AN ABSTRACT OF THE THESIS OF

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Acids contribute important flavor characteristics to many foods and beverages. They occur naturally in these products, arise from fermentation processes, or can be added. Most acids taste sour. However, little is known about their time-intensity characteristics of sourness. This project was set forth to see if selected acids could be characterized, then differentiated according to their time-intensity parameters of sourness. Astringency was also evaluated since it seemed to be another common characteristic of the acids. Power functions were determined for the sourness to investigate the slopes of the individual acids and also to calculate equi-sour concentrations for the time-intensity study. It was found that the slopes of the acids: acetic, lactic, fumaric, fumaric-QD, citric, tartaric, and malic were not significantly different. However, hydrochloric acid with a

slope value of 2.02 was significantly different than all of the other acids that had slope values of about 1.25. This study also showed that some panelists consistently responded differently to the sourness of the acids. The time-intensity studies showed that fumaric-QD and lactic acid differed from each other in maximum intensity, area under the curve, perimeter, and duration. Although hydrochloric acid was strong in its overall impact parameters, it elicited a short duration of sourness. The fruit acids - tartaric, malic, and citric - were not very different from one another in their sourness characteristics. For astringency, hydrochloric acid was the most different from all of the other acids mostly in the overall impact parameters. For the time-intensity studies, the acids were never significantly different in time to initial response and time to maximum intensity. However, these two parameters tended to be longer for the astringency response as compared to the sourness response which suggests that astringency occurs after sourness in the taste of acids. Astringency/sourness ratios were calculated based on area under the curve measurements and showed that hydrochloric and lactic acid has significantly higher ratios than all of the other acids indicating that lactic acid may also be an astringent acid. Correlation among the time-intensity parameters showed that the overall impact parameters

correlated frequently with one another and occasionally with duration. Peak area and peak time also correlated often. Correlation between the sensory responses and the chemical indices showed that the maximum intensity, area under the curve, and perimeter correlated well with normality and pK_a for sourness. For astringency, high correlations were found between maximum intensity, area under the curve, and perimeter with pK_a, number of carboxyl groups, and molarity. At level two, a strong relationship between pH and all other time-intensity parameters except time to maximum intensity and peak time is apparent. The principal component analysis for sourness showed significant separation of lactic and fumaric-QD in principal component one, and for astringency, hydrochloric acid was significantly separated from the other acids. Principal components two and three were not able to significantly differentiate the acids.

Power Function Determination for Sourness and Time-Intensity Measurements of Sourness and Astringency for Selected Acids

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1. INTRODUCTION

Acidulants contribute significantly to the food processing industry. Their antimicrobial, chelating, and leavening properties are just three of the many functions they possess. Equally important are the sensory properties that acids can offer. Whether naturally present, added to a food or beverage, or produced by fermentation processes, they impart a degree of sourness which, if not excessive, can add a delightful character to the overall flavor of the product.

Many systems rely on acids to contribute to their flavor balance. Succinic, formic, acetic, lactic, and fumaric acids arise from alcoholic fermentations in the production of wine. In addition tartaric, citric, malic, and fumaric may be added to wine to increase its acidity. Lactic, acetic, and butyric are produced by bacterial action in wine, pickled, and dairy products. Fruit beverages also benefit from many of these acids which are endogenous in the fruits from which they are made.

Sourness is a common characteristic of all acids, however, these acids may differ in their flavor and taste dynamics. Little work has been done to quantify such

differences in quality among acidulants. It has proposed that the intensity and duration of the acidic taste differ among acids (Arnold, 1975; Pszczola, 1988). These qualities enable certain acids to mask undesirable aftertastes and also to extend and enhance other flavoring effects in the product. Some have blending properties which produce uniform taste effects from unrelated flavoring agents. (Gardner, 1966).

To evaluate various properties of acids, experiments were conducted on eight aqueous solutions of acids with the following objectives:

1. To determine the sourness power function of each acid using a trained panel.
2. To determine the individual panelist differences in the sourness power function for each acid.
3. To determine equi-sourness levels at two levels of sourness for each acid.
4. To extract meaningful parameters from the time-intensity curve.
5. To determine the time-intensity characteristics of the astringency and the sourness of each acid using a trained panel.
6. To determine the individual panelist differences in time-intensity responses for each acid.
7. To differentiate the acids according to their time-intensity characteristics of sourness and astringency.

8. To try to better understand sourness perception by relating sensory differences to differences in the chemistry of the acids.

2. Summary of Experiments

2.1 Determination of the Power Functions and Two Levels of Equi-sour Concentrations for Eight Acids.

In order to evaluate the relationship between the concentration of the acid and the perceived intensity of sourness, power functions were generated from eight or ten panelists over three replicates. The results were averaged and a final function was determined for each acid. Citric acid served as a reference throughout the experiment so that the acid functions could be related to each other. Equi-sour concentrations were calculated from these results at two sourness levels so that the acids could be compared using time-intensity studies.

2.2 Generation of the Time-Intensity Profiles of Seven Acids for Sourness and Astringency.

Eight panelists evaluated two levels of seven equi-sour acidulants in three replicates. Important discriminatory parameters were extracted from this curve and analyzed. A total of four experiments were conducted. Data were collected for the sourness of the level one and level two acid solutions (S1,S2) and astringency of the level one and level two acid solutions (A1,A2).

3. Literature Review

3.1 The Power Function.

Beebe-Center and Waddel (1948) were the first to use magnitude estimation. Stevens (1957) developed and used magnitude estimation to support his psychophysical law-the power function. This ratio scaling procedure is used to measure taste intensity responses resulting from exposure to a physical stimulus. The results of many experiments on the growth of sensory intensity suggest that for many perceptual continua, a power function $Y = aX^b$ relates sensory intensity Y to physical intensity X (Stevens, 1957). This relationship happens to be linear when log-log coordinates are used to plot the function or if the log form of the equation is used ($\log Y = a + b \log X$). The constants of the linear equation are a, the Y-intercept, and b, the slope of the line. The constants of the power function are a, the coefficient, and b, the exponent. The power function shows how rapidly sensory intensity grows with physical intensity. Consequently, the slope, b, has been a parameter of interest to sensory scientists and psychologists. If b is greater than one, the response is an accelerating function of concentration. Conversely, if the slope is less than one, the response is a decelerating function of concentration. The intercept, a, will vary with the size of the modulus

used and the numbers that panelists use to rate the stimuli. The intercept can change from experiment to experiment without affecting the slope (Stevens, 1960).

3.2 Equi-Sour Determination Methodology.

Beatty and Cragg (1935) and Pangborn (1963) calculated equi-sourness by paired comparison tests, having their panelists rate the sourness of the other acids against a reference. Beatty and Cragg (1935) used hydrochloric acid as a reference and Pangborn (1963) used citric acid. They plotted the percent of the responses considering the reference acid more sour than another acid presented at a range of concentrations. The point where 50 percent of the panelists felt that the reference acid was more sour than the test acid solutions was considered equi-sour.

3.3 Time-Intensity Measurements.

a. Typical time-intensity curves.

A time intensity (TI) study is one in which a taste, flavor, aroma, texture, mouthfeel, or any other important sensory characteristic is evaluated continuously over time. Many studies show that typically, taste intensity increases rapidly and then declines slowly as time passes (Lawless and Skinner, 1979; Lewis et al., 1980; Pangborn et al., 1983; Schmitt et al., 1984; Leach and Noble, 1986). The results of such a study illustrate what one perceives as a product is consumed and is especially important when samples with a lingering aftertaste are compared. Once this time-intensity

relationship has been established, one can study in detail the dynamic qualities of that particular sensation.

A TI response curve (Fig. 1) quantifies the time on the abscissa, usually in seconds, and the ordinate is an intensity scale. Typically, at time=0, the sample is taken into the mouth. Often a lag time is observed between initial sample exposure and the first appearance of a measurable response. The curve then increases rapidly, usually exponentially, to a maximum intensity. The maximum intensity can appear as a sharp peak or can be sustained until the stimulus is no longer perceived.

b. History of time-intensity studies.

The techniques for collecting TI data began with the use of stopwatches to record intensities at given times, a technique which cannot generate an accurate curve because of the limited number of data points which can be collected. Neilson (1957) used chart paper marked in intensity units while panelists watched a clock, Jellinek (1964) used category scales to indicate intensities marked at one second intervals, while others used audible cues (McNulty and Moskowitz, 1974) or verbal cues (Lawless and Skinner, 1979) to induce the panelist to rate the sample. TI curves were constructed from these data.

Larson-Powers and Pangborn (1978) introduced an improved method of TI data collection where perceived intensity was recorded manually and continuously on a moving

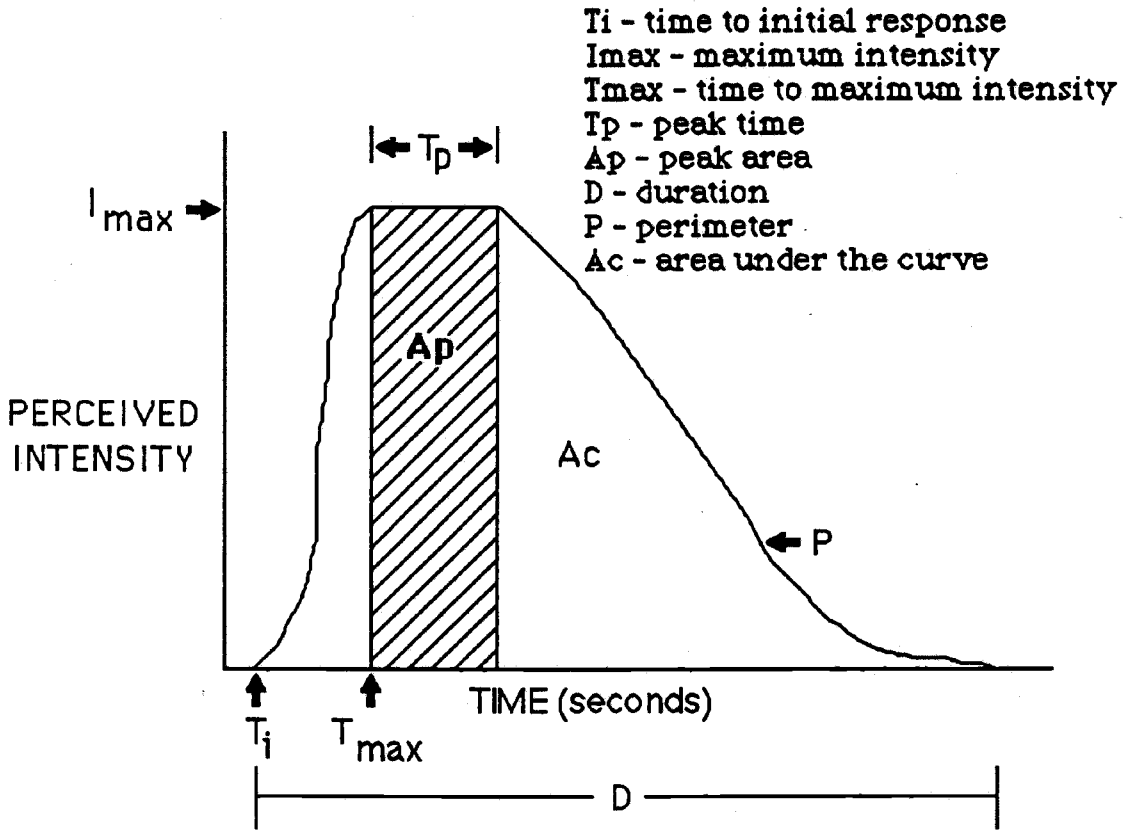

Fig. 1. A typical time-intensity curve.

chart that established the time axis. A cutting bar acted as a guideline to an intensity scale.

The latest and most efficient methods involve the computerization of data acquisition, management, and analysis. The first computerized TI procedure was developed by Birch and Munton (1981) where the taste intensity is continuously recorded by turning a dial on an intensity scale of zero to ten representing increasing or decreasing intensity of sensation, the response being eventually translated to a moving chart recorder. Schmitt et al. (1984) also developed a partially computerized system where a digitizer was used as an input device for transferring panelists' chart recorded TI curves to a computer.

For the first completely computerized method (Takagaki and Asakura, 1984) sensory intensity was expressed using a sliding scale of a variable resistor. Guinard et al. (1985) developed a completely computerized system where everything from panelist instructions to data collection was handled by a microcomputer. A joystick was used as a computer input device for recording the perceived intensity of taste with time. Lee (1985) used a game paddle to move an "X" along an intensity scale which appeared on the monitor screen to indicate the attribute intensity at each instant in time. Yoshida (1986) developed a microcomputer system which was very similar to Takagaki and Asakura's (1984) method. Computerized methods greatly minimize the labor required for

data collection and analysis data.

Sjostrom (1954) was one of the first to put the TI method to practical use by studying the bitterness and flavor of several beers. He found distinct differences in the duration of the bitter taste between two beers.

Neilson (1957) found differences in the time of maximum perception and the duration of the bitter taste between four equi-bitter aqueous solutions of caffeine, quinine sulfate, a barbiturate, and sucrose octaacetate presented at high intensity levels. The compounds were similar in that their maximum bitterness intensity occurred immediately except for caffeine which had a thirty second delay. All the compounds differed in their duration of bitterness.

Neilson also used TI to evaluate solutions where sucrose or sucrose plus monosodium glutamate (MSG) were added to mask the bitter taste of a drug. The bitter sensation occurred immediately but the maximum intensity of bitterness was delayed for thirty seconds with the addition of sucrose.

The time that flavor is present in chewing gum is one of its most important qualities. Neilson (1957) demonstrated that the peppermint flavor of a particular chewing gum developed quickly and was maintained at a moderate level for 2 minutes. The intensity gradually decreased but it remained at a low intensity for approximately 4 more minutes. After 10 minutes had passed

the flavor was just barely detectable and at 11 minutes, the peppermint flavor was gone.

There seems to be a twenty year gap in the reported TI investigations, probably because the data collection and management of TI results is very time-consuming and costly. It also requires a tremendous amount of dedication and concentration by each panelist. Most of the methods of data collection reported to date use a strip-chart recorder which was introduced by Larson-Powers and Pangborn (1978). This also involves tedious data management and analysis but was an easier task for the panelists. The development of computerized methods have lead to an increase in the use of TI studies.

c. Parameters studied.

Many parameters have been extracted from TI curves and analyzed such as maximum intensity, time to maximum intensity, duration, area under the curve, and perimeter of the curve. Rate related parameters such as the initial rate of response, rate to maximum intensity, and rate from maximum intensity to duration can be studied. Events due to swallowing or expectoration can also be evaluated. It should be noted that TI studies differ in the technique used for evaluation. Some of the important variables are: actual sample volume evaluated, extent and technique of manipulation of the sample in the mouth, time the sample is held and evaluated in the mouth, swallowing or

expectoration, degree of training, scales used, and use of standards. All of these variables may effect the data in some way. For example, intensity is usually quantified on a category scale, but some researchers use a ratio scale like magnitude estimation (Lawless and Skinner, 1979).

3.4 Attributes Studied Using Time-Intensity

a. Sweetness.

Most of the TI studies to date involve the study of alternate sweeteners. Sweeteners can be evaluated for sweetness intensity but equally intense sweeteners do not necessarily elicit equivalent taste and flavor qualities. Saccharin, for example, exhibits a lingering bitterness sensation (Harrison and Bernhard, 1984; Larson-Powers and Pangborn, 1978). Other sweeteners display undesirable cloying sensations (Dubois et al, 1977; Dubois et al., 1981b; DuBois and Lee, 1983).

Lawless and Skinner (1979) studied the intensity and durations of the sweet taste of sucrose solutions. They were interested in the TI profile of sucrose as affected by the evaluation method, scale used, and degree of training. The comparisons made in their study were:

1. sip and spit v.s. dorsal flow over the tongue
2. ratio scaling on a line scale v.s. category scaling
3. trained (experience with descriptive analysis) v.s. untrained panelists.

The TI data in the Lawless and Skinner (1979) study

were collected on verbal command at predetermined time intervals for category scaling and a strip-chart recorder was used to collect continuous data for ratio scaling. The parameters evaluated were maximum intensity, the time it took the perceived intensity of a stimulus to fall to one-half its peak height and the rate of decline in perceived intensity. In general, the sweet taste of sucrose rose to a peak within five to ten seconds and lasted for two minutes. As the concentration of sucrose increased, they were judged to have significantly greater maximum intensities, longer durations, and increases in the time to one-half its maximum intensity values. The sip and spit conditions lead to longer durations than dorsal flow conditions. Ratings of intensity and duration were unaffected by rating scale or by training level. Power functions for maximum intensity and area under the TI curve had a steeper slope for the sip and spit condition than the dorsal flow condition. The differences in training levels of the panelists had no effect on the results.

In a study by Swartz (1980), a panel evaluated sucrose solutions, solutions of ß-neohesperidin dihydrochalcone (NDHC) and monoammonium glycyrrhizinate (MAG) that were equi-sweet to 10% sucrose, and an experimental sweetener called Compound A. The panel significantly distinguished concentration differences in samples of all levels of sucrose based on initial intensity, area under the curve,

and duration. MAG had a longer taste sensation than NDHC and Compound A, which were longer than 10% sucrose solution. The lowest sucrose solution had the shortest taste sensation.

A modification of the strip-chart recorder system was used to compare varying concentrations of sucrose, lactose, glucose, and xylose (Birch and Munton, 1981). They used a potentiometer "dial box" that was connected to a moving strip-chart recorder for measurement of maximum intensity, duration, time to maximum intensity and rate of approach to maximum intensity (maximum intensity divided by the time to maximum intensity). All parameters showed increases with increasing concentrations of sucrose although no statistical analyses were performed.

Yoshida (1986) used a computerized TI system to evaluate natural and artificial sweeteners in solutions as well as several beverages and attempted to differentiate between them according to their TI parameters with the use of multidimensional scaling. The parameters studied were time to maximum intensity, maximum intensity, area under the curve, aftertaste (area after stimulation divided by the area during stimulation), and adaptation. The differences Yoshida obtained were small. Sodium cyclohexylsulfamate and aspartame showed similar TI curves to the sugars. Multidimensional scaling of the TI curves did not show any clustering of natural versus synthetic sweeteners.

With the use of their strip-chart recorder apparatus, Larson-Powers and Pangborn (1978) studied the TI characteristics of sucrose, aspartame, cyclamate, and saccharin in distilled water and in strawberry, orange, and lemon flavored drink formulations at 3°C and at 22°C. TI assessments were made of sweetness, bitterness, and sourness in the distilled water solutions, and flavor was also evaluated in the flavored drinks. The perceived sweetness and sourness of all the sweetener solutions was significantly lower at 3°C as compared to 22°C. Sweetness of saccharin solutions subsided first followed by sucrose, cyclamate, and aspartame. The saccharin solutions also imparted a persistent bitterness and sourness. Area under the curve showed that the saccharin and cyclamate solutions were more sour than the sucrose solutions. The maximum bitterness of saccharin and cyclamate was delayed for approximately fifteen seconds as compared to the sucrose and aspartame solutions. In the flavored drinks, the area under the curve also indicated greater bitterness and sourness of the saccharin sweetened drinks and less sweetness and flavor. The sweetness of sucrose subsided first followed by saccharin, then aspartame, and finally cyclamate.

Harrison and Bernhard (1984) used TI to determine if saccharin, xylitol, and galactose exhibited suppressive, additive, or synergistic properties when they were combined with lactose. These observation were based on initial

intensity, area under the curve, and duration measurements. Like Larson-Powers and Pangborn (1978), they used a strip-chart recorder and had the panelist rate the initial intensity with a first sample and continue rating with a second sample. Sweetness suppression was found in all three mixtures when only initial sweetness intensity and duration of sweetness were used for the analysis. However, according to the area under the curve measurements, they found sweetness additivity effects in the case of lactose-saccharin mixtures. They also found synergistic sweetness effects in the case of lactose-xylitol mixtures and suppression of sweetness in lactose-galactose mixtures.

Harrison and Bernhard (1984) also reported power functions constructed from TI measurements relating the initial sweetness, duration, and area to concentration of the stimuli. For lactose it was found that the power functions relating concentration to duration and to area under the curve were half that of those functions for saccharin. Xylitol had a power function similar to that of lactose for concentration vs. duration. For concentration vs. area under the curve, the exponent was in between those found for saccharin and lactose. For galactose the exponent for the duration measurements was slightly greater than those found for lactose and xylitol and much greater than the value found for saccharin. The area under the curve measurements gave an exponent that was identical to that of

lactose. These relationships are useful for observing how the concentrations of compounds affect their TI parameters.

Sensory evaluation with the TI method can also lead to a better understanding of some new sweeteners' mode of molecular interaction with the receptor site and the mechanisms of their sweet taste. The intensely sweet glycosidic flavonoid NDHC and many of its derivatives have been used to study the temporal properties of the sweet taste as well as some mechanisms (DuBois et al., 1977; DuBois et al., 1981a; DuBois et al., 1981b; DuBois and Lee, 1983). For example DuBois et al. (1977) examined fifteen derivatives of NDHC that were synthesized and rated for sweetness, sourness, saltiness, bitterness, and the presence of an aftertaste. They found that increases in the length of a sulfoakyl side chain of sulfonate analogues of NDHC and increases in the lipophilic character of a molecule are accompanied by a longer duration and higher perceived intensity of the sweet taste.

In a follow-up study DuBois et al. (1981a) evaluated NDHC and forty-four analogues of NDHC to help understand the sweet taste mechanism by trying to relate the unusual temporal properties (slow onset of the sweet taste and a lingering aftertaste) to the effects of the metabolism, conformation , chelation, or hydrophobicity of these molecules but found that none of these hypotheses were strongly supported based on the percentage of panelists

indicating a presence of an aftertaste.

Dubois and Lee (1983) found that saccharin, cyclamate, and aspartame were indistinguishable from sucrose according to the appearance and extinction times. Stevioside exhibited an appearance time similar to sucrose, however, the duration of its sweet taste lasted longer than sucrose. The two stevioside analogues were similar to stevioside in their appearance time and duration. The two dihydrochalcones evaluated were also different than sucrose in their appearance and extinction times. MAG was the most different having much longer appearance and extinction times than sucrose.

Another interesting application DuBois and Lee (1983) pursued with TI was to check the effect of the sodium salts of guanosine 5'-monophosphate, inosine 5'-monophosphate, and arabinogalactan on perceived sweetness of MAG. The data showed that none of these three compounds had an effect on the duration of the sweet taste of MAG.

A Birch et. al. (1980) time-intensity study was set forth to justify a two-phase model of chemoreception in order to account for the time factors involved with taste. They reported a mechanism to explain the differing temporal properties of sweet compounds. They proposed that an orderly queue of stimulus molecules form in the vicinity of the sweet taste receptor site followed by the depolarization at the ionophor. The length of this queue of molecules is a

function of the duration of the sweet taste and is indicative of another phase of the chemoreception process. Several equi-sweet concentrations of aqueous solutions of thaumatin and sucrose were compared on the basis of reaction time, duration of the sweet taste, time to maximum intensity, and time to end of maximum intensity. Stopwatches, although a crude way of collecting TI data, were used to record the pertinent times needed. The authors found that the reaction times as a function of concentration will reach a constant value or level off before the duration and the plateau time. They attribute the limiting reaction time to the fact that at the high concentrations, the diffusion time to reach the threshold number of queues is negligible and the constant reaction time represents the time which a threshold number of stimulus molecules need to cross a queue or queues. The rates of increase to maximum intensity do not change for increasing concentrations of sucrose but for thaumatin they do. The results of this study implied that the intense sweeteners are more efficient at reaching queues but less efficient in their stereochemical interaction with the ionophor and thus the stimulation mechanisms.

b. Bitterness.

The time-course of bitterness is the second most frequently studied attribute utilizing TI methods. Bitterness tends to be a lingering taste property and, if

present, it is usually the last taste experienced after all the other flavors and tastes have disappeared.

It is well-known that caffeine and quinine elicit a bitter taste. However, it was shown by Nielson (1957) and Leach and Noble (1986) that the temporal properties of these two compounds differ as caffeine has a longer bitterness duration. Caffeine also elicits a faster maximum rate of decay of bitterness (Leach and Noble, 1986). For both compounds, the increase in bitterness was highly correlated with an increased duration of bitter aftertaste, which increased as a linear function of concentration. Time to maximum intensity did not differ significantly between caffeine and quinine at any level. Although both compounds produced equivalent maximum intensities, the maximum rate of onset for caffeine was faster and the maximum rate of decay was slower than that for quinine. Within stimuli, the maximum rate of onset was faster for the stimulus concentration that was higher in bitterness.

Most other studies of bitterness have dealt with bitterness in beer. Pangborn et al. (1983) conducted a multifold study of the bitterness of iso-α-acids in water and in beer. In addition to these, 2.6% ethanol and/or 2.0% glucose were/was added to the beer to see the effects of alcohol and a sweetener on the perception of bitterness. In the water samples the maximum bitterness appeared after swallowing and was proportional to the iso-α-acid level.

Total duration of bitterness was positively correlated with iso-α-acid level. Maximum intensity, duration, area under the curve, and the perimeter were highly correlated with one another.

Similar results occurred for the beer solutions (Pangborn et al., 1983). Based on maximum intensity measurements, the addition of ethanol enhanced bitterness but there was no change in duration. Glucose reduced bitterness and the duration was shorter than in the control beer. The ethanol/glucose combination enhanced the bitterness effects of the lower and depressed the effects of the higher levels of iso-α-acids. Although the iso-α-acids were added to an existing bitterness level in the control beer, the two upper levels of 20 and 30 ppm were more bitter in the water than in the beer. The authors suggested that something else must be in the beer interacts with the bitterness of the iso-α-acids. High correlations were obtained between the bitterness scores obtained by category scaling and TI for maximum intensity, duration, area and perimeter.

Guinard et al. (1985) did a follow-up study on the iso-α-acids in water using a joystick linked to the computer and a strip-chart recorder to evaluate perceived bitterness. The results did not differ from each other based on maximum intensity, time to maximum intensity and duration measurements recorded.

Schmitt et al. (1984) used a method which utilized a digitizer to transfer TI curves from the strip-chart recorder to a computer. Six different brands of beer were evaluated in pairs of two (three comparisons). The authors fit a linear model (bitterness = A + (K)(time)) to the increasing segment of the bitterness perception and an exponential model to the decreasing segment (bitterness = C^{-kt}). A and C are constants. K is an increasing rate constant and k is a decreasing rate constant. None of the beers differed from each other in K within the pairs evaluated, while only one pair of the three pairs of beer differed in k. They also found differences between the beers in a pair in maximum intensity and the duration of bitterness intensity. However, there was no difference in time to maximum intensity. Excellent statistical agreement between the use of TI for maximum bitterness and the use of a line scale for maximum bitterness scores was obtained.

Guinard et al (1986a) were the first and only to publish TI data on the effects of repeated ingestion on TI sensory evaluations by exploring the effect of repeated ingestion on the bitterness of beer. One experiment required five successive ingestions of 0, 15, or 30 mg/L of iso-α-acids added to beer evaluated at 5 or 30-sec intervals between the end of one ingestion (when bitterness intensity reaches zero) and the beginning of the next ingestion. Increases in the concentration of iso-α-acids had a

significant effect on the maximum intensity, time to maximum intensity, and duration. The maximum intensity values did not change upon repeated ingestions. However, the time to maximum intensity increased significantly between the first and the subsequent ingestions. The time between measurements did not have an affect on maximum intensity, time to maximum intensity, or duration. Perceived bitterness continues to build up slightly with repeated ingestion and the subsequent drops in bitterness between sampling do not get as low as the previous ones.

In another experiment, the effect of five successive ingestions at 20- or 40-second intervals between ingestions (without waiting until the bitterness intensity reaches zero) on temporal bitterness of 0 or 20mg/L of iso-α-acids added to beer in 10 or 20 mL samples was measured (Guinard et. al., 1986a). Intensity of bitterness at ingestion time increased significantly with increased concentration of iso-α-acids and maximum intensity and intensity at ingestion increased significantly upon repeated ingestion. For maximum bitterness intensity, the increase was linear at 0 mg/L and exponential at 20 mg/L. Maximum intensity also increased with sample volume. Intensity at ingestion time decreased significantly with increased time between ingestions. The extinction of bitterness between ingestions was much less with 40 seconds between ingestions than with 20 seconds. When 20-second time intervals were placed

between ingestions, the slope of the portion of the TI curve joining intensity at ingestion to maximum intensity decreased upon repeated ingestions but remained constant when 40-second time intervals were required between ingestions. Duration of bitterness of the last sample increased significantly with concentration of iso-α-acids but was not affected by sample volume and the time intervals between ingestions.

c. Astringency.

The only TI published study on astringency is by Guinard et al. (1986b) and involved a repeated ingestion study on the astringency of tannic acid added to white wine. The objective of their work was to quantify the sensory effects of repeated ingestions on the time-course of the astringency of white wine varying in tannin content using measurement techniques that approach actual conditions of wine consumption.

In one experiment maximum intensity of astringency increased significantly with concentration of tannic acid. The curves generated both showed a linear increase and an exponential decrease in intensity. Upon repeated ingestion, with the waiting period being the time between the cessation of astringency and the evaluation of the next sample, total duration increased significantly and exponentially. Maximum intensity and time to maximum intensity did not change. No significant difference was found between the five and thirty

second intervals between sampling for total duration or maximum intensity of astringency.

In a similar experiment by Guinard et al. (1986b), in which the sampling volume was varied and twenty or forty seconds were programmed between continuous data collection, maximum intensity of astringency at ingestion increased significantly upon repeated ingestion and with concentration of added tannic acid. The area under the curve also increased with increased concentration of tannic acids. Sample size had no effect on the astringency of wine upon repeated ingestion. Intensity of astringency at ingestion decreased significantly when time between ingestions was increased from 20 to 40 seconds. Intensity at ingestion increased between the second and third ingestions and with increased concentrations of tannic acid. Time to maximum intensity of astringency increased with time between ingestion and decreased significantly with increased concentrations of added tannic acid. Duration of astringency of the last sample was not affected by concentration of added tannic acid or sample size.

d. Sourness.

Time-intensity studies of sourness are rare. Norris et al. (1984) studied the relationship of salivary flow rate to perceived maximum sourness of binary acid solutions of citric and fumaric, citric and tartaric, and tartaric and fumaric using a strip-chart recorder. One experiment was

designed to study the effect of the dominant acid in buffered (sodium hydroxide) binary acid solutions at a pH of 3.5 and titratable acidity of 4.0 g/L. They found that the maximum sourness intensity and the parotid salivary flow rate were greater when citric was the minor acid in the sample. Another experiment evaluating tartaric/fumaric acid solutions held at constant pH or at constant titratable acidity, with tartaric acid as the dominant acid, found that the samples with the lowest titratable acidity had a significantly lower maximum intensity than the other solutions, and the sample with the lowest pH had a significantly greater maximum intensity than the other solutions.

e. Other.

The effects of concentration and temperature on the perceived duration of sourness, saltiness, sweetness, and bitterness of citric acid, sodium chloride, sucrose and urea were evaluated in a study by Calvino (1984). For each solution, the duration times were recorded and related to concentration by a power function. Results indicated that citric acid, sucrose, and urea elicited a longer duration for sourness at the high temperature but the salty taste of sodium chloride had a longer duration at the low temperature. Also, steeper functions were obtained for sodium chloride at higher temperatures. The temperature variation did not affect the rate of growth of duration time

as a function of concentration.

f. Rheology.

TI studies have also made a major contribution to rheological studies. For example, Pangborn and Koyasako's (1980) panel evaluated the viscosity, sweetness, and chocolate flavor of a canned pudding and a canned creme. The formulas of these desserts were identical except for the thickening agent which was different additions of the amount of starch and agar. The TI tracings indicated that the chocolate pudding exhibited greater maximum viscosity but the duration of viscosity was almost identical between the two. This study also showed that the higher viscosity chocolate puddings displayed less sweetness and slightly less flavor than the lower viscosity creme, even though the level of chocolate was the same in both products.

Another TI texture study was carried out by Munoz et al. (1986) to rate firmness and sourness of two levels of gelatin, sodium alginate, and kappa-carrageenan gels. Gels at the high concentrations showed a greater maximum firmness except for the kappa-carrageenan gel. The gels at the high level took a longer time to reach maximum firmness and required longer times for oral manipulation than the lower concentrations. According to the TI tracings the rates of increase to maximum firmness did not differ among gels but the rates of decreasing firmness did and indicated different breakdown characteristics between the gels. At the higher

concentration of gels, there was a reduction in sourness. Sourness was most intense and persisted the longest for the kappa-carrageenan gels and there was a longer delay in the perception of sourness for the carrageenan gels than for the alginate gels.

Larson-Powers and Pangborn (1978) studied sweetened strawberry and orange flavored gel systems with the TI method. Maximum flavor and sweetness of the gelatin was perceived after 10 seconds of oral manipulation and maximum bitterness was perceived after approximately 15 seconds. Greater bitterness and less flavor and sweetness were present in the samples containing saccharin. The TI technique demonstrated the degree to which the structure of a gelatin must be manipulated orally before taste and flavor attributes are released and subsequently perceived.

A similar study of the effect of viscosity on various sensory TI properties of vanilla ice cream was carried out by Moore and Shoemaker (1981). To alter the viscosity, they varied the levels of carboxymethylcellulose (CMC). There were no significant differences found between the samples containing different concentrations of CMC for coldness based on maximum intensity, area under the curve, and duration measurements. The duration of the perception of iciness increased significantly with increasing amounts of CMC concentration. For viscosity, samples smaller amounts of CMC had significantly less viscosity than the samples

with larger amounts according to the maximum intensity and area under the curve measurements. Melting time also increased with increasing concentrations of CMC. This study showed that the concentration of CMC affected the oral viscosity and the degree of melting of ice cream which in turn affected the temporal properties of ice cream.

Birch and Ogunmoyela (1980) compared the persistence of sweetness response in chocolate drinks with several added concentrations of two surfactants, glycerol monostearate and lecithin. They showed that the persistence time of sweetness increases with increasing concentration of both surfactants.

Time-intensity data proves to offer more information about the sensory attributes of a product than does conventional intensity measurements derived from category or ratio scaling. Aftertastes associated with bitter, astringent, or sweet sensations can be quantified by TI in terms of intensity and duration. The ability to quantify both the amount and duration of lingering tastes or flavors would be a valuable advantage of the TI procedure over conventional scaling. Texture studies could also benefit from TI methods. The rate of breakdown of a substance and the release of flavors can be evaluated with this method and relay much information.

3.5 Properties of Acids.

a. Introduction.

The sensation of sourness is one of the four basic tastes. Historically, sour tastes have been associated with the hydrogen ion of acid substances. Because of the importance of this sensory attribute, many attempts have been made to relate the sourness of acids to the chemistry and the physiological reactions which occur at the receptor site.

The mechanism of sourness perception is still unclear. The expectation was that acid solutions of equal hydrogen ion concentration would be equally sour. Extensive research has shown that not only pH (the negative log of the hydrogen ion concentration) but the anion of the acid is also an important contributor to the sour taste sensation elicited by acids. Total acidity (expressed in terms of molarity, normality, or %w/v, etc.) titratable acidity, buffering capacity, dissociation constants, and saliva flow and composition can also contribute to the perception of sourness. Increasing acid concentration increases sourness, but not always at the same rate of increase. In particular, weak acids taste much more sour than strong acids at the same pH (Richards, 1898). The sensation is caused, then, not only by the mere presence of hydrogen ions, but by many other factors.

b. Acid chemistry.

Sourness is elicited by Lowry-Bronsted acid molecules which can lose or donate a proton. The tendency of any acid, HA, to lose a proton and form its conjugate base, A-, is defined by the equilibrium constant, K_a, for the reversible reaction:

$$HA \quad H^+ + A^-$$

which is $K_a = [H^+]\,[A^-]/[HA]$. Equilibrium constants for ionization reactions like these are usually called ionization or dissociation constants. Since some of the carboxyl groups ionize in aqueous solution, there are three possible candidates for participation in the stimulation processes: the hydrogen ion, the anion of the acid, and the undissociated form of the acid (Beets, 1978).

Stronger acids such as lactic have higher dissociation constants, whereas the weaker acids, such as acetic, have lower dissociation constants. Hydrochloric acid is 100% dissociated. The acidic properties of organic acids are due to the presence in their molecule of the carboxylic group (-COOH) in the free state. The hydrogen ion concentration or pH is a measure of the dissociated acid in the solution: pH = log $(1/[H^+])$ or $-\log[H^+]$. $[H^+]$ is the hydrogen ion concentration in moles/liter. The pH, although correctly representing the hydrogen ion concentration, bears no simple relation to the available acidity. However, titratable acidity measures the titratable proton concentration or the

potential hydrogen ion concentration.

c. Sourness perception.

Two general hypotheses exist as to the mechanism of the perception of sour stimuli. Early work dealt with the penetration of acids into the cell, where it was assumed the hydrogen ion would react with the taste receptor and elicit a sour taste. Crozier (1916) suggested that the potentially ionizable hydrogen is a factor influencing sourness and cell penetration power. Analysis of penetration data has shown that the ability to penetrate the cell depends on the ionizable hydrogen as well as the actual hydrogen ion concentration. Taylor et al. (1930) studied the relative permeability of different acids in order to show the influence of various substituents in the acid molecule. He assumed that only the undissociated molecules of the acid can pass through the membrane and that the physiological stimulus is purely due to the hydrogen concentration in the interior of the cell. He hypothesized that all acid solutions which taste equally sour will have the same pH in the interior of the cell.

Later work led Beidler to believe that acids, as well as other taste-eliciting substances, were adsorbed extracellularly (Beidler, 1967). A mechanism for the interaction of acid species with the receptor site has been proposed to be the binding of protons with proteins or phospholipids (Beidler, 1967). Gardner (1966) proposed an estimation of

the hydrophobicity of stimulant molecules to predict the membrane penetration and/or binding ability, which has been suggested to be a predictor of taste effectiveness. Using values from threshold studies in beer and water as estimates of equi-sour concentrations, he found significant correlations between these concentrations and the log of the octanol/water partition coefficients. The octanol/water partition coefficients appear to model aqueous membrane partitioning in biological systems. Beidler (1958, 1967, 1978a) and Makhlouf and Blum (1972) postulated that the binding of taste substances to proteins or phospholipids on the surface of the receptor leads to a rapid depolarization of the receptor surface and this spreads to the attached nerve fiber to excite it.

Most previous research with sourness perception has employed acid solutions in which the pH, total acidity and titratable acidity vary. In these systems, specifying any two variables defines the system not allowing the other variable to be independently controlled. This has led to the difficulty in obtaining a sound structure-activity relationship between sourness and acid molecules.

Degree of Dissociation, The Hydrogen Ion, and the Anion.

Richards (1898) believing that sourness was probably due to the hydrogen ion conducted a series of experiments to determine how closely sourness corresponds to the degree of dissociation. Using simple comparisons and ranking tests

with himself as the only subject, he discovered that neutralization of organic acids as compared to mineral acids resulted in more sourness for the organic acids than could be accounted for by taking into account dissociation constants. He attributed this to the possibility that the acid might become further dissociated in the mouth, or the undissociated acid causes part of sourness. Ganzevles and Kroeze (1987) found a positive relationship between the dissociation constants of tartaric, citric, formic, and proprionic acid and their sourness, with lactic and acetic as an exception.

Most researchers have concluded that the sourness of an acid does not depend totally on its pH because acids at threshold or equi-sourness levels do have the same pH values. Paul (1922) reported a pH range from 3.03 to 4.02 for threshold concentrations of acetic, butyric, formic, lactic, malic, and succinic acids (cited by Amerine et al, 1965). Berg et al. (1955) obtained a pH range of 3.55 to 4.05 at threshold concentrations for sulfurous, sulfuric, citric, lactic, malic, succinic and tartaric acids. Later, Beidler (1967) showed that solutions of 20 organic and inorganic acids that gave an equivalent neural response to 5 mM HCl in rats, had pH values ranging from 2.11 to 3.14 with concentrations of 2.2 to 150 mM.

Chauncey et al. (1963), who assumed that parotid salivary flow rate was related to sourness, found that acid

solutions at a constant pH of 2.60 induced flow rates that ranged from .21 to 4.86 ml/10 minutes. Makhlouf and Blum (1972) also established that pH had little to do with sourness based on salivary flow rate measurements. Pangborn (1963) found no relation between the pH and the relative sourness of equi-sour solutions of lactic, tartaric, and acetic acid solutions.

Many researchers also noted the ability of a weak organic acid to stimulate taste receptors at a higher pH than strong inorganic acids (Taylor, 1928, Taylor et al., 1930; Pfaffmann, 1959; Beidler, 1967). Therefore research has indicated that the hydrogen ion concentration of an acid solution does not account for all the variations in sour taste intensity.

The anion seems to have some effect on sour taste. Chauncey et. al (1967) believed that the variation in sour receptor stimulation was a function of the chemical configuration of the anion as well as the concentration of hydrogen ions based on salivary flow rates. It was observed from a plot of concentration v.s. flow rate that distinct curves could be produced for different acids (acetic, lactic, citric and tartaric) showing that increases in acid concentration caused an increase in salivary flow rates. When the hydrogen ion concentration of each solution was plotted against the salivary flow rate there was a distinct positive linear relationship for each acid. It was noticed

that a ten-fold increase in hydrogen ion concentration produced a seven-fold increase in salivary flow rate for tartaric acid and a twenty-fold increase for acetic acid. Chauncey et al. (1967) concluded from this that the molecular structure of the anion must also play an important role in sourness perception.

Beidler (1967) hypothesized that the importance of the anion to sourness perception was because its presence enhanced further binding of the hydrogen ion by preventing membrane charging. Thus, the affinity of the anion for the membrane really determines the response produced by the acid. Beidler (1978b) explained that most proteins and phospholipids bind hydrogen ions on their anionic sites to a large extent. He states that excessive binding of hydrogen ions would be electrostatically prohibitive so the anion must also bind to the membrane. This binding would decrease the net positive charge of the membrane, and thus could enhance further cation binding. Thus, hydrogen binding may be dependent on the properties of the anion. Beidler (1967) found that acetic acid produces a greater neural response than HCl at the same pH and concluded that the anion is important.

Norris et al. (1984) and Noble et al. (1986) found that binary acid mixtures of equal pH and titratable acid differed significantly in sourness intensity and saliva inducing capacity. By varying the dominant acid in the

binary mixture, significant differences were obtained and so they concluded that the sourness must also depend on the specific anion of an acid since the solutions studied were all at equal pH and titratable acidity.

The properties and the structure of an anion may affect its ability to stimulate a receptor by changing its adsorbability to a cell due to different affinities of these anions.

The Undissociated Molecule

Chauncey et al (1963) studied the importance of the undissociated molecule. They found lower salivary secretion rates with acids having higher concentrations of undisssociated acids in many cases. Therefore, they concluded that the undissociated form of the acid was not responsible in facilitating parotid salivary flow by the hydrogen ion at the receptor sites an thus not related to sourness.

Number of carboxyl groups.

CoSeteng et al. (1989) found that the sourness of citric, malic, tartaric, and lactic acids when presented in a sucrose solution depended on the number of the carboxyl groups present. The monocarboxylic acids were more sour than the dicarboxylic acids which were more sour that the tricarboxylic acids.

Molar and Normal Concentration of the Acid

Richards (1898) found that hydrochloric acid was more

sour than an equi-normal solution of tartaric, citric, and acetic acids. Fabium and Blum (1943) found that the average detection and recognition thresholds of 15 panelists were neither equi-normal nor equi-molar for hydrochloric, lactic, malic, tartaric, acetic, and citric acids. Chauncey et al. (1967) reported that at equi-molar concentrations of tartaric, lactic, acetic and citric acids produced significantly different salivary flow rates, where the flow rate was shown to significantly correlated with sourness intensity. Pangborn (1963) found that concentrations of tartaric, lactic, and acetic acids equal in sourness were not equal in molarity. Ough (1963) found that when tartaric, fumaric, adipic, and citric acid were added to a dry white wine in equimolar amounts, citric acid was judged as most sour, fumaric and tartaric acid were equal and second in sourness, and adipic acid was the least sour. Ganzevles and Kroeze (1987) found that acids equal in molarity had a rank order of HCl, tartaric, citric, formic, acetic, and lactic acid from most to least sour. The rank order was somewhat reversed for equal hydrogen ion concentration. This inversion was also noticed by Chauncey et al. (1967), Moskowitz (1971), and Makhlouf and Blum (1972). The above results indicate that sourness probably does not depend on the molar or normal concentration across acids.

