AN ABSTRACT OF THE THESIS OF

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Title: The Effect of Sucrose, Aspartame, Acesulfame-K and Blended Aspartame/acesulfame-K on Orange and Strawberry Flavor in Model Solutions.

Abstract approved: ______________________________

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The effect of sweeteners on fruit flavor perception was studied through the use of fruitiness power functions for unsweetened and sweetened model systems. In the first part of the study, two isosweet concentrations of aspartame and sucrose were determined and combined with five concentrations of orange and strawberry flavorants. Fruitiness power functions were developed and compared to determine the effect of each sweetener on the fruit flavor. For the second part of the study in the first experiment, one isosweet concentration of sucrose, aspartame, acesulfame-K and 1:1 blended APM/Ace-K was combined with five concentrations of each of three orange flavorants. Fruitiness power functions were developed and compared to determine how each sweetener effected the fruit flavor of each flavorant. The second experiment addressed the question of whether or not subjects associated sweet taste with

fruitiness or if there was an actual change in the volatile composition of the aroma between the unsweetened reference and the sweetened solutions. Fruit aroma of the middle concentration of each flavorant sweetened with the four sweeteners was compared to the corresponding unsweetened reference.

Enhancement of fruitiness was observed in the aspartame sweetened systems at low flavor levels. The power function slopes of both flavorants were lowered by the addition of aspartame which resulted in a slower rate of growth in fruitiness perception with the addition of flavorant to the system. In both the orange and strawberry flavored systems the aspartame sweetened solutions were rated higher in fruitiness than the sucrose sweetened solutions. The enhancement was more pronounced in the orange flavored system, suggesting a flavorant effect.

The sweeteners affected the fruitiness perception of the three orange flavorants in different magnitudes but the patterns were similar. The three fruitiness slopes were all lowered by the addition of each sweetener. Flavor enhancement was greatest in flavor 1 sweetened with aspartame or aspartame/acesulfame-K. The higher relative placement and low slope of the fruitiness power functions in aspartame sweetened systems caused the enhancement effect to be greatest over the lower concentrations of each flavorant. In the second experiment, the fruit aroma of aspartame sweetened solutions in flavor 1 was significantly higher than the other sweetened solutions. The fruit aroma of the second and third flavorants was not significantly changed by the sweeteners.

The Effect of Sucrose, Aspartame, Acesulfame-K and Blended Aspartame/acesulfame-K on Orange and Strawberry Flavor in Model Solutions

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INTRODUCTION

Increased usage of high intensity sweeteners in the past decade has prompted investigations of the sensory properties of these new sweeteners. Many claims have been made regarding the flavor enhancement potential of aspartame, especially with fruit flavors (Cloninger and Baldwin, 1970; Beck, 1974; McCormick, 1975; Homler, 1984a; Ripper et al. 1986). However, few studies have investigated the flavor enhancement ability of aspartame quantitatively. Baldwin and Korschgen (1979) studied this property of aspartame and found orange and cherry flavored beverages sweetened with aspartame higher in fruit flavor than those sweetened with sucrose. Fruit flavor of strawberry flavored beverages or gelatins was not increased by the addition of aspartame. More information on this enhancement by aspartame would be useful when using it to replace conventional sweeteners.

This study was designed in two parts to investigate the ability of aspartame to enhance fruit flavors in comparison to sucrose, acesulfame-K or blended aspartame/acesulfame-K in model solutions. The specific objectives of Part I were: to determine isosweet concentrations of aspartame and sucrose by developing sweetness power functions; to develop fruitiness power functions for orange and strawberry flavors unsweetened and sweetened with isosweet concentrations of sucrose and aspartame at two sweetness levels.

The results from the first study indicated a difference in the enhancement ability of aspartame with different fruit flavors. Therefore, the second study was designed to examine this flavorant specific effect using three different orange flavors sweetened with four different sweeteners. In Part II the specific objectives were: to develop fruitiness flavor power functions of three orange flavorants unsweetened and sweetened with isosweet concentrations of sucrose, aspartame, acesulfame-K or blended aspartame/acesulfame-K and compare them to determine how each sweetener effected the fruit flavor perception of each flavorant; and to compare the aroma of one concentration of each flavorant sweetened with isosweet concentrations of sucrose, APM, Ace-K and APM/Ace-K to the unsweetened reference to determine if differences in the sweeteners were causing the fruit aroma to increase or decrease.

REVIEW OF LITERATURE

I. THE SWEETENERS

Sweeteners elicit a sweet response which is pleasant to most organisms. Sweetness is of major importance in the selection and formulation of food products. The discovery of alternatives to carbohydrate or natural sugars has led to research on perceptual characteristics of these sweeteners. It is important to understand how these alternative sweeteners effect the products to which they are added and how they compare to conventional sweeteners.

The sweeteners involved in this research were sucrose, aspartame (APM), acesulfame-K (Ace-K) and blended 1:1 aspartame/acesulfame-K (APM/Ace-K). These sweeteners were chosen because they represented those most interesting to the food industry at the time of planning this research. Sucrose is the only nutritive sweetener; the other three are considered potent or high intensity sweeteners. All sweeteners are crystalline and form clear solutions in water. This section will contain a brief background on each sweetener as well as factors which pertain to the current research.

A. SUCROSE

This carbohydrate sweetener is abundant in fruits and many plant materials It is the most common sweetener used in the food industry and continues to be the most consumed by the public. It is a disaccharide containing one molecule each of D-fructose and D-glucose.

When trying to match sweetness in a product, most researchers use sucrose as the standard or ideal. The functionality of sucrose, or how it effects other ingredients in a food formulation, is also generally considered a standard by which other sweeteners are compared.

B. ASPARTAME

Aspartame was discovered in 1965 by James Schlatter, a scientist at G.D. Searle Company (Ripper et al. 1986). It is a methyl ester of the dipeptide aspartylphenylalanine made from two amino acids, L-aspartic acid and L-phenylalanine (Homler, 1984a). APM received regulatory clearance from the Food and Drug Administration in 1981 for use in dry products and in 1983 for use in carbonated beverages (FDA, 1981; 1983). Several researchers have studied the stability of aspartame under varying conditions (Beck, 1974; Mazur, 1976; Dwivedi, 1978; Homler, 1984b; Dever et al.1986) and found temperature and pH to be the most important factors. The approval of aspartame for use has been somewhat controversial, with some researchers questioning its safety (Nolan, 1984). Regardless of these concerns, there has been no evidence strong enough to counteract the original approval by the Federal Food and Drug Administration.

The clean, sweet taste of aspartame has been compared to sucrose by many investigators (Cloninger and Baldwin, 1970; 1974; Larson-Powers and Pangborn, 1978a, b; McPherson et al. 1978;

Baldwin and Korschgen, 1979; Schiffman, 1984; Schiffman et al. 1985; Thomson et al., 1987). In general, these studies have found the aspartame sweetness to be more similar to sucrose than any other alternative sweetener.

C. ACESULFAME-K

Acesulfame potassium, discovered by Dr. Karl Clauss in 1967, is the potassium salt of 6-methyl-1,2,3-oxathiazine-4(3H)-one-2,2-dioxide. It is highly stable under a variety of conditions, is highly soluble in water, and is not metabolized by the body in any way (von Rymon Lipinsky, 1982; Hoechst Celanese, 1988; Labell, 1988). The Federal Food and Drug Administration granted approval of acesulfame potassium marketed under the trade name "Sunnette", in 1988 for use in dry foods.

D. ASPARTAME/ACESULFAME-K MIXTURES

Relatively few studies have focused on mixtures of the sweeteners APM and Ace-K. Interest in these combinations is high since some of these sweetener blends exhibit better stability and taste profiles than do individual sweeteners (Gelardi, 1987). Claims that Ace-K exhibits synergistic properties in mixtures with APM are made in review articles on Ace-K product applications (von Rymon Lipinski, 1982; von Rymon Lipinski and Luck, 1983; von Rymon Lipinski and Huddart, 1983; Labell, 1988; Duxbury, 1990). However, within these articles there is no reference to specific studies which investigated this property directly. Frank et al. (1989) studied mixtures of several sweeteners, including APM/Ace-K, and compared the perceived intensity of these mixtures to the perceived intensity of "self mixtures". Self mixtures were defined as mixtures of each component with itself. Synergism was defined as the perceived intensity of the mixture of both components being greater than the perceived intensity of self mixtures. APM/Ace-K mixtures were among the combinations which exhibited synergy. A more recent study by Wiseman and McDaniel (submitted) developed and utilized sweetness power functions of APM and Ace-K alone and mixed 1:1, in order to determine isosweet concentrations in water. They found that solutions isosweet to 7.0 %w/v sucrose required 0.061 and 0.137 %w/v APM and Ace-K alone respectively, but only 0.030 %w/v of a APM/Ace-K mixture.

II. INTERACTIONS

Two types of mixtures of tastes have been studied: mixtures of stimuli that elicit the same sensory quality; and mixtures of stimuli which elicit different sensory qualities. Three types of effects can be seen: mixture suppression, additivity, and synergism. Suppression occurs when the mixture's intensity is lower than the sum of the components' intensities. Additivity occurs when the mixture intensity is equal to the sum of the components' intensities. Synergism occurs when the intensity of the mixture is greater than the sum of the components' intensities. This conventional definition of synergism is added to by Rifkin and Bartoshuk (1980) who propose that mixture intensity must also exceed the intensity of either unmixed component at the same total concentration of the mixture. Both of these criteria were met with MSG/GMP mixtures, but they questioned how much of the taste literature claiming synergism actually follows their extended definition.

A. TASTE MIXTURES WITH THE SAME QUALITY

Interest in the perceptual changes accompanying mixtures of two or more components dates back to at least the 1940's. The majority of these first studies were concerned with components in mixtures that exhibited the same or nearly the same sensory quality: predominant in these studies is sweetness and how sweetness changes in mixtures of sweeteners. How these sweeteners combine in binary mixtures has also been the focus of many investigators interested in finding a model to fit these data.

1. SWEETENERS AND SWEETNESS

Both natural and man-made foods usually contain more than one sweetener. Most fruits contain glucose and fructose, and sometimes they contain sucrose as well. With this in mind, it is natural that sweeteners in binary combinations have been studied.

