffusion is increasingly effective as both polarity and alkyl chain length increase (Taylor 1927).

It is also possible that there are multiple types of receptor systems involved in the sensation of hydrogen ions versus protonated acid species. (Ganzevles and Kroeze 1987a, 1987b). While acidic stimuli produce protons, pH and perceived sourness are poorly correlated and thus it is unlikely that dissociated proton concentration is solely responsible for sourness perception. (Desimone et al. 2001). One possibility for this lack of correlation is that protons are highly reactive with other compounds and impact cellular function (DeSimone et al. 2001).

Some studies have demonstrated that there is no relationship between pH, TA, and the perception of sourness (Pangborn 1963; Amerine 1964; Lawless 1996), while others have found that sourness intensity increases with TA when a solution is held at the same pH (Makhlouf and Blum 1972), and test subjects have had little difficulty detecting changes in TA of 0.02-0.05% in solution (Amerine 1965). The intensity of sour taste is correlated with the sum of the proton concentration and the molar concentration of acids containing at least one protonated carboxyl group (Johanningsmeiner et al. 2005; Neta et al. 2007). This makes sense because all acids dissociate into protons and anions in water (Neta et al. 2007). As molecular weight and polarity increase, the perception of sourness also increases (CoSeteng et al. 1989). However, other experiments have not found any correlation between hydrophobicity and sourness in solutions with equal pH and TA (Noble et al. 1986). It is likely that all protons, regardless of their source, share the same perception mechanism (Ganzevles & Kroeze 1987). And indeed, experiments with HCL have shown a correlation between pH and perceived sourness (Ganzevles & Kroeze 1987).

However, the relationship between sourness and pH is less clear where there are carboxylic acid groups present (Ganzevles & Kroeze 1987). It is thus possible that undissociated acid molecules are perceived by a distinct mechanism that may differ depending on the acid anion (Ganzevles & Kroeze 1987). And, studies have shown that the number of carboxylic acids (increased number of carboxylic acids = decreased sourness), molecular weight (increased molecular weight = increased sourness), and polarity (increased hydrophobicity = increased sourness) are all important to the perception of sourness (CoSeteng et al. 1989). However, there is also research showing that all protonated acids are equally sour on a molar basis, that structure does not matter to sourness (Johanningsmeiner et al. 2005), and that hydrophobicity is not predictive of sourness (Norris et al. 1984). Additionally, when present in a solution at the same pH, weak acids tend to be perceived as more sour as compared to strong acids (Amerine 1964). This is likely explained by buffer capacity, since weak acids dissociate more readily (Amerine 1964). There are studies suggesting that buffer capacity and sourness intensity are positively correlated (Beatty and Cragg 1935; Noble 1986), but others have been unable to replicate these results (Ganzevles and Kroeze 1987b). Finally, anion composition has been linked to sourness perception. There is evidence that anions may interact with cell membranes and decrease their positive charge, thereby facilitating the binding of protons (Koyama and Kurihara 1972). Others have suggested that large anions may actually suppress sourness perception by contributing their own separate and distinct tastes (Lawless 1991). Several studies noted that certain ions commonly used to adjust pH, such as sodium, may suppress sourness perception by competing for the same receptor cells (Neta et al. 2009; Neta et al. 2007; Ganzevles and Kroeze 1987a; Makhlouf and Blum 1972).