Buffer Capacity.

Kendrick (1931) proposed that the amount of phosphate buffer required to bring the pH of various acids of the same molar concentration to a fixed pH of approximately 5.0 was roughly proportional to the sourness of various acids. Beatty and Cragg (1935) carried out a similar study by examining unbuffered solutions of chloroacetic, tartaric, acetic, and malic acid at equi-sour concentrations and found that equal volumes of a phosphate buffer were needed to titrate the equi-sour solutions to an endpoint between pH 4.40 and 4.45. Fabium and Blum (1943) also found that equal volumes of buffer were needed to titrate acid solutions of HCl, malic, and lactic acid which were at threshold concentration.

Sourness of Buffered Solutions.

Buffered acid solutions, containing both the acid and the salt of the acid, have been reported to be equally or more sour than unbuffered acid solutions at the same pH. Buffered acid solutions contain more anion resulting in the acid solution having a higher ionic strength.

Beidler (1967) cited a study by Liljestrand (1922) where a buffer mixture of acetic acid and sodium acetate yielded a sour threshold at pH 5.6, while the sour threshold for acetic acid alone was at pH 3.9. Beidler (1952) suggested that perhaps the salt itself contributes to the sourness of buffered acid solutions. Beidler (1967) studied

the neural response in rats resulting from the effects of buffer solutions. He compared the results of a buffered acetic acid-sodium acetate mixture and an unbuffered acetic acid solution. The neural response to the buffered solution was slightly lower than to the unbuffered acid solution, although the free hydrogen ion concentration was decreased by a factor of 7. The acetate anion concentration was eight times higher in the buffered acid solution. Ganzevles and Kroeze (1987) also found that suppression of hydrogen ions by buffering acid solutions had no affect on sourness.

Chauncey et al. (1967) found a higher increase in parotid salivary flow rate with small increases in the hydrogen ion concentration of mixtures of sodium citrate and citric acid than when just citric acid was presented. They also noticed that with large quantities of buffer salts, it was possible to make solutions of nearly neutral pH which still tasted sour. Chauncey et al. (1967) suggested that the increased sour taste intensity of buffer solutions may result from possible potentiating effects of the sodium and hydrogen ions mixed together in solution. Again, Beidler (1958, 1967) postulated that with higher anion concentration (the result of adding a buffer), the hydrogen ion could bind more readily to the receptor cell because of less membrane charging.

Pangborn (1963) suggested that the buffering capacity of the saliva might influence both the extent of

dissociation of the acids and this in turn could influence the hydrogen ion concentration. This could explain the reason for weaker organic acids being more sour than inorganic acids at a higher pH. Pfaffmann (1959) reported that buffered acid solutions retained their sour taste longer than unbuffered solutions. This idea was based on a study by von Skramlik (1926) who found that the pH of a solution of HCl placed in the mouth for 5 sec. changed from 3.5 to 6.3 and acetic acid at the same initial pH changed to a pH of 4.4 (cited by Pfaffmann, 1959). The organic acids can continue to release more taste eliciting compounds when in contact with saliva.

Titratable Acidity.

Makhlouf and Blum (1972) studied salivary flow rate induced by hydrochloric, propionic, acetic, lactic, succinic, tartaric, and citric acids. They found that the reciprocal of the titratable acidity of the acid solution correlated with the reciprocal of the salivary response rate. They then hypothesized that stimulation involved a titration of the acid at the taste receptor. The acid is initially adsorbed at the receptor site then dissociates.

The Composition of Saliva.

The composition and flow rate of human saliva has been associated with sourness perception. Cragg (1937) found that tasters with more alkaline saliva required a higher concentration of hydrochloric acid to match an acetic acid

standard. Chauncey et al (1967) found a positive curvilinear relationship between parotid secretion rate and the concentration of acetic, lactic, and tartaric acids. When the hydrogen ion concentration was graphed against the salivary response, a positive linear relationship was observed for each acid. They also found that at constant pH the stimulating efficiency (based on salivary flow rates) of monocarboxylic acids decreased with increasing chain length and that of the dicarboxylic acids increased with chain length. They found increases in flow rates for acids that were needed in higher concentrations (for equal hydrogen ion concentration) and this lead them to believe that the total acid concentration is also an important factor.

Feller et al. (1965) also found a positive curvilinear function between citric acid concentration and salivary flow rate. Makhlouf and Blum (1972) reported the same relationship for six organic acids. From their data, a direct positive linear relationship was obtained for each acid when plotted against the reciprocal of the salivary flow rate.

Saliva composition may be an important factor contributing to sourness perception because the concentration of the acid moieties of the test solutions are probably not the same as those in saliva of which the buffering capacity differs between subjects (Beets, 1979). Most research has assumed that the various concentrations of

the acid moieties of the test solutions are the same as they are in the mouth.

The Acid Molecule.

Shamil et al. (1987) hypothesized that taste is related to the compatibility between the stimulus and water structure. They ranked stimuli according to their apparent specific volume and found that as you increase this measurement the compounds range for a salty group to sourness, then sweetness, and finally bitterness. However, they found that lactic and acetic fell into the sweet/bitter border based on their specific molar volume and attributed this to the fact that these molecules exist as dimers.

Beets (1979) hypothesized that the receptor sites are of the AH-B type (Shallenberger and Acree, 1967) and states that stimulation can occur in one step by the undissociated molecule or in two steps by the hydrogen ion followed by the anion.

Many years of research has produced a complex pattern of information on the perception of sourness and so far no clear answer to the basic question of what stimulates sourness perception has emerged. Complications occur in the study of sourness due to the fact that the three molecular species that are interdependent. There are only limited means to manipulating the concentrations of these species separately, one being by the addition of buffering salts (Beidler, 1967).

4. MATERIALS

4.1 Acids.

The following eight acids were used in this study:

1. Citric. Mallinckrodt (Paris, Kentucky). FW=210.14. Monohydrate Granular.

2. DL-Malic. Denka Chemical Corporation (Houston, Texas) now Miles Inc.(Elkhart, Indiana). FW=134.09. Fine Granular.

3. Tartaric. Mallinckrodt (Paris, Kentucky). FW=150.09. Powder.

4. Fumaric. Denka Chemical Corporation (Houston, Texas) now Miles Inc. (Elkhart, Indiana). FW=116.07. Powder.

5. Fumaric-QD. Denka Chemical Corporation (Houston, Texas) now Miles Inc (Elkhart, Indiana). FW=116.07. Quick Dissolve (6% malto-dextrin added and from 2.5 to 3% malic acid is present).

6. L-Lactic. J.T. Baker Chemical Company (Phillipsburg, New Jersey). FW=90.08. Liquid.

7. Acetic. Spectrum Chemical Manufacturing Corporation (Gardena, California). FW=60.05. Glacial.

8. Hydrochloric. Mallinckrodt (Paris, Kentucky). FW=36.46. Liquid.

Spring water (Aqua-Cool, Eugene, Oregon) was used to prepare the acid solutions. Powered alum (The R.T. French Co., Rochester, New York) was used as a standard for astringency in the time-intensity study.

4.2 Facility.

The Sensory Science Laboratory Laboratory in the Department of Food Science and Technology at Oregon State

University served as the testing facility. Evaluation took place in individual booths under white light. Spring water was available for rinsing and unsalted soda crackers (Nabisco, East Hanover, N.J.) were available for refreshing the palate.

4.3 Panelists.

The panelists, five males and five females, were student and staff volunteers from the Department of Food Science and Technology at Oregon State University and had previous trained panel experience.

5. METHODS

5.1 Power Function Determination.

a. Samples.

Six concentrations of acids were used to develop the power functions. The concentrations of the acids chosen were not done so in a consistent manner. For example, the concentrations of citric, malic, tartaric, FQD, and fumaric acids were doubled at each increment up to the fourth concentration. After that, approximately twenty percent increments were chosen for the last two concentrations because the acids were becoming very intense in their acid taste. For acetic and lactic acids, the increments range from approximately twenty to fifty percent increases in concentraton. The increments for HCL ranged between nine and seventeen percent increases because it was difficult to use as broad a range as the other acids due to the strength of the sour taste of HCL.

Table 1 shows the samples evaluated in this study. A solution of .00343 M citric acid was presented as a reference and was assigned an intensity score of 50. All acid solutions were prepared two hours prior to tasting by dissolving the appropriate amount of acid in 1 L of spring water in a 1 L volumetric flask.

Table 1. The six molar concentrations of the eight acids used to develop power functions.

	ACIDS (Molarity)							
LEVELS	HCL[a]	ACETIC	LACTIC	CITRIC	MALIC	TARTARIC	FQD[b]	FUMARIC
I	0.00343	0.00250	0.00142	0.00062	0.00089	0.00080	0.00103	0.00103
II	0.00411	0.00416	0.00236	0.00125	0.00179	0.00160	0.00207	0.00207
III	0.00480	0.00583	0.00330	0.00250	0.00358	0.00320	0.00414	0.00414
IV	0.00576	0.01166	0.00661	0.00500	0.00716	0.00640	0.00827	0.00827
V	0.00686	0.01665	0.00944	0.00625	0.00895	0.00800	0.01034	0.01034
VI	0.00754	0.02165	0.01166	0.00750	0.01074	0.00959	0.01241	0.01241

[a]HCL = hydrochloric acid

[b]FQD = fumaric-QD

b. Procedure.

All panelists were exposed to magnitude estimation in several practice sessions. Eight acids were then rated for sourness or astringency. Eight panelists were present for the first part of the study and rated 6 acids (citric, malic, HCL, fumaric, FQD, and tartaric). Panelist #8 dropped out of the study and panelists #9 and #10 joined the panel resulting in panelists #1-7 AND #9 and #10 evaluatinglactic and acetic acid. All of the acids were rated against a citric acid standard and therefore could be related to one another. Each session consisted of the presentation of the reference sample with the six concentrations of a particular acid. The samples were served at 22°C in randomized order in three-digit randomly coded three ounce plastic cups. Noseplugs were used in the evaluation of lactic and acetic acids to avoid any aroma interferences. The ballot is displayed in Appendix A.

c. Experimental design.

Panelists evaluated two sets of acids per day and tasted three days per week. One set consisted of six test samples of the same acid. The experimental design is shown in Appendix B.

d. Statistical analysis.

Due to the large panel variance that often results from magnitude estimation data, a normalization procedure was applied prior to data analysis. The data were normalized by

a method similar to modulus equalization (Lane et al., 1961). Since the distributions tend toward log-normal, the geometric mean of each panelists' scores was calculated. The reference score of 50 was not included in this calculation. Each panelists' individual geometric mean across acids was divided into each of their respective raw scores. The original ratios between magnitude levels are maintained. The data were then transformed to log values. (A sample calculation can be found in Appendix C). Power functions were generated from the means of the collected magnitude estimation data. The independent values were the log values of the molar concentrations of a particular acid. The dependent values were the log values of the respective panelists' mean scores. An average function was generated from all panelists for each acid by way of regression analysis on the mean scores. Analysis of covariance was then performed to test for differences in the slopes of the acids. Once a difference was established multiple comparisons were made by calculating an F-value from the equation:

$$F=(b_1-b_2)^2/(SE_1^2 + SE_2^2)$$

with 1,8 degrees of freedom where b is the slope in the comparison and SE is the standard error from the regression analysis for the respective slope. SAS (SAS Institute Inc., Cary, N.C.) programs were used for the regression and covariance analyses and can be found in Appendices D and E,

respectively.

5.2 Equi-Sour Determination.

Equi-sour concentrations were determined by picking a subjective intensity on the y-axis of the plot of the power functions and substituting this value into the power function equation to get the appropriate concentration from the x-axis for each acid. Two levels of sourness were chosen from the plot of the power functions to obtain two equi-sour sets of solutions, one level being approximately twice as sour as the other.

5.3 Time-Intensity Studies.

a. Samples.

The acids in this study were prepared in exactly the same manner as those prepared for the power function study. An astringency standard was prepared by dissolving 0.5 g of alum in one liter of spring water.

b. Procedure.

Panelists tasted the eight acids during seven training sessions in order to describe what they perceived. Many terms (Appendix F) were generated by the panelists but lack of agreement persisted throughout the sessions as to which acids dominated in certain characteristics. However, astringency was a common term that the panelists understood and felt would be an important discriminator for the acids. Therefore, sourness and astringency were two attributes selected to be rated using the time-intensity method. Eight

trained panelists participated on the time-intensity panel, all of whom had participated in the power function study.

Training of the panelists took place on an individual basis. The first session involved an orientation to the time-intensity apparatus. Panelists were given an acid solution and proceeded to go through a practice evaluation. From this point on, nine training sessions took place to be sure panelists were comfortable in the evaluation procedure. The training data were observed to insure that panelists could replicate their curves and correctly discriminate between different acid concentrations. Training sessions were also used to determine an optimum technique for sampling. During the training sessions, the panelists were first presented a 15 ml sample, the entire amount was taken into the mouth and gently manipulated for five seconds prior to expectoration. After several sessions, the panelists decided that a 20 ml sample was a more appropriate volume to taste, and that the sample needed to be held longer in the mouth, therefore a seven second hold was standardized.

To help the panelists in using the scale in a standardized manner, two standards were incorporated into the training sessions, one as a moderate sourness indicator (.00343 M citric acid) and one as a moderate astringency indicator (0.05 %w/v alum). During the actual tasting the panelists were to taste these standards and orient themselves to moderate sourness or moderate astringency

point on the scale before they began their evaluations.

Spring water was provided for rinsing between samples during the predetermined sixty second rest period. The panelists used noseplugs for all acid evaluations to isolate the taste or mouthfeel sensation. Evaluation took place in individual booths under white light. Each session consisted of the evaluation of all eight acid solutions at equi-sour concentrations presented randomly in three-digit coded three-ounce plastic cups served at 22°C. Written guidelines were given to the panelists prior to the experiment (Appendix G).

c. Data collection.

Data Acquisition Device.

An IBM XT personal computer was used to collect the data acquired from the manipulation of a data acquisition device which contained a category scale. This device was a variable resistor with a knob that could be moved from left to right and back across a 15 cm line scale. The scale was anchored with "none" and "extreme" with a "moderate" indicator at the center.

Procedure.

A computer monitor was used to give instructions and prompt the panelists when to evaluate a particular sample and when to expectorate. After a countdown to time zero, the panelists placed a twenty ml sample into their mouth, held it there for seven seconds, and then expectorated while

continuously recording their perceived intensity. After the attribute was no longer perceived, the panelist pushed a button on the data acquisition device. If there were more samples to be evaluated a sixty second countdown for the resting period was shown on the computer monitor. Intensity was collected every quarter second as indicated from a change in electrical resistance from a variable resistor inside the data acquisition device. The points collected were automatically transformed to a 100-point intensity scale and saved in a data file.

DASSIE.

Time was monitored and data were collected by a computerized system called DASSIE (Data Acquisition System for Sensory Input and Evaluation) developed in the Sensory Science Laboratory in the Department of Food Science and Technology at Oregon State University. The program responsible for running this system was written in BASIC and Assembly languages.

d. Experimental design.

Two equi-sour sets of solutions were evaluated for sourness and astringency, each as a separate experiment for a total of four experiments. Each experiment was replicated three times and set up as a randomized block design.

e. Statistical analysis.

A typical time-intensity curve is shown in Figure 1. Specific points on the time-intensity curve were used in the

calculation of the eight parameters that were of interest in this study. The points can be seen on Fig. 2. Pertinent data points were extracted from the time-intensity curves. A minimum of three points and a maximum of eight points were used to characterize each curve. Points one, four, and eight were mandatory and described the most basic time-intensity curve. Point one is the point at which the computer first detected an intensity score. Point four is the maximum intensity and point eight is the last on the curve. Point five is present to mark the end of a maximum intensity plateau, and will only be necessary if the panelist perceives a maximum intensity longer than a quarter of a second. Points two, three, six, and seven are points of changes in rates of increases and decreases of perception. The eight parameters defined by the curve points are:

1. Time to initial response (T_i) - time at point 0 (this point was calculated by extrapolating back .25 second from point 1)
2. Time to maximum intensity (T_{max}) - time at point 4
3. Maximum intensity (I_{max}) - intensity at point 4
4. Duration (D) - time at point 8 minus time at point 0
5. Area under the curve (A_c)
6. Perimeter (P)
7. Peak time (T_p) - time at point 5 minus time at point 4 (this parameter can only be calculated if the panelists

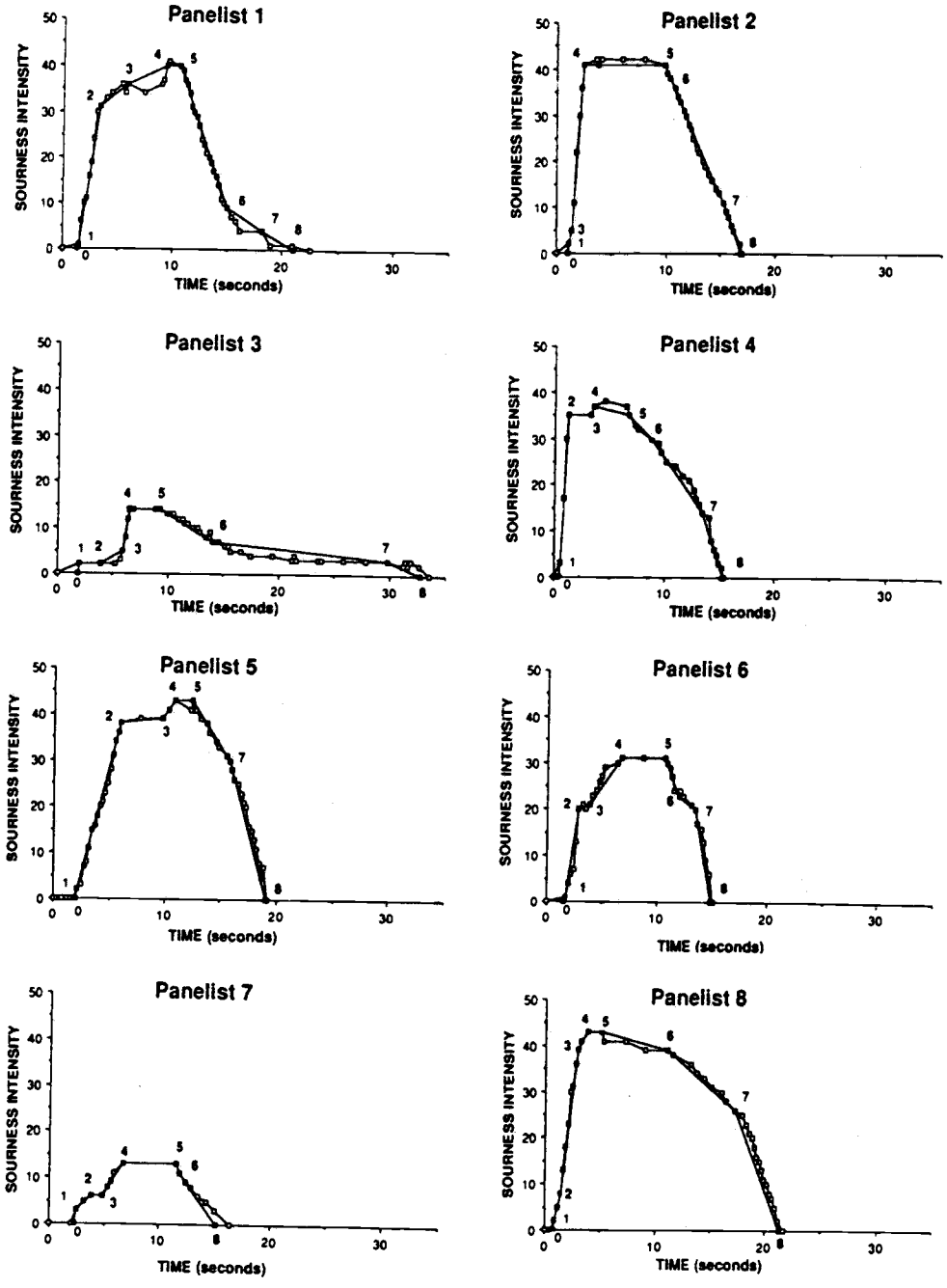

Fig. 2. Time-intensity curves for the second replication of citric acid for eight panelists.

describes the curve with a point 5)

8. Area under the peak (A_p)

Fig. 2 shows some examples of how these points were placed on the different types of time-intensity curves that were obtained. The number of points used to describe each of the curves depended on each panelist's particular response.

The data were analyzed by analysis of variance (ANOVA) using a SAS program (Appendix H). Panelists were treated as a random effect in the model (Lundahl and McDaniel, 1989) so the F-values reported for the treatment source of variation use the mean square for the panelist by treatment interaction plus the mean square for the replication by treatment interaction for the denominator in the calculation of the F-statistics. Multiple comparisons were determined by using the least significant difference (LSD) statistic. Data from individual panelists were subjected to the same analysis to see how they differed from each other. The area under the curve measurements were used to calculate astringency/sourness ratios. These ratios were then subjected to ANOVA and the panelists were again treated as random. Correlation analysis by a SAS program (Appendix I) was then used in order to see which time-intensity parameters were related to one another and to see if the chemical measurements were related to the sensory parameters (Statgraphics).

Correlation matrices were then computed from the original

variables (time-intensity parameters) and subjected to principal component analysis. ANOVA was conducted and LSD statistics were then calculated by a SAS program (Appendix J) for the scores of the chosen principal components to determine significant differences among the acids.

5.4 Chemical Measurements.

The pH of each sample was measured by a pH electrode with a microprocessor pH/mV meter (Orion Model 811) equipped with a combination pH electrode (Ross Model 81550). Titratable acidity was determined using a glass electrode and titrating with .0974 N NaOH to an end-point of pH 8.2.

6. RESULTS AND DISCUSSION

6.1 Power Function Determination.

a. Panel results.

Power function parameters [exponents (b) and coefficients (a)] and their corresponding standard errors, correlation coefficients, and F-values for each acid are listed in Table 2. The correlation coefficients were very high (> 0.991) and the regression analysis showed significance ($p < 0.001$) suggesting that the relationship between acid concentration and perceived sourness intensity was linear. The complete ANOVA table for these analyses can be found in Appendix K. The slopes from the power function equations ranged from a low of 1.13 for FQD to a high of 2.02 for HCL. The panel power functions graphed on a log-log scale are shown in Fig. 3.

In order to determine significant differences between slopes, an analysis of covariance was conducted and resulted in an F-statistic of 5.18 ($p < 0.001$)(Appendix L). The pairwise comparison results for the slope comparisons by individual panelists can be found in Table 3. For comparison the panel results are shown at the bottom of the table. HCL (b=2.02) had a significantly higher slope than all of the other acids. None of the organic acids differed in slope.

Table 2. Parameters of the power function ($Y=aX^b$) relating the perceived sourness intensity to the molar concentration of acid and their corresponding correlation coefficients (r).

ACID	Exponent(b)	Coefficient(a)	r
CITRIC	1.29	1,947	0.998
MALIC	1.25	981	0.998
TARTARIC	1.19	842	0.997
FUMARIC	1.25	826	0.996
FQD	1.13	436	0.997
LACTIC	1.25	887	0.999
ACETIC	1.27	472	0.994
HCL	2.02	39,793	0.991

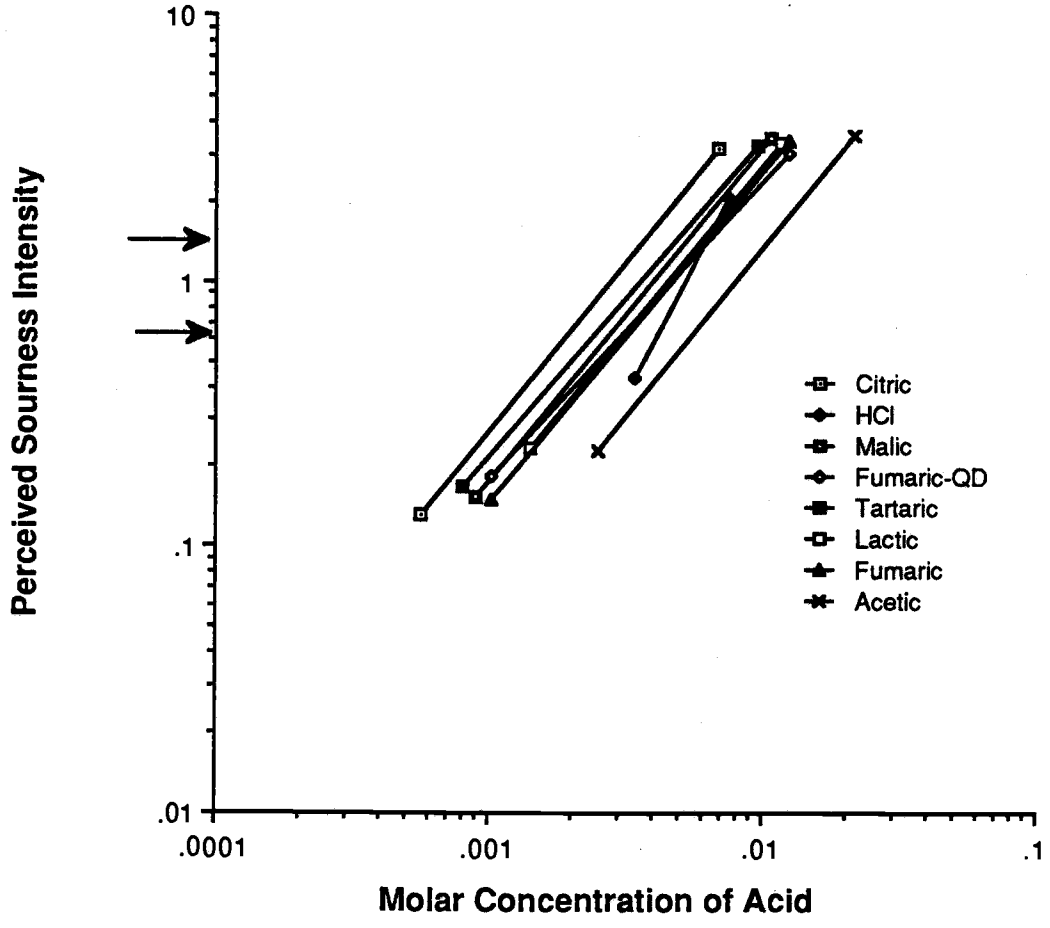

Fig. 3. Power functions for eight acids.

individual panelists can be found in Table 3. For comparison the panel results are shown at the bottom of the table. HCL (b=2.02) had a significantly higher slope than all of the other acids. None of the organic acids differed in slope.

HCl is 100% dissociated in solution (as compared to the weak carboxylic acids that have dissociation constants that range from ($k_1 = 8 \times 10^{-5}$ for acetic to $k_1 = 1 \times 10^{-3}$ for tartaric) so one may hypothesize that the hydrogen ions are responsible for this increase in sensitivity. However, the weaker acids may dissociate in the mouth releasing more free hydrogen ions that are present in an aqueous solution.

Ganzevles and Kroeze (1987b) concluded that different receptor processes may occur between organic and inorganic acids. They based this conclusion on the fact that they found that neither self- nor cross-adaptation was observed in the case of hydrochloric acid. However, with the carboxylic acids they studied--tartaric, lactic, and acetic--self and mutual cross-adaptation did occur. They hypothesized that if the stimulation processes involved were basically the same, mutual cross-adaptation would be observed between HCL and weaker carboxylic acids.

The slope values ranged from 1.13 for FQD to 2.02 for HCL for the panel as a whole. Previous studies have reported sourness power functions to be lower than the present findings and less than one (Moskowitz, 1971 and

Table 3. The average exponents and individual panelists' exponents from the power functions of the eight acids.

PAN.	FOD	TAR	LAC	MAL	FUM	ACE	CIT	HCL
1	1.16^{a23}	1.30^{ab234}	1.71^{b34}	1.08^{a12}	1.43^{ab23}	1.36^{ab12}	1.14^{a1}	1.75^{ab1}
2	0.99^{abc2}	0.89^{ab2}	0.81^{a12}	0.99^{abc12}	1.02^{abc12}	1.25^{bc12}	1.15^{abc1}	1.77^{c1}
3	1.72^{ab3}	1.96^{ab4}	2.23^{abc4}	2.01^{abc3}	1.90^{ab3}	1.67^{a2}	2.17^{bc2}	3.50^{c2}
4	1.06^{a23}	1.21^{a23}	1.31^{a123}	1.05^{a12}	1.15^{a2}	1.25^{a12}	1.08^{a1}	1.52^{a1}
5	1.02^{a23}	1.10^{ab23}	0.93^{a12}	1.18^{ab12}	1.12^{ab2}	1.06^{a12}	1.20^{ab1}	1.20^{bc12}
6	1.29^{ab23}	1.38^{b3}	0.96^{a12}	1.36^{ab123}	1.20^{ab2}	1.25^{ab12}	1.19^{ab1}	2.30^{ab12}
7	0.59^{ab1}	0.49^{a1}	0.68^{ab1}	0.77^{abc1}	0.72^{ab1}	0.90^{bc1}	1.11^{c1}	1.06^{bc1}
8	1.20^{a23}	1.24^{a23}	----	1.51^{a23}	1.44^{a23}	----	1.25^{a1}	1.66^{a12}
9	----	----	1.42^{a23}	----	----	1.45^{a12}	----	----
10	----	----	1.23^{a23}	----	----	1.24^{a12}	----	----
Panel	1.13^{a}	1.19^{a}	1.25^{a}	1.25^{a}	1.25^{a}	1.27^{a}	1.29^{a}	2.02^{b}
New Panel*	1.12	1.19	1.20	1.23	1.25	1.27	1.16	2.15

^{abc} slopes with the same letter superscript are not significantly different at the ^{1234} $p<0.01$ level across acids (row) as determined by t-tests.
slopes with the same number superscript are not significantly different at the
* $p<0.01$ level for the panelists (column) as determined by t-tests.
these are the results of the panel after eliminating panelists (#3 and #7) whose slopes were not in agreement with the rest of the panel.

Ganzevles and Kroeze, 1987b). For the present study the results indicate that the response has increased at a faster rate than the stimulus and for Moskowitz' study, the opposite is true.

Several differences in methodology could account for the differences in the slope magnitude. For example, Moskowitz' panelists had to evaluate 40-48 acids in one session and Ganzevles and Kroeze's panelists had to evaluate 44. Adaptation could have taken place in this type of situation. Also, the range of acid concentrations used in the present study was smaller than the range used in Moskowitz' study. The widest range tested in the present study was from 0.00250 M to 0.02165 M for lactic acid. In Moskowitz' study, the widest range was from 0.003 M to .1 M. A wider range of stimuli could cause a flattening of the slopes (Moskowitz, 1983).

Ganzevles and Kroeze (1987b) used a different method of stimulation in their study. The panelists evaluated the samples by placing a circular piece of filter paper on the frontal part of the tongue. In the present experiment the panelists were tasting the acid thus exposing all of their taste buds to the stimulus. This could be a factor in the increased sensitivity to the sourness solutions in the present study thus, steeper slopes.

Although the elevations of the functions for some of the acids seemed different there were no statistical tests

set forth to determine if this were not due to chance.

b. Individual panelist results.

It was of interest to observe differences between panelists in their response behavior across the eight acids. The regression analysis for the individual panelists' functions can be found in Appendix M and the analysis of covariance tables can be found in Appendix N.

Inspection of Table 3 shows that panelists did indeed respond differently and showed significant differences not observed through analysis of the data from the panelists as a whole. For example, results of the analysis of the panel as a whole showed only HCl to be different from all of the other acids. However six panelists were able to detect additional differences in other pairs of acids as shown in Table 4. For example panelist #7 rated citric as having a significantly higher slope than FQD, tartaric, lactic, and fumaric acid. Panelist #7 also rated tartaric acid as having a significantly lower slope than acetic acid and HCl. Panelist #7 tended to generate low slopes for all the acids.

Panelist #1 rated the slope of lactic acid to be significantly higher than malic, citric, and FQD and almost as high as HCl. Panelist #2 rated acetic acid as having a significantly higher slope than lactic acid. Panelist #3 rated citric acid as having a significantly higher slope than acetic acid. Panelist #6 rated tartaric acid as having a significantly higher slope than lactic acid. Although the

Table 4. Summary of the individual panelist comparisons of slope values of the eight acids[1].

	FQD	TAR	LAC	MAL	FUM	ACE	CIT	HCL
FQD		---	1	---	---	---	7	3,5
TAR			6	---	---	7	7	2,3,7
LAC				1	---	2	1,7	2,5
MAL					---	---	---	---
FUM						---	7	3
ACE							3	3,5
CIT								---
HCL								

[1] FQD = fumaric-QD, TAR = tartaric, LAC = lactic, MAL = malic, FUM = fumaric, ACE = acetic, CIT = citric, HCL = hydrochloric

panel as a whole rated HCL as having a significantly higher slope than all of the other acids, panelists #3 and #5 were the only two panelists who found HCL different than three or more of the other acids. Panelist #4 was the only panelistwho could not detect any differences at all between any ofthe eight acids (panelist #8 rated six acids and panelist #9 and #10 rated two acids). The power functions for panelists #4 as compared to panelist #7 are shown in Fig. 4a and b.

It was also of interest to determine the differences between panelists' slopes for any one acid as differences in perception between individual panelists are to be expected in any sensory experiment. Appendix O lists the analysis of covariance tables for the differences in the panelists responses. Out of the ten panelists, two of them seemed to be perceiving the acids differently than everyone else (Table 5). Panelist #3 and panelist #7 always differed from the other panelists in at least two of the acids. Panelist #3 tended to give high slope values and panelist #7 tended to give low slope values. Panelist #3 differed from panelist #7 for all eight acids studied. Panelist #2 also had slopes of small magnitude for all of the acids and differed occasionally from the other panelists in tartaric, lactic and FQD. Panelist #1 also differed from panelist #5 and panelist #6 for lactic acid. The power functions of each acid (all panelists) are shown in Fig. 5.

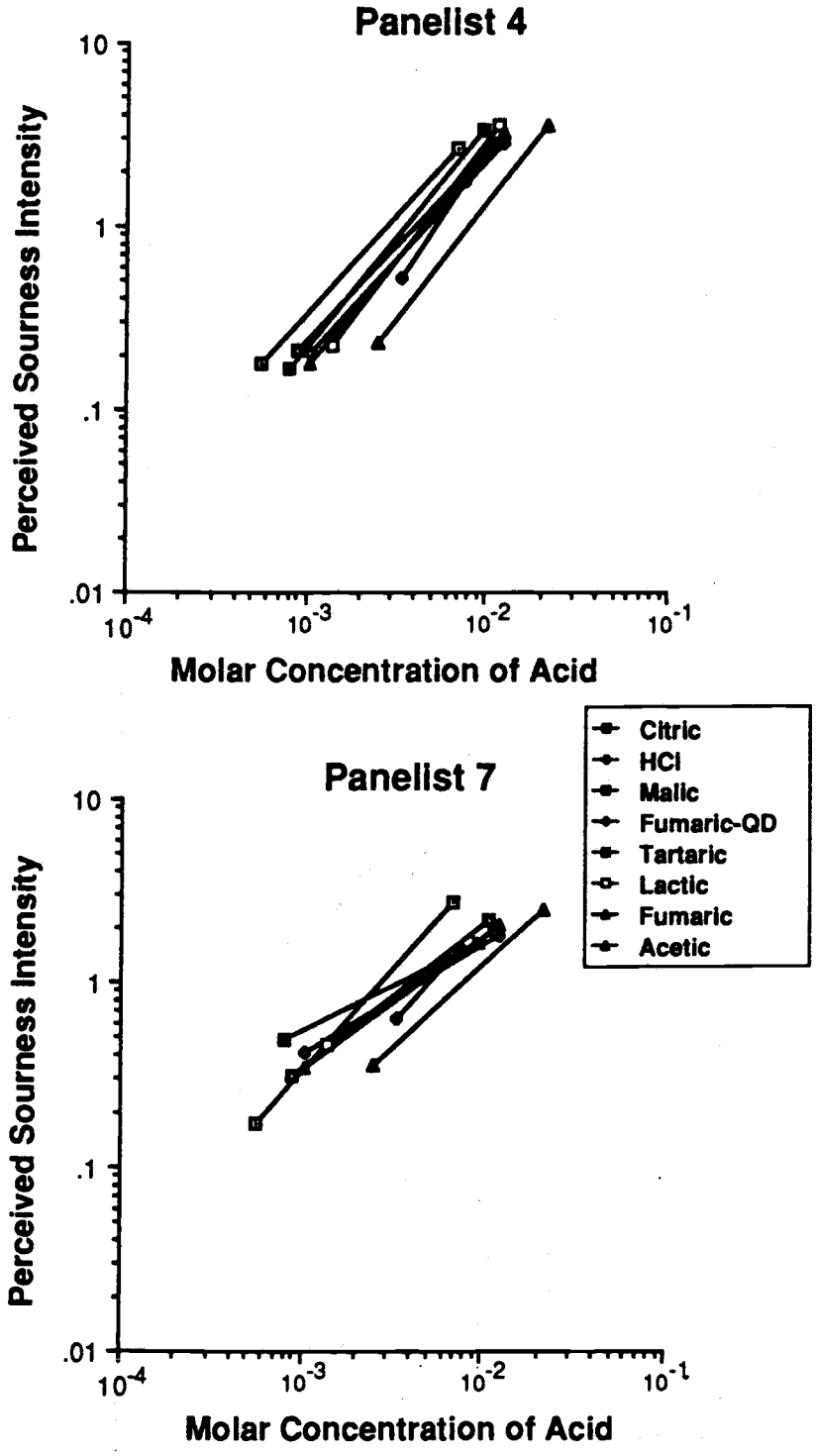

Fig. 4. The power functions of all the acids for a)panelist #4 showing how the acids were rated similarly and b)panelist #7 showing how the acids were rated differently.

Table 5. Summary of individual panelist differences for slope comparisons of the eight acids.[1]

PAN	1	2	3	4	5	6	7	8	9	10
1	-	L	MCH	-	L	L	TL FQ	-	-	-
2		-	TLMQ CHF	-	-	T	TQ	-	L	L
3			-	TLM CHF	TLM FC	TL FC	all	TC	L	L
4				-	-	-	TFQ	-	-	-
5					-	-	TFQ	-	-	-
6						-	TFQ	-	-	-
7							-	TM FQ	L	L
8								-	-	-
9									-	-
10										-

[1] T = tartaric, L = lactic, M = malic, C = citric, H = hydrochloric, F = fumaric, Q = fumaric-QD, A = acetic.

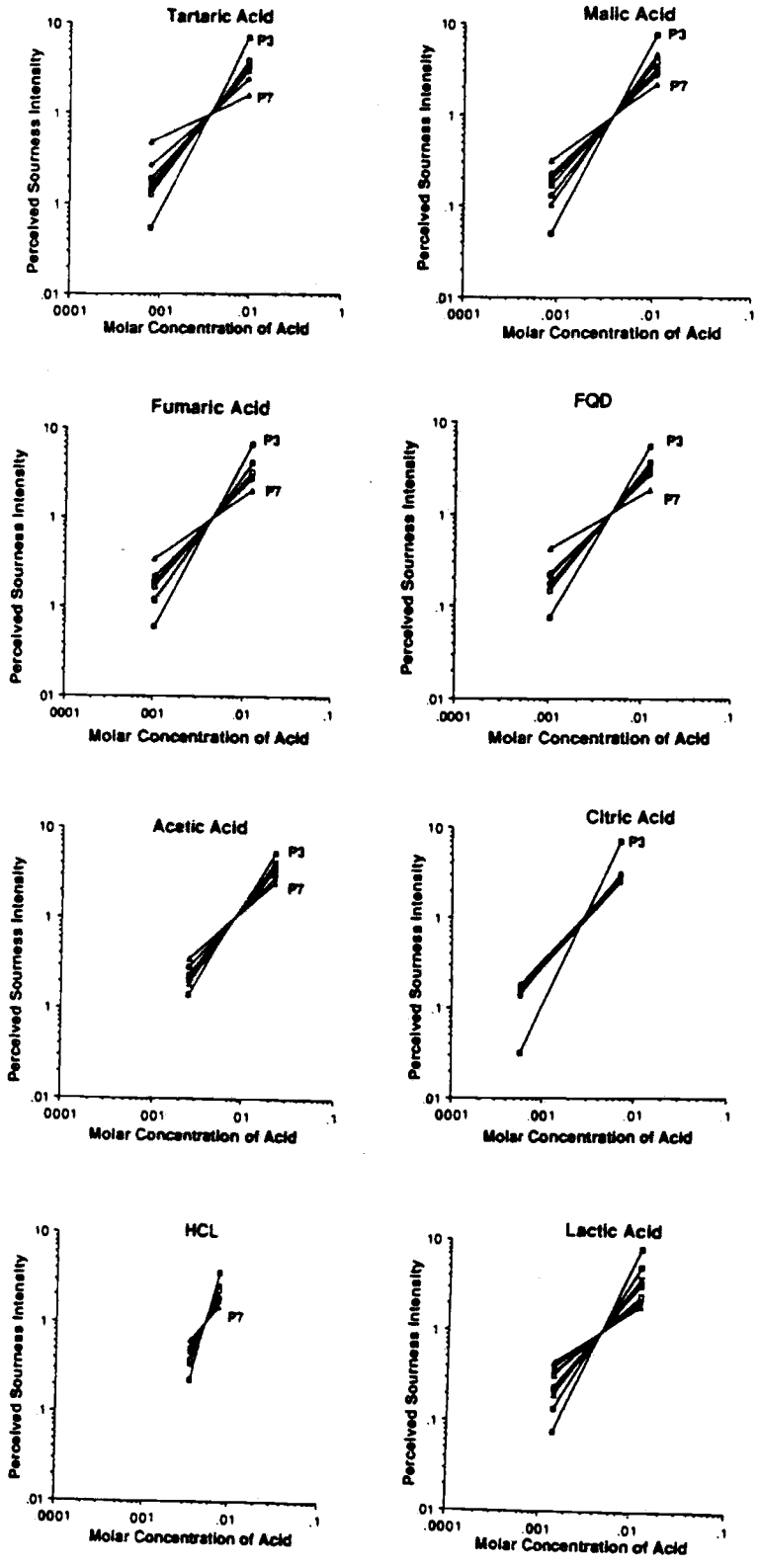

Fig. 5. The power functions for each acid showing the panelists whose ratings were different than the others.

6.2 Equi-Sour Determination.

In order for time-intensity work to proceed, it was necessary to determine equi-sour concentrations of the seven acids at two perceived sourness levels, both within a reasonable sourness range but one approximately two times more sour than the other. The goal of the powertwo times more sour than the other. The goal of the power function determination was to obtain an average power function that represented the panel so that the equi-sour calculations could be as accurate as possible. Two panelists had regression parameters that were very different from the rest of the panel. The slopes from panelist #3 were extremely high (1.67-3.50), while the slopes from panelist #7 were unusually low (0.49-1.11). It was decided that it was necessary to remove their data from the average for all acids except citric, hydrochloric, and lactic in order to produce a more accurate average of the panel as a whole. For citric only panelist #3 was removed. Panelist #7 had a slope that was in the range of the other panelists for this acid. The opposite was true for hydrochloric. Only panelist #3 was removed due to a low slope value. Incidently, the slope values were not affected very much (with the exception of citric) by the elimination of those panelists by observation of Table 3 in the row labeled new panel. For lactic the range of slopes was so wide that all panelists were considered. The equi-sour calculation results

can be found in Table 6.