The effect of mixing sucrose and calcium cyclamate were studied by Kamen (1959) at four sweetness levels. The intensity of these mixtures was higher than either component alone among intermediate sweetness levels but simply additive among the higher and lower sweetness levels. Stone and Oliver (1969) used the conventional definition of synergism; the mixture intensity is greater than the sum of component intensities, to study combinations of carbohydrate and synthetic sweeteners. They found synergism in mixtures of dextrose with fructose, sucrose or calcium cyclamate, fructose with sucrose mixtures, and additivity in dextrose with saccharin mixtures. An elaborate sweetener mixture study by Yamaguchi et al. (1970a,b) questioned the conventional definitions of additivity as well as synergism and developed several mathematical equations to determine the nature of mixture interactions. They separated additivity into three categories; component A dominant over B, component B dominant over A, or neither dominant. When component A was dominant, the mixture intensity was equivalent to the sum of the intensity of component B at a concentration expressed as component A and the intensity of component A. The reverse was true when component B was considered dominant. According to their definitions: additivity was observed in mixtures of; sucrose with glucose, xylose, sorbitol, mannitol or saccharin, fructose with glucose, xylose, xylitol or mannitol, glucose with xylose, sorbitol, xylitol, mannitol, cyclamate or saccharin, xylose with sorbitol, xylitol, mannitol, cyclamate or saccharin, xylitol with mannitol, and mannitol with cyclamate or saccharin. Synergistic effects were observed in mixtures of; sucrose with fructose, xylitol, or cyclamate, fructose with cyclamate or saccharin, sorbitol with mannitol, xylitol with cyclamate or saccharin and cyclamate with saccharin. Hyvonen et al. (1978a,b) studied the synergistic effects of mixtures of fructose/saccharin and xylitol/saccharin. They found that the synergism was greatest when the sweetness intensity of each component was nearly equal in the mixture.

van der Heyden et al. (1983) suggests another aspect of synergistic effects. Synergism, in their study, is considered a particular type of enhancement; single when one component is increased, and double when both components are increased. This idea was applied to sweeteners by testing mixtures with either component being dominant. If both mixtures were synergistic, it was considered double. Of the combinations tested, MSG with IMP and fructose with saccharin exhibited double synergism and saccharin with cyclamate exhibited single synergism. Sucrose with fructose or xylitol were synergistic but the type was not tested; glucose with fructose, xylose or sucrose, and fructose with xylose mixtures were additive. Curtis et al. (1984) employed a factorial design with several concentrations of sucrose and fructose to determine the nature of the interaction across a concentration range. They found synergism among lower levels and suppression among higher levels of sweeteners. Binary mixtures of Ace-K, APM, sodium cyclamate, fructose, glucose, stevioside, sodium saccharin, sucrose and xylitol were studied by Frank et al. (1989b) using a factorial design. A simple additive model was used to predict the sweetness of mixtures from single solutions and was compared to the observed intensity of the mixtures to determine if subadditivity, additivity or superadditivity existed. In general, mixtures at; low concentrations were superadditive, middle concentrations were additive, and higher concentration mixtures were subadditive. The determination of synergism was done by comparing mixture intensities to the intensity of "self mixtures". They found that across all mixtures, Ace-K, APM, and cyclamate produced the most synergism. Sucrose and xylitol produced some synergism. Glucose and fructose produced very little or no synergism. The largest synergistic effect was produced by saccharin with APM or sucrose.

To explain these synergistic effects, Frank et al. (1989b) suggests that the bitter side taste in intense sweeteners, like saccharin, is suppressed by the clean sweetness of the second component. Another explanation for synergism is provided by Jakinovich (1982) and McBride (1988) who suggest that there are multiple receptor sites for sweetness. Jakinovich (1982) studied the neural impulses for gerbils when stimulated with sucrose with saccharin mixtures and found responses to be characteristic of two receptors being stimulated. The model developed by Jakinovich (separate-sites model) was used by McBride (1986) with sucrose/fructose and glucose/fructose mixtures and found to work well. Although there is considerable evidence for synergism among sweetener mixtures and possible physiological reasons for these effects, not all investigators have found this synergism to be present in sweetener mixtures. McBride (1986) did not find synergism in glucose, fructose and sucrose binary mixtures. Additivity was found among low sweetness level mixtures and subadditivity at higher sweetness levels. This departure from additivity was attributed to sensory or neural interaction suggesting that sweeteners stimulate different receptor sites and then integrate at the neural level to elicit the sweet response. Likewise, synergism was not found in mixtures of fructose and glucose by De Graaf et al. (1987). In this case, the mixture intensity was rated as intermediate to the sweeteners alone, and it was closer in magnitude to the dominant sweetener in the mixture.

Equal molar comparisons of binary sugar mixtures were investigated and compared to individual sugar intensities by De

Graaf and Frijters (1987). They concluded that the intensity of the mixture was intermediate to the sweetness of each component and as the proportion of the sweetest sweetener increases the intensity of the mixture approaches the intensity of that sweetener. DeGraaf and Frijters (1988) reanalyzed the data of several previous investigators and they found the following results: The sweetness of sucrose with glucose, sucrose with lactose or lactose with glucose mixtures were intermediate of the two sweeteners in Cameron (1947). The same held true for sucrose, glucose, and fructose binary mixtures (Stone and Oliver, 1969) and with glucose and fructose mixtures at 5, 22 and 50 ^{o}C (Stone et al.1969). Studies on binary mixtures of sucrose, fructose, glucose, xylose, sorbitol, xylitol and mannitol all matched to sucrose for sweetness also indicated all mixture intensities to be intermediate of the two component intensities (Yamaguchi et al. 1970a, b). Not all mixture studies they reanalyzed supported their theory, however; conclusions that could be drawn from the data from Curtis et al. (1984) and McBride (1986) remained the same.

2. MODELS

Neurophysiological work on animals led to the development of equation 1, (the Beidler equation) which describes the relationship between stimulus concentration and neural response (Beidler, 1974).

$$R_{AB}/R_{max} = (C_A K_A + C_B K_B)/(1 + C_A K_A + C_B K_B) \qquad (1)$$

In this equation; R_{AB} is the response to a mixture of sugars A and B, R_{max} is the saturated response, C_A and C_B are the molar concentrations of sugars A and B, and K_A and K_B are the respective association constants. Several investigators have attempted to extend equation 1 to the sensory response to taste mixtures in humans. Theoretically, if a human psychophysical function simply reflects the underlying neurophysical response the Beidler model should apply to human taste. Psychophysical functions for sucrose, glucose, fructose, sodium chloride, citric acid, and caffeine obtained by accumulating just noticeable differences and by category ratings all follow equation 1 reasonably well (McBride, 1987a). De Graaf and Frijters (1986) however, found it to underestimate glucose with fructose mixtures at high concentrations and suggested that common receptors exist but additional secondary binding is also present.

The mixed success of the Beidler equation and a series of studies on gerbil neural responses prompted the development of a model termed the separate-site model.

$$R_{AB} = R_A + R_B - (R_A * R_B/R_{max}) \qquad (2)$$

In the equation; R_{AB} is the response to the mixture of A and B, R_A and R_B are the respective responses to the components, and R_{max} is the maximum response. Equation 2 could account for synergistic effects in mixtures (Jakinovich, 1982). McBride (1986) found binary mixtures of sucrose, fructose, and glucose to correspond well to this model.

A series of studies on mixtures of sweeteners investigated the use of what is termed the equi-ratio taste mixture model (Frijters and Oude Ophuis, 1983; Frijters et al., 1984; De Graaf and Frijters, 1987). This model can predict the type of psychophysical function of a mixture based on individual functions. It has been tested on a variety of sugar mixtures and has been found to predict the response well. Equi-ratio is defined as a series of mixtures in each of which the ratio of components is constant. The two assumptions of the model are that the two components are of identical sensory quality, and that the molecules of both components compete equally for adsorption at receptor sites.

B. TASTE MIXTURES WITH DIFFERENT QUALITIES

Perception of a food or beverage usually involves the integration of information relating the taste, aroma, color, and other characteristics of the product into a total impression. These multi-modal interactions probably play an important role in defining that product. In most cases, these interactions involve the relationship between two or more very different components in both chemical structure and sensory characteristics.

1. BASIC TASTES

Several studies have focused on the interrelationships between sweet, sour, salty, and bitter alone and in taste mixtures. The models that have been used to describe taste mixtures with similar qualities have also been applied. Two views on taste in mixtures can be found in the literature: taste is analytic (McBurney, 1974; McBurney and Gent, 1979) where each taste is maintained and no new tastes emerge; and taste is synthetic (Schiffman and Erikson, 1971, 1980) where taste is a continum and sweet, sour, salty, and bitter are familiar points but not distinctly separate. Evidence for the latter is presented by Kuznicki and Ashbaugh (1979, 1982) where subjects could not determine individual tastes in a mixture.

When two or more qualitatively different components are mixed, many researchers agree that the intensity of that mixture is less than the sum of unmixed components; this is termed mixture suppression (Bartoshuk, 1975; Frank and Archambo, 1986; DeGraaf and Frijters, 1989; Schifferstein and Frijters, 1990). The intensity of mixtures has been found to be directly related to the shape of the psychophysical functions of the components (Bartoshuk, 1975; Bartoshuk and Cleveland, 1977). Components with compressed functions would show suppression and those with expanded functions would show additivity or synergism. This was challenged by Frank and Archambo (1986) because components having function slopes greater than 1.0 still showed subadditivity. In this study, it was also suggested that adding one solute to another does not produce the same change in intensity across concentration. This concentration effect was confirmed by Schifferstein and Frijters (1989) where both citric acid suppressed sweetness of sucrose and the converse but not equally throughout the concentration range tested.

Several adaptation studies have addressed the question of what happens to the perception of one component in the system when the system is adapted to the other component. Lawless and Skinner (1979) found bitterness suppression to be lessened by adapting to sucrose prior to tasting. A companion study also found that adaptation to mixtures of tastants suppressed the perceived intensity of mixtures but less than adaptation of single component rinses (Lawless, 1982a,b). It was suggested that this result indicated that as the intensity of the adapting stimulus decreases so does its strength in suppressing other stimuli. Although this suppression is usually mutual, and it has not been found to be equal. Schifferstein and Frijters (1991) examined this suppression in perceptually similar stimuli (isosweet sweeteners) and found them all to have equal effects on suppressing sourness of citric acid. This suggests mixture suppression cannot be accounted for by chemical or receptor events because all these stimuli were chemically different but elicited the same response; mixture suppression might be only a perceptual event.