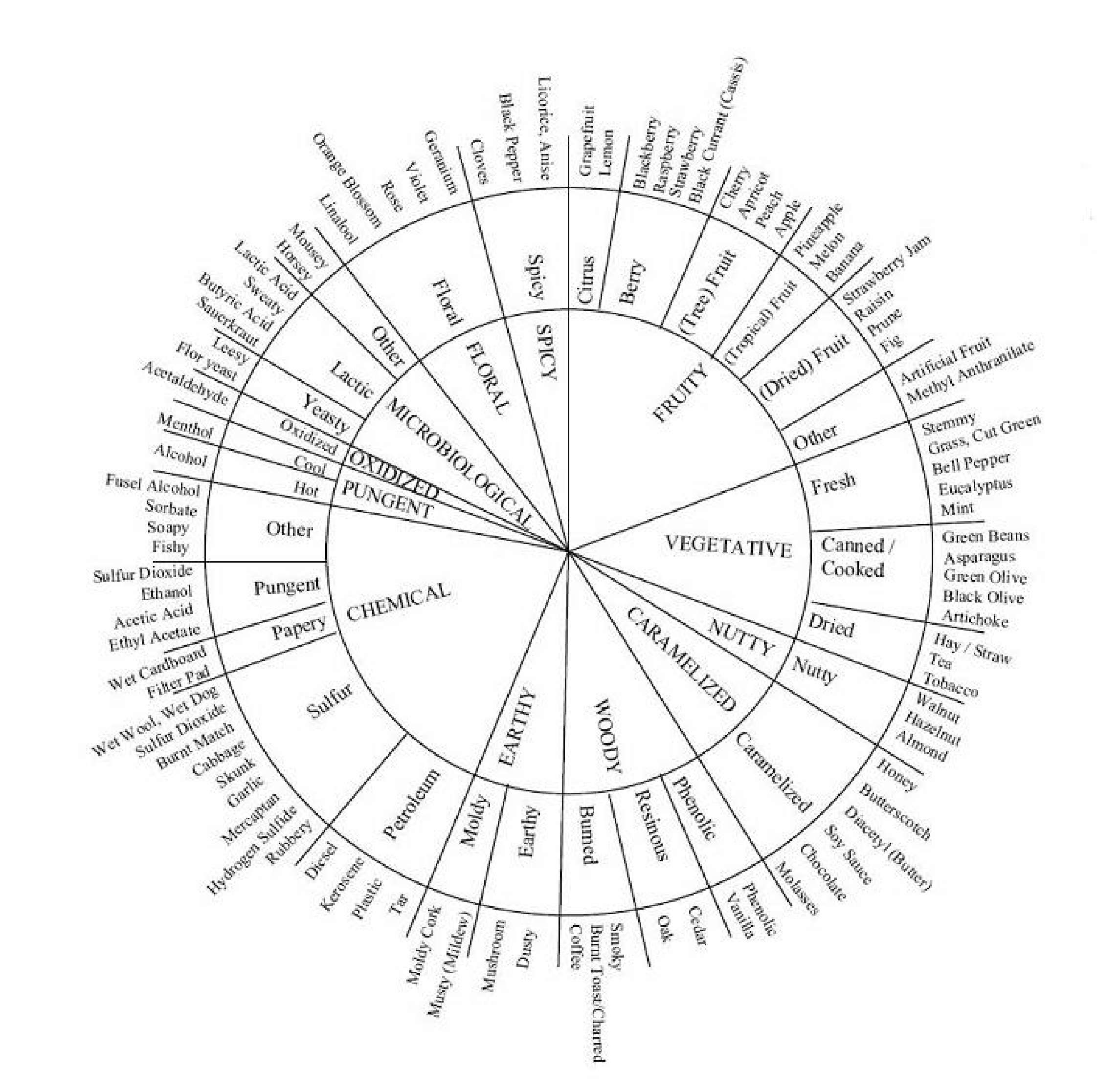
Despite over a hundred years of research, the exact mechanism for sourness perception remains unclear. Further, little research has been done into whether wine acids have any unique aromas by themselves. Yet, many winemakers add tartaric or malic acids to their musts and it would be useful to know whether there are sensory impacts other than a shift in pH and TA. In an effort to explore whether there are any sensory characteristics unique to each acid, we performed a sensory test with hydroethanolic solutions identical except for which acid is present.

MATERIALS AND METHODS

The model wines used in this experiment were prepared using 200 proof ethanol (Pharmco-AAPER, Brookfield, CT, USA), distilled deionized water, potassium bicarbonate (VWR, Radnor, PA, USA), and one or more of the following acids: D-tartaric acid (LD Carlson, Kent, OH, USA), D-malic acid (LD Carlson, Kent, OH, USA), and DL-lactic acid (LD Carlson, Kent, OH, USA). Each solution consisted of 1 L of a 12% hydroethanolic solution with a 5 g/L as tartaric acid equivalents addition of one or more of the following: tartaric acid, malic acid, lactic acid, tartaric and malic acid, and tartaric and lactic acid. The solutions were then adjusted to pH 3.2 using potassium bicarbonate. A target TA of 5 g/L as tartaric acid equivalents and pH of 3.2 were chosen because these parameters are within the range of a typical wine, while also not being overly unpleasant for the judges to taste. TA, calculated as tartaric acid equivalents (TAE) was measured via titration to pH 8.2 using a Metrohm 862 Compact Titrosampler autotitrator (Metrohm USA, Riverview, FL, USA). pH was measured by a digital pH meter (Fisher Scientific, Waltham, MA, USA).