Several other researchers calculated equi-sour concentrations of acids (Beatty and Cragg, 1935; Buechsenstein and Ough, 1979; Fabium and Blum, 1943; Pangborn, 1963) but did so by using different methods. The present study and the cited studies all agree that it takesmore acetic acid in terms of molarity to become equally sour to the fruit acids (tartaric, citric, malic, and fumaric). Lactic and hydrochloric acid also must be present in a greater amount (molarity) to be equal in sourness to the fruit acids but in lesser amounts than acetic acid. The present study and the cited studies agree with this except that the order of hydrochloric and lactic are sometimes reversed. For example, in the present study it took .00427 M of hydrochloric acid to be equally sour to .00318 M of lactic acid or .00630 M of hydrochloric acid to be equally sour to .00618 M of lactic acid. Pangborn (1963) found that it took .00078 M of hydrochloric acid to be equal in sourness to .00085 M of lactic acid. However, the two studies evaluated different ranges of acid concentrations. The fruit acids do not consistently occur in any order of needed molarity for equi-sourness. Pangborn (1963) and Beatty and Cragg (1945) calculated a group of equi-sour concentrations of acids somewhat similar to the present study. The comparison is shown in Table 7. The other equi-sour studies cited here were using concentrations of acids

Table 6. Equi-sour molar and %w/v concentrations of sourness for two sourness levels.

Acid	Level I		Level II	
	Molarity	% w/v	Molarity	% w/v
Citric	.00214	0.041	.00433	0.083
Malic	.00279	0.037	.00559	0.075
Tartaric	.00247	0.037	.00500	0.075
Fumaric-QD	.00313	0.036	.00659	0.076
Lactic	.00318	0.029	.00618	0.056
Acetic	.00567	0.034	.01095	0.066
Hydrochloric	.00427	0.016	.00630	0.023

Table 7. Equi-sour molar concentrations of acids in the present study (Straub) and those in the Pangborn (1963) and Beatty and Cragg (1935) studies.

	STRAUB	PANGBORN	BEATTY AND CRAGG
Acetic	.00567	.00516	.01400
HCL	.00427	------	.00500
Lactic	.00318	.00388	------
FQD	.00313	------	------
Malic	.00275	------	------
Tartaric	.00247	.00207	.00300
Citric	.00214	.00208	------

in a different range so no comparisons to these studies were made. It was noticed in this study and stated by Beatty and Cragg (1935) that opinions of equi-sourness varied from one panelist to another.

6.3 Time-Intensity Characteristics of the Eight Acids

a. Sourness of the level one and level two acid solutions - panel results.

Due to an incorrect normalization procedure for the fumaric acid data, an inaccurate equi-sour calculation of the concentration of the fumaric acid was determined. For this reason the fumaric acid results will not be discussed here.

The sourness of the level one and level two acid solutions will be referred to as S1 and S2, respectively. ANOVA generated the F statistics shown in Table 8 and 9 for both sets of solutions. Prior to discussing the treatment effect, other main effects and their interactions will be discussed.

There was a significant panelist effect for all parameters at both levels meaning only that judges were using different portions of the intensity scale. Therefore, standardization attempts by using the moderate sourness intensity solution were not totally successful. In future experiments it may be necessary to use more than one standard solution.

Replication was significant for five of the eight

Table 8. F-values for the time-intensity parameters for sourness of the level one acid solutions.

SOV	TIME-INTENSITY PARAMETERS[1]							
	T_i	I_{max}	T_{max}	T_p	A_p	D	P	A_c
Panelist	18.78***	17.04***	17.99***	3.35***	5.18***	43.08***	17.40***	23.67***
Treatment	0.71	14.09***	1.57	1.71	1.62	3.24**	11.78***	7.10***
Panelist x Treatment	0.78	1.22	0.90	0.94	1.34	1.72	1.08	1.48
Replication	1.51	7.52***	4.14	6.25**	6.52**	1.01	5.64**	6.52**
Panelist x Replication	2.99**	5.10***	1.93*	2.01*	0.77	1.73	4.37***	3.76***
Treatment x Replication	1.26	0.50	0.80	0.97	0.99	1.22	0.45	0.64

*, **, and *** refer to $p<0.05$, $p<0.01$, and $p<0.001$, respectively.

[1] time to maximum intensity(T_i), maximum intensity(I_{max}), time to maximum intensity(T_{max}), peak time(T_p), peak area(A_p), duration(D), perimeter(P), area under curve(A_c).

Table 9. F-values for time-intensity parameters of sourness of the level two acid solutions.

SOV	TIME-INTENSITY PARAMETERS[1]							
	T_i	I_{max}	T_{max}	T_p	A_p	D	P	A_c
Panelist	5.28***	15.49***	4.15***	7.81***	12.10***	29.27***	15.52***	36.93***
Treatment	0.92	17.93***	1.41	1.30	2.14*	11.40***	22.67***	12.76***
Panelist x Treatment	0.76	0.94	0.63*	1.29	1.47	1.04	0.88	1.49*
Replication	0.74	3.25*	0.63	5.59**	11.61***	0.34	3.14*	5.09*
Panelist x Replication	1.07	4.89***	2.04*	1.84*	3.29***	2.11*	4.12***	4.51***
Treatment x Replication	1.39	0.65	0.75	1.30	1.50	0.41	0.45	0.62

*, **, and *** refer to $p<0.05$, $p<0.01$, and $p<0.001$, respectively.

[1] time to maximum intensity(T_i), maximum intensity(I_{max}), time to maximum intensity(T_{max}), peak time(T_p), peak area(A_p), duration(D), perimeter(P), area under curve(A_c).

parameters for both levels of solutions which means, across sessions and days, panelists used different parts of the scale. Although sessions and day were not included in the model, the data were observed to see if these factors influenced the results. No outstanding differences were found that would suggest that day or session could have affected the results. All of the significant parameters were related to the shape of the curve. Replication, being significant, indicates that generating consistently scaled time-intensity curves may have been difficult for the panelists.

For S1, there were no panelist x treatment or treatment x replication effects. For S2 there was a significant panelist x treatment effect for the time to maximum intensity and the area under the curve measurements which means panelists were not consistent with each other in their judgments for these two parameters.

The treatment effect(each particular acid) was significant for S1 and S2 for maximum intensity ($p<0.001$), duration (S1 - $p<0.01$, S2 - $p<0.001$), perimeter ($p<0.001$), and area under the curve ($p<0.001$). The peak area was significant for the S2 solutions ($p<0.05$).

Because these acids were presented "theoretically" at equi-sourness levels, based on the power functions, it is appropriate to present first those parameters where no differences were found. The means of the non-significant

parameters can be found in Table 10. No differences were found in time to initial response, time to maximum intensity, and peak time, for S1 and S2 and peak area for S1. Most of these parameters are time related. This suggests that equi-sourness was driven by perceiving the sensation, reaching maximum sensation, and the duration of the sensation.the sensation at maximum intensity (peak time) at equivalent times across all acids. Although S1 and S2 were selected to provide two sourness levels, one twice as high as the other, the time parameter means for S1 and S2 are basically equivalent (Table 10). Therefore, these time elements seem to be somehow standardized regardless of acid concentration or perceived overall sourness.

Related studies of other taste qualities have found that increases in concentration of stimuli do not result in changes in time to maximum intensity for sweetness of sucrose solutions (Dubois and Lee, 1983), astringency of tannic acid added to wine (Guinard et al., 1986), and bitterness of caffeine and quinine solutions (Leach and Noble, 1986).

Many differences were found between acids across the significant parameters for both sourness levels (Table 11 and 12). For both S1 and S2, maximum intensity, area under the curve, perimeter, and duration were significant and for S2, peak area was also significant.

In order to more easily visualize the differences,

Table 10. Response means and SD's (in parenthesis) for non-significant time-intensity parameters for sourness of the level one and the level two acid solutions.

Curve Parameters*		ACIDS** L	A	M	C	T	HCL	FQD
T_i	S1	1.57 (0.98)	1.48 (0.92)	1.63 (0.73)	1.42 (0.57)	1.45 (0.85)	1.50 (0.55)	1.31 (0.60)
T_i	S2	1.82 (1.60)	1.54 (0.81)	1.66 (1.86)	1.54 (0.85)	1.37 (0.48)	1.80 (1.59)	1.12 (0.65)
T_{max}	S1	5.00 (2.24)	6.54 (3.24)	5.52 (1.96)	5.96 (2.91)	6.26 (2.42)	5.75 (2.40)	6.40 (2.65)
T_{max}	S2	5.15 (2.62)	6.12 (2.85)	5.67 (2.70)	6.62 (3.41)	5.41 (1.95)	6.17 (3.16)	6.26 (2.75)
T_p	S1	2.48 (1.99)	3.71 (2.65)	3.72 (3.21)	3.02 (2.45)	2.29 (2.13)	3.05 (2.58)	2.91 (2.35)
T_p	S2	3.17 (2.02)	3.26 (2.10)	3.69 (2.69)	2.30 (2.04)	3.40 (1.97)	2.54 (1.90)	3.36 (2.73)
A_p	S1	51 (43)	115 (99)	139 (157)	110 (114)	84 (85)	159 (153)	148 (126)

* time to initial response (T_i), time to maximum intensity (T_{max}), peak time (T_p), sourness of the level one solutions (S1), sourness of the level two solutions (S2).

** lactic(L), acetic(A), malic(M), citric(C), tartaric(T), HCl(H), fumaric-QD(FQD).

Table 11. Response means and LSD's and standard deviations (in parentheses) for significant time-intensity parameters for sourness of the level one solutions.

Curve Parameters*	ACIDS** L	A	C	M	T	H	FQD	LSD
I_{max}	21^{a} (10)	34^{b} (15)	38^{bc} (13)	38^{bc} (14)	42^{c} (18)	51^{d} (19)	53^{d} (16)	5.8
A_c	202^{a} (131)	436^{b} (249)	518^{bc} (347)	475^{bc} (275)	586^{c} (409)	545^{bc} (281)	759^{d} (397)	134.7
P	54^{a} (25)	83^{b} (31)	93^{bc} (36)	91^{bc} (34)	100^{c} (39)	114^{d} (36)	123^{d} (37)	12.8
D	15.2^{a} (5.1)	20.8^{bc} (8.5)	22.9^{c} (10.5)	20.8^{bc} (9.2)	22.1^{c} (8.5)	17.7^{ab} (6.0)	24.3^{c} (10.8)	4.20

* maximum intensity(I_{max}), area under the curve(A_c), perimeter(P), duration(D).

** acetic(A), lactic(L), citric(C), malic(M), tartaric(T), fumaric-QD(FQD), HCl(H).

^{abcd} means with the same superscript are not significantly different at the $p<0.05$ level.

Table 12. Response means and LSD's and standard deviations for significant time-intensity parameters for sourness of the level two solutions.

Curve Parameters*	ACIDS** L	A	C	M	T	H	FQD	LSD
I_{max}	26^{a} (11)	42^{b} (15)	47^{c} (13)	50^{d} (11)	52^{d} (15)	55^{e} (15)	63^{f} (15)	2.9
A_c	268^{a} (154)	622^{b} (356)	662^{bc} (270)	705^{cd} (319)	735^{d} (350)	634^{b} (285)	981^{e} (402)	64.9
P	62^{a} (24)	101^{b} (30)	114^{c} (23)	117^{cd} (28)	122^{d} (30)	121^{d} (29)	146^{e} (34)	6.4
D	15.2^{a} (4.1)	23.8^{c} (6.6)	24.8^{cd} (7.8)	24.8^{cd} (7.1)	23.6^{c} (8.7)	19.0^{b} (5.4)	25.8^{d} (7.2)	1.25
A_p	86^{a} (66)	142^{abc} (121)	105^{ab} (101)	184^{cd} (144)	172^{cd} (113)	164^{bcd} (120)	218^{d} (192)	64.5

* maximum intensity(I_{max}), area under the curve(A_c), perimeter(P), duration(D), area under the plateau (A_p)

** acetic(A), lactic(L), citric(C), malic(M), tartaric(T), fumaric-QD(FQD), HCl(H)

^{abcde} means with the same superscript are not significantly different at the $p<0.05$ level.

curve parameters which were significantly different across individual pairs of acids for S1 and S2 are presented inTable 13 and 14. In these tables, all possible pairings of samples are compared for each significant parameter. Therefore for S1, any one acid could be different from the others a maximum of 24 times (4 significant parameters by 6 acids). For S2, 30 is the maximum number of times any one acid could be different from the others (5 significant parameters by 6 acids). The greatest number of differences between the pairs of acids were found in maximum intensity and perimeter for S1 and maximum intensity for S2. Although more differences for all parameters were rated at the S2 level, duration had nearly twice as many significant pairs of acids as compared to S1.

Lactic acid, which was rated low in all parameters, stands out as being significantly different from the other acids most frequently, or 23 out of the 24 times (95.8%) for S1 (Table 13) and 28 out of the 30 times (93.3%) for S2 (Table 14). Acetic acid also had low means, yet it was significantly higher than lactic acid in all significant parameters except peak area. For the equi-sour determination noseplugs were used only for rating the lactic and acetic acid solutions. This procedural anomaly could have had some effect on the generated power functions which in turn could have affected the equi-sour calculations for these particular acids. Also, the between panelist

Table 13. Curve parameters[a] which were significantly different across pairs of acids[b] at level one sourness.

	ACIDS						
	L	A	C	M	T	HCL	FQD
L	-	all	all	all	all	1 - 3	all
A		-	none	none	1 - 3	1,3	1 - 3
C			-	none	none	1,3,4	1 - 3
M				-	none	1,3	1 - 3
T					-	1,3,4	1,3
H						-	2,4
FQD							-

[a] 1=maximum intensity, 2=area under the curve, 3=perimeter, 4=duration

[b] lactic (L), acetic (A), citric (C), malic (M), tartaric (T), hydrochloric (HCL), fumaric-QD (FQD)

Table 14. Curve parameters[a] which were significantly different across pairs of acids[b] at level two sourness.

	L	A	C	M	T	HCL	FQD
L	-	1 - 4	1 - 4	all	all	all	all
A		-	1,3,4	1 - 4	1 - 3	1,3,4	all
C			-	5	1,2,3,5	1,3,4	1,2,3,5
M				-	none	1,2,4	1 - 3
T					-	1,2,4	1 - 4
H						-	1 - 4
FQD							-

[a] 1=maximum intensity, 2=area under the curve, 3=perimeter, 4=duration, 5=peak area

[b] lactic (L), acetic (A), citric (C), malic (M), tartaric (T), hydrochloric (HCL), fumaric-QD (FQD)

variability was the largest for lactic acid with the slope values ranging from .68 to 2.23 (Table 3). This large degree of variability may have affected the equi-sour calculations. A power function could have been generated that was no representative of everyone on the panel. This would give an equi-sour concentration that was not equally sour to all of the acids for all of the panelists.

To better visualize curve differences, simple time-intensity curves can be constructed by using five parameters: time to initial response, time to maximum intensity, maximum intensity, peak time, and duration. The constructed time-intensity curves for lactic and acetic for the S1 and S2 responses are shown in Fig. 6a. Although acetic acid had low means, the lactic acid curve was still much smaller compared to acetic acid. Also, higher maximum intensity responses were related to longer duration times.

FQD which was rated highest in all significant parameters was the second most different with 17 out of 24 differences (70.8%) for S1 (Table 13) and 25 out of 30 (83.3%) for S2 (Table 14). The extreme differences in the time-intensity responses from "theoretically" equi-sour lactic acid and FQD are demonstrated in Fig. 6b.

It is also possible to observe from Table 13 and 14 and Fig. 7 how similar the major fruit acids were to each other. For S1, malic, tartaric, and citric did not differ from each other in any parameter. At the S2 level, malic acid did not

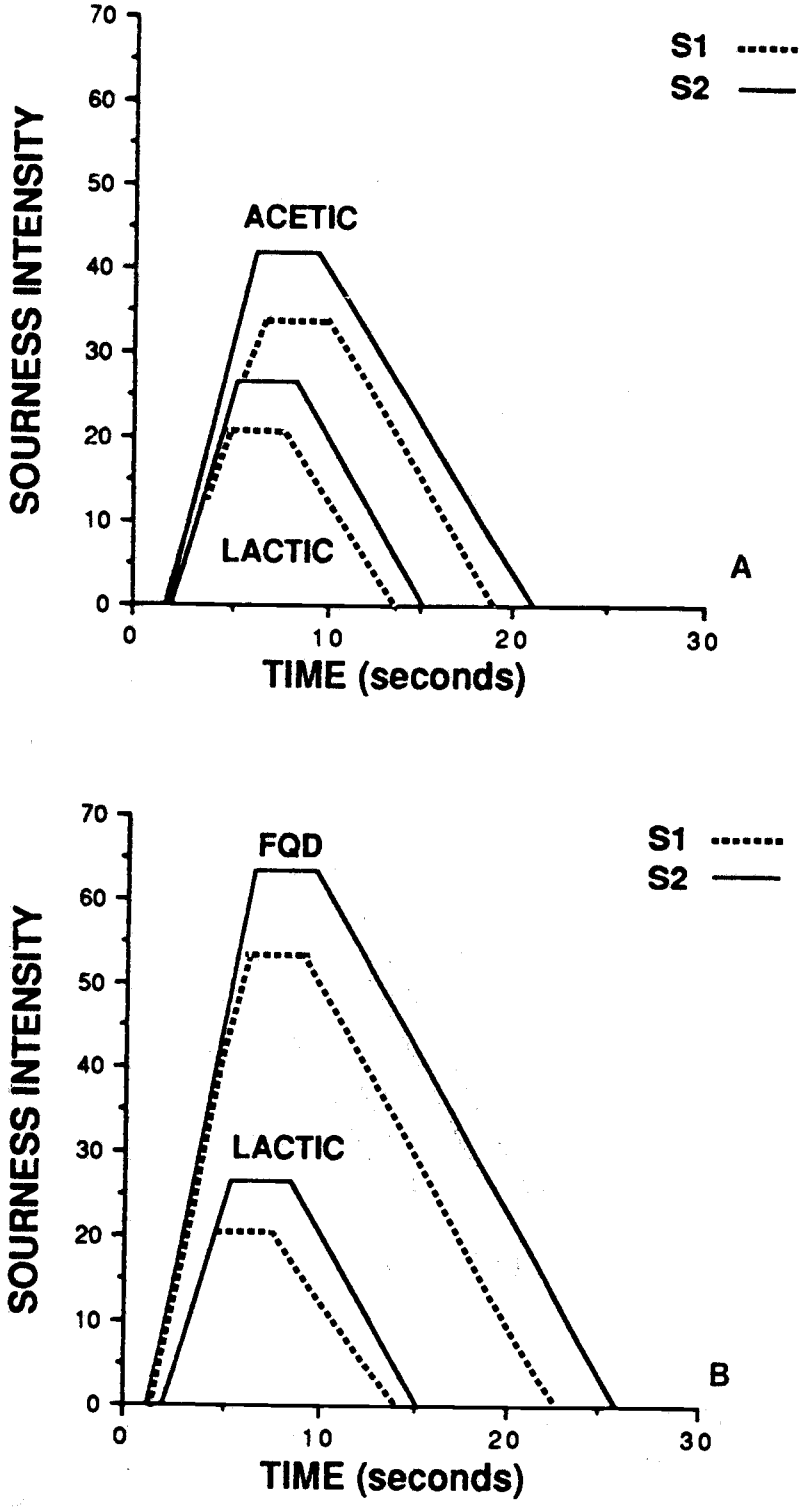

Fig. 6. Constructed time-intensity curves for the sourness of the level one and level two acid solutions for a)acetic and lactic acid and b)FQD and lactic acid.

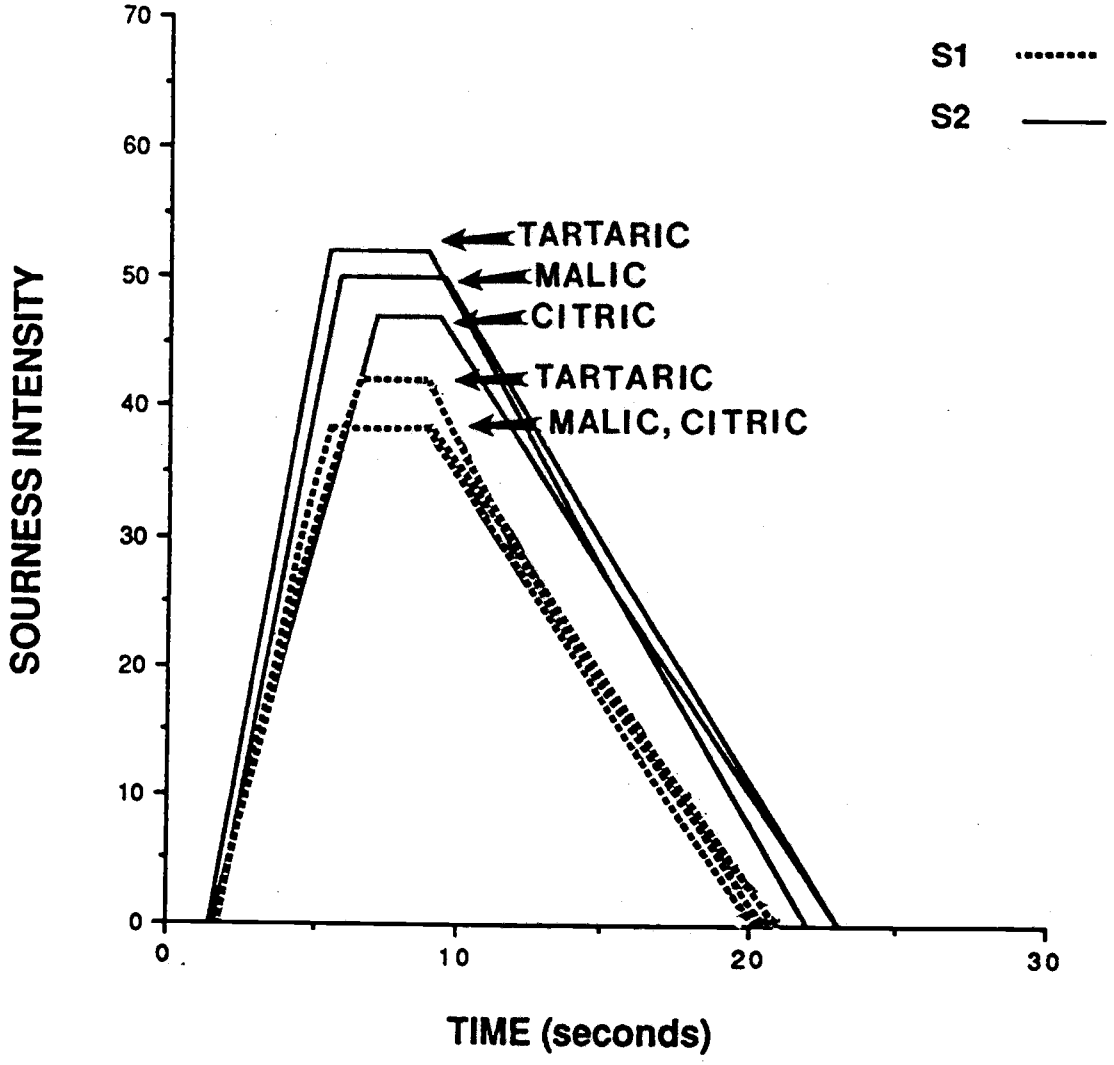

Fig. 7. Constructed time-intensity curves for the sourness of the level one and level two acid solutions for malic, citric, and tartaric acid.

differ from tartaric acid, but it was significantly higher than citric acid in peak area which is driven by both peak time and maximum intensity. Citric acid was quite different from tartaric acid at the S2 level, as it was significantly lower in maximum intensity, area under the curve, perimeter, and peak area.

HCl had unique characteristics. In terms of overall impact - maximum intensity, area under the curve, and perimeter - it is a very intense acid. However, as compared to the other acids, the sour sensation elicited by HCl was of short duration (Fig. 8). This may suggest that different stimulation processes are in effect for organic as compared to inorganic acids. Although HCl had a larger maximum intensity value than citric, its duration was shorter. Without the gathering and investigation of time-intensity data, this information would be lost.

Differences in the perception of the acids could be due to the shape of the molecules. Shamil et. al. (1987) categorized taste molecules according to their displacement of water by solute and measured it in terms of apparent specific volume. This measurement separates sapid molecules starting with salty substances with low values (< ~0.33) to sour substances (~0.33 to ~0.52) followed by sweet substances (~0.52 to ~0.71) and ending with bitter compounds that have the largest apparent specific volume values (~0.71 to ~0.93). HCl, tartaric, and citric acids have specific

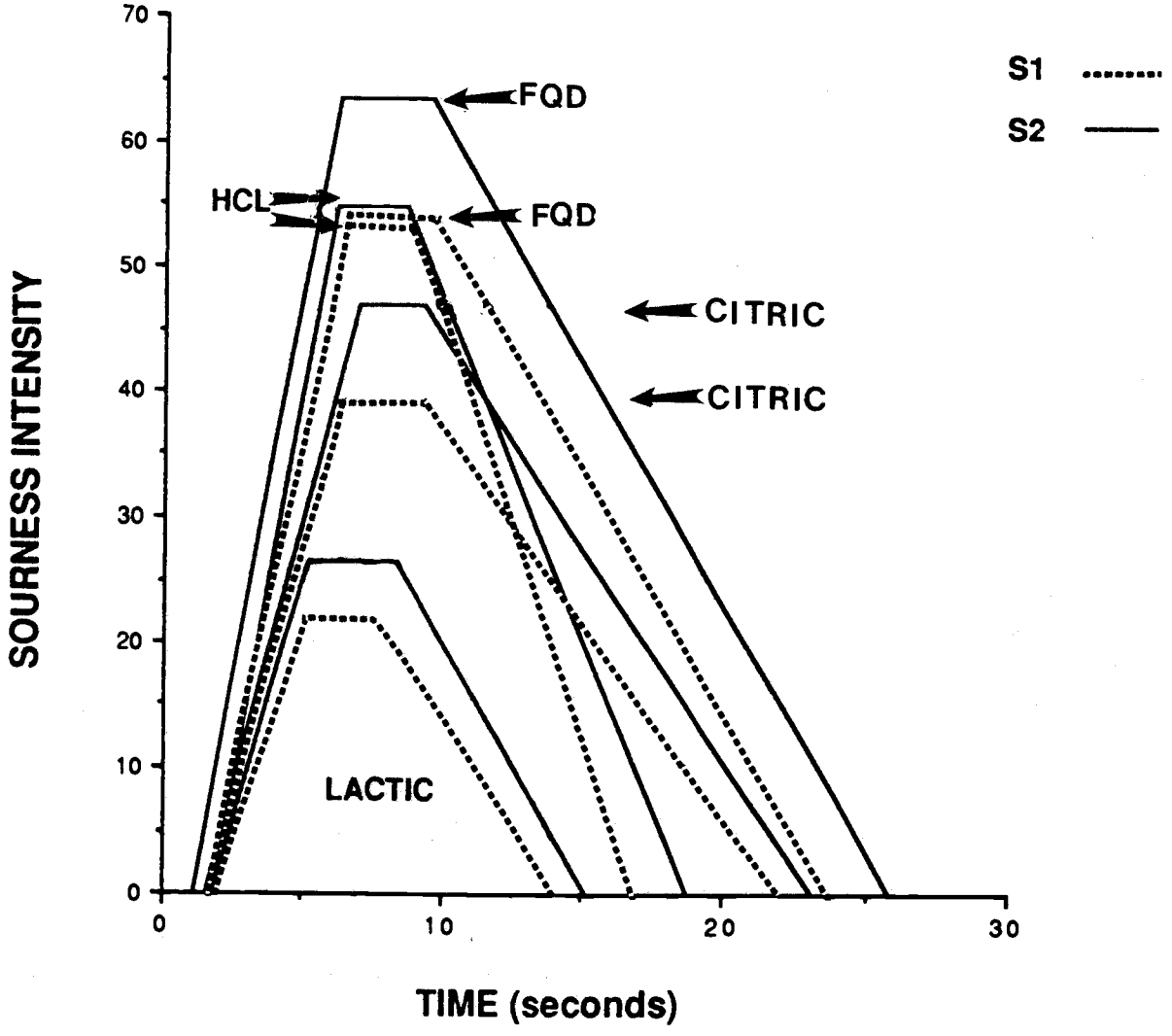

Fig. 8. Constructed time-intensity curves for the sourness of the level one and level two acid solutions for HCL, FQD, citric and lactic acid.

molar volumes of 0.5075, 0.5367, and 0.5887, respectively. Lactic and acetic acid which were different from the other acids in the present study, have values of 0.7925 and 0.8521, respectively. According to the classifications, these molecules should taste bitter. The authors account for this anomaly by stating that acetic and lactic acids have very low dissociation constants, are less hydrophilic, tend to associate more than the stronger acids, exist as dimers, and have larger specific molar volumes than expected.

The duration times of the sourness of the acids ranged from 15.2 seconds for lactic acid to 24.3 seconds for FQD for S1 (Table 12) and from 15.2 seconds for lactic acid to 25.8 seconds for FQD for S2 (Table 13). Norris et al. (1984) reported duration times of approximately 120 seconds for acid mixtures in double distilled water. However, these acids were presented to panelists at concentrations ten times that of those in the present experiment and sodium hydroxide was added to adjust pH. These differences in stimuli could have accounted for the differences in duration times.

The research reported here involved presenting solutions for time-intensity measurement which were judged to be equi-sour in a unidimensional measurement. The goal was to observe if all time-intensity parameters were basically equivalent, driven by the "overall" sourness

response, or to discover differences in time-intensity parameters which in combination, must have driven the equi-sourness response. Time-intensity characteristics of a substance could affect overall response in cases where panelists only have the opportunity to rate one aspect of the substance (i.e. average intensity). For instance if an acid has a lingering characteristic, one may translate that and express it as a higher sourness intensity in any unidimensional scaling procedure. This may be done to fulfill the panelist's desire to express this lingering characteristic.

There were no additional tests conducted after the equi-sour calculations were determined to test by other methods how equally sour the resulting solutions were to the panelists. For example, pairs of acids could have been tested by using triangle testing to show that no difference in "overall" sourness existed. Or, all samples could have been rated for "overall" sourness on an intensity scale and analyzed for differences in mean scores. However, it is likely that the results of these methods would not be in absolute agreement. An alternative approach would be to perform time-intensity studies on several concentrations of acids, calculate an equi-sour set of solutions from these maximum intensity readings, and see if they are perceived as equally sour on a unidimensional scale.

b. Sourness of the level one and level two acid solutions - individual panelists results.

The complete ANOVA tables from the S1 and S2 results are shown in Appendices N and O and the individual means are listed in Appendices P and Q, respectively. The significance levels from the individual panelists' responses for S1 and S2 are shown in Table 15 and 16, respectively. It can be observed from these tables that panelists differed in their ability to discriminate among the acids. Panelist #6 was the least able to discriminate among the acids at both S1 and S2. Panelist #1 and panelist #5 could not find any differences in the acids at S1 for the parameters that were found significant by the panel as a whole (Table 15). However, upon the increase in sourness level panelist #1 and panelist #5 found differences in the acids for most of those parameters (Table 16). There were some parameters that the panel did not find significant but some individuals did. These parameters were not consistently significant with an increase in sourness level. In fact, in some cases, the parameters were significant for S1 but not for S2. This could indicate that the sourness may be so strong for these panelists that they lose their ability to discriminate at that high of a level.

There was also a large difference in panelists' ability to replicate their time-intensity curves. Fig. 9 illustrates the panelist with the best replication

Table 15. Significant parameters[ab] for individual panelists for the sourness of the level one acid solutions.

	PANELISTS							
Parameters	1	2	3	4	5	6	7	8
Imax	-	***	*	**	-	-	***	**
Ac	-	***	*	*	-	-	***	**
P	-	***	*	**	-	*	***	**
D	-	-	*	-	-	*	**	**
Ti	-	-	-	-	***	-	-	**
Tmax	*	-	-	-	-	-	-	-
Tp	-	***	***	-	-	-	*	-
Ap	-	-	-	-	-	-	**	-

[a] parameters in bold indicate those parameters that were significant for the panel.

[b] maximum intensity (Imax), area under the curve (Ac), perimeter (P), duration (D), time to initial response (Ti), time to maximum intensity (Tmax), peak time (Tp), peak area (Ap).

*, **, and *** refer to $p<0.05$, $p<0.01$, and $p<0.001$, respectively.

Table 16. Significant parameters[ab] for individual panelists for the sourness of the level two acid solutions.

Parameters	PANELISTS 1	2	3	4	5	6	7	8
Imax	**	***	-	*	*	-	**	***
Ac	*	*	***	*	**	-	*	***
P	*	***	***	*	**	-	**	***
D	*	-	**	-	-	*	-	***
Ti	-	*	**	-	-	-	-	-
Tmax	-	-	-	-	-	-	-	-
Tp	-	-	-	**	-	-	-	-
Ap	-	-	-	-	**	-	*	-

[a]parameters in bold indicate those parameters that were significant to the panel.

[b]maximum intensity (Imax), area under the curve (Ac), perimeter (P), duration (D), time to initial response (Ti), time to maximum intensity (Tmax), peak time (Tp), peak area (Ap).

*, **, and *** refer to $p<0.05$, $p<0.01$, and $p<0.001$, respectively.

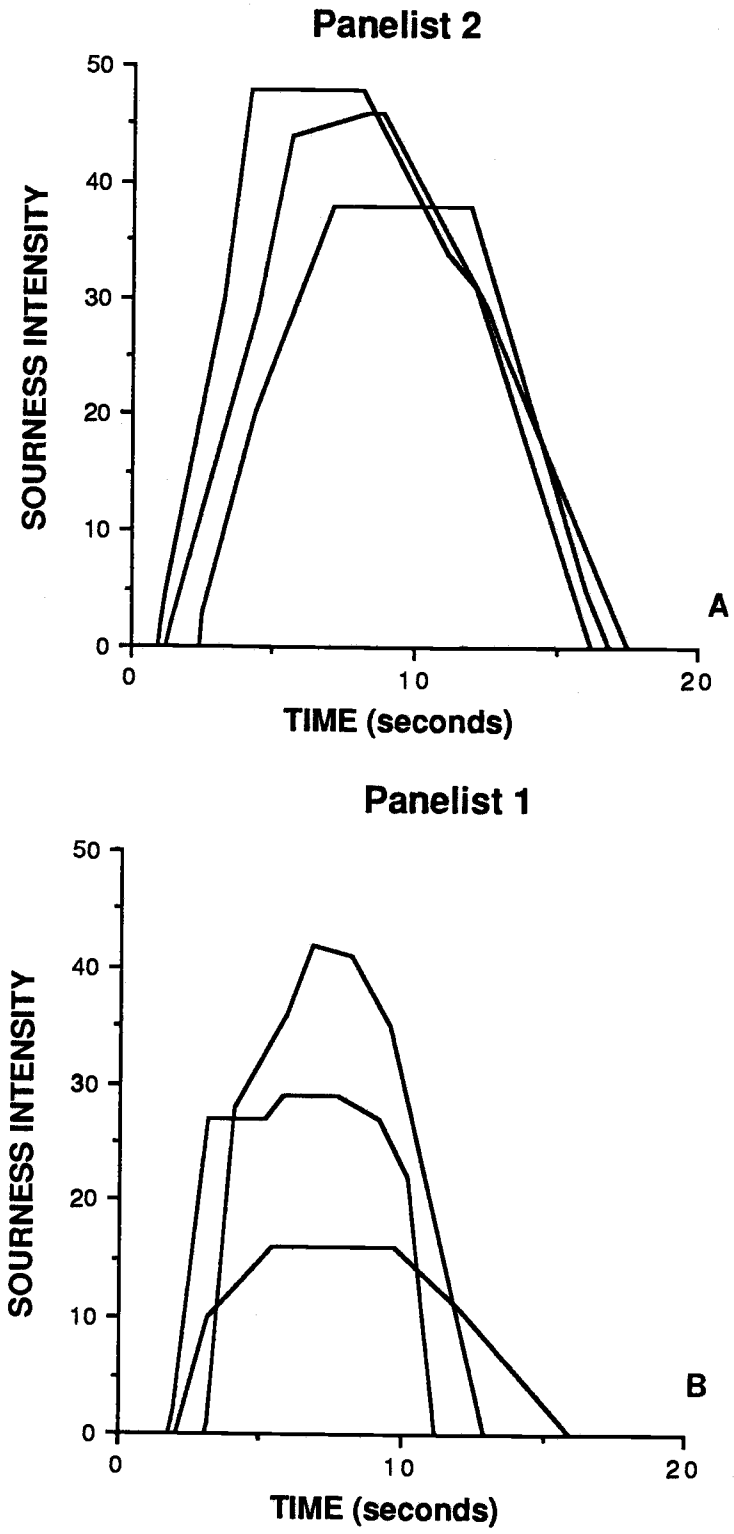

Fig. 9. Example of a)good replication and b)poor replication in the rating of the sourness of malic acid at level one sourness.

performance and the panelist with the worst, respectively.

c. Astringency of the level one and level two acid solutions - panel results.

The astringency of the level one and level two acid solutions will be referred to as A1 and A2, respectively. Analysis of variance generated the F-statistics shown in Table 17 and 18 for both sets of solutions. Prior to discussing the treatment effect, other main effects and their interactions will be discussed. There was a significant panelist effect for all parameters at both levels indicating, as in the sourness studies, that panelists were using different parts of the intensity scale and the astringency standard did not totally eliminate a panelist effect.

There were no significant panelist x treatment interaction effects for the responses for A2. However, there was a significant panelist x treatment interaction for the area under the curve parameter for A1 which indicates that the panelists were not consistent with each other in their judgments across acids for that parameter. There was a significant treatment x replication effect for peak time which means that for a given replication the panel rated the treatments in a different manner than for other replications.

Table 19 contains the response means of the parameters that were not significant for both A1 and A2, time to

Table 17. F-values for time-intensity parameters for astringency at level one acid solutions.

SOV	TIME-INTENSITY PARAMETERS[1]							
	T_i	I_{max}	T_{max}	T_p	A_p	D	P	A_c
Panelist	14.56***	28.10***	21.90***	5.21***	2.50*	25.00***	25.99***	23.73***
Treatment	1.53	26.28***	1.04	0.49	3.23**	13.13***	26.27***	28.32***
Panelist x Treatment	0.96	2.19	1.31	1.06	1.21	1.04	1.80	1.50
Replication	1.22	0.40	1.18	9.84***	7.85**	0.85	0.94	0.56
Panelist x Replication	0.92	4.37***	1.18	3.15***	3.31***	6.83***	6.09***	6.86***
Treatment x Replication	0.85	1.45	1.08	0.32**	0.78	1.18	1.51	1.84

*, **, and *** refer to $p<0.05$, $p<0.01$, and $p<0.001$, respectively.

[1] time to maximum intensity(T_i), maximum intensity(I_{max}), time to maximum intensity(T_{max}), peak time(T_p), peak area(A_p), duration(D), perimeter(P), area under curve(A_c).

Table 18. F-values for time-intensity parameters of astringency at level two acid solutions.

SOV	TIME-INTENSITY PARAMETERS[1]							
	T_i	I_{max}	T_{max}	T_p	A_p	D	P	A_C
Panelist	2.99**	24.42***	16.40***	7.03***	14.30***	21.50***	12.97***	27.70***
Treatment	1.61	22.92***	0.96	2.11*	8.69***	13.23***	20.74***	21.78***
Panelist x Treatment	1.11	1.79	0.70	1.30	2.10	1.18	1.41	1.69*
Replication	1.24	1.93	0.44	3.19*	3.35*	0.81	1.88	1.05
Panelist x Replication	2.38**	3.73***	1.19	0.94	1.15	1.49	2.51**	0.84
Treatment x Replication	0.51	1.10	0.72	1.11	1.52	1.11	1.02	1.18

*, **, and *** refer to $p<0.05$, $p<0.01$, and $p<0.001$, respectively.

[1] time to maximum intensity(T_i), maximum intensity(I_{max}), time to maximum intensity(T_{max}), peak time(T_p), peak area(A_p), duration(D), perimeter(P), area under curve(A_C).

Table 19. Response means and standard deviations (in parentheses) for non-significant time-intensity parameters for astringency of both the level one and level two acid solutions.

Curve Parameters*		ACIDS**						
		T	C	H	FQD	M	L	A
T_i	A1	2.17 (0.92)	2.28 (0.97)	2.38 (2.00)	2.46 (1.55)	3.02 (2.55)	3.18 (2.40)	3.23 (2.98)
T_i	A2	2.04 (0.81)	2.25 (1.91)	1.98 (1.24)	1.80 (0.89)	2.63 (2.39)	1.88 (1.58)	2.99 (2.48)
T_{max}	A1	9.57 (5.18)	8.53 (3.57)	9.99 (4.53)	10.17 (4.37)	9.59 (3.80)	9.12 (3.83)	8.71 (4.41)
T_{max}	A2	8.08 (2.75)	8.56 (3.02)	9.06 (3.56)	8.34 (2.90)	9.68 (3.99)	8.01 (4.38)	8.30 (4.85)
T_p	A1	3.78 (2.13)	3.98 (4.66)	4.32 (2.19)	3.88 (2.44)	3.34 (1.80)	4.32 (3.25)	4.35 (4.10)

* time to initial response (T_i), time to maximum intensity (T_{max}), peak time (T_p).

** tartaric(T), citric(C), hydrochloric(HCL), malic(M), fumaric-QD(FQD), lactic(L), acetic(A).

initial response and time to maximum intensity values generally decreased with increase in sourness level indicating the higher levels caused panelists to perceive the astringency more quickly.

There were significant treatment effects for maximum intensity, area under the curve, perimeter, duration, and peak area for A1 and A2, and peak time for A2. There were many differences between the acids based on the means of the significant time-intensity parameters (Table 20 and 21). Table 22 and 23, similar to Table 13 and 14 of the sourness studies, are summary tables showing the parameters in which any given pair of acids differed. The perimeter measurementallowed for the most differences to be detected between the acids for the astringency ratings.

For A1, HCl differed the most from the other acids, 30 out of the possible 30 times (100%), and was significantly larger in those parameters than all other acids. For A2, HCl was rated the most different based on the significant parameters and was different 29 out of the possible 36 times (80.6%). This acid generated the highest means in all the significant parameters except peak time.

Acetic acid also was different than the other acids, 13 out of the 30 times (43.3%), and was rated lower than all of the other acids in the significant parameters for A1. For A2 acetic acid was also quite different than the other acids and received low ratings for maximum intensity and area

Table 20. Response means and LSD's[1] for significant time-intensity parameters for astringency of the level one acid solutions.

Curve Parameters*	ACIDS** L	A	M	C	T	FQD	HCL	LSD
I_{max}	32^{a} (17)	40^{ab} (16)	48^{bc} (17)	45^{bc} (19)	49^{bc} (15)	55^{c} (19)	71^{d} (20)	10.5
A_c	490^{a} (418)	611^{ab} (535)	839^{bc} (512)	855^{bc} (628)	862^{bc} (484)	952^{c} (424)	1828^{d} (932)	341
P	85^{a} (45)	94^{ab} (39)	120^{c} (45)	118^{bc} (47)	122^{c} (32)	134^{c} (35)	179^{d} (51)	24.5
D	22.7^{a} (13.9)	23.1^{ab} (14.4)	28.7^{abc} (16.8)	30.6^{c} (18.4)	30.1^{bc} (11.7)	31.8^{c} (10.2)	47.1^{d} (23.4)	7.1
A_p	141^{a} (123)	173^{a} (190)	156^{a} (96)	169^{a} (178)	186^{a} (118)	196^{a} (167)	292^{b} (153)	79.4

* maximum intensity(I_{max}), area under the curve(A_c), perimeter(P), duration(D), area under the plateau (A_p).