2. SWEETNESS AND FLAVOR PERCEPTION

The relationship between sweetness perception in a food and the flavor elicited was questioned by sensory scientists in the 1950's. Swain (1951) studied the changes in strawberry preserves when the sucrose was partially replaced with corn syrup solids or dextrose monohydrate. The flavor profiles of the preserves indicated that sucrose sweetened samples were lower in sourness and higher in sweetness and the natural strawberry flavor of preserves. Chappell (1953) found higher concentrations of sucrose to increase the flavor of lemon and orange oil. Valdes et al., (1956a) found that in raspberry flavored model solutions panelists tended to associate sweetness with flavor. As the sucrose concentration was increased, the flavor perception also increased with no increase in flavorant concentration. This effect was no longer present above 15.0 %w/v sucrose and was postulated to interfere with flavor perception at these high concentrations. In addition, as flavor concentration in the solution increased, so did the rating of sweetness. A companion study with apricot, peach, and pear nectars found similar results with both 4.0% and 8.0% sucrose enhancing fruit flavor (Valdes et al., 1956b). Redlinger and Setser (1987), investigating various sensory qualities of sweeteners in lipid and aqueous systems, did not find that lemon or vanilla flavor influenced sweetness ratings of carbohydrate and potent sweeteners. In contrast, Cliff and Nobel (1990), in a time intensity study, found maximum sweetness to increase with peach concentrate as well as with glucose. In this study, they did not find that increasing glucose concentration increased fruitiness perception.

Fruit flavors have been perceived as higher in systems sweetened with APM than conventional sweeteners (Bahoshy et al., 1976, 1977). Further investigation by Baldwin and Korschgen (1979) found that isosweet orange and cherry beverages were more fruity when sweetened with APM than with sucrose. This was not the case with strawberry flavored beverages or gelatins of any of the three flavors. The time-intensity data collected by Larson-Powers and Pangborn (1978a) also suggest that orange flavored solutions were perceived as higher in fruit flavor when sweetened with APM. Wiseman and McDaniel (in press) also found that orange and strawberry flavored model solutions were higher in fruit flavor when sweetened with APM instead of sucrose. In this study, the effects of APM were greater in the orange flavored model system and among the lower flavorant concentrations. Yau and McDaniel (1989) found no differences in overall flavor, sweetness, or blueberry flavor perception in blueberry flavored carbonated milks sweetened with sucrose, aspartame, high fructose corn syrup or pear concentrate. Likewise, McPherson et al. (1978) did not find sweetening with APM instead of sucrose produced higher orange flavor ratings in orange sherbet. Matysiak and Nobel (1991) found that the duration of fruitiness was significantly longer in APM sweetened orange flavored solutions than those sweetened with sucrose or APM/Ace-K. They did not find that the fruitiness maximum of solutions were significantly different using the three sweeteners in orange flavored solutions. The various data on this subject seem to indicate that the effect of this interaction is dependent upon the flavorant and the system involved.

3. AROMA AND TASTE

Perhaps the most important interaction in foods is gustation with olfaction. Several researchers have found that subjects mix up tastants and odorants as the same sensation (Murphy et al., 1977; Murphy and Cain, 1980; Rozin, 1982; Burdach et al.1984). Much of the research in this area has focused on the question of whether or not the contribution of aroma and taste to overall flavor is independent (Pangborn, 1960; Pangborn and Hansen, 1963; Maga, 1974; Murphy et al., 1977; Dubose et al., 1980; Murphy and Cain, 1980; Cometto-Muniz, 1981; Garcia-Medina, 1981; Gillan, 1983; Hyman, 1983; Hornung and Enns, 1984; Enns and Hornung, 1985). In general, these studies have found that the total intensity of the mixture is slightly less than the sum of taste and odor components, indicating that aroma and taste do indeed contribute independently to overall flavor intensity. Cometto-Muniz (1981) suggest this is because the more salient feature dominants the intensity judgement at the expense of the other component. In a study by Garcia-Medina (1981), with other aroma and taste stimuli, this was not the case. In this study, the overall intensity was indeed less than the sum of the components, but neither the taste nor aroma were dominant in the mixture. A few researchers have attempted with some success to fit a model to this interaction of odor and taste (Murphy and Cain, 1980; Garcia-Medina, 1981; Laffort et al.1989).

A small group of researchers have focused on the ability of particular odors to modify certain taste qualities. These modifications by odors are important considering earlier research which found that people may confuse these sensations. Murphy and Cain (1980) found citral equally enhanced overall intensity of mixtures of NaCl and sucrose, which contrasts the work of Frank and Byram (1988) who found strawberry odor enhanced the sweetness of sucrose but not the saltiness of NaCl. Later, strawberry aroma again was found to enhance the sweetness of sucrose (Frank et al. 1989a). Evidence for the dependance of these effects on the specific tastant and odorant used is given by Frank and Byram (1988) who found that strawberry aroma, but not peanut butter aroma, enhanced the sweetness of the mixture. This supports the suggestion of Schifferstein and Frijters (1991) who claim mixture suppression to be a perceptual phenomenon and not a chemical or receptor event. This is an area which deserves further research to determine if humans associate aroma to specific tastants, indicating that the interaction was perceptual and not physical.

4. COLOR AND TASTE

DuBose et al. (1980) studied the effect of both flavorant and color levels on the identification and perceived intensity of fruit flavored beverages and cake. In both the solution and solid systems, they found that atypical colors decreased the ability of panelists to correctly identify flavor type, and more intense color produced higher ratings in flavor intensity. The effect of color on a single taste has also been studied. Johnson and Clydesdale (1982) found that the addition of red coloring increased the sweetness of solutions by as much as 2-10%. Similar results were obtained by Roth et al. (1988) who found the sweetness of lemon and lime beverages were significantly increased by the addition of color. In contrast to these earlier studies, Frank et al. (1989) found red color in strawberry flavored solutions did not effect the sweetness perception.

III. PSYCHOPHYSICAL MEASUREMENTS

The science of psychophysics (the study of the relationship between physical stimulus and psychological response) has emerged from the psychology laboratory to the sensory laboratory as applications have proven successful (McBride, 1987b).

A. MAGNITUDE ESTIMATION

The scaling method of magnitude estimation centers around the freedom of subjects to assign numbers to the apparent magnitude of the stimulus. The task of the subject is to assign a number which relates the intensity of the sample to either a reference sample or the first sample in the set. This method leads to ratio scales of taste intensity, which lead directly to an estimate of the psychophysical function. This estimate has been found to be much better than obtained with category scales (Stevens and Galanter, 1957). Category scales were also criticized for their restricting and finite end points and unequal physiological distance between points on the scale (Stevens, 1975; Moskowitz, 1977).

The comparison of category scales and magnitude estimation in terms of discrimination power has been studied. McDaniel and Sawyer (1981) studied the descrimination of the two scaling methods in rating attributes of whiskey sour formulations. They found no difference in using the two methods to rate differences in the formulations. However, magnitude estimation produced more panelist by mixture interaction, and category scaling produced more variability in scale range usage and replication. Lawless and Malone (1986) compared the scaling methods in terms of discrimination among products, variability, reliability, and ease of use with consumers. They found no differences in discrimination power between the two methods, but category scales were slightly lower in variability, higher in reliability, and more user friendly. Giovanni and Pangborn (1983) suggested magnitude estimation has the advantage of being indefinite, and since the data represent proportions they can be converted to percentages which can be compared among tests.

1. DATA ANALYSIS

Because panelists construct their own scale when using magnitude estimation, a method of re-scaling or normalizing the data to a common scale has been applied. There are several methods which have been used to achieve this common scale. Three of these methods; modulus normalization, equalization and external calibration were compared by Butler et al. (1987) on untransformed and logarithmically transformed data. They found that the type of method effected tests of significance when the data were untransformed but did not when the data were logarithmically transformed. They suggest that all analysis should be performed on logarithmically transformed data. Powers et al. (1990) applied ANOVA to magnitude estimation data to compare results from normalized and unnormalized logarithmically transformed analysis. They found that if the data were logarithmically transformed then normalizing or re-scaling was not needed to achieve normally distributed residuals.

B. POWER FUNCTIONS

The pioneering work of Beebe-Center and Waddell (1948) using a fractionation procedure to determine the relation between stimulus concentration and apparent strength of the resulting taste developed what is known as the "gust" scale. Stevens carried on this work using magnitude estimation as a scaling procedure and developed an equation which describes the relationship between sensory response and stimulus concentration. This linear relationship can be described as the following equation,

$$\log S = n \log C + \log k \qquad (1)$$

or as the power function (Stevens, 1969).

$$S = kC^n \qquad (2)$$

Where S is the sensory response and C is the concentration of the stimuli tested. This relationship has proven successful because it is a mathmatical function which relates expected sensory response to a given addition of a stimulus (Moskowitz, 1974). If the exponent in this function is greater than 1.0, subjects perceive more intensity in the system than is predicted by the amount of stimulus added. Conversely, if the exponent is less than 1.0, subjects perceive much less increase in intensity with a given amount of stimulus added.

The validity of using power functions to describe the relation between sensory response and stimulus concentration has been questioned by researchers since the values of the exponents are not consistant over a variety of conditions. Poulton (1968) found exponents to be higher in concentration ranges closer to threshold levels of the stimulus. Meiselman (1971) studied the change in power functions for basic tastes with three procedures; sip, anterior dorsal tongue flow and whole mouth flow. Exponents produced by the sip method were consistantly higher than the other two methods suggesting that presentation procedure has an influence on power function parameters.

MODIFICATION OF FRUIT FLAVORS BY ASPARTAME AND SUCROSE

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ABSTRACT

Power functions for fruitiness intensity of fruit flavored (orange and strawberry) solutions unsweetened and sweetened with equi-sweet concentrations of aspartame and sucrose were developed using nine experienced panel members to assess any modification of fruit flavor by sweeteners. Enhancement (at low flavor levels) of fruitiness was observed in the aspartame sweetened systems even though the power functions of both flavorants were lowered by the addition of aspartame. The enhancement was more pronounced in the orange flavored system, suggesting a flavorant effect.

INTRODUCTION

During the last decade, the popularity of aspartame (APM) as an alternative to carbohydrate and other high potency sweeteners has increased. This has prompted many studies focusing on sensory properties of aspartame in simple and complex systems. Several references have been made to aspartame's ability to enhance or modify flavors, particularly fruit flavors (Cloninger and Baldwin, 1970; Beck, 1974; McCormick, 1975; Homler, 1984a,b; Ripper et al. 1986). The earliest references to this capability are made in connection with chewing gum application patents. In these patents, Bahoshy et al. (1976) reported that aspartame produced longer-lasting sweetness and flavor and Bahoshy et al. (1977) found fruit flavors such as orange, lemon, and grapefruit were enhanced and extended by aspartame.

Baldwin and Korschgen (1979) found that orange and cherry fruit flavors were more intense when sweetened with APM than with sucrose. However, they found no significant differences between APM or sucrose sweetened strawberry flavored beverages or the three flavored gelatin systems. It can be observed from a time-intensitystudy by Larson-Powers and Pangborn (1978a) that the maximum fruit flavor was higher in APM sweetened vs other sweetened lemon and strawberry flavored model systems. The results of Larson-Powers and Pangborn (1978a) do not agree with Baldwin and Korschgen (1979) for the strawberry system. However, it is not known how the time intensity parameter of maximum intensity reported in the Larson-Powers and Pangborn (1978a) study would be expected to relate to the intensity measurements in the Baldwin and Korschgen (1979) study.