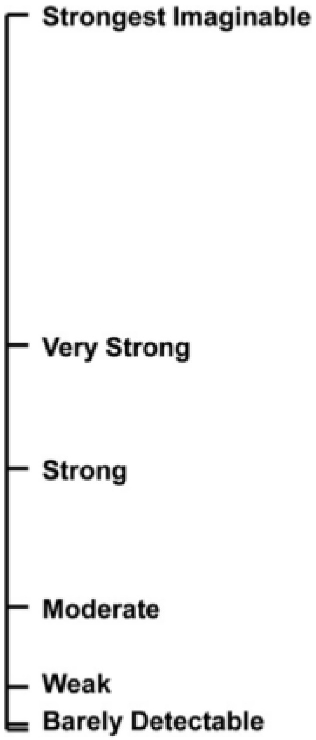
Fifteen judges, all food science or winemaking professionals, evaluated the samples. The subjects were all over the age of 21 and consisted of 10 males and 5 females, with an average age of 41 years. Each judge was simultaneously presented with all five samples along with distilled deionized water to cleanse their palate. The samples were each coded using 3-digit random numbers, and service order was randomized using a Williams Latin Square. Judges were asked to first smell the samples and rank their sourness on a labeled magnitude scale, and given space to note any specific aromas. These responses were then categorized according to the standardized aroma wheel, as shown in Figure 1 (Noble et al. 1987).

Figure 1: Standardized Aroma Wheel



The panelists were also provided with a magnitude scale, adapted from Guimaraes et al., labeled from “Barely Detectable” to “Strongest Imaginable”, as shown in Figure 2, and directed to mark the perceived sourness for each sample. These responses were then correlated to a numerical value ranging from 0 (“Barely Detectable”) to 100 (“Strongest Imaginable”).

Figure 2: Magnitude Scale



Results and Discussion

Solution Parameters

All solutions consisted of approximately 12% ethanol (v/v), potassium bicarbonate, 5 g/L as tartaric acid equivalents (TAE) of tartaric acid, malic acid, and/or lactic acid, and deionized water. The pH and titratable acidity are listed in Table 1.

Table 1: Composition of Samples

	pH	Titratable Acidity (g/L as tartaric acid equivalents)	Ethanol (% v/v)
Tartaric Acid	3.21	4.21	11.72
Malic Acid	3.27	4.69	11.67
Lactic Acid	3.26	4.08	11.57
Tartaric Acid/Malic Acid	3.27	4.31	11.60
Tartaric Acid/Lactic Acid	3.25	4.10	11.68

Sensory Analysis

The aroma descriptors provided by each subject were grouped into the general categories of the standardized aroma wheel in Figure 1 (Noble et al. 1987), and tallied in Table 2. Nearly all subjects perceived the samples to have fruity, chemical, and/or pungent characteristics. However, no consensus emerged as to descriptors specific to a particular acid or combination of acids. In many instances, subjects had difficulty discerning any difference between samples and wrote the same or similar descriptors. This general interchangeability of descriptors and difficulty in differentiating aromas between samples suggests there likely weren’t discernible aromatic differences between the various acids. Of particular note, contravening a widely held belief in the wine industry, none of the subjects perceived a yogurty aroma in the lactic acid samples. Indeed, the samples containing lactic acid were perceived similarly to the other samples with half of the subjects perceiving it as fruity. It is possible that the concentrations of acids present in these solutions were not high enough to produce aromas. Many panelists noted that the solutions had a high degree of pungency, thus it is possible that the ethanol was masking or otherwise obscuring the sensory contribution of the acids. Future research should focus on determining whether higher concentrations of the acids and/or lower concentrations of ethanol would result in different findings. There may also be reactions with other components in wine that were not present in the hydroethanolic solutions used in this experiment.