** acetic(A), lactic(L), citric(C), malic(M), tartaric(T), fumaric-quick dissolve(FQD), hydrochloric(HCL).

^{abc} means with the same superscript are not significantly different at the $p<0.05$ level.

Table 21. Response means and LSD's[1] for significant time-intensity parameters for astringency of the level two solutions.

Curve Parameters*	ACIDS** L	A	M	C	FQD	T	HCL	LSD
I_{max}	38^{a} (18)	37^{a} (15)	49^{b} (18)	50^{bc} (16)	58^{c} (16)	52^{bc} (15)	68^{d} (14)	8.5
A_c	654^{a} (482)	618^{a} (366)	910^{ab} (620)	1082^{bc} (710)	1209^{bc} (591)	1265^{c} (861)	1874^{d} (727)	342.7
P	99^{a} (36)	99^{a} (28)	122^{ab} (36)	130^{bc} (38)	148^{c} (43)	135^{bc} (44)	179^{d} (37)	24.5
D	26.4^{a} (13.5)	26.4^{a} (11.1)	30.7^{ab} (13.3)	34.2^{bc} (14.9)	38.5^{c} (16.8)	37.2^{bc} (17.6)	50.5^{d} (16.1)	7.5
A_p	167^{a} (121)	172^{a} (116)	200^{a} (188)	229^{ab} (165)	236^{ab} (145)	363^{bc} (291)	400^{c} (301)	137.9
T_p	4.7^{ab} (2.9)	5.0^{ab} (3.6)	4.1^{a} (3.2)	4.4^{a} (2.5)	4.3^{a} (2.7)	6.5^{b} (3.9)	5.9^{ab} (4.2)	2.10

* maximum intensity(I_{max}), area under the curve(A_c), perimeter(P), duration(D), area under the plateau (A_p), plateau time (P_t).

** acetic(A), lactic(L), citric(C), malic(M), tartaric(T), fumaric-quick dissolve(FQD), hydrochloric acid(HCL).

^{abc} means with the same superscript are not significantly different at the $p<0.05$ level.

Table 22. Curve parameters[a] which were significantly different across pairs of acids[b] at level one astringency.

	ACIDS						
	L	A	C	M	T	HCL	FQD
L	-	none	1 - 4	3	3	all	all
A		-	4	1 - 3	1 - 4	all	none
C			-	none	none	all	none
M				-	none	all	none
T					-	all	none
H						-	all
FQD							-

[a] 1=maximum intensity, 2=area under the curve, 3=perimeter, 4=duration, 5=peak area

[b] lactic (L), acetic (A), citric (C), malic (M), tartaric (T), hydrochloric (HCL), fumaric-QD (FQD)

Table 23. Curve parameters[a] which were significantly different across pairs of acids[b] at level two astringency.

	ACIDS						
	L	A	C	M	T	HCL	FQD
L	-	none	1,3,4	1,3	1 - 5	1 - 5	1 - 4
A		-	1,3,4	1,3	1 - 5	1 - 5	1 - 4
C			-	none	6	1 - 5	3
M				-	2,3,4	1 - 5	1,3,4
T					-	1 - 4	6
H						-	1 - 5
FQD							-

[a] 1=maximum intensity, 2=area under the curve, 3=perimeter, 4=duration, 5=peak area, 6=peak time

[b] lactic (L), acetic (A), citric (C), malic (M), tartaric (T), hydrochloric (HCL), fumaric-QD (FQD)

under the curve for the panelists. It was different 19 out of 36 times (52.8%). Lactic and acetic acid did not differ from each other in any parameter. These extremes are shown in Fig. 10. The maximum intensity of astringency did not seem to change for lactic and not very much for HCl upon increase in acid concentration.For A1 the major fruit acids, citric, malic, and tartaric, did not differ from each other in astringency (Fig. 11a and b). More differences showed up in these upon the increase of acid concentration. Citric acid was significantly lower than tartaric acid in peak time for A2 (Fig. 12). Tartaric acid had higher means than malic for area under the curve, perimeter, and duration (Fig. 13).

d. Astringency of the level one and level two acid solutions - individual panelist results.

Table 24 and 25 show how panelists differed in their ability to discriminate between acids based on the time-intensity parameters (Appendices T and U show the means for each panelist for each parameter for A1 and A2, respectively). Panelist #1 and panelist #8 could not detect differences between the acids in astringency. However, upon increase in sourness level (Table 25), panelist #8 could differentiate between the acids. Panelist #3 became less sensitive and panelist #4 could not detect any differences upon the increase. For these panelists the astringency could have become so strong that they were overwhelmed and found all the solutions very astringent.

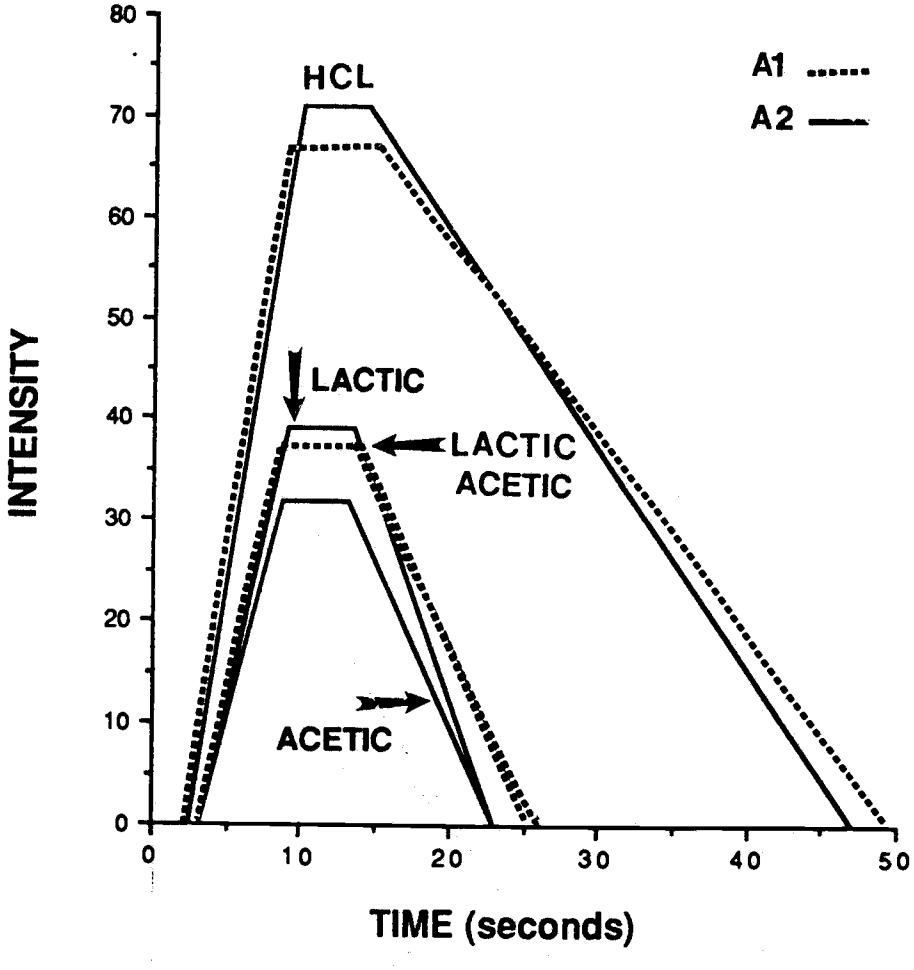

Fig. 10. Constructed time-intensity curves for the astringency of the level one acid solutions and the level two acid solutions of HCL, lactic, and acetic acid.

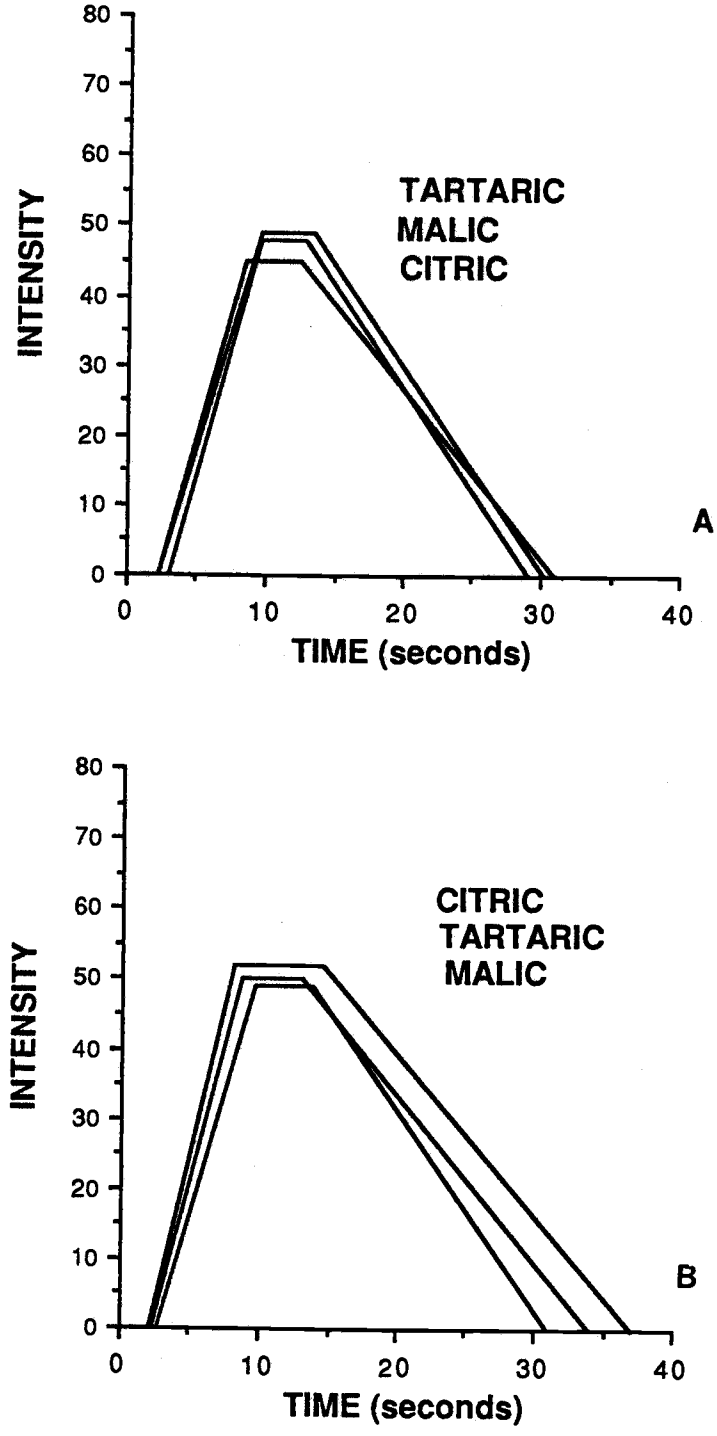

Fig. 11. Constructed time-intensity curves for the astringency of the a)level one and b)level two acid solutions for tartaric, malic and citric acid.

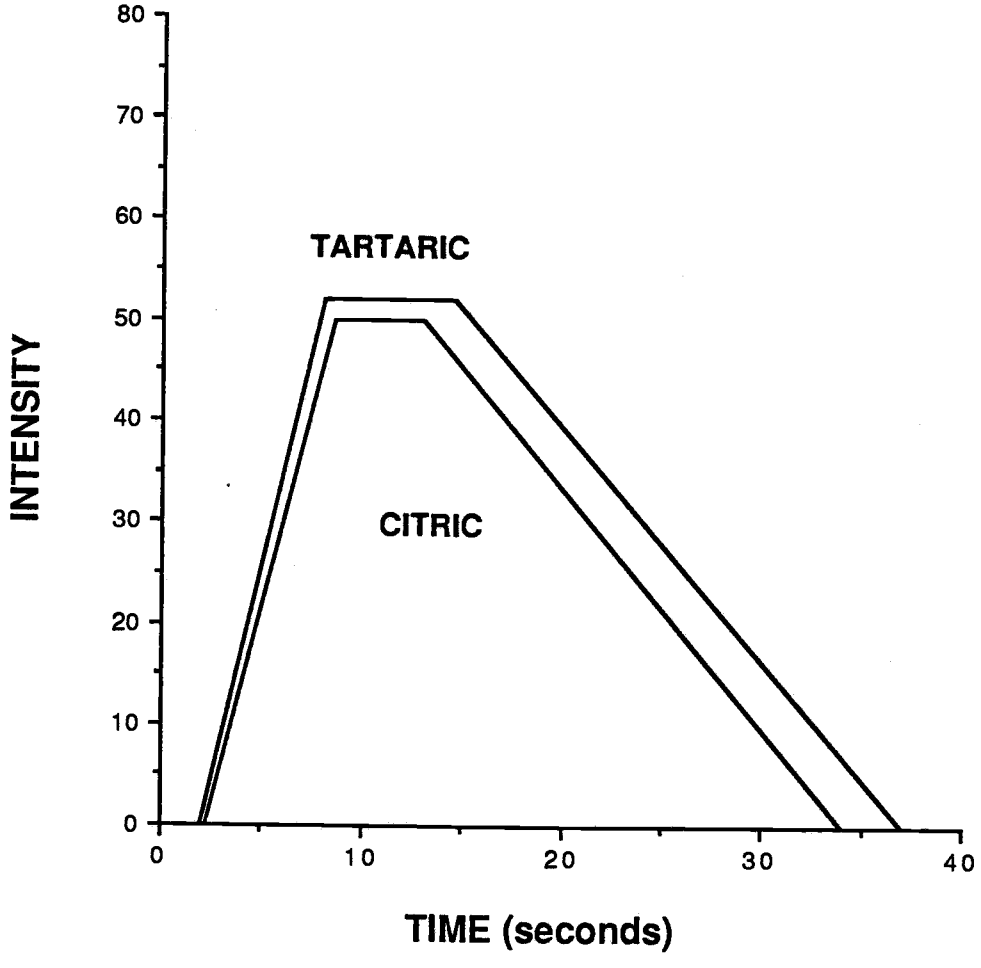

Fig. 12. Constructed time-intensity curves for the astringency of the level two acid solutions for tartaric and citric acid.

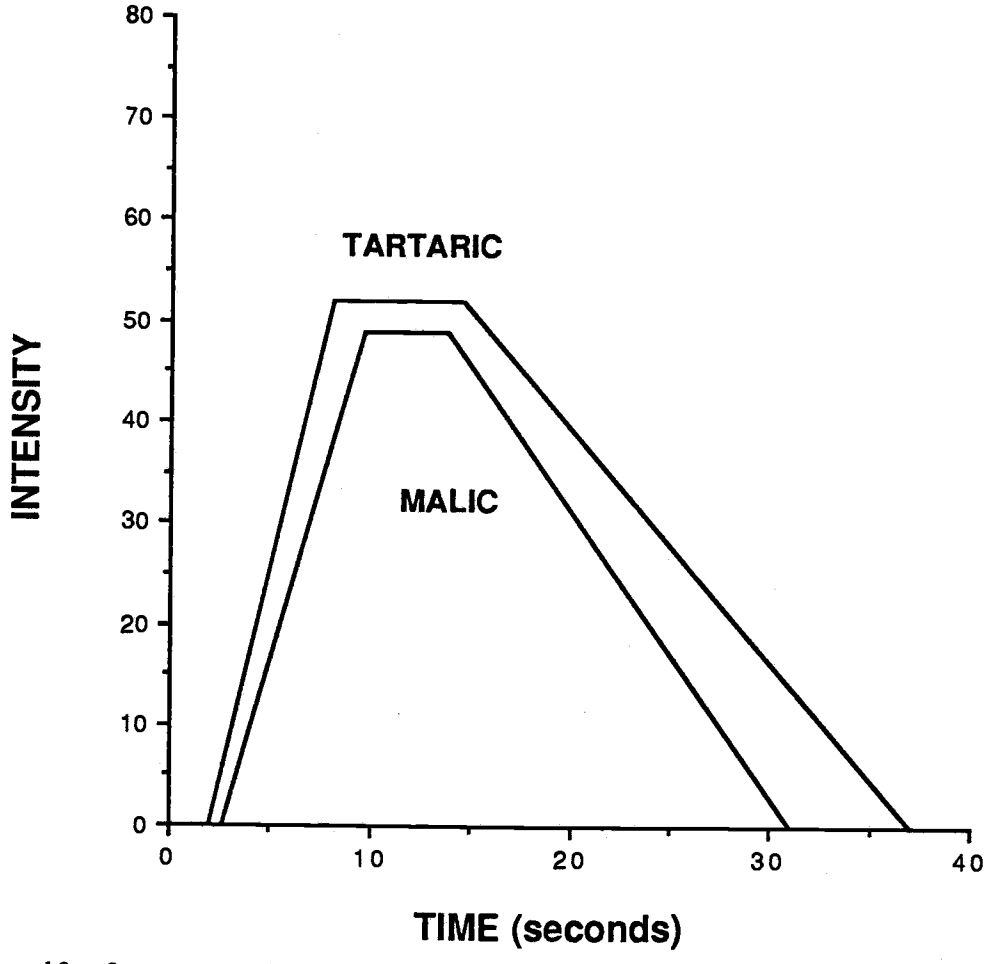

Fig. 13. Conctructed time-intensity curves for the astringency of the level two acid solutions for tartaric and malic acid.

Table 24. Significant parameters[ab] for individual panelists for the astringency of the level one acid solutions.

	PANELISTS							
Parameters	1	2	3	4	5	6	7	8
Imax	-	*	*	**	*	***	***	-
Ac	-	**	**	**	**	**	***	-
P	-	**	**	**	*	**	***	-
D	-	**	*	*	**	*	***	-
Ti	-	-	-	-	-	-	-	-
Tmax	-	-	-	-	-	-	-	-
Tp	-	-	-	-	-	-	-	-
Ap	-	*	-	-	-	-	**	-

[a] parameters in bold indicate those parameters that were significant to the panel

[b] maximum intensity (Imax), area under the curve (Ac), perimeter (P), duration (D), time to initial response (Ti), time to maximum intensity (Tmax), peak time (Tp), peak area (Ap)

*, **, and *** refer to $p<0.05$, $p<0.01$, and $p<0.001$, respectively

Table 25. Significant parameters[ab] for individual panelists for the astringency of the level two acid solutions

Parameters	PANELISTS 1	2	3	4	5	6	7	8
Imax	*	*	*	-	***	**	**	**
Ac	-	*	*	-	**	**	**	***
P	-	**	-	-	**	**	**	**
D	-	*	-	-	**	*	-	**
Ti	-	-	-	-	-	-	-	-
Tmax	-	-	-	-	-	-	-	-
Tp	-	-	-	-	-	*	-	-
Ap	*	*	**	-	-	**	*	-

[a] parameters in bold indicate those parameters that were significant to the panel

[b] maximum intensity (Imax), area under the curve (Ac), perimeter (P), duration (D), time to initial response (Ti), time to maximum intensity (Tmax), peak time (Tp), peak area (Ap)

*, **, and *** refer to $p<0.05$, $p<0.01$, and $p<0.001$, respectively

For A1, only 2 panelists could detect differences between the acids based on the peak area measurement, however that was enough to achieve panel significance. The increase in acid concentrations resulted in three more panelists being able to discriminate between the acids based on this parameter.

e. Time parameters of Sourness as compared to astringency.

It was noticed that the time parameters of sourness were shorter than those of astringency for the acids. There were no statistical tests carried out to show differences because the astringency and sourness studies were treated as separate experiments. However, the means will be mentioned here. The constructed time-intensity curves of sourness response overlaid by the astringency response for the level one and level two acid solutions are shown in Fig. 14 and 15, respectively.

The means of the time to initial response parameter show a tendency for the astringency response to occur after the sourness response. The time to initial response for S1 ranged from a low of 1.31 sec. for FQD to a high of 1.57 sec. for lactic acid. For A1 the time to initial response ranged from a low of 2.17 sec. for tartaric acid to a high of 3.23 sec. for acetic acid. For S2, time to initial response ranged from a low of 1.12 for FQD to a high of 1.82 for acetic acid. For A2, the response ranged from a low of

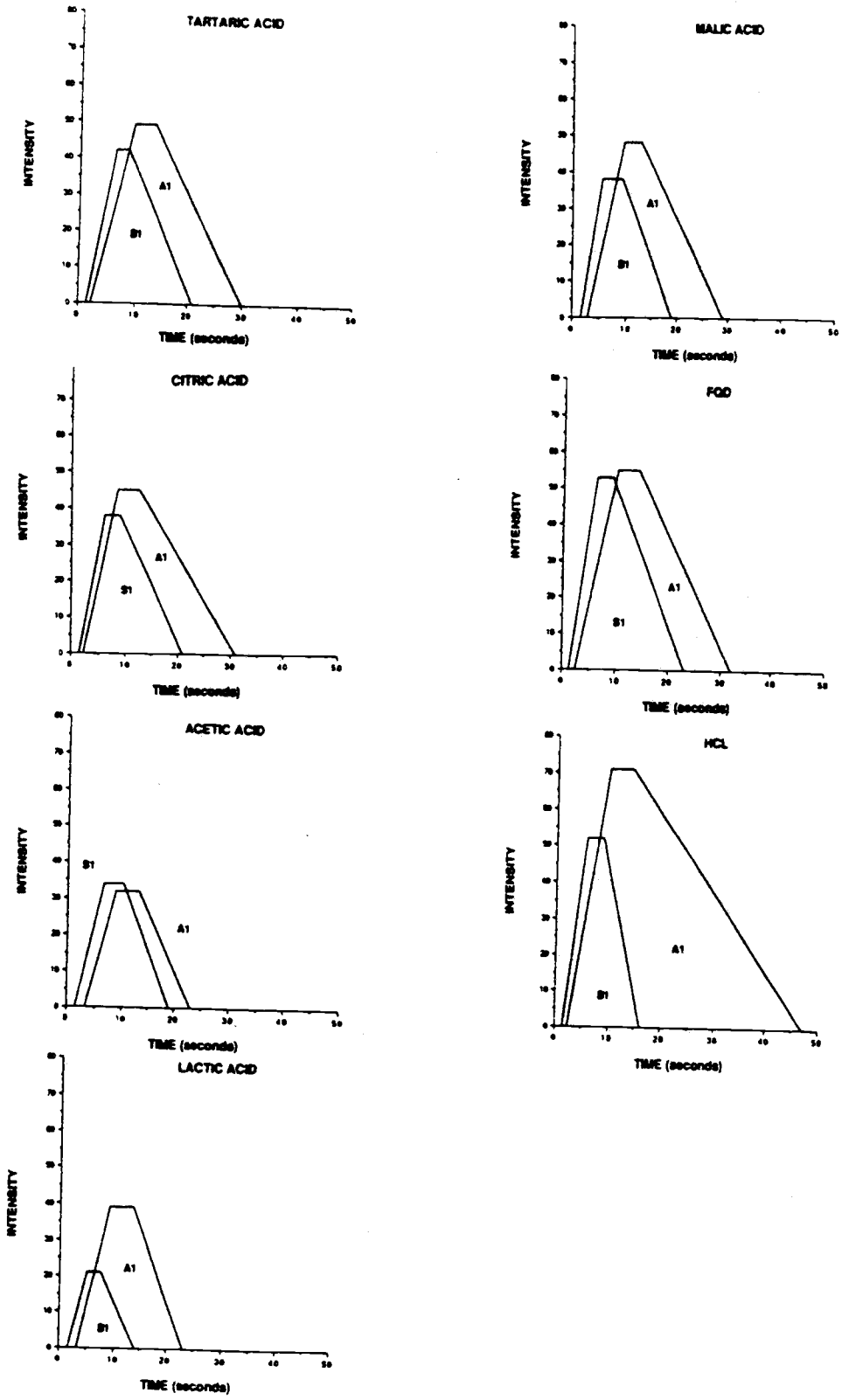

Fig. 14. Constructed time-intensity curves for seven acids showing the comparison of the sourness and astringency response for the level one acid solutions.

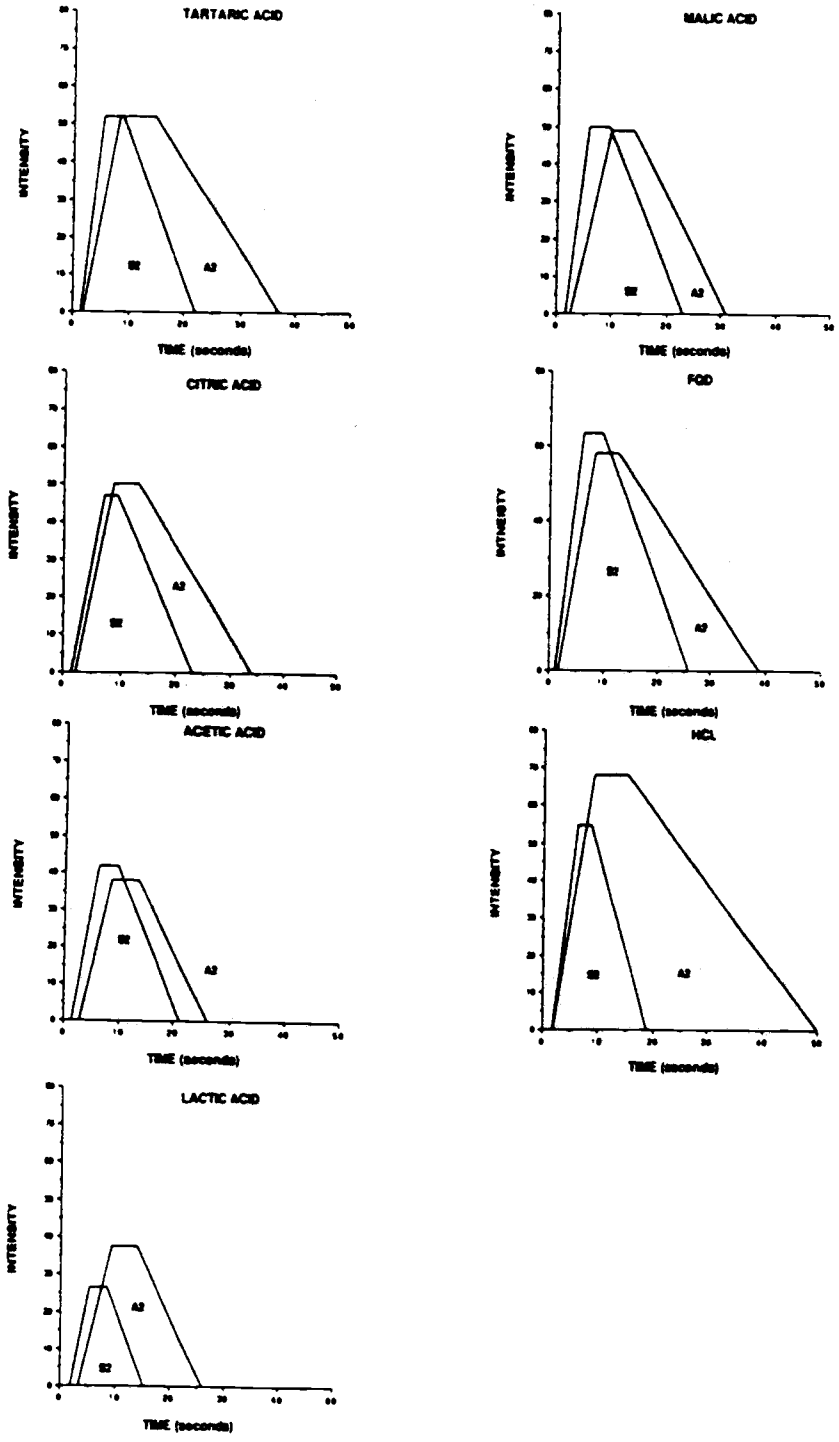

Fig. 15. Constructed time-intensity curves for seven acids showing the comparison of the sourness and astringency response for the level two acid solutions.

1.80 sec. for FQD to a high of 2.99 sec. for acetic acid.

The results also showed a tendency for the maximum astringency response to occur after the maximum sourness response. For sourness the time to maximum intensity values were between 5.0 and 6.6 seconds and for astringency the values ranged from 8.5 to 10.2 seconds. The peak time also tended to persist longer for astringency (3.3 to 6.5 sec.) as compared to sourness (2.3 to 3.7 sec.). The duration of the astringency response (23 to 50 sec.) was sometimes almost twice as long as the sourness response (15 to 26 sec.). The above tendencies indicated that astringency may be an aftertaste of the acid solutions.

f. Astringency/sourness ratios.

Some of the acids were much more astringent than they were sour so the ratio of the astringency to sourness response was calculated based on the area under the curve measurements. The astringency/sourness ratios (A/S) and their SD's for the level one and level two acid solutions are listed in Table 26. For level one, the F-statistic (1.78) generated did not show a significant difference between the acids even though mean ratio differences were large. This was probably due to the large SDs. However, for level two (F=3.54), the A/S for HCL and lactic acid was significantly larger than all of the other acids. HCL and lactic acid seem to be astringent acids as compared to the others. Also, lactic acid had a much larger SD than HCL

Table 26. Mean astringency/sourness ratios and their standard deviations of the level one and level two acid solutions.

Level One		Level Two	
HCL	4.4 (0.24)	HCL	3.7[a] (0.22)
Lactic	3.2 (1.87)	Lactic	3.2[a] (0.95)
Acetic	2.8 (1.30)	Tartaric	1.8[b] (0.72)
Tartaric	2.2 (0.96)	Citric	1.8[b] (0.63)
Malic	2.2 (0.59)	Malic	1.5[bc] (1.08)
Citric	2.1 (1.92)	FQD	1.5[bc] (0.68)
FQD	1.6 (0.65)	Acetic	1.4[c] (0.99)
		LSD[1]	0.36

[1] Least significant difference statistic ($p<0.05$).

[abc] means with the same superscript are not significantly different at the $p<0.05$ level.

especially at level one (approximately seven times higher).

Results from the power function study indicated that the power functions for lactic acid for each individual hada wide range (0.68-2.23) suggesting that lactic acid was perceived differently by each panelist. The high SD here also indicates high variability in the response to lactic acid. Tartaric and citric acid had significantly higher A/S values than acetic acid suggesting that tartaric and citric have more astringent characteristics as compared to acetic acid.

6.4 Correlation Analysis among Time-Intensity Parameters.

A correlation analysis was run to see the degree to which parameters studied described the same type of response. The parameters that described overall impact of a sensation, maximum intensity, perimeter, and area under the curve, would beexpected to correlate with one another as they often did in this analysis. The duration of sensation correlated with some of these overall impact parameters. Pangborn et al. (1983) found that the above four parameters were highly correlated in their study of the bitterness of iso- -acids. Another pair of parameters that frequently correlated in this study were peak time and peak area which was also expected. The presence of any correlation for two given parameters depended on which acid was involved in the correlation.

a. Sourness of the level one and the level two acid solutions.

Appendix Y displays the correlation coefficients and their degrees of significance for the eight acids. Tables 27 and 28 list which acids showed a correlation between two given parameters. Inspection of these tables show that the overall impact parameters, maximum intensity, perimeter, and area under the curve, and duration correlated for many of the acids which was expected. In fact, for both levels of sourness, maximum intensity and perimeter always correlated. Also, peak time correlated well with peak area which was also expected.

For S1, area under the curve and duration did not correlate for acetic acid. Also, perimeter and duration did not correlate for acetic acid. Increasing the acid concentrations resulted in area under the curve not correlating with maximum intensity, perimeter, or duration for tartaric acid. The frequency of this lack of correlation may suggest that acetic and tartaric acids have different temporal properties than the remaining five acids in the study.

The parameters involving time did not correlate with other parameters as frequently as did the overall impact parameters. This was expected because time parameters were relatively constant across acids. For example, maximum intensity and duration only correlated for lactic and HCL

Table 27. Frequency of correlations[a] between the time-intensity parameters[b] for the sourness of the level one solutions.[c]

	Ac	P	Imax	D	Ti	Tmax	Ap	Tp
Ac	-	all	AMCTHQ	LMCHQ	-M	-M	LH	LH
P		-	all	LMCTHQ	-Q	none	H	H
Imax			-	LH	-Q	-Q-C	LH	LH
D				-	none	-M	H	-A
Ti					-	LHQ	none	none
Tmax						-	-T	none
Ap							-	LMCHQ
Tp								-

[a] a negative sign before an acid indicates a negative correlation

[b] area under the curve (Ac), perimeter (P), maximum intensity (Imax), duration (D), time to initial response (Ti), time to maximum intensity (Tmax), peak area (Ap), peak time (Tp)

[c] L=lactic, A=acetic, M=malic, C=citric, T=tartaric, H=HCL, Q=FQD

Table 28. Frequency of correlations[a] between the time-intensity parameters[b] for the sourness of the level two solutions.[c]

	Ac	P	Imax	D	Ti	Tmax	Ap	Tp
Ac	-	LAMCHQ	LAMHQ	LAMH	none	-Q	AMT	none
P		-	all	LAMTH	none	none	none	none
Imax			-	ALH	none	none	none	none
D				-	none	none	none	none
Ti					-	L	L	none
Tmax						-	none	none
Ap							-	AMCTQH
Tp								-

[a] a negative sign before an acid indicates a negative correlation

[b] area under the curve (Ac), perimeter (P), maximum intensity (Imax), duration (D), time to initial response (Ti), time to maximum intensity (Tmax), peak area (Ap), peak time (Tp)

[c] L=lactic, A=acetic, M=malic, C=citric, T=tartaric, H=HCL, Q=FQD

acid for S1 and S2 and acetic for S2. The results of the time-intensity studies indicated that lactic acid was the weakest acid out of the group followed by acetic acid, while HCL was a strong acid. These two extremes could have somehow facilitated a correlation. For example, since lactic acid was such a weak acid, it is possible that it could have a shorter duration than the other acids. However, HCL was shown to have a short duration even though it was a strong acid.

Time to initial response occasionally correlated negatively with the overall impact parameters of maximum intensity, area under the curve, and perimeter. In a few instances, time to maximum intensity correlated negatively with area under the curve, perimeter, and duration. This is understandable, as a stronger stimulant might be perceived more quickly. For S1 malic acid and FQD were involved independently in three negative correlations, each between time and overall impact parameters. This suggests that the time parameters have a substantial influence on the overall impact parameters of malic acid and FQD.

Lactic acid was not involved in the S1 correlations and acetic and tartaric acid were not involved in the S2 correlations of peak time and peak area. For S1 peak area and peak time were frequently correlated with the overall impact parameters and duration for lactic and HCL only. This was not observed for S2. This, again, may suggest that

the weakness or strength of these two acids may make them sensitive to the correlation analysis.

The time parameters, excluding duration, in general did not correlate with each other. Time to initial response and time to maximum intensity correlated for lactic, HCL, and FQD for S1, but only for lactic acid for S2. Again, these acids were extremes, FQD being the most intense acid based on the time-intensity studies. If HCL and FQD had a short time to initial response, they would be considered "quick" and would probably also have a short time to maximum intensity. One might expect a weak acid to have a longer time to initial response followed by a long time to maximum intensity.

Overall, more correlations were found in S1 than in S2. More differences between acids may have been noticed at lower sourness levels while they were hidden at higher sourness levels simply due to the higher overall impact.

b. Astringency of the level one and level two acid solutions.

Correlations between the overall impact parameters were not as frequent for astringency as for sourness (Table 29 and 30). For A1, citric acid was never involved in a significant correlation for these parameters. However, for A2 there was always a significant correlation between area under the curve and perimeter with maximum intensity for lactic, acetic, malic, and citric acid. The major

Table 29. Frequency of correlations[a] between the time-intensity parameters[b] for the astringency of the level one solutions.[c]

	Ac	P	Imax	D	Ti	Tmax	Ap	Tp
Ac	-	LACTQ	LAMC	LAMT	-H	-Q	LTH	T
P		-	LAMTHQ	LT	-T -H	-H -Q	LT	none
Imax			-	none	-T	none	-H	ATF
D				-	none	none	LA	T
Ti					-	LAMC	C	LC
Tmax						-	none	none
Ap							-	ACT
Tp								-

[a] a negative sign before an acid indicates a negative correlation

[b] area under the curve (Ac), perimeter (P), maximum intensity (Imax), duration (D), time to initial response (Ti), time to maximum intensity (Tmax), peak area (Ap), peak time (Tp)

[c] L=lactic, A=acetic, M=malic, C=citric, T=tartaric, H=HCL, Q=FQD

Table 30. Frequency of correlations[a] between the time-intensity parameters[b] for the astringency of the level two solutions.[c]

	Ac	P	Imax	D	Ti	Tmax	Ap	Tp
Ac	-	LAMCQ	LAMC	LC	M	none	LC	none
P		-	LAMCQ	LAC	M -H	-T	LC	none
Imax			-	L	none	-T -H	LC	none
D				-	M	none	L	none
Ti					-	A	none	AT
Tmax						-	none	A
Ap							-	MCH
Tp								-

[a] a negative sign before an acid indicates a negative correlation

[b] area under the curve (Ac), perimeter (P), maximum intensity (Imax), duration (D), time to initial response (Ti), time to maximum intensity (Tmax), peak area (Ap), peak time (Tp)

[c] L=lactic, A=acetic, M=malic, C=citric, T=tartaric, H=HCL, Q=FQD

difference between the astringency correlations and the sourness correlations is that duration did not correlate with area under the curve and perimeter for the astringency data.

For A1 time to initial response and time to maximum intensity correlated negatively with perimeter and for A2 time to maximum intensity correlated negatively with maximum intensity for HCL. For tartaric acid time to initial response correlated negatively with perimeter and maximum intensity for A1 and time to maximum intensity correlated negatively with perimeter and duration.

Peak area and peak time correlated less frequently for the astringency studies. For both A1 and A2 this correlation occurred only three times and for different acids at each level. For A2 peak area correlated with all overall impact parameters but for lactic and citric only. Peak area correlated with four out of eight acids for A1 and A2 and the common acids were citric and fumaric.

For time to initial response and time to maximum intensity at both A1 and A2 there were many negative correlations involving HCL and tartaric acid and some involving FQD.

6.5 Correlation Analysis between Sensory Measurements and Chemical Measurements.

An attempt was made to relate the sourness and astringency responses to some of the chemical

characteristics of the acids. The results of the chemical measurements and some of their inherent characteristics of the acids are listed in Table 31. To determine if any of the sensory responses could be related to the acid characteristics a correlation analysis was run. The results for S1, S2, A1, and A2 can be found in Table 32, 33, 34, and 35, respectively.

HCL was excluded from these analyses because it is 100% dissociated and therefore does not have a pK_a. The pK_a (from the first dissociation constant) and the number of carboxyl groups (# COOH) are constant for a given acid. Total acidity and titratable acidity depend on how much acid is in the solution. The pH, molarity (M), and normality (N) depend on the acids characteristics which are basically constant and the amount of acid present in the solution.

a. Sourness of the level one and level two acid solutions.

Most of the correlations included the curve shape parameters, area under the curve and perimeter, in addition to maximum intensity and duration. For level one, the highest correlations were obtained for pK_a with each of the above four parameters suggesting that the sourness of an acid is related to its respective pK_a. The next highest correlations were with normality.

For level two the highest correlations were obtained for normality with pK_a following close behind. The data in

Table 31. The chemical indices of the level one and level two acid solutions.

Chemical Indices	Level	Lactic	Acetic	Malic	Citric	Tartaric	FQD	HCL
pH	I	3.07	3.47	3.16	3.10	2.99	2.98	2.33
	II	2.95	3.35	3.01	2.77	2.72	2.73	2.16
Titratable Acidity (%w/v)	I	0.33	0.44	0.46	0.51	0.43	0.46	0.24
	II	0.64	0.71	0.83	1.00	0.93	0.89	0.36
Total Acidity (%w/v)	I	0.029	0.034	0.037	0.041	0.037	0.036	0.016
	II	0.056	0.066	0.075	0.083	0.0754	0.076	0.023
Molarity	I	0.00318	0.00567	0.00279	0.00214	0.00247	0.00313	0.00427
	II	0.00618	0.01095	0.00559	0.00433	0.00500	0.00659	0.00630
Normality	I	0.00318	0.00567	0.00558	0.00642	0.00494	0.00626	0.00427
	II	0.00618	0.01095	0.01118	0.01299	0.01000	0.01318	0.00630
# COOH[1]		1	1	2	3	2	2	0
pK_a[2]		3.86	4.74	3.40	3.09	2.98	3.00	-

[1] number of carboxyl groups (# COOH).

[2] the pK_a is from the first dissociation constant.

Table 32. Correlation coefficients for the sensory responses compared to the chemical characteristics of the acids for the sourness of the level one acid solutions.

Chemical Indices	Sensory[1]							
	A_c	P	I_{max}	D	T_i	T_{max}	A_p	T_p
pH	-0.36	-0.38	-0.38	-0.15	0.20	0.08	0.03	0.38
Total Acidity (g/L)	-0.38	-0.40	-0.40	-0.45*	0.11	-0.47*	-0.49*	-0.38
Titratable Acidity (g/L)	-0.48*	-0.49*	-0.47*	-0.63**	0.21	-0.51*	-0.34	-0.19
Molarity	-0.50*	-0.52*	-0.50*	-0.50*	0.11	-0.04	-0.21	0.12
Normality	0.66**	0.71***	0.71***	0.56**	-0.28	0.35	0.57**	0.13
# COOH[2]	0.51*	0.52*	0.50*	0.57**	-0.17	0.11	0.28	-0.04
pKa[3]	0.73***	0.74***	0.75***	0.60**	-0.31	0.27	0.22	-0.26

[1] area under the curve (A_c), perimeter (P), maximum intensity (I_{max}), duration (D), time to initial response (T_i), time to maximum intensity (T_{max}), peak area (A_p), peak time (T_p).
[2] number of carboxyl groups (# COOH).
[3] the pK_a is from the first dissociation constant.

Table 33. Correlation coefficients for the sensory responses compared to the chemical characteristics of the acids for the sourness of the level two acid solutions.

Chemical Indices	Sensory[1]							
	A_c	P	I_{max}	D	T_i	T_{max}	A_p	T_p
pH	-0.35	-0.43	-0.45	-0.25	0.28	-0.09	-0.06	0.22
Total Acidity (g/L)	-0.29	-0.25	-0.24	-0.38	0.04	-0.26	-0.13	0.02
Titratable Acidity (g/L)	-0.35	-0.34	-0.28	-0.56**	0.11	-0.32	-0.10	0.09
Molarity	-0.43	-0.53*	-0.50*	-0.54*	0.14	-0.23	-0.13	0.17
Normality	0.80***	0.80***	0.82***	0.70***	-0.31	0.47*	0.36	-0.15
# COOH[2]	0.48*	0.57**	0.53*	0.63**	-0.17	0.42	0.09	-0.26
pKa	0.67***	0.74***	0.75***	0.58**	-0.32	0.27	0.25	-0.20

[1] area under the curve (A_c), perimeter (P), maximum intensity (I_{max}), duration (D), time to initial response (T_i), time to maximum intensity (T_{max}), peak area (A_p), peak time (T_p).
[2] number of carboxyl groups (# COOH).
[3] the pK_a is from the first dissociation constant.

Table 34. Correlation coefficients for the sensory responses compared to the chemical characteristics of the acids for the astringency of the level one acid solutions.

Chemical Indices	Sensory[1]							
	A_c	P	I_{max}	D	T_i	T_{max}	A_p	T_p
pH	-0.38	-0.46*	-0.39	-0.48*	0.33	-0.28	-0.08	0.18
Total Acidity (g/L)	-0.18	-0.17	-0.27	-0.02	-0.15	0.07	-0.17	0.02
Titratable Acidity (g/L)	-0.39	-0.36	-0.37	-0.30	0.22	0.18	-0.23	0.04
Molarity	-0.62**	-0.66**	-0.57**	-0.66**	0.51*	-0.09	-0.12	0.23
Normality	0.55*	0.61**	0.65**	0.45*	-0.01	0.06	0.31	-0.14
# COOH[2]	0.60**	0.62**	0.53*	0.64*	-0.48*	-0.02	0.13	-0.18
pKa	0.69***	0.77***	0.73***	0.70***	-0.51*	0.15	0.31	-0.18

[1] area under the curve (A_c), perimeter (P), maximum intensity (I_{max}), duration (D), time to initial response (T_i), time to maximum intensity (T_{max}), peak area (A_p), peak time (T_p).
[2] number of carboxyl groups (# COOH).
[3] the pK_a is from the first dissociation constant.