Psychophysical relationships that relate physical concentration of a stimulus to sensory perception, in the form of power functions, were used in some of the earliest work on relative sweetness (Stone and Oliver, 1969; Moskowitz, 1970a, 1970b). Changes in the slope or elevation of these power functions are good indices of how an attribute is affected by other components in the system. Frank and Archambo (1986) used power functions as a baseline of sensory perception and then determined how the addition of another stimulus over the concentration range would affect the intensity ratings. Schiffman (1984) also developed power functions to compare taste properties of aspartame to other sweeteners. Orange and strawberry flavors were chosen in this study to help determine if citrus flavors vs other flavors were affected differently by the sweeteners. Because Baldwin and Korschgen (1979) found no enhancement with strawberry flavors as opposed to Larson-Powers and Pangborn (1978a) whose work did show an enhancement of flavor by aspartame this study will aid in clarifying the issue. To further investigate and quantify the enhancement capability of aspartame in comparison with sucrose, the objectives of the present study were to develop sweetness power functions for sucrose and APM in spring water allowing equi-sweetness determination and then to develop fruitiness power functions for orange and strawberry flavored spring water unsweetened and sweetened with two equi-sweet levels of APM and sucrose. From these psychophysical relationships, it was possible to quantify the modification of each flavor when combined with either APM or sucrose.

MATERIALS AND METHODS

Sample preparation

The following materials were used: aspartame (APM), (The NutraSweet Company, No. AD0120, GD. Searle Food Resources Inc., Skokie,IL); sucrose (My-Te-Fine, Fred Meyer, Inc., Portland, OR); natural orange flavor WONF (No. 24627, Food Materials Inc., Chicago, IL); natural strawberry flavor WONF (No 9157L, Borden Industrial Food Products, Columbus, OH); and spring water (5 gallon carboys, Aqua Cool, Salem, OR).

Solutions were prepared 24 hrs in advance, stored at 5 ^{o}C, and brought to ambient temperature (22 ^{o}C) prior to serving. Solutions were prepared in spring water and concentrations for each stimuli are presented in Table 1. The concentration range for each stimuli was based on a reasonable usage level of sweetener or flavorant in this system. Orange and strawberry flavorants were also prepared with equi-sweet levels of APM (0.04 and 0.093% w/v) and sucrose (5.0 and 10.0% w/v). Equi-sweetness was determined by the use of the sweetness power function for each sweetener. References of sucrose (8.5% w/v) for sweetness intensity and unsweetened orange (0.95% w/v) or strawberry (1.2% w/v) flavorants for fruitiness intensity were available at all times.

Sensory method

Magnitude estimation was used by panelists to rate solution intensities. Panelists were instructed to taste the reference sample and assign its intensity a value of 50. After rinsing, they tasted the first sample and assigned it any value (except 0) corresponding to its ratio of sweetness or fruitiness intensity to the reference. For example, a sweetness intensity 3 times that of the reference was assigned a value of 150. All stimuli in the session were rated in the same manner and panelists took 15-20 min breaks between sessions. When fruitiness intensity was rated, panelists were instructed to ignore sweetness and concentrate only on the fruit flavor perceived.

Panelists

Nine students and staff from Oregon State University's Food Science and Technology Department were selected on the basis of experience with magnitude estimation for intensity ratings of solutions as well as motivation. Eight females and one male participated in an orientation session involving reviews of magnitude estimation, testing times, and length of the study. During this session, a series of sucrose solutions were judged by panelists and results were discussed in order to answer any questions about the procedure.

Environment

Testing took place in the Sensory Science Laboratory at Oregon State University. Samples were evaluated in individually partitioned booths that were equipped with red lights to mask any color differences. The series of five solutions (20 mL) were served in 85 mL plastic cups, with an unlimited amount of the corresponding reference for each assessment.

Design

A randomized complete block design was completed for each stimuli series (sucrose or aspartame and orange or strawberry flavor unsweetened and sweetened with sucrose or aspartame). The five-concentration series was presented in random order to each panelist along with the corresponding reference for evaluation at each session. Aspartame and sucrose sweetened solutions were evaluated on separate days and orange or strawberry flavored systems were tested on different weeks to facilitate panelist concentration on the specific fruit flavor. Two reps were completed.

Statistical analysis

In all experiments, magnitude estimates were normalized by geometric mean normalization (McDaniel and Sawyer, 1981). A three-way ANOVA was used to compare panelist, treatment, replication, and panelist by treatment interaction effects for each experiment. Individual panelist regressions were adjusted by the least squares method to the best fitting line, and slopes were compared by multiple regression to determine if significant differences were present. Combined data regressions for each solution were adjusted by the least squares method to the best fitting line; then slopes and elevations for each experiment were compared by multiple regression.

RESULTS AND DISCUSSION

Sweetness power functions

A three way ANOVA determined no significant differences ($p>0.05$) in the panelist or replication main effects and significance ($p<0.05$) in the treatment main effect as well as panelist by treatment interaction. The significant interaction was due to a magnitude difference in panelist's ratings of solution intensities. All data were combined to construct the power functions presented in Fig. 1. Table 2 contains the intercept, slope, and coefficient of determination (r2) for each power function. The slopes for both power functions were higher than other published values (Moskowitz, 1970a, 1970b, 1971); however, the sucrose slope was appreciably higher than the aspartame slope, which agree with the before-mentioned research. This difference in actual slope value could have been due to the concentration range of the sweeteners used, the panelists themselves, or the testing conditions. Two sweetness levels were selected by drawing two lines intersecting both power functions (Fig. 1), resulting in two equi-sweetness levels for each sweetener. These levels were not tested formally for equi-sweetness in the system with added orange or strawberry flavor.

Orange fruitiness power functions

Results for the regression analysis of orange flavor power functions are presented in Table 2 and graphically represented in Fig. 2. The linear model was significant ($p<0.05$) for all formulations except the 0.040% and 0.093%w/v aspartame sweetened solutions. However, the linear model did fit both levels of the APM sweetened systems data better than other models explored. The slopes for both aspartame sweetened systems were very low (0.20, 0.21), and there was no significant difference in fruitiness rating among data points across flavorant levels. Multiple regression was conducted to test differences in slope and elevation caused by the addition of both sweeteners. The slope of the unsweetened flavorant was not significantly lowered by either level of sucrose but was significantly ($p<0.05$) lowered by both levels of aspartame. No significant difference in fruitiness was found for either system sweetened with sucrose as compared to the flavorant alone, but fruitiness of both systems sweetened with aspartame was significantly enhanced below the 0.040% and 0.06%v/v flavorant concentration. The difference in magnitude and growth of fruitiness perception is easily seen in Fig. 2 where sweetening with aspartame greatly enhanced initial fruitiness by as much as 100%. Fruitiness intensity of APM and sucrose sweetened solutions were not significantly different at higher flavor levels due to the low slopes of fruitiness power functions for APM sweetened systems.

Strawberry fruitiness power functions

Results for the regression analysis of strawberry flavored power functions are presented in Table 2 and graphically represented in Fig. 3. All systems were significantly ($p<0.05$) described by a linear model. Multiple regression resulted in no significant differences in slopes of fruitiness power functions except at the 0.093% APM sweetened system which was significantly ($p<0.05$) different than all other slopes. The magnitude of fruitiness perception was increased by the lower level of sucrose and both levels of aspartame but was significant only for the 0.093% aspartame sweetened system at 0.60 and 0.90%v/v flavorant concentrations. The differences in fruitiness modification is evident in Fig. 3, where the greatest increase in initial fruitiness perception is produced by the higher level of aspartame. As with the orange-flavored system, APM sweetened fruitiness power functions had lower slopes than the sucrose or unsweetened systems; therefore, differences in fruitiness intensity were not significantly different among higher flavorant levels. The modification of slope and elevation was less in the strawberry-flavored system than in the orange-flavored system, which indicates a possible flavorant difference.

Key to this study was the determination of equi-sweetness without any influence from the fruit flavor; therefore, equi-sweetness was determined based on taste only. Subsequent addition of flavorant might influence the previous sweetness rating as well as adding fruitiness. In addition, the rating of fruitiness might be influenced by any additional sweetness perception. One possible explaination for the enhancement of fruitiness by aspartame is the mutual enhancement of sweetness and fruitiness in the sweetened and flavored system. This could only be tested by setting equi-sweetness levels prior to adding flavorant.

The fruitiness slopes of the aspartame sweetened systems were flat, but all points were at a high fruitiness level. Therefore, even at the lowest flavorant levels for aspartame sweetened systems, the fruitiness was as high as the highest flavorant level samples for the sucrose sweetened systems. Again, this may have been the result of mutual enhancement of fruitiness and sweetness, although only fruitiness was measured in this study.

The orange and strawberry flavorants used in this study were modified by sucrose and aspartame. As in the Larson-Powers and Pangborn (1978) and the Baldwin and Korschgen (1976) studies, the enhancement effect appeared stronger in the orange rather than the strawberry flavored systems. This may be due to the fact that there is more of a retronasal sweetness aromatic component in orange flavor than in strawberry flavor. More sweetness aromatics in the orange flavored system would account for the larger effect of sweetening with aspartame than observed in the strawberry system. This lower level of sweetness aromatics in the strawberry flavored systems could also account for the lack of enhancement by aspartame on strawberry flavor found by Baldwin and Korschgen (1976). Aspartame sweetened solutions showed as much as 100% increased fruitiness perception from 0.40 to 0.90% flavorant level in the orange system and from 0.60 to 1.20% flavorant level in the strawberry flavored system. Sucrose sweetened solutions did not show this enhancement of either orange or strawberry fruitiness.

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FLAVORANT SPECIFIC ENHANCEMENT OF FRUITINESS BY ASPARTAME AND OTHER SWEETENERS

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ABSTRACT

Fruit flavor intensity was rated using magnitude estimation for three orange flavored solutions unsweetened and sweetened with equi-sweet levels of sucrose, aspartame, acesulfame-K, and blended aspartame/acesulfame-K. Power functions of orange fruitiness were determined for all solutions and compared within each orange flavorant system. In all cases, the slope of the unsweetened fruitiness power function was lowered by addition of each sweetener. Flavor enhancement was greatest when sweetening with aspartame or blended aspartame/acesulfame-K in all three flavorant systems, the largest effect being with flavorant 1. The higher relative placement and flat slope of the fruitiness power functions in aspartame sweetened systems caused the enhancement effect to be greatest over the lower concentrations of each flavorant. Fruit aroma was rated significantly higher in the first orange flavorant sweetened with aspartame than when sweetened with the other sweeteners; there was no significant difference in fruit aroma for the second or third flavorant systems.