Table 2: Sensory Descriptors for Acids

	Fruity	Vegetative	Nutty	Woody	Earthy	Chemical	Pungent	Microbiological	Floral
Tartaric Acid	4	-	-	1	1	5	5	-	2
Malic Acid	4	1	-	-	2	3	8	-	1
Lactic Acid	7	-	1	-	1	3	5	-	4
Tartaric & Malic Acids	4	1	1	2	1	1	3	1	1
Tartaric & Lactic Acids	3	-	1	-	2	5	7	-	1

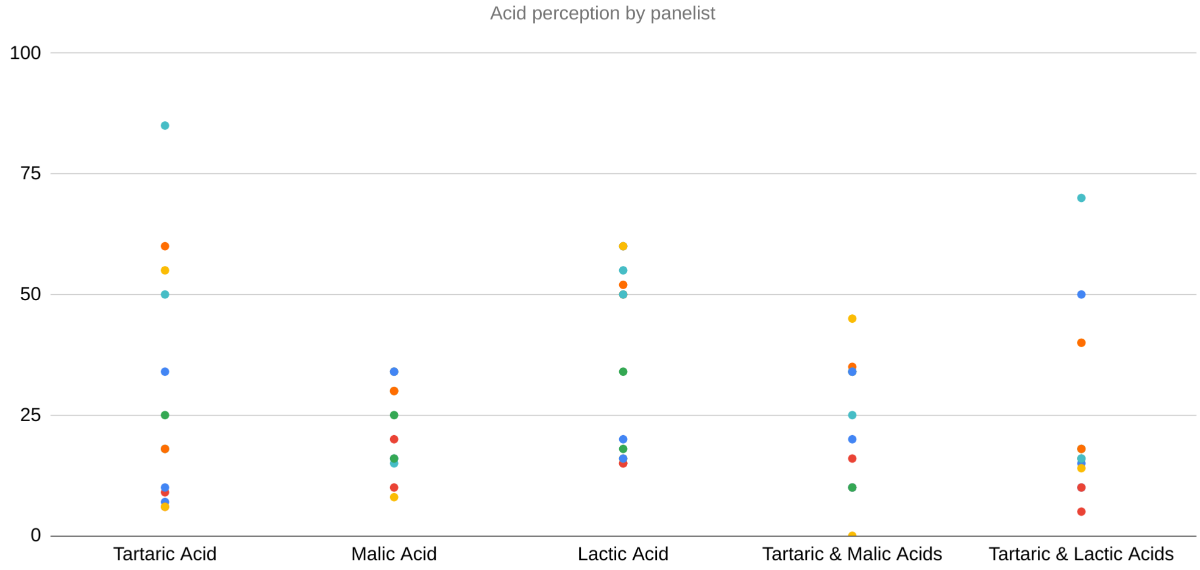
Sourness Analysis

Panelists exhibited a broad range of perceived sourness both within and across the samples (Table 3 and Figure 3), with a difference of over 70 points in one instance. The panelists showed no consistency in ranking any particular acid as more or less sour than the others.

Table 3: Sourness Intensity by Panelist

	Tartaric Acid	Malic Acid	Lactic Acid	Tartaric & Malic Acids	Tartaric & Lactic Acids
Panelist A	7	30	60	20	10
Panelist B	9	20	15	10	5
Panelist C	55	30	60	45	40
Panelist D	18	25	18	34	18
Panelist E	18	34	50	34	18
Panelist F	85	15	55	25	70
Panelist G	10	16	20	10	15
Panelist H	6	10	15	16	10
Panelist I	6	8	16	0	14
Panelist J	25	16	34	10	16
Panelist K	60	30	52	35	40
Panelist L	50	34	50	34	16
Panelist M	34	34	16	34	50
Panelist N	25	30	15	6	20
Panelist O	34	6	6	34	16

Figure 3: Acid perception by panelist



One potentially confounding factor is that panelists were not asked their PROP tasting status, a genetic condition known to impact sourness perception (Sowalsky et al. 1998). Adjusting the samples to the same pH inevitably had an impact on the TA, with samples ranging from 4.08 g/L to 4.69g/L as tartaric acid equivalents (Table 1), though this appeared to have little impact since the highest TA sample (malic acid) is similar to the others. Finally, the small size and single trial of this study may also be obscuring any trends. Further research should focus on a larger cohort, repeated trials, should distinguish PROP groups, minimize TA differences, and investigate results at higher acid concentrations.

Conclusion

Many winemakers, wine writers, and other industry professionals believe that each of the acids in wine have a unique sensory profile and different perceived sourness. However, these results instead suggest that all acids common in wine present similar sensory characteristics and sourness. Indeed, given the lack of any trends in sourness ranking or aroma perception, it appears that individual variations in sensory perception likely account for the differences between the acids. Future experiments with larger panels and repeated trials, along with higher acid concentrations and lower ethanol concentrations, may provide further insight into whether there are any sensory differences between the acids.

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