Table 35. Correlation coefficients for the sensory responses compared to the chemical characteristics of the acids for the astringency of the level two acid solutions.

Chemical Incices	Sensory[1] A_c	P	I_{max}	D	T_i	T_{max}	A_p	T_p
pH	-0.70***	-0.66**	-0.66	-0.64**	0.64**	0.08	-0.52*	-0.15
Total Acidity (g/L)	0.22	0.14	0.14	0.13	-0.61**	-0.20	0.15	0.01
Titratable Acidity (g/L)	0.03	0.01	0.01	0.01	-0.59**	-0.12	-0.04	-0.08
Molarity	-0.70***	-0.66**	-0.69***	-0.58*	0.24	-0.22	-0.48*	-0.03
Normality	0.45*	0.64**	0.66**	0.54*	-0.06	0.25	0.09	-0.21
# COOH[2]	0.63**	0.64**	0.66**	0.55**	-0.15	0.21	0.35	-0.08
pKa	0.87***	0.85***	0.85***	0.82***	-0.40	0.05	0.67***	0.21

[1] area under the curve (A_c), perimeter (P), maximum intensity (I_{max}), duration (D), time to initial response (T_i), time to maximum intensity (T_{max}), peak area (A_p), peak time (T_p).
[2] number of carboxyl groups (# COOH).
[3] the pK_a is from the first dissociation constant.

Table 32 and 33 also show significant negative correlations for molarity, pH, total acidity, and titratable which is expected because it takes a more concentrated solution of a weak acid to be equally sour to a stronger one.

Area under the curve, perimeter, maximum intensity, and duration also correlated with # COOH. As stated above the pK_a and # COOH are constant for a given acid. The calculation of molarity and normality both depend to an extent on the endogenous characteristics of an acid (# COOH and molecular weight). There is not as much correlation between pH, titratable acidity and total acidity with area under the curve, perimeter, maximum intensity, and duration. These chemical indices all depend on how much acid is present.

Many studies have been conducted whose goal was to attempt to relate chemical measurements of acids to their sourness. A strong theory on what elicits the sour taste has not resulted. Since there is not a complete understanding of the mechanism involved in sourness perception, it is difficult to fully explain the results. For example, why is duration related to all but pH in level one and all but pH and total acidity in level two? It may be due to the fact that duration appeared to depend on maximum intensity, area under the curve, and perimeter and if they are influenced by these chemical measurements, they probably influence duration indirectly. However, titratable

acidity is not related to area under the curve, perimeter, and maximum intensity, but is very highly correlated with duration (Table 33).

Few correlations were found for time to maximum intensity, and peak area, and none were found for time to initial response or peak time. For S1, time to maximum intensity was correlated with total and titratable acidity which indicates that time to maximum was dependent on how much acid was used in making up the solutions. For S2, normality correlated with time to maximum intensity. This measurement combines the amount of acid added and its constant characteristics (molecular weight and #COOH).

Peak area was correlated (negatively) with total acidity in S1 and normality suggesting that this parameter was related to the strength of the acid and its constant characteristics. No correlations were found for peak area for S2.

b. Astringency of the level one and level two solutions.

Similar results were obtained for the astringency ratings where area under the curve, perimeter, maximum intensity, and duration were highly correlated with molarity, normality, # COOH, and pK_a (Table 34 and 35). However, these relationships seemed to be slightly stronger than those for sourness.

Total and titratable acidity were never related to the

above four chemical parameters and in fact had correlation coefficients that were almost zero as compared to those of sourness which were between .3 and .4. For A1 pH correlated negatively with perimeter and duration which suggests that the pH of an acid is related to the length of time of the perceived intensity of astringency. For A2 those correlations were much stronger and area under the curve and maximum intensity also correlated with pH. This may suggest that the pH of an acid is more related to astringency than sourness since there were no correlations for pH paired with the sourness ratings. Another difference is that the duration of astringency was not related to titratable acidity as it was in the sourness ratings.

Time to initial response, which was not significantly correlated in for sourness, was correlated for some of the chemical measurements in the astringency studies. For A1, molarity, # COOH, and pK_a was related to time to initial response. Three different parameters correlated with time to initial response for A2, these being pH, total and titratable acidity. This suggests that as the acid concentration is increased, the astringency response depends more on the amount of acid present rather than the actual chemistry of the acid itself. For A2, pH and molarity correlated with peak area. There was a very strong correlation for pK_a and peak area.

6.6 Principal Component Analysis.

The objective of this portion of the data analysis was first to see the relationship among the acids and to try to separate them based on their time-intensity parameters. Another objective was to see if any of the time-intensity parameters could be grouped in order to find parameters that were possibly measuring the same sensory characteristics. The weights, eigenvalues, proportion of variation, and cumulative variation for each of the four experiments can be found in Table 36, 37, 38 and 39.

The number of components retained in the discussion of the time-intensity parameters and scores of the acids was determined by the rule of "eigenvalue greater than one" (Piggott and Sherman, 1986). A component is considered important if at least as much variance of the individual variable is accounted for (Bernstein et al., 1988). Based on the ANOVA (Appendix Z) of the scores, for all four experiments, S1, S2, A1, and A2, some acids were separated significantly according to principal component one.Principal component two and three did not include significantly different acids.

a. Sourness of the level one acid solutions.

The first two components accounted for 51.50% and 20.01% of the variation for a total of 71.51% (Table 36). The acids were separated the most according to principal component one (Fig. 16a). The time-intensity parameters

Table 36. The weights, eigenvalues, proportion of variation, and cumulative variation of the results of sourness of the level one acid solutions.

Curve Parameters[1]	Prin. Comp.1	Prin. Comp.2	Prin. Comp.3
A_c	**0.47767**	-0.12873	0.03999
P	**0.46663**	-0.12609	0.01444
I_{max}	**0.45595**	-0.09764	0.04010
D	0.38337	0.02003	-0.01324
T_{max}	0.25100	-0.01907	0.62216
T_p	0.04718	**0.75795**	-0.12155
A_p	0.32497	**0.54252**	-0.19643
T_i	-0.16850	0.29734	0.74564
Eigenvalue	4.12002	1.60087	0.89228
Proportion	51.50%	20.01%	11.15%
Cumulative	51.50%	71.51%	82.67%

[1] area under the curve (A_c), perimeter (P), maximum intensity (I_{max}), duration (D), time to maximum intensity (T_{max}), peak time (T_p), peak area (A_p), time to initial response (T_i).

Table 37. The weights, eigenvalues, proportion of variation, and cumulative variation of the results of sourness of the level two acid solutions.

Curve Parameters[1]	Prin. Comp.1	Prin. Comp.2	Prin. Comp.3	Prin. Comp.4
A_c	0.47238	0.06299	-0.01266	-0.03762
P	0.45744	0.15647	-0.02604	-0.29420
I_{max}	0.44053	0.16233	-0.00889	-0.46392
D	0.41868	0.04881	-0.09563	0.55240
T_p	0.14064	-0.62522	0.36797	0.27133
T_{max}	0.12847	0.59057	0.32054	0.50239
A_p	0.36544	-0.40075	0.29171	-0.05336
T_i	-0.16855	0.20628	0.81665	-0.25061
Eigenvalue	4.33763	1.84341	1.09651	0.47969
Proportion	54.22%	23.04%	13.71%	6.00%
Cumulative	54.22%	77.26%	90.97%	96.97%

[1] area under the curve (A_c), perimeter (P), maximum intensity (I_{max}), duration (D), time to maximum intensity (T_{max}), peak time (T_p), peak area (A_p), time to initial response (T_i).

Principal component two and three did not include significantly different acids.

a. Sourness of the level one acid solutions.

The first two components accounted for 51.50% and 20.01% of the variation for a total of 71.51% (Tab. 36). The acids were separated the most according to principal component one (Fig. 16a). The time-intensity parameters plotted on the first two principal components are shown in Fig. 16b. It can be observed from Fig. 16b. and Tab. 36 that area under the curve, perimeter, and maximum intensity received the most weight in principal component one, and duration and time to maximum intensity received slightly less weight. This suggests that the acids were separated mostly in terms of area under the curve, perimeter, and maximum intensity. Peak area and peak time are weighted the most in principal component two with less weight on time to initial response. In the plane formed by the first two principal components FQD had significantly higher scores than all other acids in principal component one and lactic acid had significantly lower scores than all other acids. None of the other acids were different from each other.

b. Sourness of the level two acid solutions.

The data from S2 generated three principal components. These components accounted for 54.22%, 23.04%, and 13.71% of the variation, respectively for a total of 90.97% (Tab. 37). The acids were separated mainly by principal component one

Table 39. The weights, eigenvalues, proportion of variation, and cumulative variation of the results of astringency of the level two acid solutions.

Curve Parameters[1]	Prin. Comp.1	Prin. Comp.2	Prin. Comp.3	Prin. Comp.4
A_c	0.45258	0.07416	0.02335	-0.01004
P	0.43976	0.16251	-0.03023	-0.31176
I_{max}	0.43618	0.13184	-0.09059	-0.31248
D	0.43563	0.14554	0.04809	0.06769
A_p	0.38379	-0.35778	0.19480	0.10226
T_{max}	0.06546	0.66478	0.33793	0.61016
T_p	0.19259	-0.59117	0.38905	0.39762
T_i	-0.18191	0.10052	0.82735	-0.50954
Eigenvalue	4.78294	1.76007	1.13540	0.17810
Proportion	59.79%	22.00%	14.19%	1.20%
Cumulative	59.79%	81.79%	95.98%	97.18%

[1] area under the curve (A_c), perimeter (P), maximum intensity (I_{max}), duration (D), time to maximum intensity (T_{max}), peak time ($Tp_)$, peak area (A_p), time to initial response (T_i).

plotted on the first two principal components are shown in Fig. 16b. It can be observed from Fig. 16b. and Table 36 that area under the curve, perimeter, and maximum intensity received the most weight in principal component one, and duration and time to maximum intensity received slightly less weight. This suggests that the acids were separated mostly in terms of area under the curve, perimeter, and maximum intensity. Peak area and peak time are weighted the most in principal component two with less weight on time to initial response. In the plane formed by the first two principal components FQD had significantly higher scores than all other acids in principal component one and lactic acid had significantly lower scores than all other acids. None of the other acids were different from each other.

b. Sourness of the level two acid solutions.

The data from S2 generated three principal components. These components accounted for 54.22%, 23.04%, and 13.71% of the variation, respectively for a total of 90.97% (Table 37). The acids were separated mainly by principal component one (Fig. 17a). Area under the curve, perimeter, and maximum intensity were weighted heavily in principal component one and were able to separate the acids the most. Duration was weighted slightly less (Table 37).The acids are plotted on the first two principal components and principal component 1 v.s. principal component 3 in Fig. 17b and Fig. 18b, respectively. For principal component one, FQD had

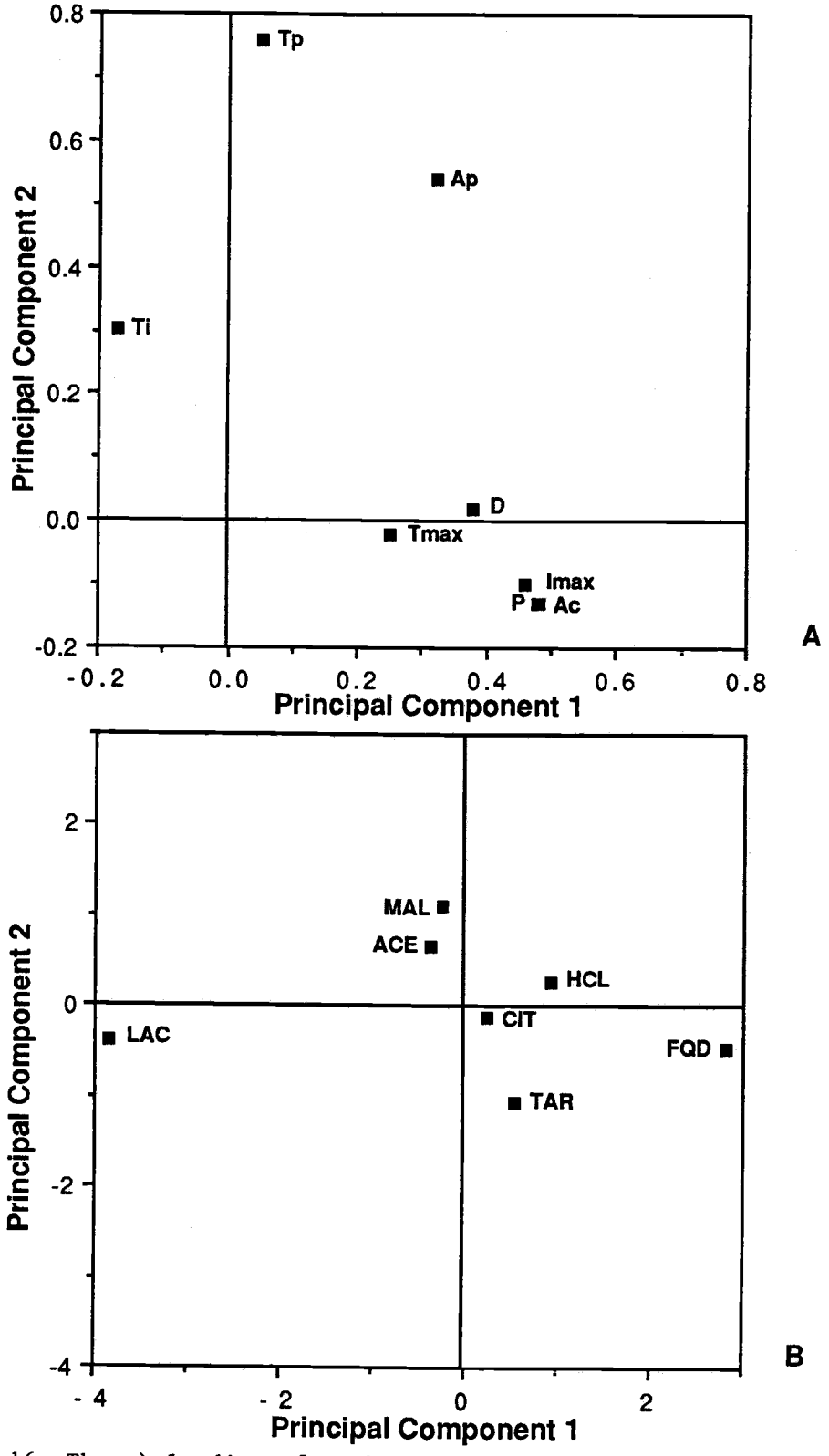

Fig. 16. The a) loadings for the time-intensity parameters and b)scores of the seven acids on the first and second principal components for the sourness of the level one acid solutions.

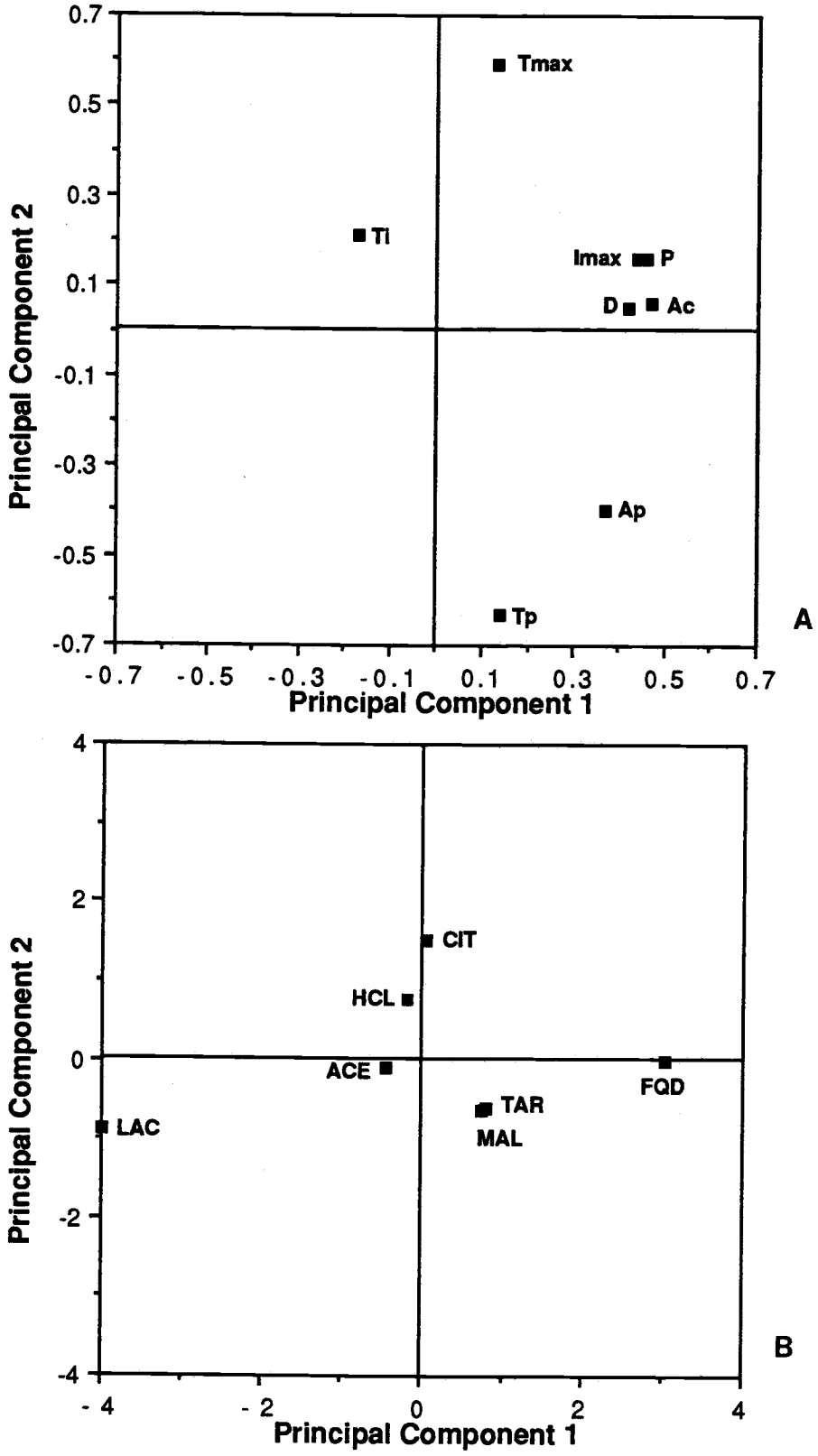

Fig. 17. The a)loadings for the time-intensity parameters and b)scores of the seven acids on the first and second principal components for the sourness of the level two acid solutions.

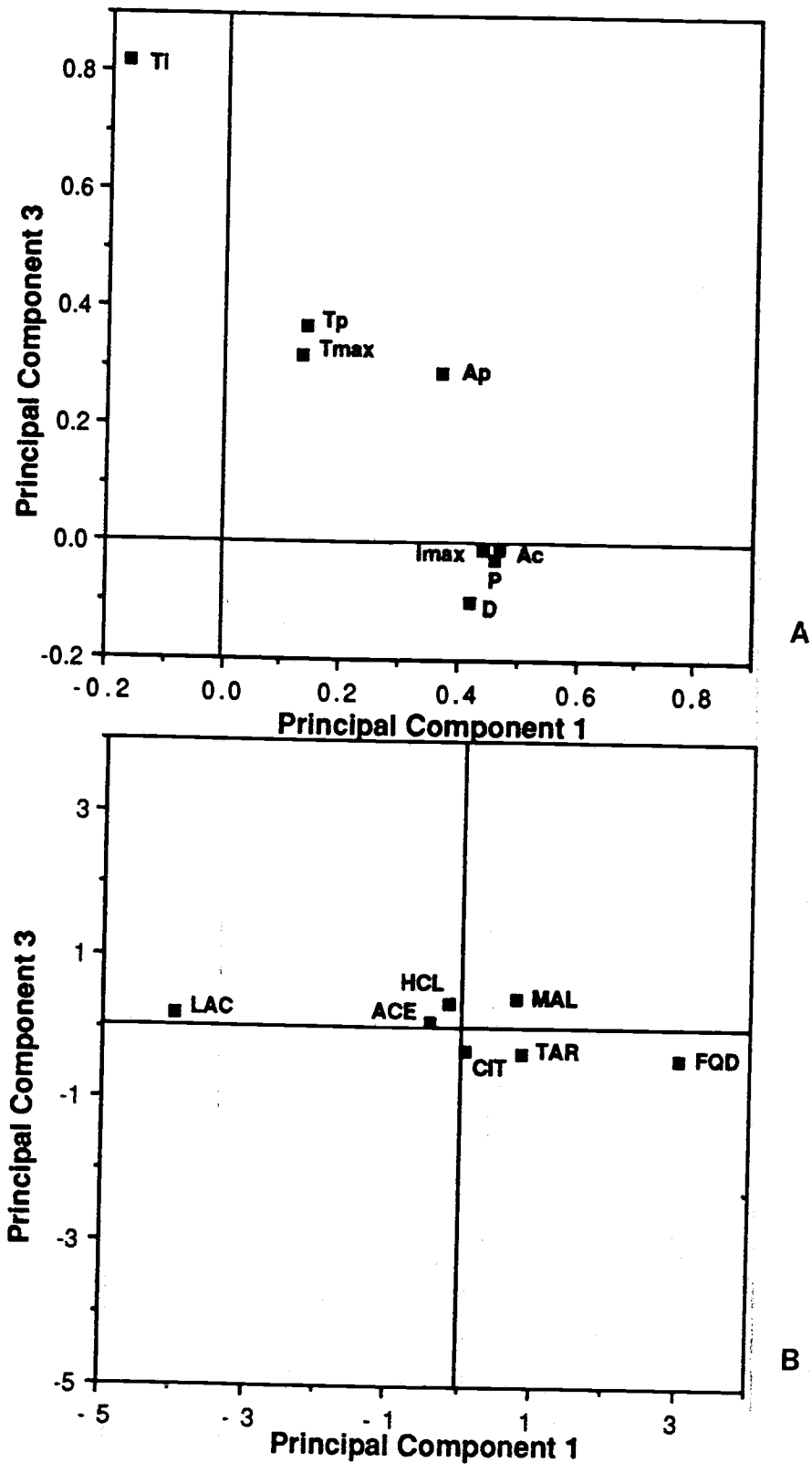

Fig. 18. The loadings of the time-intensity parameters and b)scores of seven acids on the first and third principal components for the sourness of the level two acid solutions.

significantly higher and lactic acid had significantly lower scores than all of the other acids. Tartaric acid had significantly higher scores than acetic acid. Malic acid, citric acid, and HCL were not significantly different in principal component 1. Time to maximum intensity, peak area, and peak time were weighted heavily in principal component two. In this component time to maximum intensity was negatively correlated with peak area and peak time. Principal component three had a large loading for time to initial response. The time-intensity parameters plotted on the first two principal components and principal component 1 v.s. principal component 3, respectively are shown in Fig. 17a and Fig. 18a.

c. Astringency of the level one acid solutions.

The first two principal components accounted for 62.58% and 20.43% for a total of 83.02% of the variation (Table 38). The time-intensity parameters and the acids are plotted on the first two principal components in Fig. 19a and b. Duration, area under the curve, perimeter, and maximum intensity were weighted heaviest in principal component one and with slightly less weight on peak area. For principal component two peak time, time to initial response, and time to maximum intensity received high weights. Time to initial response and time to maximum intensity were negatively correlated with peak time. For principal component one, HCL had significantly higher scores

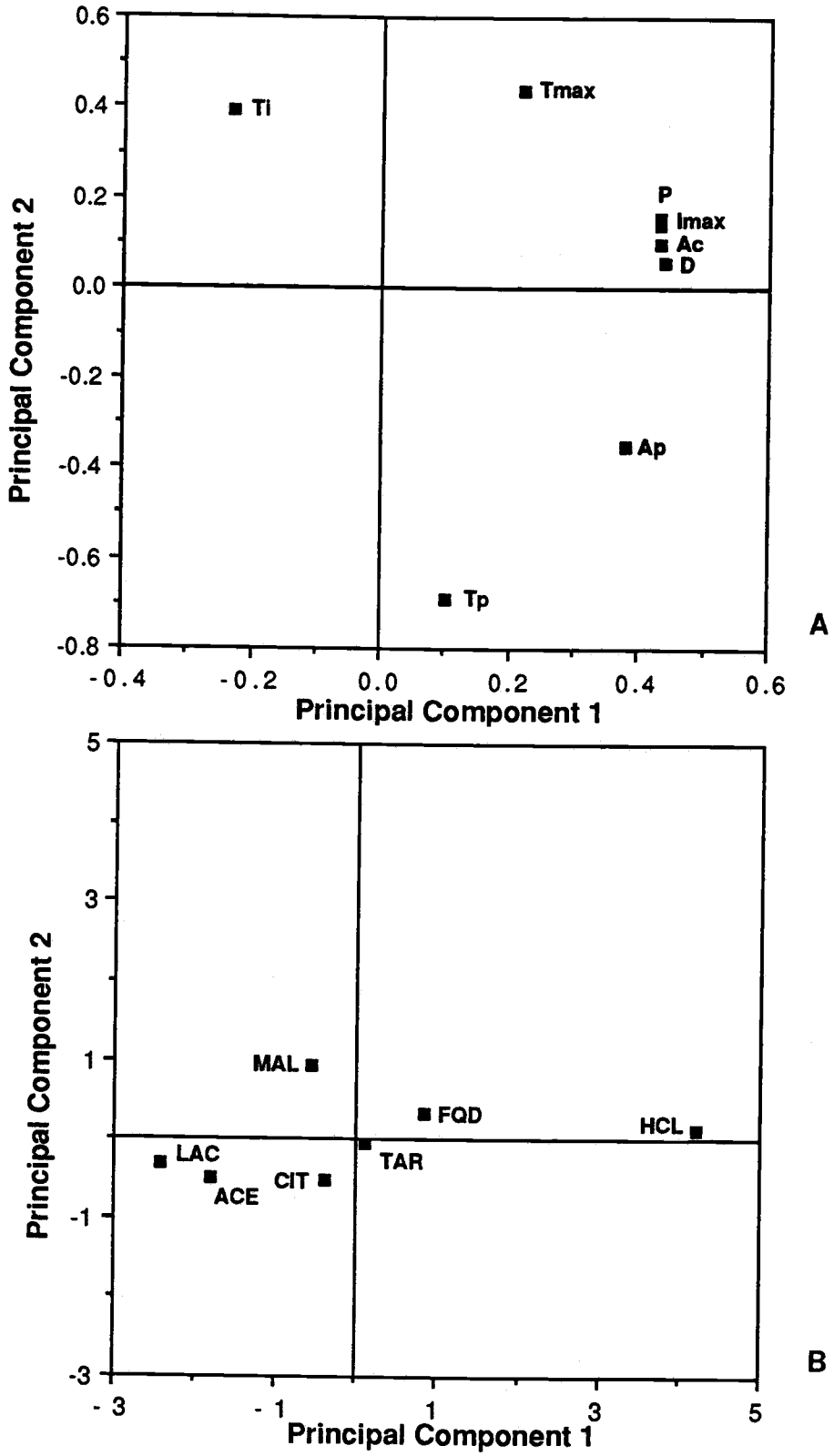

Fig. 19. The a)loadings of the time-intensity parameters and b)scores of seven acids on the first and second principal components for the astringency of the level one acid solutions.

than all other acids and lactic acid had significantly lower scores than all others except acetic and malic acid. Acetic acid had significantly lower scores than tartaric and FQD. Malic and citric acid were not significantly different.

d. Astringency of the level two acid solutions.

Three principal components were able to describe the data from A2. These principal components accounted for 59.79%, 22.00%, and 14.19% of the variation, respectively, for a total of 95.98% (Table 39). The acids and the time-intensity parameters are plotted on the first two principal components in Fig. 20a and b, respectively. The same are plotted on principal component one and principal component three in Fig. 21a and b. Again, principal component one was the only separator of the acids based on significant ANOVA results of the scores. Area under the curve, perimeter, maximum intensity, and duration were weighted heavily in principal component one with slightly less weight on peak area (Table 39). HCl had significantly higher scores than all other acids and acetic acid had significantly lower scores than all of other acids except lactic. Malic acid had significantly lower scores than FQD and tartaric acid. For principal component two, time to maximum intensity and peak time were weighted heavily and also were negatively correlated.

For the sourness responses duration was not as important as it was for the astringency responses in

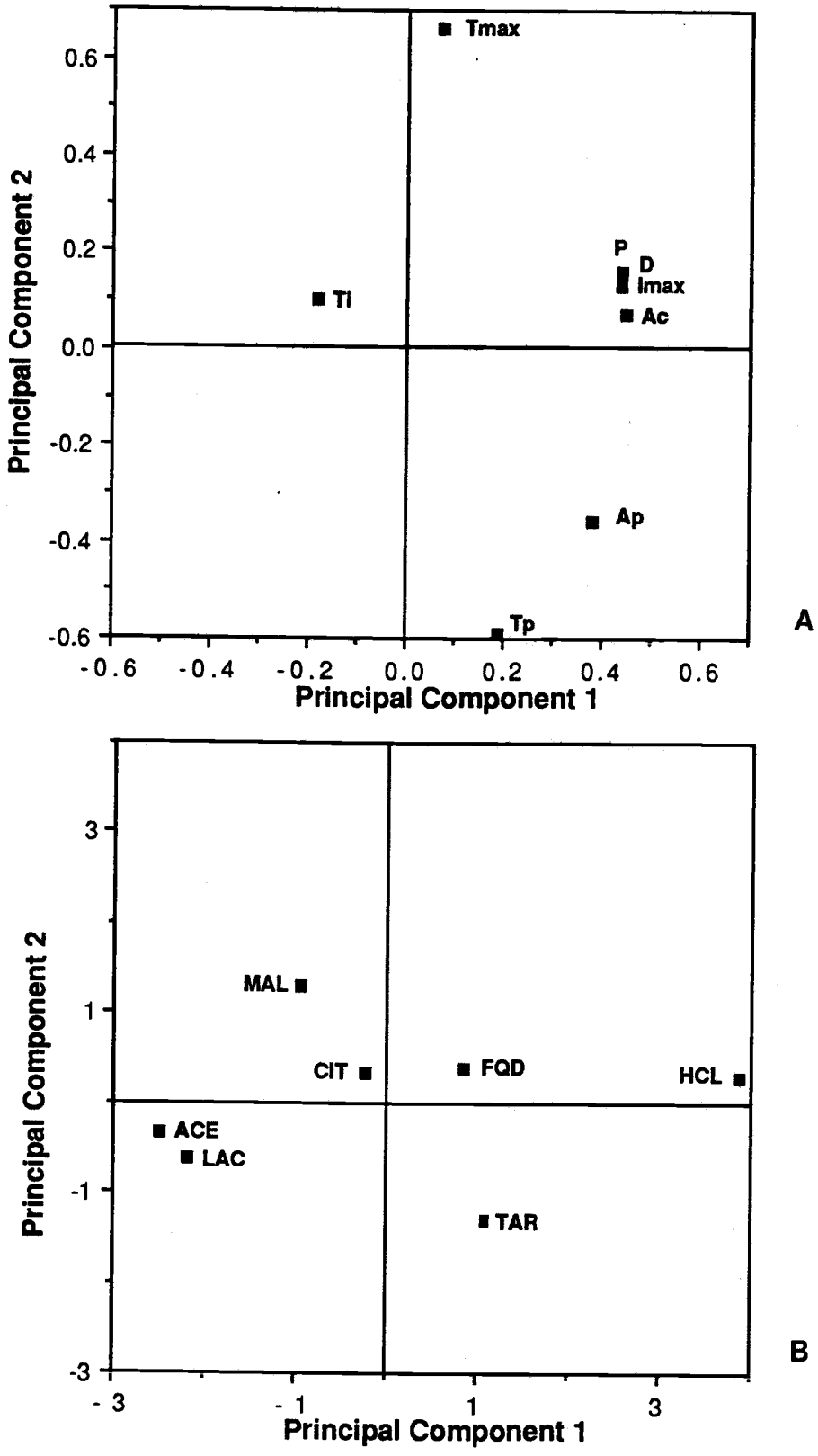

Fig. 20. The a)loadings of the time-intensity parameters and b)scores of the seven acids on the first and second principal components for the astringency of the level two acid solutions.

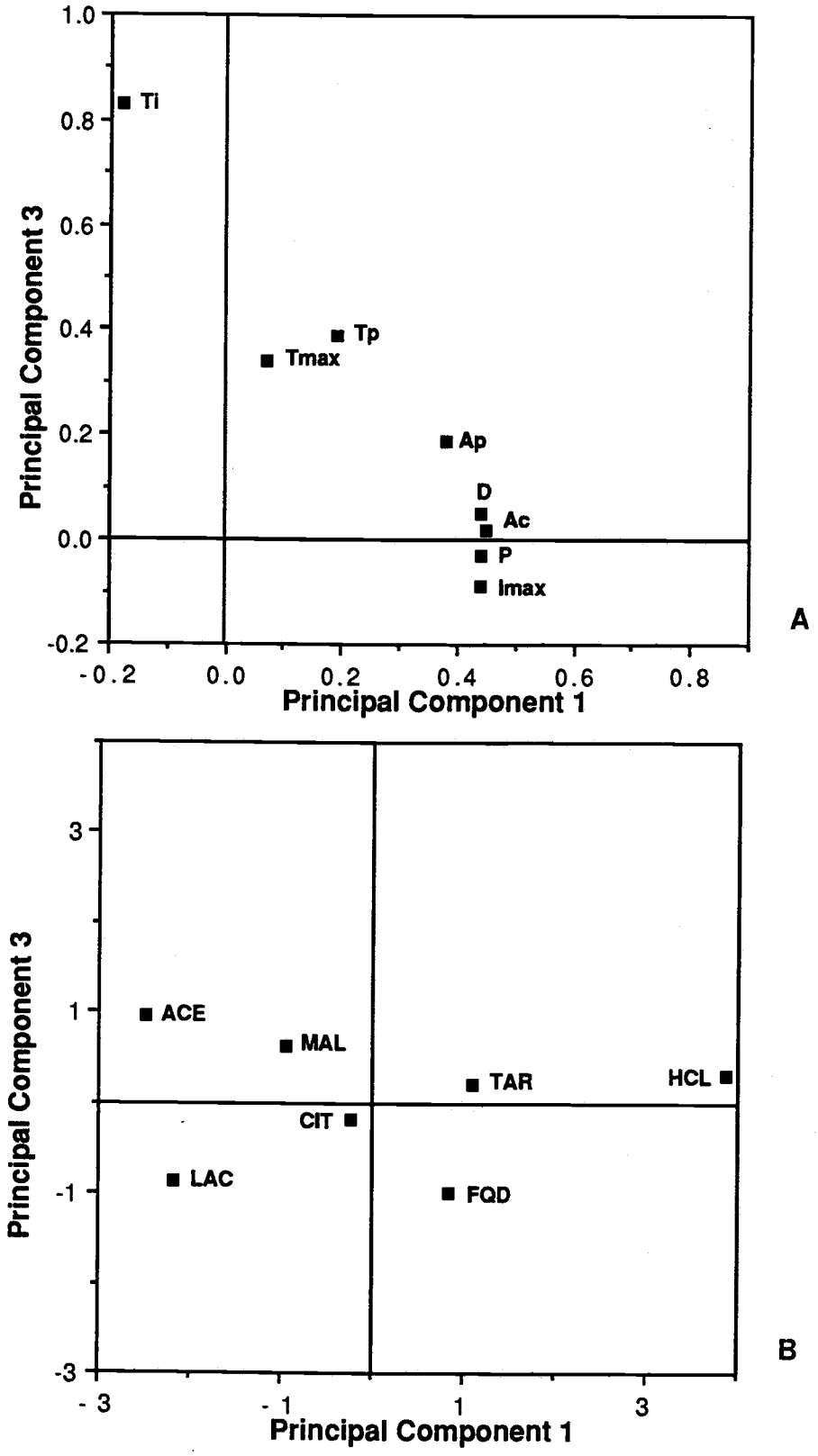

Fig. 21. The a)loadings of the time-intensity parameters and b)scores of the seven acids on the first and third principal components for the astringency of the level two acid solutions.

principal component one. Also, peak area was weighted heavily in principal component one for the sourness responses but it was weighted heavily in principal component two for the astringency responses. For both sourness and astringency, principal component three became important with the increase in acid level and included the time to initial response as the parameter with the most weight.

7. Summary and Conclusions

The power function study showed that HCL, which is an inorganic acid was perceived differently than all of the organic acids. It also showed that individual panelists seem to perceive lactic acid differently since there was a large range of slope values for lactic acid. By analyzing the individual panelist results, it was observed that some panelists rated all of the acids the same according to their slope values and some found more differences in the slopes of the acids than the panel as a whole did.

The equi-sour determination results indicated that different concentrations of acids were needed to achieve equi-sourness. The fact that a low concentration was needed for lactic acid and a high concentration was needed for FQD could have affected the time-intensity results since lactic acid was rated low many times and FQD high.

The time-intensity studies for sourness showed that the major fruit acids (malic, citric, and tartaric) were not appreciably different from each other. Lactic acid was rated low in intensity while FQD was rated high in intensity. Acetic acid was also rated low, lower than the fruit acids. HCL was an intense acid but it had a short duration. HCL was much more astringent than all of the other acids. All of the above differences were based mostly

on area under the curve, maximum intensity, perimeter, and duration measurements. Some acids were different based on peak area and peak time but were never different based on time to initial response or time to maximum intensity. By calculating astringency/sourness ratios based on area under the curve measurements, it was found that lactic acid was also an astringent acid.

Correlations among the time-intensity parameters showed that area under the curve, maximum intensity, and perimeter were frequently correlated and many times duration correlated with this group. Peak area and peak time were also frequently correlated. For other correlations to be significant, it depended on the acid.

Correlations between sensory ratings and chemical measurements occurred many times between the chemical characteristics that are constant (pK_a and number of carboxyl groups) as well as normality, and area under the curve, maximum intensity, and perimeter. Some correlations were found with the other sensory ratings but need further experimentation for explanation.

Principal component analysis verified the frequent correlations between area under the curve, maximum intensity, perimeter, and duration since these four parameters were always in principal component one. The acids could be separated by principal component one only, for both astringency and sourness.

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9. APPENDICES

BALLOT FOR MAGNITUDE ESTIMATION OF SOURNESS

NAME_____
DATE_____

You are being presented with 6 coded samples and a reference sample. Your task is to evaluate each sample relative to the reference sample by assigning numbers to represent the degree of apparent sourness. Give the reference sample a score of 50. Then, for succeeding samples, assign other numbers in proportion to the sourness of the reference sample. If one sample seems three times as sour as the reference, assign it a 150. If it seems one-fifth as sour, assign it a 10. Any type of number-whole number, decimal, or fraction-may be used (except zero).

REFERENCE = 50

Sample	Score
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____

THANK-YOU VERY MUCH!!!!! AMS

Appendix B

EXPERIMENTAL DESIGN FOR POWER FUNCTION STUDY

DAY	ACID	REP
1	CITRIC	1
1	CITRIC	2
2	CITRIC	3
2	HYDROCHLORIC	1
3	HYDROCHLORIC	2
3	HYDROCHLORIC	3
4	MALIC	1
4	MALIC	2
5	MALIC	3
5	FUMARIC-QD	1
6	FUMARIC-QD	2
6	FUMARIC-QD	3
7	TARTARIC	1
7	TARTARIC	2
8	TARTARIC	3
8	FUMARIC	1
9	FUMARIC	2
9	FUMARIC	3
10	LACTIC	1
10	LACTIC	2
11	LACTIC	3
11	ACETIC	1
12	ACETIC	2
12	ACETIC	3

Appendix C

Normalization Example

Panelist	Replication	.00057M	.00114M	.00228M	.00457M	.00571M	.0068M	GM
1	1	5	10	50	75	125	100	36.45
	2	10	20	80	150	100	125	55.74
	3	10	20	40	95	80	150	45.71
2	1	20	30	40	100	150	200	64.50
	2	10	40	45	125	180	200	65.78
.	.	.	.	.	.	.	.	
.	.	.	.	.	.	.	.	
.	.	.	.	.	.	.	.	
8	3							

1. Calculate the geometric mean for each panelist.

2. Divide each raw data point by its respective geometric mean to normalize the data.

1	1	.13717	.27427	1.37174	2.05761	3.42936	2.74348
	2	0.17940	.35881	1.43524	2.69107	1.79404	2.24255
	3	0.21877	.43754	.87508	2.07832	1.75016	3.28156
2	1	.31008	.46512	.62016	1.55039	2.32558	3.10078
	2	.15200	.60809	.68410	1.90027	2.73639	3.04044
.	.	.	.	.	.	.	.
8							
		0.16301	0.30757	0.88255	2.09416	3.00635	3.58963

3. Calculate the geometric mean of the normalized response.

4. Transform the X-values and the geometric means to log values and perform a linear regression.

Appendix C (continued)

Log X	Log Y
-3.24413	-0.78779
-2.94310	-0.51205
-2.64207	-0.05426
-2.34008	0.32101
-2.24336	0.47804
-2.16431	0.55505

Result: $Y = 3.2894 + 1.2865X$ or $1947X^{1.2865}$

slope = 1.29

y-intercept = 3.29

Appendix D

SAS Program for Regression Analysis.

```
TITLE 'CITRIC';
DATA DAT1 (KEEP = PAN SAM YN2);
INFILE 'B:TRANSBK.DAT';
INPUT PAN SAM _NAME_ $ YN1-YN8;
RUN;

DATA DAT2;
INFILE 'A:INDEPCM.DAT';
INPUT MOLCIT;
RUN;

DATA DAT3;
MERGE DAT1 DAT2;
RUN;

DATA DAT4;
SET DAT3;
PROC REG;
MODEL YN1=MOLCIT;
BY PAN;
RUN;
```

SAS Program for Covariance Analysis.

```
TITLE 'CITRIC';
DATA DAT1 (KEEP = PAN SAM YN1);
INFILE 'B:TRANSBK.DAT';
INPUT PAN SAM _NAME_ $ YN1-YN8;
RUN;

DATA DAT2;
INFILE 'A:INDEPCM.DAT';
INPUT MOLCIT;
RUN;

DATA DAT3;
MERGE DAT1 DAT2;
RUN;

DATA DAT4;
SET DAT3;
PROC GLM;
CLASS PAN;
MODEL YN1=PAN MOLCIT PAN*MOLCIT;
RUN;
```

Descriptive Terms Developed Prior to the Time-Intensity Study

MALIC

m. astringency-10[a]
smooth-4
citrus-4
sharp-3
"pure" sourness-3
sweet/fruity-3
lingering-2
slow to start-2
quick-2
aspirin-2
sl. astringency
builds to a high intensity
bland
salty
similar to fumaric
over time-astringency overcomes sourness
medicinal
lingering bitterness
astringency upon repeated sampling

LACTIC

m. astringency-8
sl. astringency-4
very astringent-4
sharp-4
not lingering-4
late sourness-2
aftertaste>pain
smooth
burst
bland
more sour as sips continue
sourness-distinct area in mouth-back
medicinal
aspirin
"clean/pure"
quick to start
lingering

[a] number of times the attribute was used.