INTRODUCTION

Various investigators have studied the relationship between components in taste mixtures. Moskowitz (1971) studied the change in psychophysical functions for sweet, sour, salt, and bitter with a second background component present in the system. Less than a 25 % increase or decrease in the exponents was found when the second component was present. Moskowitz (1972) quantified the perceptual changes in the four basic tastes when combined in mixtures. In general, mixing two stimuli resulted in a lower intensity of each attribute. In addition, the difference in flavor of glucose or fructose was rated when other taste stimuli were present. It was concluded that the presence of the second stimulus modified the quality of the sweetness. Bartoshuk (1975) related the shape of the psychophysical functions of components to the interaction of these components in mixtures. Components which showed the greatest compression when unmixed were suppressed the most in mixtures. She postulated that enhancement or synergism in mixtures would only be possible if one of the components' psychophysical functions when unmixed showed expansion. The interaction of the basic tastes and total taste intensity in mixtures has been the focus of many investigations (Frank and Archambo, 1986; De Graaf and Frijters, 1989; Schifferstein and Frijters, 1989).

Several studies have found that the addition of sweeteners to flavored solutions affects the perception of flavor intensity. Valdes et al. (1956a) found that the addition of sucrose to imitation raspberry flavoring resulted in it being rated higher in raspberry flavor. The same result was obtained with apricot, peach and pear nectars (Valdes et al.1956b). Cliff and Nobel (1990) found that increasing glucose concentration did not increase ratings of peach intensity of peach flavored solutions but that increasing the level of peach flavorant did increase sweetness perception of the system. The type of sweetener added to the system has also been found to effect the flavor intensity. Sweetening with APM increases the perceived intensity of some fruit flavors more than sweetening with sucrose (Bahoshy et. al. 1976; 1977; Baldwin and Korschgen, 1979). In contrast, Yau and McDaniel (1989) found that the type of sweetener did not effect the intensity of blueberry in blueberry flavored carbonated milk samples. Likewise, Matysiak and Noble (1991) did not find significant differences in the intensity of orange flavored solutions sweetened with isosweet levels of sucrose, APM or a APM/Ace-K blend.

Wiseman and McDaniel (in press) found that orange and strawberry flavored solutions sweetened with APM were rated higher in fruitiness than those sweetened with sucrose. The effect was greater in the orange flavored system suggesting different flavors are not affected equally by sweetening. The present study was designed to investigate this flavorant effect with three orange flavorants, each having different predominant sensory characteristics. The fruitiness power functions of the three unsweetened flavorants represent the fruitiness baseline in each system. How the fruitiness perception changes with flavorant addition for each sweetener can be measured by comparing fruitiness power functions of the unsweetened and sweetened systems. The different effect of sweeteners on fruitiness perception of each flavorant can then be compared to the different sensory qualities of each flavorant. The specific objectives for experiment 1 were to develop and compare fruitiness power functions of three orange flavorants sweetened with isosweet concentrations of sucrose, APM, Ace-K and APM/Ace-K, and to compare the results for each flavorant.

Several investigators have studied the effects of sucrose concentration on the concentration of volatiles in the headspace of a sucrose sweetened system. High concentrations of sucrose or invert sugar decreased peak heights in gas chromatograms of headspace volatiles of strawberry or synthetic compounds (Wientjes, 1968). Nawar (1971) found the addition of sucrose to an acetone solution increased its headspace concentration while decreasing the headspace concentration of heptanone and heptanal solutions. Ahmed et al. (1978) found the addition of sucrose increased the threshold of *d*-limonene in solution. In contrast, Ebeler et al. (1988) found sucrose had no significant effect on the magnitude of sensory and GC responses to headspace concentrations of methonone and isoamyl acetate solutions. Whether the effect of sweeteners on flavorants is a perceptual phenomenum or the product of a physico-chemical interaction between the sweetener and the flavorant is addressed in the second experiment. If a sweetener in solution affects the concentration of volatiles in the headspace then this would be reflected in the aroma perception of the solution, either increasing or decreasing the aroma. The specific objectives for experiment 2 were to compare the aroma of one concentration of each flavorant sweetened with the four sweeteners to an unsweetened reference, and to compare these results for the three flavorants.

MATERIALS AND METHODS

Sample preparation

The following materials were used: Flavor 1, Natural Orange Flavor #24627, WONF, (Food Materials Corporation Chicago, ILL); Flavor 2, Veri-essence Natural Orange Flavor #555, (Food Materials Corporation Chicago, ILL); Flavor 3, Natural and Artificial Ripe Orange Flavor #710409U, (Hercules Incorporated Middletown, NJ); Sucrose (Fred Meyer Portland, OR); Aspartame (APM), (The NutraSweet Company, Skokie, ILL); Acesulfame-K (Ace-K), Hoechst Celanese Corporation-Sunnette, Sommerville, NJ); and bottled drinking water in 5 gallon carboys, (Aqua Cool, Portland, OR).

Stock solutions were prepared 24 hours in advance, stored at 5°C, and brought to ambient temperature (22°C) prior to serving. Concentrations for each stimuli are presented in Table 3; the sweetener concentrations were determined to be isosweet in a previous study (Wiseman and McDaniel, submitted).

Flavorant selection

The three orange flavorants were chosen on the basis of flavor quality, solubility in spring water, and the concentration range in which the flavorant could be used without bitterness development.

was similar to orange juice in aroma and was sweeter in aroma than flavor 2 which had more aroma and had the flavor of orange peels. Flavor 3 was more artificial, candylike and had a sweet aroma which was less intense than flavor 2.

Environment

Testing took place in the Sensory Science Laboratory in the Department of Food Science at Oregon State University. Panelists were seated in individually partitioned booths which were equipped with red lights.

Experiment 1 methodology

Panel

Eleven volunteers from the students and staff of the Department of Food Science and Technology at Oregon State University were selected on the basis of motivation and experience with magnitude estimation. All panelists were able to identify the basic tastes and were oriented to all procedures prior to testing.

Sensory methods

Magnitude estimation was used by panelists to rate all solutions for fruitiness intensity. Panelists were instructed to place 10-15 mls of the 0.729 %v/v flavor 1 reference in their mouth, assign its fruitiness intensity a value of 50, and expectorate. After rinsing they tasted the first coded sample and assigned it a value corresponding to its ratio of fruitiness to the reference. All stimuli were rated in the same manner. Panelists took breaks between sets.

corresponding to its ratio of fruitiness to the reference. All stimuli were rated in the same manner. Panelists took breaks between sets. A set consisted of a five concentration series of the same flavorant either unsweetened or sweetened with one of the four sweeteners. The samples of 20 mL solutions were served in coded 75 mL plastic cups with three-digit random numbers. An unlimited amount of reference was available for each assessment.

Experimental design

A completely randomized design was used. The 5 concentrations of each of the 3 orange flavors were evaluated unsweetened and sweetened with, sucrose, APM, Ace-K, or APM/Ace-K. The 5 concentration series was presented to the panelists in random order along with the reference; each 5 concentration series was also randomized for each panelist. The treatments were evaluated in duplicate by each panelist. Three sets were completed each testing day.

Statistical analysis

Individual magnitude estimates were adjusted to a common scale across all treatments for each flavorant using geometric mean normalization (McDaniel and Sawyer, 1981). The rescaled data were subjected to simple regression analysis for each orange flavorant + sweetener system. Residuals were examined for each of these regressions to determine if these data needed transformation. From this residual, the log(Y), log(X) transformation was chosen. Subsequent residual plots indicated the variance was approximately regressions to determine if these data needed transformation. From this residual, the log(Y), log(X) transformation was chosen. Subsequent residual plots indicated the variance was approximately equal throughout the range tested and the responses were linear. Simple regression analyses were performed on the transformed data for each flavor + sweetener system. A three-way ANOVA for the main effects of panelist, replication and sweetener was also performed for each flavorant system. The five simple regressions for each of the 3 orange flavors were then compared using multiple regression analysis to determine if significant differences were present in the slopes of the power functions, or in their elevation if the slopes were not significantly different. The SAS statistical package (SAS Institute, Cary, NC) was used for all statistical analyses.

Experiment 2 methodology

Panel

Twenty volunteers with extensive experience on sensory panels were selected.

Sensory methods

Panelists rated how sure they were of the difference in aroma between each sweetened solution and the unsweetened control for each flavorant using a 7-point category scale. The scale ranged from definitely less than the reference (-3) to definitely more than the reference (+3) with same as the reference as the middle category (0). The 20 mL samples were placed in identical 225 ml wine glasses and covered with metal weighing dishes to collect the volatiles.

Experimental design

The panelists evaluated the five pairs of solutions (unsweetened control and sweetened solution) in duplicate each testing day. Treatments were randomized among panelists and each flavorant was evaluated on separate days.

Statistical analysis

A three-way ANOVA for the main effects of panelist, replication and sweetener was performed for each flavorant system. The SAS statistical package (SAS Institute, Cary, NC) was used for all statistical analyses .

RESULTS

Experiment 1

Regression analyses parameters for fruitiness power functions of each flavorant, unsweetened and sweetened are presented in Table 4. Figures 4-6 contain the five fruitiness functions for each flavorant. The common reference allows comparison of all fruitiness power functions sweetened and unsweetened for each flavorant as well as the comparison of the magnitude of fruitiness of each sweetener at each flavorant concentration.

Flavor 1

The linear model accurately described each system except the one sweetened with APM/Ace-K. In the case of the APM/Ace-K sweetened system, additional flavorant did not produce higher fruitiness perception. Fruitiness of the APM sweetened system increased when more flavorant was added to the system but the slope was very low thus the increase in fruitiness was small. The systems sweetened with APM and APM/Ace-K received the highest fruit flavor ratings across all concentrations but the difference in fruitiness was not significant at the highest flavorant level. The sucrose and Ace-K sweetened systems were also significantly higher in fruit flavor than the unsweetened solutions at the two lowest flavor levels.

The fruitiness slope of 0.513 for the unsweetened system was significantly higher than the slopes for the sweetened systems. The sucrose, APM and APM/Ace-K sweetened system slopes did not differ significantly from one another but were all significantly lower than the slope of the Ace-K system. Wiseman and McDaniel (in press), using the same orange flavorant unsweetened and sweetened with APM and sucrose, found that the unsweetened slope was significantly lower in the APM but not the sucrose sweetened systems. They also found the APM sweetened systems were higher in fruitiness magnitude among lower flavorant concentrations.

Flavor 2

The differences in magnitude of fruit flavor perception were not nearly as evident in this second flavor system. However, the APM sweetened system still produced the highest fruit flavor ratings across all concentrations.