Appendix F (continued)

CITRIC

citrus-15
sl. astringency-9
"clean"-8
very astringent-5
m. astringency-5
smooth-4
sl. sweet-4
quick-4
sharp-4
aspirin-4
high impact-3
bitter/metallic aftertaste-3
lingering-3
green-2
slow to start-2
bitter-2
delayed sourness
slight burst
harsh
lemon
"sting"
medicinal
mellow
vinegar
burst of sourness after expectoration
low impact
tooth coating
unpure

ACETIC

sl. astringency-3
vinegar-3
acetic-3
m. astringent-2
very astringent
smooth-2
another flavor ??-2
sour
quick start
sl. sweet
bland
"fullness"
artificial flavor-fruity
chemical
elmer's glue
aspirin

Appendix F (continued)

TARTARIC

sl. astringency
m. astringency-3
sharp-2
short-2
quick hit
lingering
medicianl
lingering bitterness
teeth coating-dryness

FUMARIC

sl. astringency-3
citrus-3
sharp-2
m. astringency
astringent-latent
aspirin
lingering
sharp rise
medicinal

HCl

quick-16
m. astringency-8
citrus-6
sl. sweet-6
"clean" sourness-5
astringency covers sourness-5
tooth and gum coating-4
sl. astringency-3
tasteless-2
lingering astringency-2
sharp-2
astringent upon repeated evaluations
bitter
sourness comes with repeated evaluations
lingering
moderate impact
m. sweet-artificial
high impact
not pure
lingering bitterness
HCl

Panelist's Instructions.

Friday-July 1, 1988

ACID PANELISTS: Bob, Newton, Nancy, Nora, Rita, Brian, Dave, Visith

The acids I am studying seem to exhibit subtle differences in their taste properties-especially the time-course of sourness and astringency.

I am hoping that with this time-intensity method and set-up that you have been using, we can capture these time dependent differences. Since they may be difficult to obtain due to the large amount of variation between panelists and the difficulty to control every factor, it is very important that each of you concentrate as much as you can while evaluating the solutions.

In order to try to control as many factors as I can, I have come up with come important instructions and things you need to think about when testing.

1.RINSE BEFORE EVALUATING.

2.TASTE REFERENCE SAMPLE. TRY TO REMEMBER ITS INTENSITY AS MODERATE. EVALUATE YOUR SAMPLES ACCORDINGLY.

3.IT IS VERY IMPORTANT TO USE THE LINE SCALE TO MEASURE THE INTENSITIES. LOOK AT AND CONCENTRATE ON USING THE SCALE.

4.COORDINATION-IT TAKES A WHILE TO BECOME COMFORTABLE WITH MANIPULATING THE LEVER, THE SAMPLES AND THE EXPECTORATION CUP.
IN ORDER TO BE SURE EVERYONE IS EVALUATING THE SAMPLES IN THE SAME WAY, I WOULD LIKE EVERYONE TO EVALUATE IN THE FOLLOWING WAY:

*PLACE YOUR RIGHT HAND ON THE LEVER AS SOON AS THE 20 SEC. COUNTDOWN BEGINS. (DON'T FORGET YOUR NOSEPLUG!!!)
*PICK UP THE DESIGNATED CODED SAMPLE WITH YOUR LEFT HAND. BE SURE TO HAVE THE TOTAL SAMPLE IN YOUR MOUTH AFTER THE 20 SEC. COUNTDOWN AT TIME-0.
*PUT THE EMPTY CUP DOWN AND BE PREPARD TO EXPECTORATE AFTER 7 SEC. AT TIME-0. USE YOUR LEFT HAND TO HOLD THE EXPECTORATION CUP.
*CONTINUE EVALUATING UNTIL YOU NO LONGER PERCEIVE THE SOUR OR ASTRINGENT SENSATION.(depending on whcih you are evaluating)
*AT THAT TIME BE SURE THE GLIDER HAS BEEN MOVED ALL THE WAY TO THE LEFT (none) BEFORE PUSHING THE RED BUTTON.
*YOU WILL HAVE A 60 SEC. REST BEFORE THE NEXT 20 SEC. COUNTDOWN CAN BEGIN.
*BE SURE TO RINSE IN BETWEEN SAMPLES.

5.TRY TO EVALUATE THE SAMPLES IN THE SAME WAY FOR EVERY SESSION THROUGHOUT THE TESTING SCHEDULE.

6.IF YOU HAVE MADE A MISTAKE OR YOU ARE NOT HAPPY WITH YOUR PERFORMANCE ON A PARTICULAR SAMPLE, PLEASE WRITE DOWN THE APPROPRIATE SAMPLE # AND TELL ME AND I WILL GIVE YOU AN OPPORTUNITY TO REPEAT.THIS IS VERY IMPORTANT.

7.THIS TESTING WILL GO ON FOR 3 WEEKS (July 5-July 21). THERE WILL BE 2 SESSIONS PER DAY ON TUESDAYS AND THURSDAYS FOR A TOTAL OF 12 SESSIONS. A SIGN-UP SHEET WILL BE PASSED AROUND. IF YOU CANNOT BE HERE AT YOUR SCHEDULED TIME PLEASE MAKE ARRANGEMENTS WITH ME.

MOST IMPORTANT- THANKS SO MUCH FOR YOUR PARTICIPATION AND COOPORATION SO FAR. ANGEL

SAS Program for ANOVA of the Time-Intensity Results

```
PROC ANOVA DATA=DAT5;
 CLASS PAN TRT REP;
 MODEL AR8 PA8 IN4 RANGE TI0 TI8=PAN TRT PAN*TRT REP
    PAN*REP TRT*REP;


TITLE 'ACID DATA: COMPOUND F-VALUES';
OPTIONS PS=65;

DATA DAT1;
  NVBL=8;
  INFILE 'A:LIAMS.DAT';
  INPUT DF1-DF4@@;
  OUTPUT;
  DO VBL=1 TO NVBL;
    INPUT MS1-MS4@@;
    OUTPUT;
  END;
RUN;

PROC PRINT DATA=DAT1;
  VAR VBL MS1-MS4 DF1-DF4;
RUN;

DATA DAT1(KEEP=VBL DF1-DF4 MS1-MS4);
  SET DAT1;
  IF VBL=. THEN DELETE;
RUN;

DATA DAT3;
  ARRAY MS(4) MS1-MS4; ARRAY DF(4) DF1-DF4;
  SET DAT1; NREP1=24;
  FP1=MS(2)/MS(4);
  FB1=MS(3)/MS(4);
  DFN1=((MS(1)+MS(4))**2)/((MS(1)**2/DF(1))+(MS(4)**2/DF(4)));
  DFD1=((MS(2)+MS(3))**2)/((MS(2)**2/DF(2))+(MS(3)**2/DF(3)));
  F1=((MS(1)+MS(4))/(MS(2)+MS(3)));
  MSLSD1=MS(2)+MS(3)-MS(4);
  IF MSLSD1>0 THEN DO;
    DFLSD1=MSLSD1**2/((MS(2)**2/DF(2))+(MS(3)**2/DF(3))+(MS(4)**2/DF(4)));
    LSD1=TINV(.975,DFLSD1)*(SQRT(2*MSLSD1/NREP1));
  END;
  ELSE DO; LSD1=.; DFLSD1=.; END;
  DFPOOL1=DF(2)+DF(3)+DF(4);
  MSPOOL1=(DF(2)*MS(2)+DF(3)*MS(3)+DF(4)*MS(4))/DFPOOL1;
  FPOOL1=MS(1)/MSPOOL1;
  LSDPOOL1=TINV(.975,DFPOOL1)*(SQRT(2*MSPOOL1/NREP1));
  PPOOL1=1-PROBF(FPOOL1,DF1,DFPOOL1);
  P1=1-PROBF(F1,DFN1,DFD1);
  PP1=PROBF(FP1,DF2,DF4);
  PB1=PROBF(FB1,DF3,DF4);
RUN;

TITLE 'F-VALUES TO TEST PRC MODEL';
PROC PRINT;
  VAR FP1 PP1 FB1 PB1;
RUN;

TITLE 'F-VALUES AND LSD FOR PROCESS';
RUN;

TITLE 'LSD VALUES FOR PAIRED COMPARISONS';
PROC PRINT;
  VAR LSD1 LSDPOOL1;
RUN;

DATA SOUND;
  CALL SOUND(500,1000);
RUN;
```

SAS Program for Correlation Analysis

```
TITLE 'CORRELATION BY TREATMENT';
TITLE2 'LEVEL I SOURNESS';
DATA DAT1;
INFILE 'B:RESONE.IS';
INPUT PAN TRT SES AR8 PA8 IN4 RANGE TI0 TI8;
RUN;

DATA DAT2;
INFILE 'B:RESTHREE.IS';
INPUT PAN TRT SES TI4 PEAKAR PEAKTI;
RUN;

DATA MERGE;
MERGE DAT1 DAT2;
RUN;
DATA SORT;
SET MERGE;
PROC SORT;
BY TRT PAN;
RUN;

DATA AVE;
SET SORT;
PROC SUMMARY;
VAR AR8 PA8 IN4 RANGE TI0 TI8 TI4 PEAKAR PEAKTI;
BY TRT PAN;
OUTPUT OUT= AVERAGE MEAN=;
RUN;

DATA _NULL_;
SET AVERAGE;
FILE 'B:AVE.COR';
PUT TRT PAN AR8 PA8 IN4 RANGE TI0 TI8 TI4 PEAKAR PEAKTI;
RUN;

DATA IN;
INFILE 'B:AVE.COR';
INPUT TRT PAN AR8 PA8 IN4 RANGE TI0 TI8 TI4 PEAKAR PEAKTI;
RUN;

DATA SLOPE;
INFILE 'B:SLOPES.NE';
INPUT SLOPE;
RUN;
DATA DAT3;
MERGE IN SLOPE;
RUN;

DATA DAT4;
SET DAT3;
PROC CORR;
VAR AR8 PA8 IN4 RANGE TI0 TI8 TI4 PEAKAR PEAKTI SLOPE;
BY TRT;
RUN;
```

SAS Program for Principal Component Analysis

```
DATA SOUR1;
INFILE 'A:SOUR1RAS.DAT';
INPUT SAMPLE PAN REP AREA PERIMETE MAXINTEN DURATION INITRESP
TIMEMAX PEAKAREA PEAKTIME;
RUN;

DATA TWO;
 SET SOUR1;
  PROC SORT;
   BY SAMPLE REP;
RUN;

DATA THREE;
 SET TWO;
  PROC SUMMARY;
   VAR AREA PERIMETE MAXINTEN DURATION INITRESP TIMEMAX PEAKAREA
    PEAKTIME;
   BY SAMPLE REP;
   OUTPUT OUT=AVE MEAN=;
RUN;

DATA FOUR;
 SET AVE;
  PROC PRINCOMP DATA=FOUR OUT=PRIN;
   VAR AREA PERIMETE MAXINTEN DURATION INITRESP TIMEMAX PEAKAREA
 PEAKTIME;
RUN;

DATA FIVE;
 MERGE FOUR PRIN;
RUN;

DATA _NULL_;
 SET FIVE;
  DROP _TYPE_ _FREQ_;
  FILE 'A:PRSOUR1.DAT';
  PUT SAMPLE REP PRIN1 PRIN2;
RUN;

DATA SOUR1;
 INFILE 'A:PRSOUR1.DAT';
 INPUT SAMPLE REP PRIN1 PRIN2;
RUN;
 PROC ANOVA;
  CLASS SAMPLE REP;
  MODEL PRIN1 PRIN2 = SAMPLE;
  MEANS SAMPLE/LSD;
RUN;
```

Appendix K

Regression tables for the eight acids of all panelists combined.

SOV	DF	SS	MS	F
HYDROCHLORIC:				
Regression	1	0.352	0.352	209.572***
Error	4	0.007	0.002	
Total	5	0.359		
FUMARIC-QD:				
Regression	1	1.169	1.169	610.440***
Error	4	0.008	0.002	
Total	5	1.177		
FUMARIC:				
Regression	1	1.428	1.428	543.943***
Error	4	0.010	0.003	
Total	5	1.438		
TARTARIC:				
Regression	1	1.308	1.308	784.678***
Error	4	0.007	0.002	
Total	5	1.315		
MALIC:				
Regression	1	1.424	1.424	790.064***
Error	4	0.007	0.002	
Total	5	1.431		
CITRIC:				
Regression	1	1.518	1.518	852.507***
Error	4	0.007	0.002	
Total	5	1.525		
ACETIC:				
Regression	1	1.087	1.087	399.424***
Error	4	0.013	0.003	
Total	5	1.100		
LACTIC:				
Regression	1	1.025	1.025	3280.526***
Error	4	0.001	0.000	
Total	5	1.026		

Analysis of covariance for all panelists and all acids combined.

SOV	DF	SS	MS	F
Response	7	0.337	0.048	25.55***
Acid	1	9.243	9.243	4902.30***
Response x Acid	7	0.068	0.010	5.18***
Error	32	0.060	0.002	
Total	47	9.709		

Appendix M

Regression tables form eight panelists for each acid.

Regression tables from eight panelists for hydrochloric acid.

SOV	DF	SS	MS	F
PANELIST 1:				
Regression	1	0.267	0.267	52.970**
Error	4	0.020	0.005	
Total	5	0.287		
PANELIST 2:				
Regression	1	0.272	0.272	51.422***
Error	4	0.021	0.005	
Total	5	0.293		
PANELIST 3:				
Regression	1	1.062	1.062	65.552***
Error	4	0.065	0.016	
Total	5	1.127		
PANELIST 4:				
Regression	1	0.201	0.201	29.400**
Error	4	0.027	0.007	
Total	5	0.228		
PANELIST 5:				
Regression	1	0.547	0.547	36.478**
Error	4	0.060	0.015	
Total	5	0.607		
PANELIST 6:				
Regression	1	0.460	0.460	24.186**
Error	4	0.076	0.019	
Total	5	0.536		
PANELIST 7:				
Regression	1	0.106	0.106	53.241**
Error	4	0.008	0.002	
Total	5	0.114		
PANELIST 8:				
Regression	1	0.239	0.239	24.085**
Error	4	0.040	0.010	
Total	5	0.278		

Appendix M (continued)

Regression tables from eight panelists for fumaric-QD acid.

SOV	DF	SS	MS	F
PANELIST 1:				
Regression	1	1.239	1.239	145.003**
Error	4	0.034	0.009	
Total	5	1.274		
PANELIST 2:				
Regression	1	0.900	0.900	253.747***
Error	4	0.014	0.004	
Total	5	0.914		
PANELIST 3:				
Regression	1	2.714	2.714	87.344***
Error	4	0.124	0.031	
Total	5	2.838		
PANELIST 4:				
Regression	1	1.022	1.022	125.458***
Error	4	0.033	0.008	
Total	5	1.054		
PANELIST 5:				
Regression	1	0.963	0.963	96.444***
Error	4	0.040	0.010	
Total	5	1.003		
PANELIST 6:				
Regression	1	1.523	1.523	362.511***
Error	4	0.017	0.004	
Total	5	1.540		
PANELIST 7:				
Regression	1	0.321	0.321	623.118***
Error	4	0.002	0.001	
Total	5	0.323		
PANELIST 8:				
Regression	1	1.320	1.320	129.727***
Error	4	0.041	0.010	
Total	5	1.361		

Regression tables from eight panelists for tartaric acid.

SOV	DF	SS	MS	F
PANELIST 1:				
Regression	1	1.548	1.548	50.601**
Error	4	0.122	0.031	
Total	5	1.671		
PANELIST 2:				
Regression	1	0.725	0.725	220.183***
Error	4	0.013	0.003	
Total	5	0.738		
PANELIST 3:				
Regression	1	3.512	3.512	233.376***
Error	4	0.060	0.015	
Total	5	3.572		
PANELIST 4:				
Regression	1	1.333	1.333	44.028**
Error	4	0.121	0.030	
Total	5	1.454		
PANELIST 5:				
Regression	1	1.120	1.120	194.023**
Error	4	0.023	0.006	
Total	5	1.143		
PANELIST 6:				
Regression	1	1.740	1.740	1090.348***
Error	4	0.006	0.002	
Total	5	1.747		
PANELIST 7:				
Regression	1	0.217	0.217	144.547***
Error	4	0.006	0.002	
Total	5	0.223		
PANELIST 8:				
Regression	1	1.398	1.398	76.366***
Error	4	0.073	0.018	
Total	5	1.472		

Appendix M (continued)

Regression tables from eight panelists for malic acid.

SOV	DF	SS	MS	F
PANELIST 1:				
Regression	1	1.079	1.079	134.620**
Error	4	0.032	0.008	
Total	5	1.111		
PANELIST 2:				
Regression	1	0.898	0.898	177.571***
Error	4	0.020	0.005	
Total	5	0.918		
PANELIST 3:				
Regression	1	3.705	3.705	325.936***
Error	4	0.045	0.011	
Total	5	3.751		
PANELIST 4:				
Regression	1	1.008	1.008	1188.662***
Error	4	0.003	0.001	
Total	5	1.012		
PANELIST 5:				
Regression	1	1.289	1.289	96.029***
Error	4	0.055	0.014	
Total	5	1.343		
PANELIST 6:				
Regression	1	1.697	1.697	69.007**
Error	4	0.098	0.025	
Total	5	1.796		
PANELIST 7:				
Regression	1	0.543	0.543	86.386***
Error	4	0.025	0.006	
Total	5	0.569		
PANELIST 8:				
Regression	1	2.115	2.115	99.533***
Error	4	0.085	0.021	
Total	5	2.200		

Appendix M (continued)

Regression tables from eight panelists for citric acid.

SOV	DF	SS	MS	F
PANELIST 1:				
Regression	1	1.187	1.187	150.778**
Error	4	0.031	0.008	
Total	5	1.218		
PANELIST 2:				
Regression	1	1.219	1.219	130.599***
Error	4	0.037	0.009	
Total	5	1.218		
PANELIST 3:				
Regression	1	4.333	4.333	1479.173***
Error	4	0.012	0.003	
Total	5	4.345		
PANELIST 4:				
Regression	1	1.066	1.066	489.461***
Error	4	0.009	0.002	
Total	5	1.075		
PANELIST 5:				
Regression	1	1.311	1.311	47.435**
Error	4	0.111	0.028	
Total	5	1.422		
PANELIST 6:				
Regression	1	1.302	1.302	528.755***
Error	4	0.010	0.002	
Total	5	1.312		
PANELIST 7:				
Regression	1	1.130	1.130	213.878***
Error	4	0.021	0.005	
Total	5	1.151		
PANELIST 8:				
Regression	1	1.441	1.441	59.455**
Error	4	0.097	0.024	
Total	5	1.538		

Regression tables from nine panelists for acetic acid.

SOV	DF	SS	MS	F
PANELIST 1:				
Regression	1	1.238	1.238	71.461**
Error	4	0.069	0.017	
Total	5	1.307		
PANELIST 2:				
Regression	1	1.055	1.055	149.230***
Error	4	0.028	0.007	
Total	5	1.083		
PANELIST 3:				
Regression	1	1.913	1.913	164.103***
Error	4	0.047	0.012	
Total	5	1.960		
PANELIST 4:				
Regression	1	1.050	1.050	119.692***
Error	4	0.035	0.009	
Total	5	1.085		
PANELIST 5:				
Regression	1	0.757	0.757	94.282***
Error	4	0.032	0.008	
Total	5	0.789		
PANELIST 6:				
Regression	1	1.049	1.049	360.122***
Error	4	0.012	0.003	
Total	5	1.061		
PANELIST 7:				
Regression	1	0.546	0.546	100.446***
Error	4	0.022	0.005	
Total	5	0.568		
PANELIST 9:				
Regression	1	1.409	1.409	80.545***
Error	4	0.070	0.017	
Total	5	1.479		
PANELIST 10:				
Regression	1	1.031	1.031	61.041**
Error	4	0.068	0.017	
Total	5	1.098		

Regression tables from eight panelists for fumaric acid.

SOV	DF	SS	MS	F
PANELIST 1:				
Regression	1	1.879	1.879	86.521***
Error	4	0.087	0.022	
Total	5	1.966		
PANELIST 2:				
Regression	1	0.952	0.952	348.673***
Error	4	0.011	0.003	
Total	5	0.963		
PANELIST 3:				
Regression	1	3.325	3.325	307.311***
Error	4	0.043	0.011	
Total	5	0.963		
PANELIST 4:				
Regression	1	1.216	1.216	648.137***
Error	4	0.008	0.002	
Total	5	1.224		
PANELIST 5:				
Regression	1	1.149	1.149	555.735***
Error	4	0.008	0.002	
Total	5	1.158		
PANELIST 6:				
Regression	1	1.310	1.310	830.444***
Error	4	0.006	0.002	
Total	5	1.316		
PANELIST 7:				
Regression	1	0.476	0.476	81.287***
Error	4	0.023	0.006	
Total	5	0.500		
PANELIST 8:				
Regression	1	1.901	1.901	93.650***
Error	4	0.081	0.020	
Total	5	1.982		

Analysis of covariance tables for each panelist for all acids.

SOV	DF	SS	MS	F
Panelist 1:				
Response	7	0.342	0.049	3.62**
Acid	1	10.117	10.117	748.93***
Response x Acid	7	0.231	0.033	2.45*
Error	32	0.432	0.014	
Total	47	11.122		
Panelist 2:				
Response	7	0.385	0.055	11.20***
Acid	1	6.295	6.295	1282.57***
Response x Acid	7	0.149	0.021	4.34**
Error	32	0.157	0.005	
Total	47	6.986		
Panelist 3:				
Response	7	0.303	0.043	3.09*
Acid	1	23.400	23.400	1670.69***
Response x Acid	7	0.400	0.057	4.08**
Error	32	0.448	0.014	
Total	47	24.551		
Panelist 4:				
Response	7	0.351	0.050	5.00***
Acid	1	7.959	7.959	792.19***
Response x Acid	7	0.062	0.009	0.88
Error	32	0.321	0.010	
Total	47	8.693		
Panelist 5:				
Response	7	0.317	0.045	3.92**
Acid	1	7.494	7.494	648.82***
Response x Acid	7	0.210	0.030	2.60*
Error	32	0.370	0.012	
Total	47	8.390		
Panelist 6:				
Response	7	0.329	0.047	6.11***
Acid	1	9.506	9.506	1236.36***
Response x Acid	7	0.182	0.026	3.38**
Error	32	0.246	0.008	
Total	47	10.263		
Panelist 7:				
Response	7	0.339	0.048	12.33***
Acid	1	3.408	3.408	868.26***
Response x Acid	7	0.236	0.034	8.60***
Error	32	0.126	0.004	
Total	47	4.108		

Appendix N (continued)

SOV	DF	SS	MS	F
Panelist 8:				
Response	5	0.319	0.064	3.68*
Acid	1	8.332	8.332	479.84***
Response x Acid	5	0.082	0.016	0.95
Error	24	0.417	0.017	
Total	35	9.151		
Panelist 9:				
Response	1	0.000	0.000	0.00
Acid	1	2.715	2.715	174.98***
Response x Acid	1	0.000	0.000	0.02
Error	8	0.124	0.016	
Total	11	2.839		
Panelist 10:				
Response	1	0.000	0.000	0.00
Acid	1	2.017	2.017	182.82***
Response x Acid	1	0.000	0.000	0.00
Error	8	0.088	0.011	
Total	11	2.106		

Appendix O

Analysis of covariance tables for each acid for all panelists.

SOV	DF	SS	MS	F
HYDROCHLORIC:				
Response	7	0.000	0.000	0.00
Acid	1	2.819	2.819	284.50***
Response x Acid	7	0.334	0.048	4.82***
Error	32	0.317	0.010	
Total	47	3.470		
FUMARIC-QD:				
Response	7	0.000	0.000	0.00
Acid	1	9.353	9.353	982.24***
Response x Acid	7	0.647	0.092	9.71**
Error	32	0.305	0.010	
Total	47	10.306		
FUMARIC:				
Response	7	0.003	0.000	0.06
Acid	1	11.421	11.421	1364.73***
Response x Acid	7	0.789	0.113	13.46***
Error	32	0.268	0.008	
Total	47	12.481		
TARTARIC:				
Response	7	0.000	0.000	0.00
Acid	1	10.465	10.465	786.85***
Response x Acid	7	1.129	0.161	12.13***
Error	32	0.426	0.013	
Total	47	12.019		
MALIC:				
Response	7	0.000	0.000	0.00
Acid	1	11.388	11.388	999.71***
Response x Acid	7	0.947	0.135	11.88***
Error	32	0.365	0.011	
Total	47	12.700		
CITRIC:				
Response	7	0.000	0.000	0.00
Acid	1	12.146	12.146	1185.72***
Response x Acid	7	0.844	0.121	11.77***
Error	32	0.328	0.010	
Total	47	13.318		
ACETIC:				
Response	8	0.000	0.000	0.00
Acid	1	9.783	9.783	921.17***
Response x Acid	8	0.265	0.033	3.12**
Error	36	0.382	0.011	
Total	53	10.431		

Appendix O (continued)

SOV	DF	SS	MS	F
LACTIC:				
Response	8	0.000	0.000	0.00
Acid	1	9.226	9.226	978.05***
Response x Acid	8	1.239	0.155	16.41***
Error	36	0.340	0.009	
Total	35	10.804		

Analysis of Variance Tables for Individual Panelists for Each of the Eight Time-Intensity Parameters for the Level One Acid Solutions

parameter: peak time of sourness

SOV	DF	SS	MS	F
Panelist 1:				
Treatment	7	23.32	3.33	1.74
Replication	2	9.09	4.54	2.38
Error	14	26.73	1.91	
Total	23	59.14		
Panelist 2:				
Treatment	7	29.31	4.19	1.06
Replication	2	6.78	3.39	0.86
Error	14	55.27	3.95	
Total	23	91.36		
Panelist 3:				
Treatment	7	48.89	6.98	1.20
Replication	2	109.72	54.86	9.43***
Error	14	81.47	5.82	
Total	23	240.07		
Panelist 4:				
Treatment	7	38.17	5.45	0.87
Replication	2	9.98	4.99	0.80
Error	14	87.34	6.24	
Total	23	135.49		
Panelist 5:				
Treatment	7	65.74	9.39	0.78
Replication	2	13.45	6.72	0.56
Error	14	168.25	12.02	
Total	23	247.44		
Panelist 6:				
Treatment	7	19.08	2.73	0.74
Replication	2	1.52	0.76	0.21
Error	14	51.39	3.67	
Total	23	71.98		
Panelist 7:				
Treatment	7	15.68	2.24	1.27
Replication	2	20.90	10.45	5.94*
Error	14	24.64	1.76	
Total	23			
Panelist 8:				
Treatment	7	39.41	5.63	1.02
Replication	2	37.37	18.68	3.38
Error	14	77.43	5.53	
Total	23	154.22		

*, **, *** - significant at $p \leq 0.05, 0.01, 0.001$ respectively

parameter: peak area of sourness

SOV	DF	SS	MS	F
Panelist 1:				
Treatment	7	8600.73	1228.68	1.90
Replication	2	4178.42	2089.21	3.23
Error	14	9051.17	646.51	
Total	23	21830.33		
Panelist 2:				
Treatment	7	200548.68	28649.81	2.71
Replication	2	10060.94	5030.47	0.48
Error	14	147787.51	10556.25	
Total	23	358397.13		
Panelist 3:				
Treatment	7	120656.08	17236.58	1.60
Replication	2	1092.15	546.08	0.05
Error	14	150613.90	10758.14	
Total	23	272362.14		
Panelist 4:				
Treatment	7	139711.43	19958.78	1.38
Replication	2	20115.83	10057.91	0.69
Error	14	203106.45	14507.60	
Total	23	362933.70		
Panelist 5:				
Treatment	7	204131.87	29161.70	0.98
Replication	2	24945.32	12472.66	0.42
Error	14	418117.29	29865.52	
Total	23	647194.48		
Panelist 6:				
Treatment	7	16664.97	2380.71	0.85
Replication	2	328.85	164.43	0.06
Error	14	39199.24	2799.95	
Total	23	56193.06		
Panelist 7:				
Treatment	7	75372.63	10767.52	9.81***
Replication	2	229.76	114.88	0.10
Error	14	15358.92	1097.07	
Total	23	90961.31		
Panelist 8:				
Treatment	7	154559.19	22079.88	1.33
Replication	2	83343.21	41671.60	2.52
Error	14	231918.73	16565.62	
Total	23	469821.13		

*, **, *** - significant at $p \leq$ 0.05, 0.01, 0.001 respectively

parameter: area under the curve of sourness

SOV	DF	SS	MS	F
Panelist 1:				
Treatment	7	5779.74	825.68	0.83
Replication	2	3354.50	1677.25	1.69
Error	14	13863.39	990.24	
Total	23	22997.64		
Panelist 2:				
Treatment	7	1007880.49	143982.93	8.26***
Replication	2	192372.81	96186.40	5.22*
Error	14	243985.78	17427.56	
Total	23	1444239.08		
Panelist 3:				
Treatment	7	754060.45	107722.92	2.98*
Replication	2	1463175.48	731587.74	20.23***
Error	14	506173.01	36155.22	
Total	23	2723408.94		
Panelist 4:				
Treatment	7	1185646.65	169378.09	3.01*
Replication	2	67355.15	33677.58	0.60
Error	14	788272.94	56305.21	
Total	23	2041274.74		
Panelist 5:				
Treatment	7	1938566.88	276938.13	2.08
Replication	2	785539.14	392769.57	2.94
Error	14	1868156.45	133439.75	
Total	23	4592262.47		
Panelist 6:				
Treatment	7	148894.20	21270.60	2.50
Replication	2	138609.94	69304.97	8.14**
Error	14	119178.81	8512.77	
Total	23	406682.96		
Panelist 7:				
Treatment	7	462337.24	66048.18	17.97***
Replication	2	46901.65	23450.82	6.38*
Error	14	51448.88	3674.92	
Total	23	560687.77		
Panelist 8:				
Treatment	7	1615349.19	230764.17	4.81**
Replication	2	28543.04	14271.52	0.30
Error	14	672171.10	48012.22	
Total	23	2316063.33		

*, **, *** - significant at $p \leq$ 0.05, 0.01, 0.001 respectively

parameter: maximum intensity of sourness

SOV	DF	SS	MS	F
Panelist 1:				
Treatment	7	1589.62	227.09	1.32
Replication	2	324.25	162.12	0.94
Error	14	2409.75	172.12	
Total	23	4323.62		
Panelist 2:				
Treatment	7	4591.96	655.99	8.71***
Replication	2	1057.75	528.88	7.02**
Error	14	1054.92	75.35	
Total	23	6704.62		
Panelist 3:				
Treatment	7	1678.29	239.76	4.16*
Replication	2	5754.33	2877.17	49.95***
Error	14	806.33	57.60	
Total	23	8238.96		
Panelist 4:				
Treatment	7	3349.83	478.55	6.80**
Replication	2	669.00	334.50	4.75*
Error	14	985.67	70.40	
Total	23	5004.50		
Panelist 5:				
Treatment	7	3630.96	518.71	2.33
Replication	2	200.08	100.04	0.45
Error	14	3121.92	222.99	
Total	23	6952.96		
Panelist 6:				
Treatment	7	1187.29	169.61	1.82
Replication	2	831.00	415.50	4.45*
Error	14	1306.33	93.31	
Total	23	3324.62		
Panelist 7:				
Treatment	7	4575.83	653.69	16.73***
Replication	2	661.33	330.67	8.47**
Error	14	546.67	39.05	
Total	23	5783.83		
Panelist 8:				
Treatment	7	3802.50	543.21	5.66**
Replication	2	30.33	15.17	0.16
Error	14	1343.00	95.93	
Total	23	5175.83		

*, **, *** - significant at $p \leq$ 0.05, 0.01, 0.001 respectively

parameter: time to initial response of sourness

SOV	DF	SS	MS	F
Panelist 1:				
Treatment	7	5.07	0.72	1.16
Replication	2	2.70	1.35	2.17
Error	14	8.71	0.62	
Total	23	16.48		
Panelist 2:				
Treatment	7	3.04	0.43	1.43
Replication	2	0.22	0.11	0.36
Error	14	4.26	0.34	
Total	23	7.52		
Panelist 3:				
Treatment	7	1.70	0.24	0.98
Replication	2	0.00	0.00	0.01
Error	14	3.48	0.25	
Total	23	5.19		
Panelist 4:				
Treatment	7	3.17	0.45	0.89
Replication	2	0.57	0.28	0.56
Error	14	7.13	0.51	
Total	23	10.87		
Panelist 5:				
Treatment	7	1.19	0.17	1.09
Replication	2	6.75	3.37	21.61***
Error	14	2.19	0.16	
Total	23	10.12		
Panelist 6:				
Treatment	7	1.00	0.14	1.26
Replication	2	0.64	0.32	2.83
Error	14	1.58	0.11	
Total	23	3.22		
Panelist 7:				
Treatment	7	4.76	0.68	1.34
Replication	2	1.84	0.92	1.81
Error	14	7.10	0.51	
Total	23	13.70		
Panelist 8:				
Treatment	7	0.93	0.13	1.83
Replication	2	1.04	0.52	7.14**
Error	14	1.02	0.07	
Total	23	2.98		

*, **, *** - significant at $p \leq$ 0.05, 0.01, 0.001 respectively

parameter: sourness

SOV	DF	SS	MS	F
Panelist 1:				
Treatment	7	5779.74	825.68	0.83
Replication	2	3354.50	1677.25	1.69
Error	14	13863.39	990.24	
Total	23	22997.64		
Panelist 2:				
Treatment	7	17957.33	2565.33	9.11***
Replication	2	4486.82	2243.41	7.97***
Error	14	3942.34	281.60	
Total	23	26386.49		
Panelist 3:				
Treatment	7	14591.87	2084.55	3.48*
Replication	2	26107.81	13053.90	21.77***
Error	14	8394.49	599.61	
Total	23	49094.17		
Panelist 4:				
Treatment	7	16625 59	2375.08	5.04**
Replication	2	2013.71	1006.85	2.14
Error	14	6592.27	470.88	
Total	23	25231.56		
Panelist 5:				
Treatment	7	13040.51	1862.93	1.55
Replication	2	2663.99	1331.99	1.11
Error	14	16810.75	1200.77	
Total	23	32515.24		
Panelist 6:				
Treatment	7	6153.37	879.05	2.92*
Replication	2	3770.18	1885.09	6.26*
Error	14	4214.45	301.03	
Total	23	14138.01		
Panelist 7:				
Treatment	7	15685.46	2240.78	9.90***
Replication	2	1283.63	641.81	2.84
Error	14	3167.31	226.24	
Total	23	20136.39		
Panelist 8:				
Treatment	7	14848.42	2121.20	4.67**
Replication	2	356.26	178.13	0.39
Error	14	6360.46	454.32	
Total	23	21565.14		

*, **, *** - significant at $p \leq$ 0.05, 0.01, 0.001 respectively

parameter: duration of sourness

SOV	DF	SS	MS	F
Panelist 1:				
Treatment	7	105.15	15.02	2.01
Replication	2	97.94	48.97	6.54**
Error	14	104.84	7.49	
Total	23	307.94		
Panelist 2:				
Treatment	7	66.11	9.44	2.60
Replication	2	78.05	39.03	10.74**
Error	14	50.85	3.63	
Total	23	195.01		
Panelist 3:				
Treatment	7	1451.84	207.41	3.20*
Replication	2	68.55	34.28	0.53
Error	14	908.64	64.90	
Total	23	2429.03		
Panelist 4:				
Treatment	7	980.92	140.13	2.03
Replication	2	19.56	9.78	0.14
Error	14	966.02	69.00	
Total	23	1966.50		
Panelist 5:				
Treatment	7	448.00	64.00	1.49
Replication	2	282.29	141.15	3.29
Error	14	600.52	42.89	
Total	23	1330.81		
Panelist 6:				
Treatment	7	76.43	10.92	3.26*
Replication	2	60.07	30.04	8.98**
Error	14	46.82	3.34	
Total	23	148.13		
Panelist 7:				
Treatment	7	90.77	12.97	5.03**
Replication	2	21.28	10.64	4.13*
Error	14	36.08	2.58	
Total	23	148.13		
Panelist 8:				
Treatment	7	418.14	59.73	4.30**
Replication	2	37.09	18.54	1.33
Error	14	194.68	13.91	
Total	23	649.91		

*, **, *** - significant at $p \leq$ 0.05, 0.01, 0.001 respectively

parameter: time to maximum intensity of sourness

SOV	DF	SS	MS	F
Panelist 1:				
Treatment	7	53.73	7.68	1.28
Replication	2	69.16	34.58	5.77*
Error	14	83.90	5.99	
Total	23	206.80		
Panelist 2:				
Treatment	7	21.97	3.14	1.81
Replication	2	7.68	3.81	2.22
Error	14	24.24	1.73	
Total	23	53.89		
Panelist 3:				
Treatment	7	27.54	3.93	0.43
Replication	2	34.38	17.19	1.89
Error	14	127.41	9.10	
Total	23	189.33		
Panelist 4:				
Treatment	7	19.41	2.77	0.62
Replication	2	7.86	3.93	0.88
Error	14	62.88	4.49	
Total	23	90.15		
Panelist 5:				
Treatment	7	65.05	9.29	2.09
Replication	2	18.01	9.01	2.03
Error	14	62.19	4.44	
Total	23	145.25		
Panelist 6:				
Treatment	7	8.76	1.25	0.78
Replication	2	0.37	0.19	0.12
Error	14	22.53	1.61	
Total	23	31.67		
Panelist 7:				
Treatment	7	19.39	2.77	1.07
Replication	2	0.61	0.30	0.12
Error	14	36.35	2.60	
Total	23	56.35		
Panelist 8:				
Treatment	7	3.11	0.44	0.69
Replication	2	0.38	0.19	0.29
Error	14	8.96	0.64	
Total	23	12.45		

*, **, *** - significant at $p \leq$ 0.05, 0.01, 0.001 respectively

Analysis of Variance Tables for Individual Panelists for Each of the Eight Time-Intensity Parameters of the Sourness of the Level Two Acid Solutions

parameter: maximum intensity of sourness

SOV	DF	SS	MS	F
Panelist 1:				
Treatment	7	3279.96	468.57	6.42**
Replication	2	4390.75	2195.38	30.08***
Error	14	1021.92	72.99	
Total	23	8692.62		
Panelist 2:				
Treatment	7	4101.62	585.95	10.67***
Replication	2	207.25	103.62	1.89
Error	14	768.75	54.91	
Total	23	5077.62		
Panelist 3:				
Treatment	7	2131.96	304.57	6.74
Replication	2	29.08	14.54	0.32
Error	14	632.92	45.21	
Total	23	2793.96		
Panelist 4:				
Treatment	7	1081.17	154.45	3.86*
Replication	2	186.33	93.17	2.33
Error	14	560.33	40.02	
Total	23	1827.83		
Panelist 5:				
Treatment	7	2725.33	389.33	4.25*
Replication	2	305.08	152.54	1.66
Error	14	1282.92	91.64	
Total	23	4313.33		
Panelist 6:				
Treatment	7	4378.62	625.52	1.84
Replication	2	738.25	369.12	1.09
Error	14	4749.75	339.27	
Total	23	9866.62		
Panelist 7:				
Treatment	7	3908.96	558.42	4.47**
Replication	2	1804.75	902.38	7.23**
Error	14	1747.92	124.85	
Total	23	7461.62		
Panelist 8:				
Treatment	7	3947.62	563.95	11.02***
Replication	2	377.08	188.54	3.69
Error	14	716.25	51.16	
Total	23	5040.96		

*, **, *** - significant at $p \leq$ 0.05, 0.01, 0.001 respectively

parameter: area under the curve of sourness

SOV	DF	SS	MS	F
Panelist 1:				
Treatment	7	981201.84	140172.55	2.91*
Replication	2	1380290.70	690145.35	14.35***
Error	14	673429.63	48102.12	
Total	23	3034928.17		
Panelist 2:				
Treatment	7	2441235.25	348747.89	4.07*
Replication	2	180660.78	90330.39	1.05
Error	14	1199959.13	85711.37	
Total	23	3821855.16		
Panelist 3:				
Treatment	7	1239187.03	177026.72	22.19***
Replication	2	36791.58	18395.79	2.31
Error	14	111675.53	7976.82	
Total	23	1387654.14		
Panelist 4:				
Treatment	7	456511.94	65215.99	2.84*
Replcation	2	199942.31	99971.15	4.35*
Error	14	321612.12	22972.29	
Total	23	978066.36		
Panelist 5:				
Treatment	7	549593.71	78513.39	4.80**
Replication	2	300442.68	150221.34	9.18***
Error	14	229063.82	16361.70	
Total	23	1079100.21		
Panelist 6:				
Treatment	7	836247.94	119463.99	2.42
Replication	2	42614.75	21307.38	0.43
Error	14	691988.80	49427.77	
Total	23	1570851.50		
Panelist 7:.				
Treatment	7	568110.93	81158.70	2.78*
Replication	2	490409.67	245204.84	8.41**
Error	14	408017.72	29144.12	
Total	23	1466538.32		
Panelist 8:				
Treatment	7	2257325.45	322475.06	16.51***
Replication	2	56678.72	28339.36	1.45
Error	14	273476.89	19534.06	
Total	23	2587481.06		

*, **, *** - significant at $p \leq 0.05, 0.01, 0.001$ respectively

parameter: sourness

SOV	DF	SS	MS	F
Panelist 1:				
Treatment	7	20013.13	2859.02	5.77*
Replication	2	14671.47	7335.73	14.81***
Error	14	6936.51	495.47	
Total	23	41621.11		
Panelist 2:				
Treatment	7	18328.19	2618.31	7.38***
Replication	2	1229.81	614.90	1.73
Error	14	4966.16	354.73	
Total	23	24524.17		
Panelist 3:				
Treatment	7	14276.80	2039.54	16.58***
Replication	2	108.02	54.01	0.44
Error	14	1722.09	123.01	
Total	23	16106.91		
Panelist 4:				
Treatment	7	5066.35	723.76	3.62*
Replication	2	1157.18	558.59	2.89
Error	14	2802.88	200.21	
Total	23	9026.41		
Panelist 5:				
Treatment	7	10720.26	1531.47	4.57**
Replication	2	1249.18	624.59	1.86
Error	14	4693.32	335.24	
Total	23	16662.76		
Panelist 6:				
Treatment	7	21143.81	3020.54	2.08
Replication	2	2604.55	1302.27	0.89
Error	14	20732.95	1455.21	
Total	23	44121.31		
Panelist 7:				
Treatment	7	14302.77	2043.25	4.58**
Replication	2	8714.38	4357.19	9.76**
Error	14	6252.56	446.61	
Total	23	29269.71		
Panelist 8:				
Treatment	7	17274.16	2467.74	11.20***
Replication	2	1403.44	701.72	3.18
Error	14	3085.77	220.41	
Total	23	21763.37		

*, **, *** - significant at $p \leq$ 0.05, 0.01, 0.001 respectively

Appendix Q (continued)

parameter: duration of sourness

SOV	DF	SS	MS	F
Panelist 1:				
Treatment	7	420.96	60.14	3.57*
Replication	2	40.55	20.27	1.20
Error	14	235.61	16.83	
Total	23	697.11		
Panelist 2:				
Treatment	7	399.33	57.05	2.35
Replication	2	36.08	18.04	0.74
Error	14	340.32	24.31	
Total	23	775.74		
Panelist 3:				
Treatment	7	1039.42	148.49	5.22**
Replication	2	40.40	20.20	0.71
Error	14	397.97	28.43	
Total	23	1477.79		
Panelist 4:				
Treatment	7	548.15	78.31	1.76
Replication	2	184.80	92.40	2.08
Error	14	623.14	44.51	
Total	23	1356.09		
Panelist 5:				
Treatment	7	311.27	44.47	2.47
Replication	2	263.40	131.70	7.37**
Error	14	250.18	17.87	
Total	23	824.85		
Panelist 6:				
Treatment	7	157.14	22.45	3.37*
Replication	2	23.79	11.90	1.79
Error	14	244.21	17.44	
Total	23	573.72		
Panelist 7:				
Treatment	7	264.71	37.82	2.17
Replication	2	64.81	32.40	1.86
Error	14	244.21	17.44	
Total	23	573.72		
Panelist 8:				
Treatment	7	354.42	50.63	8.38***
Replication	2	8.56	4.28	0.71
Error	14	84.59	6.04	
Total	23	447.57		

*, **, *** - significant at $p \leq$ 0.05, 0.01, 0.001 respectively

Appendix Q (continued)

parameter: time to initial response of sourness

SOV	DF	SS	MS	F
Panelist 1:				
Treatment	7	0.89	0.13	0.83
Replication	2	0.36	0.18	1.17
Error	14	2.14	0.15	
Total	23			
Panelist 2:				
Treatment	7	32.94	4.71	0.78
Replication	2	11.97	5.99	1.00
Error	14	83.99	6.00	
Total	23	128.91		
Panelist 3:				
Treatment	7	0.54	0.08	0.48
Replication	2	1.25	0.62	3.92
Error	14	2.23	0.16	
Total	23	4.02		
Panelist 4:				
Treatment	7	7.25	1.04	0.54
Replication	2	2.84	1.42	0.74
Error	14	26.71	1.91	
Total	23	36.80		
Panelist 5:				
Treatment	7	0.94	0.13	0.64
Replication	2	0.15	0.07	0.35
Error	14	2.93	0.21	
Total	23	4.01		
Panelist 6:				
Treatment	7	12.95	1.85	0.74
Replication	2	4.65	2.33	0.93
Error	14	35.07	2.51	
Total	23	52.68		
Panelist 7:				
Treatment	7	0.40	0.06	0.76
Replication	2	0.52	0.26	3.43
Error	14	1.05	0.08	
Total	23	1.97		
Panelist 8:				
Treatment	7	2.16	0.31	8.64***
Replication	2	0.02	0.01	0.29
Error	14	0.50	0.40	
Total	23	2.68		

*, **, *** - significant at $p \leq 0.05$, 0.01, 0.001 respectively

Appendix Q (continued)

parameter: peak area of sourness

SOV	DF	SS	MS	F
Panelist 1:				
Treatment	7	84070.88	12010.13	0.99
Replication	2	256574.91	128287.45	10.55**
Error	14	170172.11	12155.15	
Total	23	510817.90		
Panelist 2:				
Treatment	7	197735.62	28247.95	3.66*
Replication	2	37264.91	18632.45	2.41
Error	14	108119.83	7722.85	
Total	23	343120.36		
Panelist 3:				
Treatment	7	169929.40	24275.63	4.82**
Replication	2	2793.81	1396.91	0.28
Error	14	70495.98	5035.43	
Total	23	243219.19		
Panelist 4:				
Treatment	7	65875.10	9410.73	2.59
Replication	2	58507.54	29253.77	8.04**
Error	14	50949.71	3639.27	
Total	23	175332.35		
Panelist 5:				
Treatment	7	91979.62	13139.95	1.21
Replication	2	70966.35	35483.17	3.26
Error	14	152171.56	10869.40	
Total	23	315117.52		
Panelist 6:				
Treatment	7	54822.20	7831.74	0.62
Replication	2	83106.08	41553.04	3.29
Error	14	177084.58	12648.90	
Total	23	315012.87		
Panelist 7:				
Treatment	7	85217.75	12173.96	2.35
Replication	2	63743.27	31871.64	6.15*
Error	14	72571.15	5183.65	
Total	23	221532.17		
Panelist 8:				
Treatment	7	168911.07	24130.15	1.70
Replication	2	9638.43	4819.21	0.34
Error	14	199168.96	14226.35	
Total	23	377718.46		

*, **, *** - significant at $p \leq$ 0.05, 0.01, 0.001 respectively

parameter: peak time of sourness

SOV	DF	SS	MS	F
Panelist 1:				
Treatment	7	24.35	3.48	0.82
Replication	2	32.41	16.20	3.81
Error	14	59.46	4.25	
Total	23	116.22		
Panelist 2:				
Treatment	7	21.19	3.03	1.81
Replication	2	3.86	1.93	1.16
Error	14	23.38	1.67	
Total	23	48.44		
Panelist 3:				
Treatment	7	34.52	4.93	2.18
Replication	2	0.70	0.35	0.15
Error	14	31.69	2.26	
Total	23	66.91		
Panelist 4:				
Treatment	7	29.05	4.15	1.94
Replication	2	32.55	16.28	7.62**
Error	14	29.89	2.13	
Total	23	91.49		
Panelist 5:				
Treatment	7	45.84	6.55	1.40
Replication	2	27.26	13.63	2.91
Error	14	65.65	4.69	
Total	23	138.75		
Panelist 6:				
Treatment	7	11.22	1.60	0.56
Replication	2	15.35	7.67	2.68
Error	14	40.16	2.87	
Total	23	66.73		
Panelist 7:				
Treatment	7	7.45	1.06	0.43
Replication	2	4.68	2.34	0.95
Error	14	34.45	2.46	
Total	23	46.58		
Panelist 8:				
Treatment	7	82.20	11.74	1.87
Replication	2	1.66	0.83	0.13
Error	14	87.94	6.28	
Total	23	171.80		

*, **, *** - significant at $p \leq 0.05, 0.01, 0.001$ respectively

parameter: time to maximum intensity of sourness

SOV	DF	SS	MS	F
Panelist 1:				
Treatment	7	49.43	7.06	0.50
Replication	2	9.23	4.66	0.33
Error	14	196.92	14.07	
Total	23	255.67		
Panelist 2:				
Treatment	7	34.74	4.96	0.74
Replication	2	17.63	8.81	1.32
Error	14	93.59	6.68	
Total	23	149.95		
Panelist 3:				
Treatment	7	50.82	7.26	0.50
Replication	2	3.60	1.80	0.12
Error	14	203.98	14.57	
Total	23	258.40		
Panelist 4:				
Treatment	7	51.72	7.39	1.72
Replication	2	31.61	15.80	3.68
Error	14	60.08	4.29	
Total	23	143.42		
Panelist 5:				
Treatment	7	50.68	7.24	1.05
Replication	2	118.35	59.18	8.55**
Error	14	96.89	6.29	
Total	23	265.92		
Panelist 6:				
Treatment	7	20.63	2.95	0.52
Replication	2	17.23	8.61	1.51
Error	14	80.01	5.71	
Total	23	117.86		
Panelist 7:				
Treatment	7	21.85	3.12	1.28
Replication	2	18.35	9.18	3.75*
Error	14	34.22	2.44	
Total	23			
Panelist 8:				
Treatment	7	2.67	0.38	0.54
Replication	2	0.08	0.04	0.05
Error	14	9.94	0.71	
Total	23	12.69		

*, **, *** - significant at $p \leq 0.05, 0.01, 0.001$ respectively

Appendix R

Means and LSD's ($p < 0.05\%$) for the sourness of the level one acid solutions.

Maximum Intensity

Panelist	Lactic	Acetic	Malic	Citric	Tartaric	FOD	HCL	LSD
#1	13.33 a	24.33 ab	29.00 ab	37.33 b	27.67 ab	42.00 b	27.67 ab	22.98
#2	60.99 a	71.43 ab	94.50 bc	70.52 ab	112.52 cd	124.12 de	142.60 e	15.20
#3	21.33 a	31.67 ab	39.33 bc	41.33 bc	41.33 bc	45.67 c	49.67 c	13.29
#4	25.67 a	42.00 bc	43.67 bc	39.67 cd	50.33 abc	60.33 a	64.67 a	14.69
#5	28.67 a	37.33 ab	48.33 abc	54.33 abc	62.67 bc	68.33 c	56.00 bc	26.15
#6	22.00 a	28.67 a	27.00 a	28.67 a	34.67 ab	46.33 b	38.00 ab	16.92
#7	12.67 a	26.33 bc	21.00 ab	21.67 ab	21.67 ab	39.33 d	60.00 e	10.94
#8	15.33 a	48.67 bc	49.67 bc	48.00 bc	47.33 bc	63.00 c	48.33 bc	17.15

Panelist	Lactic	Acetic	Malic	Citric	Tartaric	FOD	HCL	LSD
#1	43.18 a	67.91 ab	63.15 ab	82.54 ab	69.03 ab	98.53 ab	68.19 b	55.11
#2	60.59 a	71.43 ab	94.50 bc	70.52 ab	112.52 cd	124.12 de	142.60 e	29.39
#3	51.23 a	92.61 b	118.55 b	132.65 b	112.50 b	125.27 b	120.35 b	42.88
#4	58.13 a	101.39 b	108.42 bc	88.99 ab	120.48 bc	143.34 c	141.50 c	38.00
#5	95.58 a	91.77 a	116.42 ab	132.07 ab	147.96 ab	164.71 b	120.68 ab	60.68
#6	52.18 a	67.75 ab	58.26 ab	65.48 ab	79.99 abc	106.63 c	84.73 bc	30.38
#7	33.80 a	61.69 bc	60.06 ab	63.20 bc	53.86 ab	86.52 c	126.32 d	26.14
#8	136.48 a	108.70 bc	109.67 bc	107.57 bc	104.14 bc	136.46 c	102.72 bc	37.33

Perimeter

Area Under the Curve

Panelist	Lactic	Acetic	Malic	Citric	Tartaric	FOD	HCL	LSD
#1	101.30 a	255.60 ab	221.40 ab	314.90 ab	251.10 ab	423.50 b	181.70 ab	270.45
#2	245.50 a	364.90 a	434.40 ab	332.70 a	609.90 bc	727.10 cd	881.50 d	231.18
#3	218.00 a	575.50 b	623.80 b	816.70 b	703.10 b	792.50 b	701.00 b	332.98
#4	242.70 a	607.00 ab	653.70 ab	448.10 ab	707.30 bc	1061.50 c	659.00 b	415.54
#5	381.40 a	438.10 ab	790.10 abc	925.60 abc	1213.30 c	1053.90 bc	530.30 ab	639.71
#6	182.26 a	285.99 ab	228.41 ab	284.31 ab	356.21 bc	463.98 c	316.00 abc	161.57
#7	93.48 a	245.34 b	189.36 ab	227.01 b	194.92 ab	397.03 c	573.91 d	106.16
#8	149.90 a	714.70 b	694.10 b	791.40 bc	649.40 b	1132.50 c	519.90 ab	383.72

Panelist	Lactic	Acetic	Malic	Citric	Tartaric	FOD	HCL	LSD
#1	10.25 a	14.35 ab	11.16 ab	13.80 ab	15.79 b	15.49 b	10.32 a	4.79
#2	14.11 a	14.70 bc	15.30 abc	14.62 ab	17.18 abc	17.67 bc	18.47 c	3.34
#3	14.45 a	15.47 b	15.52 b	15.69 b	14.12 b	18.52 ab	18.00 ab	14.11
#4	13.55 a	15.45 ab	15.59 ab	10.33 a	12.77 ab	16.27 b	16.97 a	14.55
#5	23.05 abc	18.31 ab	23.12 abc	27.40 bc	30.30 c	21.67 abc	15.84 a	11.47
#6	10.29 a	14.19 bcd	11.39 bcd	14.42 cd	14.46 d	15.23 d	11.06 ab	3.20
#7	9.78 a	13.00 b	13.92 bcd	16.58 d	12.35 ab	15.37 cd	13.92 bcd	2.81
#8	13.27 a	19.42 ab	19.39 ab	23.73 bc	17.99 ab	23.87 bc	15.17 a	6.53

Duration

Appendix R (continued)

Means and LSD's ($p < 0.05$) for the sourness of the level one acid solutions.

Time to Initial Response

Panelist	Lactic	Acetic	Malic	Citric	Tartaric	FDD	HCL	LSD
#1	1.55 ab	2.73 b	2.20 ab	1.48 ab	1.97 ab	1.46 ab	1.64 ab	1.38
#2	0.84 a	1.04 b	1.52 ab	1.22 ab	1.90 b	1.06 ab	1.64 ab	0.96
#3	1.58 a	0.96 a	1.69 a	1.32 a	1.02 a	1.58 a	1.07 a	0.87
#4	1.35 a	0.65 a	1.01 a	0.63 a	0.15 a	0.80 a	1.24 a	1.25
#5	2.67 b	2.11 ab	2.32 ab	2.20 ab	2.43 ab	2.05 ab	2.05 ab	0.69
#6	1.32 ab	1.00 ab	1.20 ab	1.36 ab	1.24 ab	0.96 a	1.56 b	0.59
#7	2.54 ab	1.50 a	2.13 ab	2.04 ab	1.56 a	1.73 ab	1.74 ab	1.25
#8	0.71 a	1.05 ab	0.90 a	1.14 ab	1.57 b	0.84 b	1.06 ab	0.47

Panelist	Lactic	Acetic	Malic	Citric	Tartaric	FDD	HCL	LSD
#1	85.11 ab	148.00 ab	139.21 ab	37.78 a	108.01 ab	242.42 b	87.06 ab	193.07
#2	154.99 a	313.86 b	340.08 bc	237.71 ab	382.58 bc	474.37 c	261.66 ab	153.90
#3	71.98 a	52.70 a	151.13 a	112.50 a	104.81 a	330.19 b	98.55 a	124.27
#4	86.52 ab	144.91 b	154.06 b	83.68 ab	147.49 b	6.38 a	66.39 ab	105.64
#5	106.24 ab	111.85 ab	184.03 ab	12.06 a	203.07 b	88.78 ab	196.52 b	182.57
#6	49.73 a	80.36 a	69.73 a	156.58 a	93.60 a	201.92 a	137.68 a	196.95
#7	69.88 c	85.74 c	140.84 abc	115.81 bc	121.61 bc	248.03 a	227.24 ab	126.08
#8	61.85 b	203.70 ab	314.94 a	84.48 b	198.72 ab	151.81 ab	93.23 b	208.87

Peak Area

Time to Maximum Intensity

Panelist	Lactic	Acetic	Malic	Citric	Tartaric	FDD	HCL	LSD
#1	7.69 a	9.45 a	5.99 a	5.70 a	7.11 a	9.42 a	5.78 a	4.23
#2	3.64 a	4.91 abc	6.52 c	4.20 ab	5.38 bc	4.66 abc	5.00 abc	2.30
#3	5.37 a	0.47 a	4.27 a	4.60 a	6.74 a	7.07 a	5.90 a	5.28
#4	3.76 a	6.10 a	4.07 a	4.03 a	5.15 a	5.39 a	4.15 a	3.71
#5	6.83 b	10.84 ab	6.65 a	11.39 b	9.74 ab	7.83 ab	9.19 ab	3.69
#6	4.53 a	5.17 a	6.38 a	5.99 a	6.47 a	5.66 a	5.68 a	2.22
#7	5.80 a	5.44 a	6.63 a	7.95 a	5.66 a	7.84 a	6.10 a	2.82
#8	2.99 a	3.76 a	3.67 a	3.83 a	3.80 a	3.37 a	4.21 a	1.40

Panelist	Lactic	Acetic	Malic	Citric	Tartaric	FDD	HCL	LSD
#1	0.37 a	3.02 b	2.10 ab	1.46 ab	0.59 a	0.42 a	1.61 ab	2.42
#2	3.07 ab	4.51 ab	3.08 ab	5.07 ab	2.16 a	4.39 ab	5.71 b	3.48
#3	1.90 a	2.57 ab	6.65 b	3.90 ab	2.49 ab	3.61 ab	2.29 a	4.22
#4	3.46 a	2.45 a	5.47 a	2.38 a	1.70 a	1.39 a	4.15 a	6.07
#5	3.67 a	3.51 a	5.90 a	3.95 a	1.16 a	4.66 a	1.17 a	3.36
#6	2.64 a	4.23 a	1.63 a	3.94 a	2.44 a	1.98 a	3.26 a	2.32
#7	2.43 a	4.87 b	3.62 ab	2.88 ab	4.43 ab	2.68 ab	3.79 ab	4.12
#8	2.34 a	4.53 a	1.26 a	0.58 a	3.55 a	4.22 a	2.44 a	

Peak Time

Appendix S

Means and LSD's ($p < 0.05$) for the sourness of the level two acid solutions.

Maximum Intensity

Panelist	Lactic	Acetic	Malic	Citric	Tartaric	PDD	HCL	LSD
#1	21.67 a	46.00 a	53.00 bc	47.33 b	56.00 bc	64.00 c	49.33 bc	14.96
#2	34.33 a	56.33 a	65.33 c	54.67 b	64.00 bc	76.67 c	72.00 c	12.98
#3	33.33 a	45.67 ab	51.33 bc	48.67 bc	56.67 cd	67.00 d	54.00 bc	11.78
#4	32.33 a	48.67 bc	50.67 bc	41.67 ab	47.00 bc	48.33 bc	34.67 c	11.08
#5	30.33 a	45.00 ab	50.00 bc	52.67 bc	45.67 ab	64.00 c	65.00 c	16.67
#6	20.67 a	33.67 ab	46.33 abc	45.67 abc	56.00 bc	68.33 c	44.33 abc	32.26
#7	19.67 a	17.00 ab	53.67 bc	28.67 abc	27.67 abc	46.67 cd	33.33 c	19.57
#8	23.33 a	46.67 b	47.67 bc	56.67 bc	59.33 c	72.67 d	45.67 b	12.33

Area Under the Curve

Panelist	Lactic	Acetic	Malic	Citric	Tartaric	PDD	HCL	LSD
#1	155.10 a	659.70 bc	757.20 bc	324.20 abc	645.90 bc	851.90 c	397.00 ab	584.08
#2	428.70 a	997.60 b	1210.00 bc	1045.90 bc	1309.00 bc	1518.50 c	1155.10 bc	512.69
#3	349.46 a	630.70 b	759.00 bcd	786.47 bcd	877.36 d	1209.94 e	713.34 bc	156.41
#4	380.50 a	885.00 c	661.80 bc	312.20 ab	720.70 bc	672.50 bc	650.50 bc	265.42
#5	303.60 a	533.20 b	722.60 bc	724.50 bc	533.40 b	807.40 c	717.00 bc	224.00
#6	141.80 a	525.10 a	414.00 a	476.10 ab	504.50 ab	839.80 b	554.50 a	389.34
#7	121.20 a	190.10 ab	379.10 abc	586.30 abc	532.10 abc	601.50 c	539.70 c	298.96
#8	265.00 a	731.70 b	785.40 b	856.30 b	956.40 b	1349.50 c	446.30 a	244.76

Perimeter

Panelist	Lactic	Acetic	Malic	Citric	Tartaric	PDD	HCL	LSD
#1	43.18 a	67.91 ab	63.15 ab	82.54 ab	69.05 ab	98.33 b	68.19 ab	33.11
#2	60.59 a	71.45 ab	94.50 bc	70.52 ab	112.52 cd	124.12 de	142.60 e	29.39
#3	51.23 a	92.61 ab	118.33 b	132.63 b	112.50 b	123.27 b	120.33 b	42.88
#4	78.39 a	124.57 a	116.23 a	104.43 a	123.19 a	116.93 a	122.58 a	24.78
#5	68.93 a	102.31 b	112.56 bc	122.18 bc	101.81 b	136.91 c	138.24 c	32.06
#6	45.37 a	78.54 ab	101.11 abc	101.69 abc	123.17 bc	132.47 c	96.60 abc	66.80
#7	33.71 a	49.26 ab	78.37 bc	80.06 bc	79.78 bc	104.57 c	112.24 c	39.01
#8	63.42 a	109.43 ab	112.48 ab	127.19 ab	154.64 b	163.56 c	104.34 a	26.00

Duration

Panelist	Lactic	Acetic	Malic	Citric	Tartaric	PDD	HCL	LSD
#1	10.23 a	14.33 ab	11.16 ab	13.80 ab	13.79 b	13.49 b	10.33 a	4.79
#2	14.11 a	14.70 ab	15.32 abc	14.62 ab	17.18 abc	17.67 bc	18.47 c	5.34
#3	14.43 a	13.47 a	13.52 a	11.69 a	14.12 a	18.52 a	28.00 a	14.11
#4	13.33 a	23.43 ab	23.39 ab	19.33 a	22.77 ab	36.27 b	16.97 a	14.33
#5	23.03 abc	18.31 ab	23.12 abc	27.40 bc	30.30 c	21.67 abc	15.84 a	11.47
#6	10.29 a	14.19 bcd	11.39 abc	14.42 cd	14.66 d	13.23 d	11.06 ab	5.20
#7	9.78 a	13.00 ab	13.92 bcd	16.58 d	12.33 ab	13.37 cd	13.92 bcd	2.81
#8	13.27 a	19.42 ab	19.39 ab	23.73 bc	17.99 ab	23.87 bc	15.17 a	6.53

Appendix S (continued)

Means and LSD's ($p < 0.05$) for the sourness of the level two acid solutions.

Peak Area

Panelist	Lactic	Acetic	Malic	Citric	Tartaric	FCD	HCL	LSD
#1	85.11 ab	148.80 ab	139.21 ab	57.78 a	106.01 ab	262.62 b	87.06 ab	193.07
#2	154.99 a	313.06 b	340.08 bc	237.71 ab	382.58 bc	476.37 c	261.66 ab	153.90
#3	71.98 a	52.78 a	131.13 a	112.50 a	104.81 a	330.19 b	98.55 a	124.27
#4	86.52 ab	144.91 b	154.06 b	83.68 ab	167.49 b	0.38 a	66.39 ab	105.64
#5	106.24 ab	111.85 ab	164.03 ab	12.06 a	203.07 b	88.78 ab	196.52 b	182.57
#6	49.73 a	80.56 a	69.73 a	156.58 a	93.60 a	201.92 a	137.68 a	196.95
#7	69.88 c	83.76 c	140.84 abc	115.81 bc	121.61 bc	248.03 a	227.26 ab	126.06
#8	61.85 b	203.78 ab	316.94 a	84.68 b	198.72 ab	151.83 ab	93.23 b	208.87

Panelist	Lactic	Acetic	Malic	Citric	Tartaric	FCD	HCL	LSD
#1	1.50 a	1.06 a	0.96 a	1.00 a	0.98 a	1.11 a	1.22 a	0.68
#2	3.84 a	2.60 a	0.57 a	2.54 a	1.24 a	0.76 a	2.36 a	4.29
#3	1.17 a	1.03 a	1.37 a	1.14 a	1.06 a	1.08 a	1.21 a	0.70
#4	1.10 a	0.54 a	0.84 a	0.96 a	1.44 a	0.70 a	1.88 a	2.62
#5	2.29 a	1.88 a	1.70 a	1.90 a	1.97 a	2.07 a	1.89 a	0.80
#6	1.56 a	1.94 a	1.05 a	1.31 a	1.52 a	0.93 a	3.40 a	2.77
#7	1.88 a	2.00 a	2.00 a	2.00 a	1.92 a	1.95 a	1.59 a	0.68
#8	0.91 cd	1.22 bc	0.80 b	1.47 d	0.81 b	0.38 a	0.87 b	0.33

Time to Inital Response

Peak Time

Panelist	Lactic	Acetic	Malic	Citric	Tartaric	FCD	HCL	LSD
#1	3.40 a	2.09 a	2.43 a	0.89 a	1.78 a	3.09 a	1.00 a	3.61
#2	8.40 ab	5.60 ab	8.98 ab	4.28 ab	5.93 b	6.17 b	3.66 a	2.26
#3	5.90 a	9.07 a	5.08 a	7.02 a	4.59 a	0.51 a	5.96 a	6.68
#4	2.88 abc	2.98 bc	3.20 bc	2.12 abc	3.75 c	0.14 a	1.16 ab	2.56
#5	3.77 ab	2.87 ab	3.35 ab	0.26 a	0.40 b	1.81 ab	3.53 ab	3.79
#6	1.78 a	2.41 a	1.39 a	3.35 a	1.72 a	3.19 a	2.51 a	2.97
#7	5.27 a	8.68 a	4.22 a	3.72 a	8.34 a	8.91 a	8.28 a	2.75
#8	1.93 a	0.27 ab	7.04 b	1.37 a	3.50 ab	2.14 a	2.20 a	4.39

Panelist	Lactic	Acetic	Malic	Citric	Tartaric	FCD	HCL	LSD
#1	3.64 a	6.08 a	5.92 a	7.47 a	7.35 a	7.77 a	8.00 a	0.57
#2	7.17 a	6.52 a	7.68 a	6.16 a	5.61 a	3.88 a	8.73 a	0.53
#3	5.90 a	9.07 a	5.08 a	7.02 a	4.59 a	0.51 a	5.96 a	6.68
#4	8.11 a	5.35 ab	8.36 a	8.72 ab	8.86 ab	7.54 ab	8.48 b	3.03
#5	6.63 ab	8.75 ab	8.58 ab	10.13 b	5.35 a	8.09 ab	8.28 ab	4.01
#6	5.46 a	8.12 a	5.83 a	6.12 a	5.11 a	8.01 a	7.32 a	8.19
#7	8.78 a	5.71 ab	8.58 ab	8.04 b	7.25 ab	7.09 ab	8.27 ab	2.78
#8	3.49 a	3.37 a	3.36 a	3.72 a	3.19 a	3.23 a	8.23 a	1.88

Time to Maximum Intensity

Analysis of Variance Tables for Individual Panelists for Each of the Eight Time-Intensity Parameters of the Astringency of the Level One Acid Solutions

parameter: astringency

SOV	DF	SS	MS	F
Panelist 1:				
Treatment	7	4496.45	642.35	0.77
Replication	2	16953.87	8476.93	10.16**
Error	14	11676.18	834.01	
Total	23	33126.50		
Panelist 2:				
Treatment	7	22616.57	3230.94	5.18**
Replication	2	713.77	356.89	0.57
Error	14	8726.67	623.33	
Total	23	32057.01		
Panelist 3:				
Treatment	7	19855.06	2836.44	4.58**
Replication	2	10161.55	5080.77	8.20**
Error	14	8762.64	619.47	
Total	23	38689.25		
Panelist 4:				
Treatment	7	19625.58	2803.65	5.46**
Replication	2	329.24	164.62	0.32
Error	14	7184.96	513.21	
Total	23	27139.78		
Panelist 5:				
Treatment	7	22966.90	3285.27	3.63*
Replication	2	27050.43	13525.22	14.94***
Error	14	12670.55	905.04	
Total	23	62717.88		
Panelist 6:				
Treatment	7	35834.88	5119.27	6.65**
Replication	2	4286.67	2143.33	2.79
Error	14	10769.45	769.25	
Total	23	50891.00		
Panelist 7:				
Treatment	7	61225.72	8746.53	8.35***
Replication	2	2534.25	1267.12	1.21
Error	14	14658.12	1047.01	
Total	23	78418.09		
Panelist 8:				
Treatment	7	11582.87	1654.70	1.86
Replication	2	1512.42	756.21	0.85
Error	14	12450.09	889.29	
Total	23	25545.38		

*, **, *** - significant at $p \leq$ 0.05, 0.01, 0.001 respectively

Appendix T (continued)

parameter: area under the curve of astringency

SOV	DF	SS	MS	F
Panelist 1:				
Treatment	7	1732358.47	247479.78	1.31
Replication	2	5550180.89	2775090.45	14.73***
Error	14	2637202.26	188371.59	
Total	23	9919741.62		
Panelist 2:				
Treatment	7	4872407.30	696058.18	4.53**
Replication	2	126908.68	63454.34	0.41
Error	14	2151841.36	153702.95	
Total	23	7151157.34		
Panelist 3:				
Treatment	7	10748692.03	1535527.43	5.68**
Replication	2	3618333.35	1809166.67	6.69**
Error	14	3785401.85	270385.85	
Total	23	18152427.22		
Panelist 4:				
Treatment	7	3051326.27	435903.75	4.49**
Replication	2	566113.21	283056.60	2.91
Error	14	1359992.19	97142.30	
Total	23	4977431.67		
Panelist 5:				
Treatment	7	2143764.40	306252.06	4.93**
Replication	2	1934249.49	967124.74	15.56***
Error	14	870132.73	62152.34	
Total	23	4948146.62		
Panelist 6:				
Treatment	7	6263119.59	894731.37	5.31**
Replication	2	837522.80	418761.40	2.49
Error	14	2357801.93	168414.42	
Total	23	9458444.32		
Panelist 7:				
Treatment	7	4110953.27	587279.04	11.39***
Replication	2	196715.90	98357.95	1.91
Error	14	721846.27	51560.45	
Total	23	5029515.44		
Panelist 8:				
Treatment	7	3950284.19	564326.31	2.72
Replication	2	344937.16	172468.58	0.83
Error	14	2906996.19	207642.58	
Total	23	7202217.54		

*, **, *** - significant at $p \leq$ 0.05, 0.01, 0.001 respectively

Appendix T (continued)

parameter: maximum intensity of astringency

SOV	DF	SS	MS	F
Panelist 1:				
Treatment	7	645.17	92.17	1.32
Replication	2	1356.75	678.38	9.74**
Error	14	974.58	69.61	
Total	23	2976.50		
Panelist 2:				
Treatment	7	3141.29	448.76	4.22*
Replication	2	36.75	18.38	0.17
Error	14	1488.58	106.33	
Total	23	4666.62		
Panelist 3:				
Treatment	7	1865.96	240.85	3.57*
Replication	2	396.08	198.04	2.94
Error	14	943.92	67.42	
Total	23	3025.96		
Panelist 4:				
Treatment	7	3205.96	457.99	4.89**
Replication	2	14.08	7.04	0.08
Error	14	1309.92	93.57	
Total	23	4529.96		
Panelist 5:				
Treatment	7	5224.62	746.38	3.50*
Replication	2	4683.58	2341.79	10.99**
Error	14	2983.75	213.12	
Total	23	12891.96		
Panelist 6:				
Treatment	7	4510.67	644.38	8.41***
Replication	2	526.75	263.38	3.44
Error	14	1072.58	76.61	
Total	23	6110.00		
Panelist 7:				
Treatment	7	14366.96	2052.42	8.43***
Replication	2	306.58	153.29	0.63
Error	14	3409.42	243.53	
Total	23	18082.96		
Panelist 8:				
Treatment	7	2012.67	287.52	2.06
Replication	2	91.58	45.79	0.33
Error	14	1953.08	139.51	
Total	23	4057.33		

*, **, *** - significant at $p \leq$ 0.05, 0.01, 0.001 respectively

parameter: peak area of astringency

SOV	DF	SS	MS	F
Panelist 1:				
Treatment	7	320336.96	45762.42	1.24
Replication	2	690397.51	345198.75	9.37**
Error	14	515929.74	36852.12	
Total	23	1526664.21		
Panelist 2:				
Treatment	7	229428.45	32775.49	3.74*
Replication	2	1273.85	636.93	0.07
Error	14	122583.95	8756.00	
Total	23	353286.25		
Panelist 3:				
Treatment	7	77355.02	11050.72	0.36
Replication	2	79957.80	39978.90	1.30
Error	14	430042.33	30717.31	
Total	23	587355.15		
Panelist 4:				
Treatment	7	88515.07	12645.01	0.81
Replication	2	39447.35	19723.67	1.26
Error	14	218929.04	15637.79	
Total	23	346891.46		
Panelist 5:				
Treatment	7	78784.54	11254.93	1.75
Replication	2	62294.61	31147.30	4.84*
Error	14	90007.98	6429.14	
Total	23	231087.13		
Panelist 6:				
Treatment	7	80330.86	11475.84	1.90
Replication	2	58476.29	29238.15	4.83*
Error	14	84746.72	6053.34	
Total	23	223553.87		
Panelist 7:				
Treatment	7	241903.30	34557.61	5.36**
Replication	2	54264.87	27132.43	4.21*
Error	14	90319.83	6451.42	
Total	23	386488.00		
Panelist 8:				
Treatment	7	193671.44	27667.35	2.05
Replication	2	4896.58	2448.29	0.18
Error	14	188809.21	13486.37	
Total	23	387377.23		

*, **, *** - significant at $p \leq$ 0.05, 0.01, 0.001 respectively

parameter: duration of astringency

SOV	DF	SS	MS	F
Panelist 1:				
Treatment	7	1002.60	143.23	0.58
Replication	2	5978.25	2989.13	12.12***
Error	14	3453.04	246.65	
Total	23	10433.89		
Panelist 2:				
Treatment	7	1958.41	279.77	4.62**
Replication	2	97.51	48.76	0.80
Error	14	848.14	60.58	
Total	23	2904.07		
Panelist 3:				
Treatment	7	3082.15	440.31	3.07*
Replication	2	1956.96	978.48	6.82**
Error	14	2009.34	143.52	
Total	23	7048.46		
Panelist 4:				
Treatment	7	2036.21	290.89	3.75*
Replication	2	534.91	267.45	3.45
Error	14	1085.21	77.51	
Total	23	3656.32		
Panelist 5:				
Treatment	7	805.85	115.12	4.92**
Replication	2	742.61	371.30	15.88***
Error	14	327.38	23.38	
Total	23	1875.84		
Panelist 6:				
Treatment	7	3843.22	549.03	2.89*
Replication	2	311.87	155.93	0.82
Error	14	2661.57	190.11	
Total	23	6816.66		
Panelist 7:				
Treatment	7	837.79	119.68	7.22***
Replication	2	143.21	71.60	4.32*
Error	14	232.03	16.57	
Total	23	1213.03		
Panelist 8:				
Treatment	7	1208.27	172.61	1.95
Replication	2	310.03	155.02	1.75
Error	14	1240.57	88.61	
Total	23	2758.87		

*, **, *** - significant at $p \leq$ 0.05, 0.01, 0.001 respectively

parameter: time to maximum intensity of astringency

SOV	DF	SS	MS	F
Panelist 1:				
Treatment	7	206.21	29.46	0.98
Replication	2	96.24	48.12	1.59
Error	14	442.83	30.20	
Total	23	725.27		
Panelist 2:				
Treatment	7	176.69	25.24	2.52
Replication	2	12.74	6.37	0.64
Error	14	140.44	10.03	
Total	23	329.87		
Panelist 3:				
Treatment	7	72.37	10.34	1.45
Replication	2	12.62	6.31	0.89
Error	14	99.73	7.12	
Total	23	184.72		
Panelist 4:				
Treatment	7	72.76	10.39	1.50
Replication	2	22.53	11.27	1.63
Error	14	97.00	6.93	
Total	23	192.30		
Panelist 5:				
Treatment	7	21.85	3.12	0.79
Replication	2	9.09	4.55	1.15
Error	14	55.17	3.94	
Total	23	86.11		
Panelist 6:				
Treatment	7	31.66	4.52	0.85
Replication	2	11.25	5.62	1.06
Error	14	74.12	5.29	
Total	23	117.02		
Panelist 7:				
Treatment	7	19.14	2.73	0.75
Replication	2	4.60	2.30	0.63
Error	14	51.11	3.65	
Total	23	74.84		
Panelist 8:				
Treatment	7	40.75	5.82	1.11
Replication	2	0.48	0.24	0.05
Error	14	73.15	5.22	
Total	23	114.38		

*, **, *** - significant at $p \leq$ 0.05, 0.01, 0.001 respectively

parameter: peak time of astringency

SOV	DF	SS	MS	F
Panelist 1:				
Treatment	7	242.01	34.57	1.52
Replication	2	366.14	183.07	8.05**
Error	14	318.43	22.75	
Total	23	926.58		
Panelist 2:				
Treatment	7	45.26	6.47	4.22
Replication	2	0.15	0.08	0.05
Error	14	21.45	1.53	
Total	23	66.87		
Panelist 3:				
Treatment	7	21.75	3.11	0.30
Replication	2	30.88	15.44	1.47
Error	14	147.42	10.53	
Total	23	200.05		
Panelist 4:				
Treatment	7	22.38	3.20	0.60
Replication	2	14.67	7.33	1.37
Error	14	74.77	5.34	
Total	23	111.81		
Panelist 5:				
Treatment	7	8.18	1.17	0.41
Replication	2	1.82	0.91	0.32
Error	14	40.28	2.88	
Total	23	50.23		
Panelist 6:				
Treatment	7	7.73	1.10	0.04
Replication	2	10.84	5.42	2.16
Error	14	35.08	2.51	
Total	23	53.64		
Panelist 7:				
Treatment	7	8.54	1.22	0.76
Replication	2	17.27	8.63	5.39
Error	14	22.42	1.60	
Total	23	48.23		
Panelist 8:				
Treatment	7	27.87	3.98	1.07
Replication	2	1.65	0.83	0.22
Error	14	52.27	3.73	
Total	23	81.81		

*, **, *** - significant at $p \leq$ 0.05, 0.01, 0.001 respectively

parameter: time to the initial response of astringency

SOV	DF	SS	MS	F
Panelist 1:				
Treatment	7	81.08	11.58	0.94
Replication	2	20.14	10.07	0.81
Error	14	173.21	12.37	
Total	23	274.44		
Panelist 2:				
Treatment	7	49.54	7.08	1.62
Replication	2	12.76	6.38	1.46
Error	14	61.06	4.36	
Total	23	123.37		
Panelist 3:				
Treatment	7	13.47	1.92	2.18
Replication	2	0.47	0.24	0.27
Error	14	12.35	0.88	
Total	23	26.27		
Panelist 4:				
Treatment	7	7.51	1.07	1.96
Replication	2	2.75	1.37	2.51
Error	14	7.65	0.55	
Total	23	17.91		
Panelist 5:				
Treatment	7	1.24	0.18	0.74
Replication	2	1.35	0.68	2.81
Error	14	3.37	0.24	
Total	23	5.97		
Panelist 6:				
Treatment	7	8.15	1.16	0.37
Replication	2	0.12	0.06	0.02
Error	14	43.57	3.11	
Total	23	51.84		
Panelist 7:				
Treatment	7	9.92	1.42	1.00
Replication	2	2.51	1.26	0.87
Error	14	19.83	1.42	
Total	23	32.26		
Panelist 8:				
Treatment	7	0.45	0.06	0.18
Replication	2	5.26	2.63	7.25***
Error	14	5.08	0.36	
Total	23	10.79		

*, **, *** - significant at $p \leq$ 0.05, 0.01, 0.001 respectively

Appendix U

Analysis of Variance Tables for Individual Panelists for Each of the Eight Time-Intensity Parameters of the Astringency of the Level Two Acid Solutions

parameter: maximum intensity of astringency

SOV	DF	SS	MS	F
Panelist 1:				
Treatment	7	44.07	6.30	0.53
Replication	2	65.16	32.58	2.77
Error	14	264.96	11.78	
Total	23	274.19		
Panelist 2:				
Treatment	7	61.86	8.84	0.49
Replication	2	3.09	1.54	0.09
Error	14	252.70	18.05	
Total	23	317.65		
Panelist 3:				
Treatment	7	58.55	8.36	1.03
Replication	2	8.03	4.01	0.49
Error	14	113.54	8.11	
Total	23	180.11		
Panelist 4:				
Treatment	7	46.80	6.69	0.63
Replication	2	21.87	10.94	1.04
Error	14	147.53	10.54	
Total	23	216.20		
Panelist 5:				
Treatment	7	86.68	12.38	1.47
Replication	2	8.39	4.20	0.50
Error	14	117.89	8.42	
Total	23	212.96		
Panelist 6:				
Treatment	7	23.47	3.35	0.64
Replication	2	22.78	11.39	2.16
Error	14	73.67	5.26	
Total	23	119.91		
Panelist 7:				
Treatment	7	14.38	2.05	0.52
Replication	2	11.46	5.73	1.45
Error	14	55.33	3.95	
Total	23	81.17		
Panelist 8:				
Treatment	7	28.12	4.02	1.50
Replication	2	15.96	7.98	2.98
Error	14	37.48	2.68	
Total	23	81.56		

*, **, *** - significant at $p \leq$ 0.05, 0.01, 0.001 respectively

parameter: time to the initial response of astringency

SOV	DF	SS	MS	F
Panelist 1:				
Treatment	7	27.01	3.86	1.27
Replication	2	21.41	10.70	3.54
Error	14	42.38	3.03	
Total	23	90.80		
Panelist 2:				
Treatment	7	41.38	5.91	1.03
Replication	2	19.51	9.76	1.70
Error	14	80.40	5.74	
Total	23	141.29		
Panelist 3:				
Treatment	7	2.49	0.36	0.71
Replication	2	0.32	0.16	0.32
Error	14	7.05	0.50	
Total	23	9.86		
Panelist 4:				
Treatment	7	60.79	8.68	1.48
Replication	2	38.26	19.13	3.27
Error	14	81.90	5.85	
Total	23	180.96		
Panelist 5:				
Treatment	7	1.93	0.28	2.00
Replication	2	0.20	0.10	0.71
Error	14	1.93	0.14	
Total	23	4.05		
Panelist 6:				
Treatment	7	21.08	3.01	1.31
Replication	2	2.15	1.07	0.47
Error	14	32.15	2.30	
Total	23	55.39		
Panelist 7:				
Treatment	7	1.90	0.27	0.69
Replication	2	3.41	1.70	4.34
Error	14	5.50	0.39	
Total	23	10.81		
Panelist 8:				
Treatment	7	2.23	0.32	1.40
Replication	2	1.46	0.73	3.19
Error	14	3.20	0.23	
Total	23	6.89		

*, **, *** - significant at $p \leq$ 0.05, 0.01, 0.001 respectively

parameter: peak time of astringency

SOV	DF	SS	MS	F
Panelist 1:				
Treatment	7	117.44	16.78	0.99
Replication	2	46.79	23.40	1.37
Error	14	238.40	17.03	
Total	23	402.64		
Panelist 2:				
Treatment	7	279.57	39.94	2.62
Replication	2	6.09	3.04	0.20
Error	14	213.60	15.26	
Total	23	499.26		
Panelist 3:				
Treatment	7	74.77	10.68	2.59
Replication	2	19.49	9.75	2.36
Error	14	57.74	4.12	
Total	23	152.00		
Panelist 4:				
Treatment	7	64.06	9.15	0.76
Replication	2	34.48	17.24	1.42
Error	14	169.54	12.11	
Total	23	268.07		
Panelist 5:				
Treatment	7	23.65	3.38	1.11
Replication	2	0.45	0.22	0.07
Error	14	42.51	3.04	
Total	23	66.61		
Panelist 6:				
Treatment	7	53.17	7.60	2.99*
Replication	2	5.45	2.72	1.07
Error	14	35.52	2.54	
Total	23	94.14		
Panelist 7:				
Treatment	7	14.59	2.08	0.98
Replication	2	2.81	1.41	0.66
Error	14	29.90	2.14	
Total	23	47.31		
Panelist 8:				
Treatment	7	15.80	2.26	0.22
Replication	2	44.09	22.05	2.16
Error	14	142.72	10.19	
Total	23	202.61		

*, **, *** - significant at $p \leq$ 0.05, 0.01, 0.001 respectively

parameter: peak area of astringency

SOV	DF	SS	MS	F
Panelist 1:				
Treatment	7	292572.09	41796.01	3.81*
Replication	2	54434.05	27217.03	2.48
Error	14	153441.93	10960.14	
Total	23	500448.06		
Panelist 2:				
Treatment	7	1644663.75	234951.96	2.98*
Replication	2	15973.89	7986.94	0.10
Error	14	1104896.68	78921.19	
Total	23	2765534.32		
Panelist 3:				
Treatment	7	236134.73	33733.53	4.91**
Replication	2	43879.72	21939.86	3.20
Error	14	96091.24	6863.66	
Total	23	376105.69		
Panelist 4:				
Treatment	7	260916.09	37273.73	1.23
Replication	2	110692.61	55346.30	1.83
Error	14	424520.65	30322.90	
Total	23	796129.34		
Panelist 5:				
Treatment	7	68351.70	9764.53	1.88
Replication	2	5782.28	2891.14	0.56
Error	14	72869.35	5204.95	
Total	23	147003.32		
Panelist 6:				
Treatment	7	379672.03	54238.86	5.37**
Replication	2	8105.43	4052.72	0.40
Error	14	141454.00	10103.86	
Total	23	529231.46		
Panelist 7:				
Treatment	7	217372.26	31053.18	2.85*
Replication	2	124816.74	62408.37	5.72*
Error	14	152662.61	10904.47	
Total	23	494851.61		
Panelist 8:				
Treatment	7	281316.85	40188.12	1.79
Replication	2	107529.50	53764.75	2.40
Error	14	314203.68	22443.12	
Total	23	703050.02		