The slopes of the functions were not significantly different. The unsweetened flavorant intercept was found to be significantly lower than all other intercepts.

Flavor 3

The same pattern is seen in the third flavorant system, where the APM sweetened solutions were rated as higher in fruitiness across all concentrations of flavorant. In this system, the other three sweetened systems were also higher in fruitiness perception than the unsweetened system but little difference between the sweeteners was evident.

The slopes of the functions were not significantly different. The intercept of the unsweetened system was found to be significantly lower than the sucrose and APM/Ace-K intercepts.

Experiment 2

The mean sureness values of the difference in aroma between the unsweetened reference and the four sweetened samples are presented in Figure 7.

For flavor 1, the significant treatment main effect in ANOVA and subsequent LDS multiple comparison indicated the APM sweetened samples were significantly higher than the unsweetened reference. The sucrose, Ace-K and APM/Ace-K sweetened samples were rated less than but not significantly different from the reference. No significant differences were found between the sweetened samples and the unsweetened reference for flavors 2 and 3.

From this study it is apparent that the fruitiness of the three flavorants is increased to some degree when sweetened with each sweetener system tested. This increase was greatest for all flavorants when sweetened with APM, as seen by the higher elevation of the fruitiness power function (Fig 4-6) in the APM sweetened systems. The differences among flavorants indicate that the magnitude of increase is dependant on the specific flavorant. For flavor 1 the slopes of the fruitiness power functions were all significantly lowered after sweetening the system; but there was no significant difference in the slopes of the other two flavors. This indicates that for flavor 1, fruitiness perception was higher after sweetening with APM but additional flavorant did not increase this perception as much as when the system was unsweetened. The lower the slope of the fruitiness power function the more significant the effect. For the other two flavors, the rate of fruitiness increase was not significantly affected by sweetening. However, the magnitude of fruitiness was significantly higher in sweetened systems.

The fruitiness slopes of the flavorants in the unsweetened systems ranged from 0.287 for the third flavorant to 0.525 for the first flavorant. Cometto-Muniz (1981) found taste exponents for vanillin, piperonal, benzaldehyde, natural vanilla extract and artificial almond essence averaged 0.60 ± 0.02 while the exponents for aroma functions averaged 0.31 ± 0.06. The values for fruitiness exponents obtained in the present study are more similar to aroma exponents for the second and third flavorants and to taste exponents for the first flavorant. Cometto-Muniz (1981) suggest that the size of the function of a flavor reflects the more salient feature of that flavorant. Thus, it follows that taste of the first orange flavorant is the dominant feature while the aroma of the second and third flavorants are the more important feature.

Sweet is a common discriptor for the fruity aroma of most fruits. This sweetness comes from the sweet aromatics and not sweet taste, but perceptually sweet aroma and taste may be inseparable. The sweet taste, in the systems tested in this study, was not rated when flavorant was present. The increase of fruitiness with the addition of APM, could then reflect higher sweetness perception caused by the addition of flavorant to the system. It was not possible with the present experimental design to separate the sweetness and fruitiness percepts. Cliff and Nobel (1990) found the addition of peach essence increased the sweetness of a glucose sweetened system; Frank and Byram (1988) found strawberry flavorant enhanced the sweetness of sucrose but that peanut butter flavorant did not. They concluded that taste-smell interactions are both tastant and odorant dependent. Enns and Hornung (1985) studied the integration of gustation and olfaction with a two mode delivery system. They found that almond flavoring in the mouth effected almond aroma through retronasal perception; almond aroma delivered in the nose affected the taste perception of almond. They suggested that subjects generally added taste and aroma to produce estimates of overall intensity. These results might suggest that the sweetness of the systems is increased by the addition of flavorant to the system. Although, Matysiak and Noble (1991) found no difference in flavor perception among solutions sweetened with isosweet concentrations of sucrose, APM, or APM/Ace-K they did find that the duration of fruitiness was significantly longer in APM or

APM/Ace-K sweetened solutions. This extended fruitiness in these systems may contribute to the higher flavor ratings observed in the present study.

A few investigators have studied mixture suppression and theorized whether it is a product of physical interaction between molecules or simply a perceptual phenomenon. Schifferstein and Frijters (1991) determined the effectiveness of different sweeteners in suppressing citric acid sourness. Isosweet concentrations of sucrose and APM equally suppressed the sourness of citric acid suggesting that the suppression was at the perceptual level rather than the chemical or receptor level. In the present study, isosweet concentrations of the four sweeteners did not effect fruitiness perception equally. According to Schifferstein and Frijters (1991) this might suggest that an actual difference in physico-chemical interaction is present between the four sweeteners and the flavorants used. The fact that the three flavorants were effected differently would also support this idea.

If an actual physico-chemical interaction is present the headspace volatiles might reflect this difference. The results from experiment 2 indicate that the aroma of the first flavorant was higher when sweetened with aspartame but the aromas of the second and third flavorants were not significantly different from the unsweetened reference. This increased fruit aroma would contribute to the higher fruitiness perception in the APM sweetened samples in the first orange flavorant. From the two experiments in the present study the flavorant specific enhancement of fruitiness by APM seems to be on the physico-chemical as well as the perceptual level. In flavor 1, where the greatest enhancement of fruit flavor by APM was seen, the fruity aroma of the headspace volatiles was also increased by sweetening with APM. This could be an important factor when substituting sweeteners in orange flavored beverages, since using APM or blended APM/Ace-K may result in a change in fruit flavor perception.

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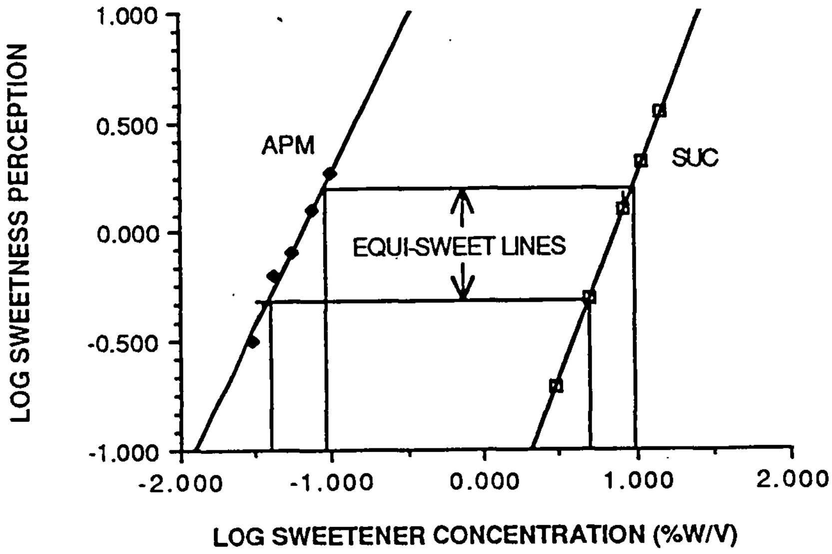

Figure 1. Power functions of sweetness in sucrose (SUC) and aspartame (APM) sweetened spring water.

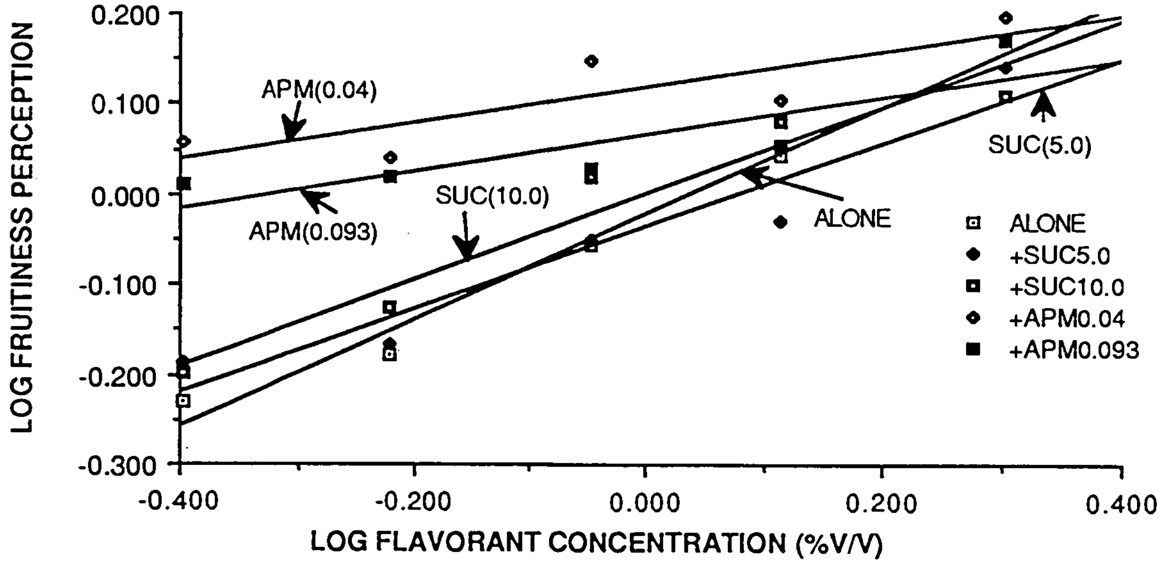

Figure 2. Power functions of fruitiness in orange flavored spring water sweetened and unsweetened with two levels of sucrose(SUC) and aspartame(APM). Concentrations for sweeteners are expressed in % w/v.

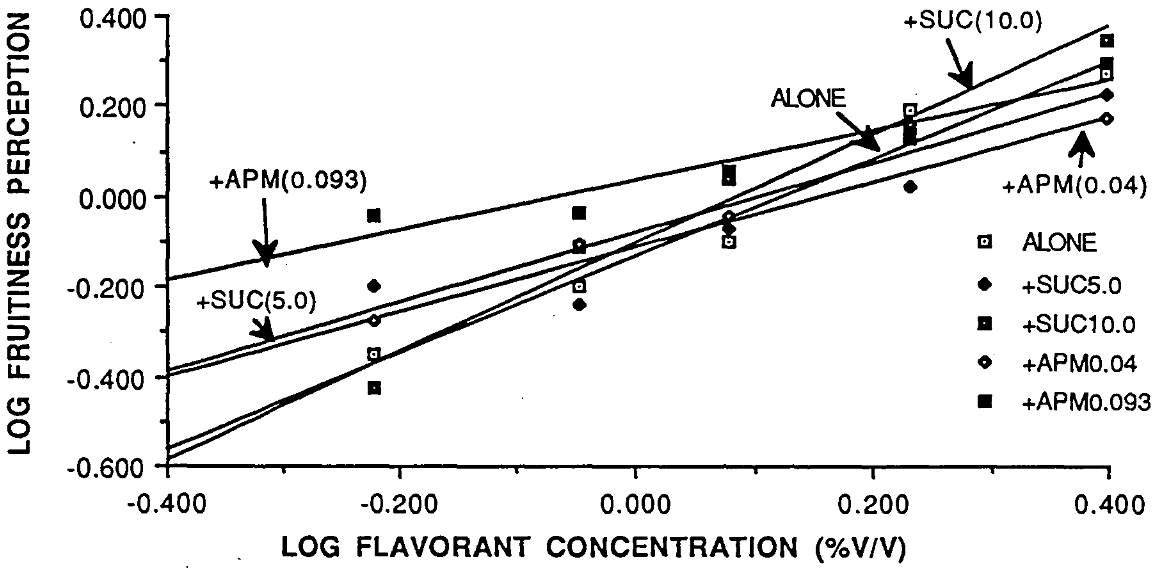

Figure 3. Power functions of fruitiness in strawberry flavored spring water sweetened and unsweetened with two levels of sucrose(SUC) and aspartame(APM). Concentrations for sweeteners are expressed in % w/v.