*, **, *** - significant at $p \leq$ 0.05, 0.01, 0.001 respectively

parameter: duration of astringency

SOV	DF	SS	MS	F
Panelist 1:				
Treatment	7	916.44	130.92	1.54
Replication	2	302.87	151.44	1.78
Error	14	1190.82	85.06	
Total	23	2410.13		
Panelist 2:				
Treatment	7	2506.65	358.09	3.12*
Replication	2	275.88	137.94	1.20
Error	14	1605.50	114.68	
Total	23	4388.03		
Panelist 3:				
Treatment	7	3154.57	450.65	2.33
Replication	2	560.53	280.27	1.45
Error	14	2704.30	193.16	
Total	23	6419.41		
Panelist 4:				
Treatment	7	2011.94	287.42	1.20
Replication	2	431.50	215.75	0.90
Error	14	3349.92	239.28	
Total	23	5793.35		
Panelist 5:				
Treatment	7	661.10	95.16	5.84**
Replication	2	69.76	34.88	2.14
Error	14	227.98	16.28	
Total	23	963.85		
Panelist 6:				
Treatment	7	5412.40	773.20	4.23*
Replication	2	318.21	159.10	0.87
Error	14	2559.47	182.82	
Total	23	8290.08		
Panelist 7:				
Treatment	7	604.79	86.40	2.23
Replication	2	285.56	142.78	3.69
Error	14	542.05	38.72	
Total	23	1432.39		
Panelist 8:				
Treatment	7	1669.44	238.49	5.48**
Replication	2	282.19	142.10	3.24
Error	14	609.73	43.55	
Total	23			

*, **, *** - significant at $p \leq$ 0.05, 0.01, 0.001 respectively

parameter: astringency

SOV	DF	SS	MS	F
Panelist 1:				
Treatment	7	8776.14	1253.73	1.55
Replication	2	340.53	170.27	0.21
Error	14	11317.02	808.36	
Total	23	20433.69		
Panelist 2:				
Treatment	7	11100.22	1585.75	4.69**
Replication	2	1834.04	917.02	2.71
Error	14	4730.57	337.90	
Total	23	17664.83		
Panelist 3:				
Treatment	7	18953.20	2707.60	2.37
Replication	2	5443.18	2721.59	2.39
Error	14	15971.89	1140.85	
Total	23	40368.26		
Panelist 4:				
Treatment	7	13959.72	1994.25	1.90
Replication	2	304.82	152.41	0.15
Error	14	14698.06	1049.86	
Total	23	28962.60		
Panelist 5:				
Treatment	7	18693.14	2670.45	6.99**
Panelist	2	1271.55	635.77	1.67
Error	14	5345.62	381.83	
Total	23	25310.31		
Panelist 6:				
Treatment	7	50776.14	7253.73	5.32**
Replication	2	3156.27	1578.14	1.16
Error	14	19078.04	1362.72	
Total	23	25310.31		
Panelist 7:				
Treatment	7	24179.11	3454.16	4.76**
Replication	2	16386.62	8193.31	11.28**
Error	14	10169.56	726.40	
Total	23	50735.29		
Panelist 8:				
Treatment	7	22647.00	3235.29	6.14**
Replication	2	2024.69	1012.35	1.92
Error	14	7377.71	526.98	
Total	23	32049.40		

*, **, *** - significant at $p \leq$ 0.05, 0.01, 0.001 respectively

parameter: area under the curve of astringency

SOV	DF	SS	MS	F
Panelist 1:				
Treatment	7	1083273.19	154753.31	1.79
Replication	2	361977.71	180988.86	2.10
Error	14	1207102.44	86221.60	
Total	23	2652353.35		
Panelist 2:				
Treatment	7	9690104.43	1384300.63	3.20*
Replication	2	594475.15	297237.58	0.69
Error	14	6054089.48	432434.96	
Total	23	16338669.06		
Panelist 3:				
Treatment	7	5185619.71	740802.82	4.21*
Replication	2	522570.33	261285.17	1.49
Error	14	2461073.11	175790.94	
Total	23	8169263.16		
Panelist 4:				
Treatment	7	3477846.46	496835.21	1.46
Replication	2	84133.01	42066.50	0.12
Error	14	4760453.81	340032.42	
Total	23	8322433.28		
Panelist 5:				
Treatment	7	1544739.35	220677.05	14.19**
Replication	2	46189.00	23094.50	1.48
Error	14	217763.94	15554.57	
Total	23	1808692.29		
Panelist 6:				
Treatment	7	8675131.69	1239304.53	6.49**
Replication	2	106716.43	53358.22	0.28
Error	14	2673636.79	190974.06	
Total	23	11455484.92		
Panelist 7:				
Treatment	7	3026262.86	432323.26	5.49**
Replication	2	693241.39	346620.70	4.40*
Error	14	1102914.67	78779.62	
Total	23	4822418.92		
Panelist 8:				
Treatment	7	8330592.15	1190084.59	10.73***
Replication	2	7553.77	3776.89	0.03
Error	14	1552933.39	110923.81	
Total	23	9891079.31		

*, **, *** - significant at $p \leq$ 0.05, 0.01, 0.001 respectively

parameter: time to maximum intensity of astringency

SOV	DF	SS	MS	F
Panelist 1:				
Treatment	7	2594.67	370.67	3.03*
Replication	2	363.25	181.62	1.49
Error	14	1710.08	122.15	
Total	23	4668.00		
Panelist 2:				
Treatment	7	1352.29	193.19	4.02*
Replication	2	95.58	47.79	0.99
Error	14	673.08	48.08	
Total	23	2120.96		
Panelist 3:				
Treatment	7	1595.62	227.95	3.58*
Replication	2	825.08	412.54	6.49*
Error	14	890.25	63.59	
Total	23	3310.96		
Panelist 4:				
Treatment	7	1743.33	249.05	1.57
Replication	2	34.75	17.38	0.11
Error	14	2217.92	158.42	
Total	23	3996.00		
Panelist 5:				
Treatment	7	5234.67	747.81	7.11***
Replication	2	141.58	70.79	0.67
Error	14	1473.08	105.22	
Total	23	6849.33		
Panelist 6:				
Treatment	7	5427.96	775.42	6.32**
Replication	2	64.08	32.04	0.26
Error	14	1717.92	122.71	
Total	23	7209.96		
Panelist 7:				
Treatment	7	4598.96	656.99	4.50**
Replication	2	3710.08	1855.04	12.69***
Error	14	2045.92	146.14	
Total	23	10354.96		
Panelist 8:				
Treatment	7	4007.96	572.57	5.63**
Replication	2	770.58	385.29	3.79*
Error	14	1423.42	101.67	
Total	23	6201.96		

*, **, *** - significant at $p \leq$ 0.05, 0.01, 0.001 respectively

Appendix V

Means and LSD's for the astringency of the level one acid solutions.

Panelist	Lactic	Acetic	Malic	Citric	Tartaric	FOD	HCL	LSD
# 1	18.00 a	32.00 a	28.67 a	19.67 a	25.00 a	21.67 a	30.33 a	14.61
# 2	46.33 ab	32.00 a	61.00 bc	55.33 b	50.33 b	60.33 bc	74.00 c	18.06
# 3	52.67 a	53.00 a	70.00 bc	56.00 ab	63.00 ab	64.33 ab	79.00 c	14.38
# 4	40.00 a	57.33 bc	57.00 bc	60.67 bc	49.00 ab	63.67 bc	82.00 d	16.94
# 5	30.33 a	36.67 ab	46.67 abc	45.00 abc	47.33 abc	62.67 cd	79.00 d	25.57
# 6	18.00 a	32.67 ab	38.00 bc	39.00 bc	48.00 cd	56.33 de	66.00 e	15.33
# 7	12.67 a	17.33 a	37.00 ab	33.67 ab	56.67 ab	72.00 cd	86.33 d	27.33
# 8	42.00 a	49.67 a	48.67 a	48.00 a	50.00 a	37.67 a	71.00 b	20.68

Maximum Intensity

Panelist	Lactic	Acetic	Malic	Citric	Tartaric	FOD	HCL	LSD
# 1	397.70 ab	882.90 ab	888.10 ab	678.30 ab	514.70 ab	363.50 ab	975.40 a	760.06
# 2	573.60 bc	388.20 c	1150.70 b	960.60 bc	797.00 bc	887.40 bc	1996.30 a	686.56
# 3	1262.30 b	1396.30 b	1244.30 b	1706.70 b	1523.50 b	1528.60 b	3442.60 b	910.61
# 4	489.90 c	764.90 bc	796.30 bc	969.30 bc	698.00 c	933.60 bc	1718.30 a	545.81
# 5	369.10 c	496.10 bc	596.10 bc	635.10 bc	787.30 bc	834.40 b	1420.50 a	436.58
# 6	122.20 c	260.80 c	404.10 c	466.70 c	790.00 bc	1203.70 ab	1765.50 a	718.67
# 7	103.30 c	146.00 c	473.30 cde	336.60 de	662.30 bcd	1057.70 ab	1371.00 a	397.65
# 8	601.00 b	551.80 b	1161.20 ab	1086.20 b	1124.70 b	807.20 b	1937.10 a	797.99

Area Under the Curve

Panelist	Lactic	Acetic	Malic	Citric	Tartaric	FOD	HCL	LSD
# 1	65.42 a	98.76 a	86.16 a	96.40 a	91.15 a	76.74 a	91.71 a	50.57
# 2	99.63 ab	73.98 a	135.16 b	126.43 b	113.81 ab	136.14 b	187.61 c	43.72
# 3	157.33 ab	138.63 a	187.91 cd	160.37 ab	167.56 ab	174.93 abc	231.56 d	43.59
# 4	95.56 a	127.22 ab	135.61 b	143.47 b	115.22 ab	136.30 b	200.12 c	39.67
# 5	76.62 a	88.90 ab	106.61 abc	105.70 abc	110.13 abc	140.16 bcd	178.81 d	52.68
# 6	44.39 a	72.81 ab	89.45 abc	103.98 bc	130.73 cd	144.62 de	173.87 c	48.57
# 7	32.57 a	44.55 ab	90.76 bc	77.07 abc	122.47 cd	156.01 de	187.55 c	56.66
# 8	105.38 a	107.77 a	125.74 ab	131.13 ab	125.39 ab	104.79 a	176.68 b	52.22

Perimeter

Panelist	Lactic	Acetic	Malic	Citric	Tartaric	FOD	HCL	LSD
# 1	32.87 a	40.69 a	37.15 a	39.77 a	34.24 a	30.58 a	42.02 a	27.50
# 2	21.11 a	18.16 a	31.26 a	29.15 a	23.40 a	29.61 a	49.89 b	13.63
# 3	48.82 a	41.32 a	47.98 a	54.77 a	47.84 a	48.31 a	81.17 ba	20.98
# 4	20.12 a	23.54 ab	23.19 ab	31.74 ab	23.92 ab	24.14 ab	49.24 c	15.42
# 5	15.84 a	18.50 ab	18.74 ab	22.68 ab	26.12 a	24.61 a	35.73 b	8.47
# 6	9.95 a	13.91 a	18.84 ab	20.81 ab	31.03 abc	38.82 bc	50.51 c	24.15
# 7	10.77 a	10.80 a	18.84 b	13.26 ab	18.76 b	26.83 c	26.36 c	7.13
# 8	22.15 ab	17.92 a	33.87 abc	32.68 abc	35.29 bc	31.40 c	41.94 a	16.48

Duration

Appendix V (continued)

Means and LSD's ($p < 0.05$) for the astringency of the level one acid solutions.

Panelist	Lactic	Acetic	Malic	Citric	Tartaric	FOD	HCL	LSD
#1	209.60 ab	404.60 b	157.10 ab	334.60 ab	171.50 ab	104.00 ab	190.20 ab	336.18
#2	95.13 a	86.05 a	232.33 ab	133.18 a	247.21 ab	248.55 ab	345.78 b	163.87
#3	275.80 a	172.00 a	177.00 a	260.60 a	267.90 a	349.30 a	313.60 a	306.92
#4	149.60 a	244.70 a	228.80 a	99.10 a	93.90 a	172.00 a	174.00 a	218.99
#5	151.36 a	176.13 ab	155.22 a	182.29 ab	200.47 ab	315.01 b	291.54 ab	140.42
#6	62.07 a	81.96 a	82.47 a	124.14 ab	146.79 ab	152.63 ab	256.96 b	136.25
#7	44.75 a	82.18 ab	129.57 abc	112.26 abc	200.35 bc	241.55 cd	380.84 d	140.66
#8	137.10 a	137.01 a	82.31 a	102.93 a	160.50 a	81.25 a	379.60 b	203.37

Peak Area

Panelist	Lactic	Acetic	Malic	Citric	Tartaric	FOD	HCL	LSD
#1	9.89 b	10.24 b	5.56 ab	10.68 b	5.18 ab	5.06 ab	6.07 ab	8.35
#2	2.09 a	2.53 ab	3.77 abc	2.34 a	4.72 cd	4.08 abc	4.56 bcd	2.17
#3	5.04 a	3.17 a	2.62 a	4.54 a	4.36 a	5.58 a	3.90 a	5.68
#4	3.18 a	4.51 a	4.12 a	1.79 a	2.31 a	2.64 a	2.12 a	4.05
#5	4.25 a	4.52 a	3.48 a	4.23 a	3.81 a	5.35 a	4.14 a	2.97
#6	3.26 a	2.32 a	2.10 a	2.85 a	3.35 a	2.63 a	3.79 a	2.77
#7	3.64 a	4.76 a	3.55 a	2.84 a	3.42 a	3.48 a	4.52 a	2.22
#8	3.26 ab	2.78 ab	1.51 a	2.58 ab	3.04 ab	2.25 ab	5.48 b	3.83

Peak Time

Panelist	Lactic	Acetic	Malic	Citric	Tartaric	FOD	HCL	LSD
#1	7.23 a	5.21 a	7.72 a	3.80 a	3.33 a	3.78 a	6.39 a	6.16
#2	3.98 ab	6.42 a	2.45 b	2.54 b	2.65 ab	3.98 ab	1.56 b	3.66
#3	2.39 ab	1.94 a	3.97 b	1.81 a	1.34 a	1.84 a	1.72 a	1.64
#4	1.45 ab	0.44 a	0.78 a	1.33 ab	0.86 a	1.06 a	1.22 ab	1.29
#5	2.40 a	2.17 a	2.96 a	2.48 a	2.29 a	2.46 a	2.17 a	0.86
#6	2.05 a	3.59 a	1.56 a	1.81 a	2.42 a	2.30 a	1.84 a	3.09
#7	3.70 a	3.71 a	2.44 a	2.46 a	2.54 a	2.06 a	1.93 a	2.08
#8	2.23 a	2.34 a	2.26 a	2.03 a	1.92 a	2.20 a	2.03 a	1.05

Time to Initial Response

Panelist	Lactic	Acetic	Malic	Citric	Tartaric	FOD	HCL	LSD
#1	15.27 a	12.97 a	14.87 a	12.62 a	20.48 a	17.78 a	18.52 a	9.62
#2	12.98 ab	16.43 b	12.68 ab	12.97 ab	8.87 a	9.36 a	10.33 a	5.55
#3	8.67 ab	7.27 ab	8.14 ab	5.96 a	6.22 a	8.40 ab	4.67 b	4.67
#4	9.44 b	4.72 a	7.99 ab	10.13 b	9.31 ab	9.89 b	10.64 b	4.61
#5	6.94 a	4.95 a	8.30 a	6.15 a	7.37 a	6.92 a	7.63 a	3.48
#6	6.10 a	9.86 a	7.99 a	7.21 a	8.42 a	9.49 a	9.03 a	4.03
#7	6.85 a	7.02 a	8.10 a	7.07 a	8.68 a	9.64 a	7.51 a	3.35
#8	6.67 ab	6.45 ab	8.65 ab	6.12 ab	7.22 ab	9.90 b	5.71 a	4.00

Time to Maximum Intensity

Appendix W

Means and LSD's ($p < 0.05$) for the astringency of the level two acid solutions.

Panelist	Lactic	Acetic	Malic	Citric	Tartaric	FOD	HCL	LSD
#1	22.00 ab	19.33 a	21.67 a	29.00 abc	42.33 c	41.33 bc	46.00 c	19.36
#2	57.00 ab	54.67 a	55.00 a	68.67 bc	71.67 c	73.00 c	72.67 c	12.14
#3	50.00 ab	19.67 a	37.67 ab	54.33 b	54.00 b	51.00 ab	71.33 c	13.96
#4	47.33 a	50.00 a	67.00 ab	66.67 ab	58.33 ab	59.00 ab	75.00 b	22.04
#5	14.67 a	31.00 ab	59.33 de	45.67 bcd	41.00 bc	64.00 c	52.00 cde	17.96
#6	19.67 a	26.33 ab	33.00 ab	43.33 bc	44.67 bc	60.00 cd	67.33 d	19.40
#7	37.33 a	40.33 a	46.00 a	51.67 ab	58.00 abc	70.67 bc	75.67 c	21.17
#8	51.00 ab	38.67 a	56.33 b	44.00 ab	48.00 ab	43.00 ab	83.00 c	17.66

Maximum Intensity

Panelist	Lactic	Acetic	Malic	Citric	Tartaric	FOD	HCL	LSD
#1	439.10 ab	389.30 a	551.10 abc	563.60 abc	964.80 c	771.50 abc	882.30 abc	514.22
#2	1368.10 a	1133.10 a	1474.40 a	2058.90 abc	3056.40 c	1925.10 abc	2781.20 bc	1151.60
#3	881.10 ab	748.80 a	872.50 ab	1532.40 bc	1423.70 ab	1105.30 ab	2247.20 c	734.24
#4	884.20 a	961.80 a	1365.30 ab	1743.70 ab	1635.40 ab	1515.40 ab	2079.60 b	1021.20
#5	119.60 a	402.10 b	746.60 de	559.90 bcd	508.30 bc	921.50 c	929.90 c	218.41
#6	177.10 a	291.10 ab	502.00 ab	797.30 abc	844.30 abc	1544.20 cd	2084.70 d	765.29
#7	342.20 a	323.60 ab	590.20 ab	620.80 ab	889.50 bc	1126.20 cd	1454.20 d	491.52
#8	1031.70 ab	498.60 a	981.20 ab	779.40 ab	797.20 ab	766.00 ab	2537.60 c	583.24

Area under the Curve

PanelNo	Lactic	Acetic	Malic	Citric	Tartaric	FOD	HCL	LSD
#1	187.85 abc	184.66 abc	108.13 ab	79.43 a	291.93 cd	280.54 bcd	325.77 cd	183.34
#2	225.90 a	336.90 a	525.00 ab	342.00 a	949.90 b	406.60 a	954.90 b	491.97
#3	197.78 a	163.58 a	195.68 a	428.91 b	399.79 b	182.12 a	235.60 a	145.08
#4	170.60 ab	105.30 ab	140.30 ab	299.70 ab	315.50 ab	219.10 ab	69.00 a	304.95
#5	66.00 a	145.33 ab	187.33 ab	169.25 ab	189.97 ab	108.50 a	256.53 b	126.34
#6	53.25 a	100.87 ab	69.98 ab	116.40 ab	240.58 b	236.85 b	459.19 c	176.03
#7	117.51 a	155.50 abc	132.34 ab	228.19 abcd	325.87 cd	313.77 bcd	399.30 d	182.87
#8	320.90 ab	184.10 a	244.00 ab	168.70 a	190.20 a	144.20 a	500.70 b	262.35

Perimeter

Panelist	Lactic	Acetic	Malic	Citric	Tartaric	FOD	HCL	LSD
#1	33.58 a	32.64 a	32.49 a	32.39 a	41.52 a	38.67 a	46.82 a	16.16
#2	39.54 ab	31.44 a	34.58 a	44.86 abc	63.39 c	40.17 ab	56.78 bc	18.75
#3	34.74 a	37.65 a	38.88 a	51.48 ab	45.53 a	42.65 a	72.49 b	24.34
#4	35.75 a	34.35 a	43.17 ab	45.60 ab	51.93 ab	53.32 ab	63.12 b	27.09
#5	11.29 a	21.14 b	20.66 b	22.22 bc	18.66 b	24.52 bc	28.44 c	7.07
#6	13.63 a	15.83 ab	28.90 ab	31.87 abc	27.19 ab	53.05 cd	58.43 d	23.68
#7	14.20 a	19.34 ab	20.93 ab	19.72 ab	24.42 ab	29.58 b	29.32 b	10.90
#8	28.86 ab	18.44 a	26.19 ab	25.02 ab	24.68 ab	26.19 ab	48.44 c	11.56

Duration

Appendix W (continued)

Means and LSD's ($p < 0.05$) for the astringency of the level two acid solutions.

Peak Area

Panelist	Lactic	Acetic	Malic	Citric	Tartaric	FOD	HCL	LSD
#1	96.88 ab	85.95 a	85.74 a	101.80 ab	123.44 ab	113.62 ab	129.06 ab	49.79
#2	133.18 ab	123.17 a	137.22 abc	159.37 bcd	183.45 d	165.94 cd	185.79 d	32.19
#3	129.68 a	116.22 a	136.80 a	164.91 ab	146.32 a	159.57 ab	214.10 b	59.15
#4	116.51 a	123.95 a	160.11 ab	172.73 ab	157.13 ab	155.97 ab	198.23 b	56.74
#5	47.54 a	81.75 ab	128.37 de	108.50 bcde	93.88 bc	141.54 c	124.47 cde	34.22
#6	60.18 a	76.80 ab	96.08 ab	110.53 ab	124.92 cd	175.30 cd	207.99 d	64.65
#7	81.13 a	91.95 a	101.37 ab	113.15 abc	141.88 bcd	160.49 d	171.07 d	47.20
#8	122.00 ab	92.70 a	134.33 b	109.42 ab	106.90 ab	108.37 ab	199.15 c	40.20

Peak Time

Panelist	Lactic	Acetic	Malic	Citric	Tartaric	FOD	HCL	LSD
#1	8.87 a	9.33 a	4.86 a	3.32 a	6.98 a	6.77 a	6.88 a	7.23
#2	3.91 a	6.32 ab	8.75 abc	4.87 a	12.12 bc	5.45 a	13.33 c	6.84
#3	4.63 abc	4.13 ab	3.68 a	7.94 c	7.64 bc	3.88 a	3.26 a	3.56
#4	3.74 a	3.02 a	2.84 a	4.49 a	5.57 a	3.73 a	0.86 a	6.09
#5	4.72 ab	4.60 ab	3.16 ab	3.63 ab	4.45 ab	1.92 a	5.25 b	3.05
#6	2.91 ab	4.09 abc	1.90 a	2.68 ab	5.11 bc	3.86 ab	6.77 c	2.79
#7	1.32 a	3.88 a	3.03 a	4.47 a	5.37 a	4.39 a	4.97 a	2.56
#8	5.84 a	4.48 a	4.45 a	3.67 a	3.83 a	4.45 a	6.04 a	5.59

Time to Initial Response

Panelist	Lactic	Acetic	Malic	Citric	Tartaric	FOD	HCL	LSD
#1	2.40 ab	5.21 b	2.10 a	3.79 ab	2.27 ab	3.16 ab	4.15 ab	3.05
#2	3.60 a	4.53 a	3.81 a	1.08 a	1.33 a	1.32 a	1.26 a	4.20
#3	2.42 a	2.74 a	2.30 a	2.12 a	2.83 a	1.92 a	2.32 a	1.24
#4	0.38 a	1.29 ab	4.73 b	4.44 ab	1.45 ab	0.76 ab	1.04 ab	4.24
#5	1.62 a	2.02 abc	1.99 ab	2.33 bc	2.30 bc	2.20 abc	2.18 abc	0.65
#6	1.38 a	4.30 b	1.82 ab	1.26 a	2.36 ab	1.69 ab	1.26 a	2.65
#7	1.57 a	2.43 a	2.02 a	1.64 a	1.74 a	1.50 a	1.83 a	1.10
#8	1.47 ab	1.34 a	2.22 b	1.34 a	2.08 ab	1.82 ab	1.85 ab	0.84

Time to Maximum Intensity

Panelist	Lactic	Acetic	Malic	Citric	Tartaric	FOD	HCL	LSD
#1	12.33 a	15.47 a	13.88 a	13.10 a	11.39 a	11.14 a	13.06 a	6.01
#2	13.98 a	12.08 a	12.29 a	12.20 a	8.98 a	10.46 a	9.17 a	7.44
#3	5.92 a	7.02 a	8.34 a	6.65 a	10.13 a	5.32 a	9.42 a	4.99
#4	9.87 a	8.10 a	12.65 a	9.63 a	8.79 a	11.30 a	10.64 a	5.68
#5	4.29 a	4.85 ab	8.49 ab	6.83 ab	5.79 ab	7.49 ab	9.30 ab	5.08
#6	5.66 a	8.57 a	8.77 a	8.26 a	6.70 a	7.46 a	8.27 a	4.02
#7	7.10 a	6.18 a	7.81 a	6.19 a	6.51 a	6.26 a	8.11 a	3.48
#8	4.94 ab	4.12 a	5.22 ab	5.56 ab	6.32 ab	7.25 b	4.53 ab	2.87

APPENDIX X

ANOVA for the Sourness/Astringency Ratios of Level One and Level Two Solutions

level one

SOV	DF	SS	MS	F
Pan	7	193.27	27.61	4.66***
Trt	7	139.99	20.00	1.77^{ns}
Pan*Trt	49	439.96	8.98	1.51*
Rep	2	51.74	25.87	4.36*
Pan*Rep	14	565.30	38.95	6.57***
Trt*Rep	14	78.95	5.64	0.95^{ns}

level two acid solutions

SOV	DF	SS	MS	F
Pan	7	60.47	8.63	3.17**
Trt	7	121.35	17.34	3.54**
Pan*Trt	49	184.05	3.76	1.38^{ns}
Rep	2	27.09	13.55	4.97**
Pan*Rep	14	84.39	6.03	2.21*
Trt*Rep	14	26.66	1.90	0.70^{ns}

Correlation Coefficients for the Time-Intensity Parameters for Each of the Acids at Each Sourness Level for Sourness and Astringency

parameter: tartaric acid

	AREA	PERIMETER	MAX INT	DURATION	T INITIAL	TMAX	PEAK AREA	PEAK TIME
AREA	1.00	0.981***	0.965**	0.863*	NS	NS	NS	NS
PERIMETER		1.00	0.963***	0.880*	NS	NS	NS	NS
MAX INT			1.00	NS	NS	NS	NS	NS
DURATION				1.00	NS	NS	NS	NS
T INITIAL					1.00	NS	NS	NS
TMAX						1.00	-0.894*	NS
PEAK AREA							1.00	NS
PEAK TIME								1.00

S1

	AREA	PERIMETER	MAX INT	DURATION	T INITIAL	TMAX	PEAK AREA	PEAK TIME
AREA	1.00	NS	NS	NS	NS	NS	0.917*	NS
PERIMETER		1.00	0.973**	0.839**	NS	NS	NS	NS
MAX INT			1.00	NS	NS	NS	NS	NS
DURATION				1.00	NS	NS	NS	NS
T INITIAL					1.00	NS	NS	NS
TMAX						1.00	NS	NS
PEAK AREA							1.00	0.836*
PEAK TIME								1.00

S2

	AREA	PERIMETER	DURATION	T INITIAL	TI0	TMAX	PEAK AREA	PEAK TIME
AREA	1.00	0.928*	0.864*	0.992*	NS	NS	0.933**	0.921**
PERIMETER		1.00	0.913*	0.832*	-0.875*	NS	0.865*	0.814*
MAX INT			1.00	NS	-0.943**	NS	0.843*	NS
DURATION				1.00	NS	NS	NS	0.821*
T INITIAL					1.00	NS	NS	NS
TMAX						1.00	NS	NS
PEAK AREA							1.00	0.975***
PEAK TIME								1.00

A1

	AREA	PERIMETER	MAX INT	DURATION	T INITIAL	TMAX	PEAK AREA	PEAK TIME
AREA	1.00	NS	NS	NS	NS	NS	NS	NS
PERIMETER		1.00	0.845*	NS	NS	-0.921**	NS	NS
MAX INT			1.00	NS	NS	-0.948**	NS	NS
DURATION				1.00	NS	NS	NS	NS
T INITIAL					1.00	NS	NS	0.899*
TMAX						1.00	NS	NS
PEAK AREA							1.00	NS
PEAK TIME								1.00

A2

parameter: malic acid

	AREA	PERIMETER	MAX INT	DURATION	T INITIAL	TMAX	PEAK AREA	PEAK TIME
AREA	1.00	0.980***	0.934**	0.904*	-0.837*	-0.89	NS	NS
PERIMETER		1.00	0.958**	0.891*	NS	NS	NS	NS
MAX INT			1.00	NS	NS	NS	NS	NS
DURATION				1.00	NS	-0.824*	NS	NS
T INITIAL					1.00	NS	NS	NS
TMAX						1.00	NS	NS
PEAK AREA							1.00	0.893*
PEAK TIME								1.00

S1

	AREA	PERIMETER	MAX INT	DURATION	T INITIAL	TMAX	PEAK AREA	PEAK TIME
AREA	1.00	0.904*	0.904*	0.938**	NS	NS	0.835*	NS
PERIMETER		1.00	0.976***	0.830*	NS	NS	NS	NS
MAX INT			1.00	NS	NS	NS	NS	NS
DURATION				1.00	NS	NS	NS	NS
T INITIAL					1.00	NS	NS	NS
TMAX						1.00	NS	NS
PEAK AREA							1.00	0.866*
PEAK TIME								1.00

S2

	AREA	PERIMETER	MAX INT	DURATION	T INITIAL	TMAX	PEAK AREA	PEAK TIME
AREA	1.00	NS	NS	0.837*	NS	NS	NS	NS
PERIMETER		1.00	0.960**	NS	NS	NS	NS	NS
MAX INT			1.00	NS	NS	NS	NS	NS
DURATION				1.00	NS	NS	NS	NS
T INITIAL					1.00	0.844*	NS	NS
TMAX						1.00	NS	NS
PEAK AREA							1.00	NS
PEAK TIME								1.00

A1

	AREA	PERIMETER	MAX INT	DURATION	T INITIAL	TMAX	PEAK AREA	PEAK TIME
AREA	1.00	0.941**	0.841*	NS	0.943**	NS	NS	NS
PERIMETER		1.00	0.949**	NS	0.855*	NS	NS	NS
MAX INT			1.00	NS	NS	NS	NS	NS
DURATION				1.00	0.848*	NS	NS	NS
T INITIAL					1.00	NS	NS	NS
TMAX						1.00	NS	NS
PEAK AREA							1.00	0.923**
PEAK TIME								1.00

A2

parameter: HCl

	AREA	PERIMETER	MAX INT	DURATION	T INITIAL	TMAX	PEAK AREA	PEAK TIME
AREA	1.00	0.948***	0.960***	0.967***	NS	NS	0.981***	0.900*
PERIMETER		1.00	0.996***	0.920**	NS	NS	0.967**	0.866*
MAX INT			1.00	0.920**	NS	NS	0.968**	0.871*
DURATION				1.00	NS	NS	0.929**	NS
T INITIAL					1.00	0.890*	NS	NS
TMAX						1.00	NS	NS
PEAK AREA							1.00	0.941**
PEAK TIME								1.00

S1

	AREA	PERIMETER	MAX INT	DURATION	T INITIAL	TMAX	PEAK AREA	PEAK TIME
AREA	1.00	0.962**	0.983***	0.957**	NS	NS	NS	NS
PERIMETER		1.00	0.982***	0.991***	NS	NS	NS	NS
MAX INT			1.00	0.972**	NS	NS	NS	NS
DURATION				1.00	NS	NS	NS	NS
T INITIAL					1.00	NS	NS	NS
TMAX						1.00	NS	NS
PEAK AREA							1.00	0.925**
PEAK TIME								1.00

S2

	AREA	PERIMETER	MAX INT	DURATION	T INITIAL	TMAX	PEAK AREA	PEAK TIME
AREA	1.00	NS	NS	NS	-0.826*	NS	0.748*	NS
PERIMETER		1.00	0.970**	NS	-0.990***	-0.825*	NS	NS
MAX INT			1.00	NS	-0.936**	-0.829*	NS	NS
DURATION				1.00	NS	NS	NS	NS
T INITIAL					1.00	NS	NS	NS
TMAX						1.00	NS	NS
PEAK AREA							1.00	NS
PEAK TIME								1.00

A1

	AREA	PERIMETER	MAX INT	DURATION	T INITIAL	TMAX	PEAK AREA	PEAK TIME
AREA	1.00	NS	NS	NS	NS	NS	NS	NS
PERIMETER		1.00	NS	NS	-0.916*	NS	NS	NS
MAX INT			1.00	NS	NS	-0.823*	NS	NS
DURATION				1.00	NS	NS	NS	NS
T INITIAL					1.00	NS	NS	NS
TMAX						1.00	NS	NS
PEAK AREA							1.00	0.959**
PEAK TIME								1.00

A2

parameter: lactic acid

	AREA	PERIMETER	MAX INT	DURATION	T INITIAL	TMAX	PEAK AREA	PEAK TIME
AREA	1.00	0.963***	0.926***	0.929**	NS	NS	0.742*	0.723*
PERIMETER		1.00	0.848**	0.923**	NS	NS	NS	NS
MAX INT			1.00	0.709*	NS	NS	0.852**	0.757*
DURATION				1.00	NS	NS	NS	NS
T INITIAL					1.00	0.726*	NS	NS
TMAX						1.00	NS	NS
PEAK AREA							1.00	0.908**
PEAK TIME								1.00

S1

	AREA	PERIMETER	MAX INT	DURATION	T INITIAL	TMAX	PEAK AREA	PEAK TIME
AREA	1.00	0.964***	0.954***	0.951***	NS	NS	NS	NS
PERIMETER		1.00	0.987***	0.861**	NS	NS	NS	NS
MAX INT			1.00	0.825*	NS	NS	NS	NS
DURATION				1.00	NS	NS	NS	NS
T INITIAL					1.00	0.734*	0.868**	NS
TMAX						1.00	NS	NS
PEAK AREA							1.00	NS
PEAK TIME								1.00

S2

	AREA	PERIMETER	MAX INT	DURATION	T INITIAL	TMAX	PEAK AREA	PEAK TIME
AREA	1.00	0.974***	0.853**	0.896**	NS	NS	0.818*	NS
PERIMETER		1.00	0.940***	0.803*	NS	NS	0.758*	NS
MAX INT			1.00	NS	NS	NS	NS	NS
DURATION				1.00	NS	NS	0.931***	NS
T INITIAL					1.00	0.792*	NS	0.777*
TMAX						1.00	NS	NS
PEAK AREA							1.00	NS
PEAK TIME								1.00

A1

	AREA	PERIMETER	MAX INT	DURATION	T INITIAL	TMAX	PEAK AREA	PEAK TIME
AREA	1.00	0.938***	0.931***	0.849**	NS	NS	0.822*	NS
PERIMETER		1.00	0.917**	0.917**	NS	NS	0.845**	NS
MAX INT			1.00	0.716*	NS	NS	0.757*	NS
DURATION				1.00	NS	NS	0.730*	NS
T INITIAL					1.00	NS	NS	NS
TMAX						1.00	NS	NS
PEAK AREA							1.00	NS
PEAK TIME								1.00

A2

parameter: FQD

	AREA	PERIMETER	MAX INT	DURATION	T INITIAL	TMAX	PEAK AREA	PEAK TIME
AREA	1.00	0.923**	0.833*	NS	NS	-0.886*	NS	NS
PERIMETER		1.00	0.975***	NS	NS	-0.833*	NS	NS
MAX INT			1.00	NS	NS	NS	0.823*	NS
DURATION				1.00	NS	NS	NS	NS
T INITIAL					1.00	NS	NS	NS
TMAX						1.00	NS	NS
PEAK AREA							1.00	NS
PEAK TIME								1.00

S1

	AREA	PERIMETER	MAX INT	DURATION	T INITIAL	TMAX	PEAK AREA	PEAK TIME
AREA	1.00	0.840*	0.881*	NS	NS	-0.893*	NS	NS
PERIMETER		1.00	0.979***	NS	NS	NS	NS	NS
MAX INT			1.00	NS	NS	NS	NS	NS
DURATION				1.00	NS	NS	NS	NS
T INITIAL					1.00	NS	NS	NS
TMAX						1.00	NS	NS
PEAK AREA							1.00	0.954**
PEAK TIME								1.00

S2

	AREA	PERIMETER	MAX INT	DURATION	T INITIAL	TMAX	PEAK AREA	PEAK TIME
AREA	1.00	0.952**	0.934**	0.832*	NS	NS	NS	NS
PERIMETER		1.00	0.965**	0.823*	-0.900*	NS	NS	NS
MAX INT			1.00	NS	-0.855*	-0.871*	NS	NS
DURATION				1.00	NS	NS	NS	NS
T INITIAL					1.00	0.818*	NS	NS
TMAX						1.00	NS	NS
PEAK AREA							1.00	0.977***
PEAK TIME								1.00

A1

	AREA	PERIMETER	MAX INT	DURATION	T INITIAL	TMAX	PEAK AREA	PEAK TIME
AREA	1.00	0.854*	NS	NS	NS	NS	NS	NS
PERIMETER		1.00	0.873*	NS	NS	NS	NS	NS
MAX INT			1.00	NS	NS	NS	NS	NS
DURATION				1.00	NS	NS	NS	NS
T INITIAL					1.00	NS	NS	NS
TMAX						1.00	NS	NS
PEAK AREA							1.00	NS
PEAK TIME								1.00

A2

parameter: acetic acid

	AREA	PERIMETER	MAX INT	DURATION	T INITIAL	TMAX	PEAK AREA	PEAK TIME
AREA	1.00	0.970***	0.896**	NS	NS	NS	NS	NS
PERIMETER		1.00	0.913**	NS	NS	NS	NS	NS
MAX INT			1.00	NS	NS	NS	NS	NS
DURATION				1.00	NS	NS	NS	-0.708*
T INITIAL					1.00	NS	NS	NS
TMAX						1.00	NS	NS
PEAK AREA							1.00	NS
PEAK TIME								1.00

S1

	AREA	PERIMETER	MAX INT	DURATION	T INITIAL	TMAX	PEAK AREA	PEAK TIME
AREA	1.00	0.939***	0.928***	0.893**	NS	NS	0.748*	NS
PERIMETER		1.00	0.970***	0.839**	NS	NS	NS	NS
MAX INT			1.00	0.746*	NS	NS	NS	NS
DURATION				1.00	NS	NS	NS	NS
T INITIAL					1.00	NS	NS	NS
TMAX						1.00	NS	NS
PEAK AREA							1.00	0.721*
PEAK TIME								1.00

S2

	AREA	PERIMETER	MAX INT	DURATION	T INITIAL	TMAX	PEAK AREA	PEAK TIME
AREA	1.00	0.884**	NS	0.921**	NS	NS	NS	NS
PERIMETER		1.00	0.936***	NS	NS	NS	NS	NS
MAX INT			1.00	NS	NS	NS	NS	NS
DURATION				1.00	NS	NS	0.743*	NS
T INITIAL					1.00	0.931***	NS	NS
TMAX						1.00	NS	NS
PEAK AREA							1.00	0.882**
PEAK TIME								1.00

A1

	AREA	PERIMETER	MAX INT	DURATION	T INITIAL	TMAX	PEAK AREA	PEAK TIME
AREA	1.00	0.954***	0.903**	NS	NS	NS	NS	NS
PERIMETER		1.00	0.851**	0.754*	NS	NS	NS	NS
MAX INT			1.00	NS	NS	NS	NS	NS
DURATION				1.00	NS	NS	NS	NS
T INITIAL					1.00	0.851**	NS	0.761*
TMAX						1.00	NS	0.817*
PEAK AREA							1.00	NS
PEAK TIME								1.00

A2

parameter: citric acid

	AREA	PERIMETER	MAX INT	DURATION	T INITIAL	TMAX	PEAK AREA	PEAK TIME
AREA	1.00	0.935**	0.887*	0.902*	NS	NS	NS	NS
PERIMETER		1.00	0.967**	0.820*	NS	NS	NS	NS
MAX INT			1.00	NS	NS	-0.822*	NS	NS
DURATION				1.00	NS	NS	NS	NS
T INITIAL					1.00	0.887*	NS	NS
TMAX						1.00	NS	NS
PEAK AREA							1.00	0.901*
PEAK TIME								1.00

S1

	AREA	PERIMETER	MAX INT	DURATION	T INITIAL	TMAX	PEAK AREA	PEAK TIME
AREA	1.00	NS	0.814*	NS	NS	NS	NS	NS
PERIMETER		1.00	0.941**	NS	NS	NS	NS	NS
MAX INT			1.00	NS	NS	NS	NS	NS
DURATION				1.00	NS	NS	NS	NS
T INITIAL					1.00	NS	NS	NS
TMAX						1.00	NS	NS
PEAK AREA							1.00	0.884*
PEAK TIME								1.00

S2

	AREA	PERIMETER	MAX INT	DURATION	T INITIAL	TMAX	PEAK AREA	PEAK TIME
AREA	1.00	0.906*	NS	NS	NS	NS	NS	NS
PERIMETER		1.00	0.830*	NS	NS	NS	NS	NS
MAX INT			1.00	NS	NS	NS	NS	-0.816*
DURATION				1.00	NS	NS	NS	NS
T INITIAL					1.00	NS	0.889*	0.880*
TMAX						1.00	NS	NS
PEAK AREA							1.00	.990***
PEAK TIME								1.00

A1

	AREA	PERIMETER	MAX INT	DURATION	T INITIAL	TMAX	PEAK AREA	PEAK TIME
AREA	1.00	0.947**	0.888*	0.875*	NS	NS	0.870*	NS
PERIMETER		1.00	0.913*	0.840*	NS	NS	0.881*	NS
MAX INT			1.00	NS	NS	NS	0.974**	NS
DURATION				1.00	NS	NS	NS	NS
T INITIAL					1.00	NS	NS	NS
TMAX						1.00	NS	NS
PEAK AREA							1.00	0.908*
PEAK TIME								1.00

A2

Analysis of Variance Results for the Principal Component Scores for Both Sourness Levels

Sourness Level 1 - PC1

SOV	DF	SS	MS	F
Acid	6	72.22	12.04	16.54***
Error	14	10.19	0.73	
Total	20	82.40		

Sourness Level 1 - PC2

SOV	DF	SS	MS	F
Acid	6	9.51	1.58	0.99^{ns}
Error	14	22.51	1.61	
Total	20	32.02		

Sourness Level 2 - PC1

SOV	DF	SS	MS	F
Acid	6	79.79	13.30	26.76***
Error	14	6.96	0.50	
Total	20	86.75		

Sourness Level 2 - PC2

SOV	DF	SS	MS	F
Acid	6	13.19	2.20	1.30^{ns}
Error	14	23.68	1.69	
Total	20	36.89		

Appendix Z (continued)

Sourness Level 2 - PC3

SOV	DF	SS	MS	F
Acid	6	2.08	0.35	0.24^{ns}
Error	14	19.85	1.42	
Total	20	21.93		

Astringency Level 1 - PC1

SOV	DF	SS	MS	F
Acid	6	83.98	13.97	12.13***
Error	14	16.15	1.15	
Total	20	100.13		

Astringency Level 1 - PC2

SOV	DF	SS	MS	F
Acid	6	5.65	0.94	1.93^{ns}
Error	14	6.84	0.49	
Total	20	12.49		

Astringency Level 2 - PC1

SOV	DF	SS	MS	F
Acid	6	86.16	14.36	21.10***
Error	14	9.49	0.68	
Total	20	95.66		

Appendix Z (continued)

Astringency Level 2 - PC2

SOV	DF	SS	MS	F
Acid	6	12.81	2.14	1.33^{ns}
Error	14	22.39	1.60	
Total	20	35.20		

Astringency Level 2 - PC3

SOV	DF	SS	MS	F
Acid	6	9.70	1.62	1.74^{ns}
Error	14	13.01	0.93	
Total	20	22.71		