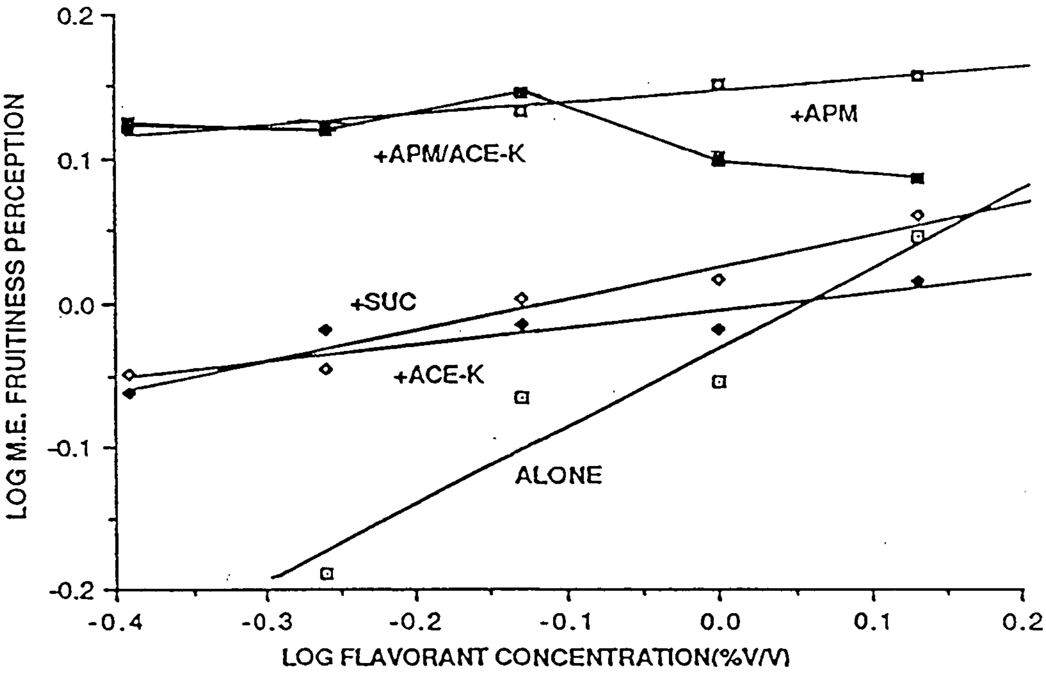

Figure 4. Power functions of orange fruitiness for Flavor 1, in bottled water, unsweetened and sweetened with sucrose, aspartame (APM), acesulfame-K (Ace-K) or APM/Ace-K blended 1:1.

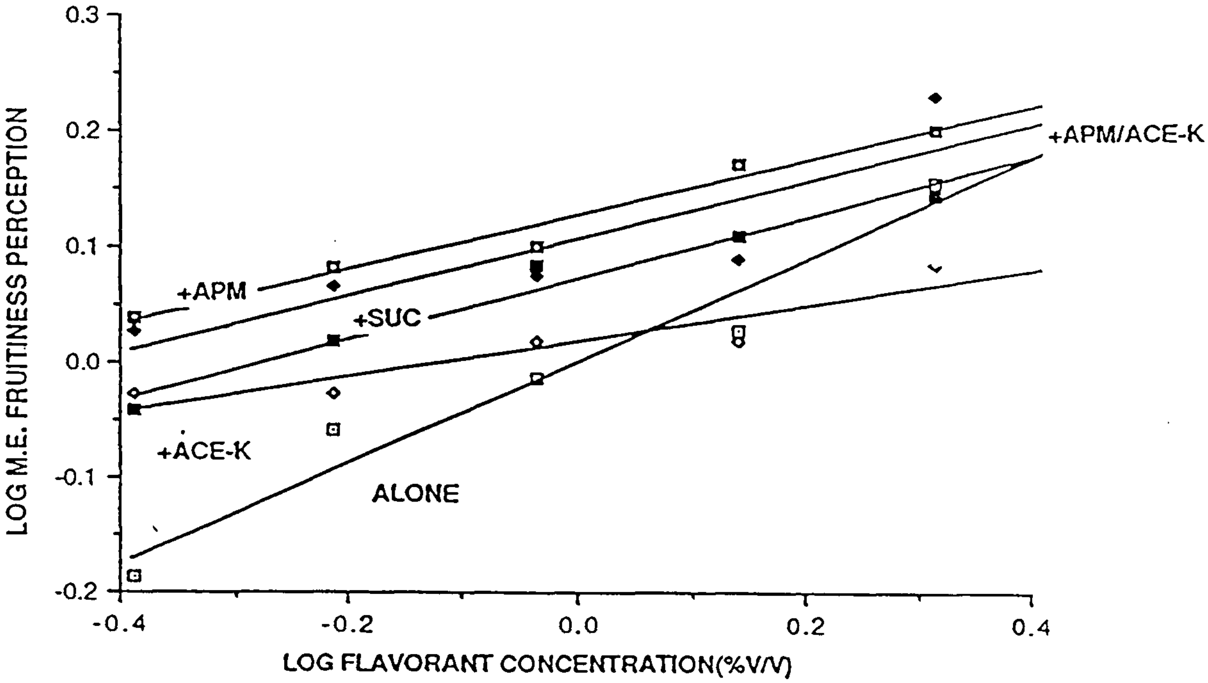

Figure 5. Power functions of orange fruitiness for Flavor 2, in bottled water, unsweetened and sweetened with sucrose, aspartame (APM), acesulfame-K (Ace-K) or APM/Ace-K blended 1:1.

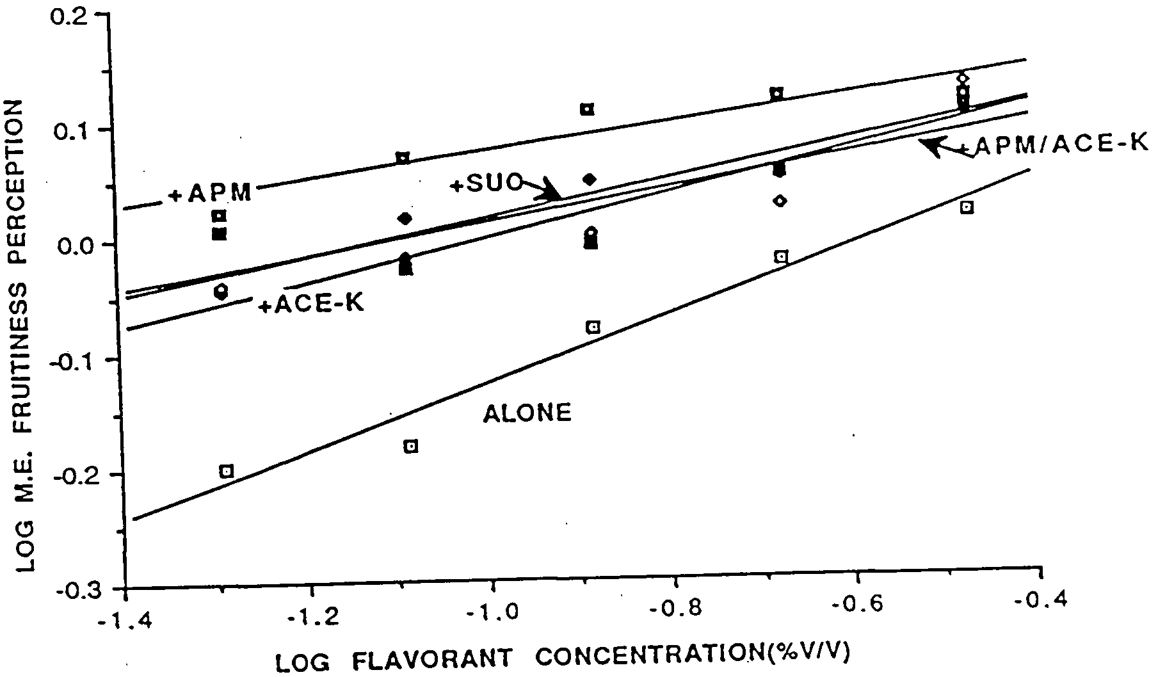

Figure 6. Power functions of orange fruitiness for Flavor 3, in bottled water, unsweetened and sweetened with sucrose, aspartame (APM), acesulfame-K (Ace-K) or APM/Ace-K blended 1:1.

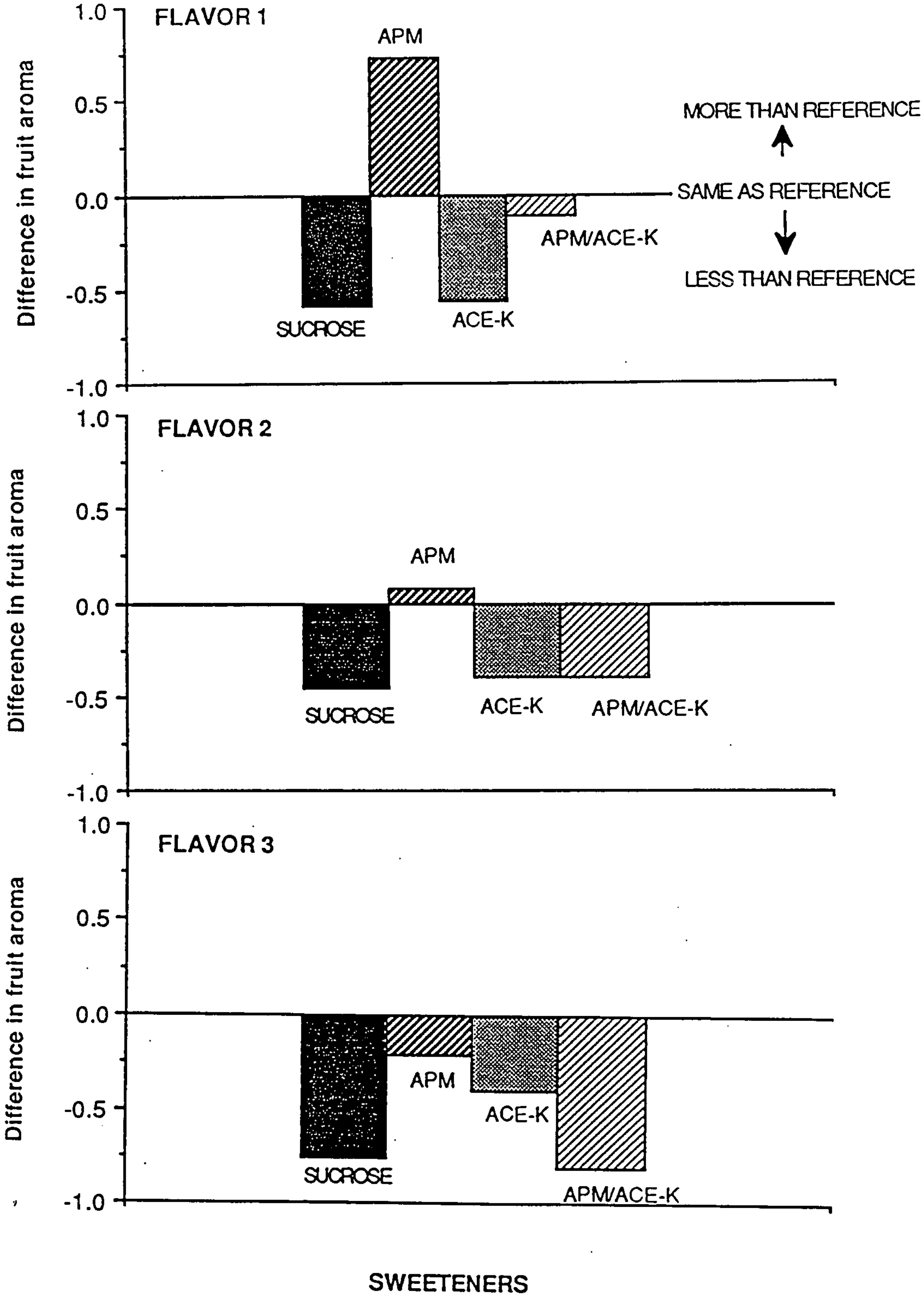

Figure 7. Mean difference in fruit aroma for three orange flavored solutions sweetened with sucrose, aspartame (APM), acesulfame-K (Ace-K) or APM/Ace-K blended 1:1.

Table 1. Concentrations of sweeteners and fruit flavorants in single and binary solutions.

Attribute[a] rated	Stimuli	Stimuli concentrations[b] 1	2	3	4	5
Sweetness	APM	0.03	0.041	0.056	0.07	0.10
	Sucrose	3.00	5.00	8.50	11.20	15.00
Fruitiness[c]	Orange	0.40	0.60	0.90	1.30	2.00
	Strawberry	0.60	0.90	1.20	1.70	2.50

a) With a reference of sucrose (8.5% w/v) for sweetness and unsweetened orange (0.90% v/v) or strawberry (1.20% v/v) flavorants for fruitiness.

b) All sucrose and APM concentrations were % w/v and flavorant (orange, strawberry) concentrations were % v/v.

c) Also combined with equi-sweetness concentrations of aspartame and sucrose at 0.04, 0.093% w/v and 5.00, 10.00% w/v, respectively.

Table 2. Parameters from regression analysis of sweetness perception versus sweetener concentration and of fruitiness perception versus flavorant concentration for sweetened and unsweetened orange and strawberry solutions.

Sweetener added to flavorant[x]	Y-Intercept[y]	Slope (n)	Coefficient of Determination (r2)	p-value
		SWEETENER		
Sucrose	-1.56	1.79[a]	0.99	0.000
APM	+1.67	1.39[b]	0.98	0.001
		ORANGE FLAVORANT		
none	-0.021	0.59[a]	0.98	0.000
sucrose(5.00)	-0.035	0.46[a]	0.92	0.010
sucrose(10.00)	+0.019	0.48[a]	0.94	0.006
APM(0.04)	+0.119	0.20[b]	0.72	0.059
APM(0.093)	+0.076	0.21[b]	0.74	0.052
		STRAWBERRY FLAVORANT		
none	-0.134	1.08[a]	0.97	0.003
sucrose(5.00)	-0.115	0.72[a]	0.87	0.021
sucrose(10.00)	-0.105	1.20[a]	0.98	0.002
APM(0.04)	-0.084	0.77[a]	0.95	0.005
APM(0.093)	+0.032	0.55[b]	0.90	0.014

x) All sweetener concentrations are % w/v.
y) Y-intercept expressed in log values.
ab) Slopes with the same letter are not significantly ($p<0.05$) different.

Table 3. Stimuli concentrations for fruitiness power function determinations.

Stimuli	Concentrations				
	1	2	3	4	5
	ORANGE FLAVORANTS (% v/v)				
Flavor 1	0.40	0.54	0.73	0.98	1.33
Flavor 2	0.40	0.60	0.90	1.35	2.03
Flavor 3	0.05	0.08	0.13	0.21	0.33
	SWEETENERS				
Sucrose	5.0				
Aspartame (APM)	0.043				
Acesulfame-K (Ace-K)	0.090				
APM/Ace-K	0.021				

Table 4. Parameters from the regression analysis of fruitiness perception versus stimuli concentrations.

Sweetener added to flavorant	Regression Parameters: LOG Y-intercept	Slope(n)	Coefficient of Determination (r^2)
FLAVOR 1			
Unsweetened	0.032	0.525[a]	0.96
Sucrose	-0.011	0.118[c]	0.79
APM	0.140	0.077[c]	0.89
Ace-K	0.019	0.241[b]	0.95
APM/Ace-K	0.097	-0.082[c]	0.49
FLAVOR 2			
Unsweetened	-0.004	0.436[a]	0.96
Sucrose	0.100	0.244[a]	0.77
APM	0.120	0.233[a]	0.98
Ace-K	0.011	0.153[a]	0.87
APM/Ace-K	0.066	0.260[a]	0.97
FLAVOR 3			
Unsweetened	0.152	0.287[a]	0.96
Sucrose	0.165	0.158[a]	0.92
APM	0.177	0.112[a]	0.83
Ace-K	0.173	0.185[a]	0.84
APM/Ace-K	0.138	0.136[a]	0.66

ab) Slopes with the same letter are not significantly ($p<0.05$) different.

BIBLIOGRAPHY

Ahmed, E.M., Dennison, R.A., Dougherty, R.H., and Shaw, P.E. 1978. Effect of nonvolatile orange juice components, acid, sugar, and pectin on the flavor threshold of *d*-limonene in water. J. Agric. Food Chem. 26(1):192.

Bahoshy, B.J., Klose, R.E., and Nordstrom, H.A. 1976. Chewing gum of longer lasting sweetness and flavor. U. S. Patent No. 3,943,258.

Bahoshy, B.J., Klose, R.E., and Nordstrom, H.A. 1977. Chewing gum of longer lasting sweetness and flavor. U. S. Patent No. 4,036,992.

Baldwin, R.E., and Korschgen, B.M. 1979. Intensification of fruit flavors by aspartame. J. Food Sci. 44: 938.

Bartoshuk, L.M. 1975. Taste mixtures: Is mixture suppression related to compression. Physiol. Behav. 14:643.

Bartoshuk, L.M., and Cleveland, R.M. 1977. Mixtures of substances with similar tastes. A test of a psychophysical model of taste mixture interactions. Sens. Proc. 1:177.

Beck, C.I. 1974. Sweetness, character, and applications of aspartic acid-based sweeteners. In *Symposium: Sweeteners*, Inglett, G.E. (Ed), The Avi publishing Co., Inc., Westport, CT.

Beebe-Center, J.G., and Waddell, D. 1948. A general psychological scale of taste. J. of Psy. 26:517.

Beidler, L.M. 1974. Biophysics of sweetness. In G.E. Inglett (Ed.), *Symposium Sweeteners* pp. 10-22. Westport, CT: Avi Publishing Co.

Burdach, K.J., Krose, J.H.A., and Koster, E.P. 1984. Nasal, retronasal and gustatory perception: an experimental comparison. Percept. Psychophys. 36:205.

Butler, G., Poste, L.M., Wolynetz, M.S., Agar, V.E., and Larmond, E. 1987. Alternative analysis of magnitude estimation data. J. Sensory Studies. 2:243.

Cameron, A.T. 1947. The taste sense and relative sweetness of sugars and other sweet substances. Sci. Rep. Ser. No. 9, Sugar Research Foundation, New York.

Chappell, G.M. 1953. Flavour assessment of sugar solutions. J. Sci. Food Agric. 7:346.

Cliff, M., and Noble, A.C. 1990. Time-Intensity Evaluation of Sweetness and Fruitiness and Their Interaction in a Model Solution. J. Food Sci. 55(2):450.

Cloninger, M.R. and Baldwin, R.E. 1970. A low-calorie sweetener. Science 170:81.

Cloninger, M.R., and Baldwin, R.E. 1974. L-Aspartyl-L-Phenylalanine Methyl Ester (Aspartame) as a Sweetener. J. Food Sci. 39:374.

Cometto-Muniz, J.E. 1981. Odor, taste, and flavor of some flavoring agents. Chem. Senses. 6(3):215.

Curtis, D.W., D.A. Stevens, and H.T. Lawless. 1984. Percieved ntensity of the taste of sugar mixtures and acid mixtures. Chem Senses. 9(2):107.

De Graaf, C., and Frijters, J.E.R. 1986. A psychophysical investigation of Beidler's mixture equation. Chem. Senses. 1 1(3):295.

De Graaf, C., Frijters, J.E.R., and VanTrijp, H.C.M. 1987. Taste interaction between glucose and fructose assessed by functional measurement. Percept. & Psych. 41:383.

De Graaf, C., and Frijters, J.E.R. 1987. Sweetness intensity of a binary sugar mixture lies between intensities of its components when each is taste alone and at the same total molarity as the mixture. Chem. Senses. 12(1):113.

De Graaf, C., and Frijters, J.E.R. 1988. Assessment of the taste interaction between two quantitatively similar tasting substances: a comparison between comparison rules. J. Exp. Psychol.: Hum. Percept. Perform., 14:526.

De Graaf, C., and Frijters, J.E.R. 1989. Interrelationships among sweetness, saltiness and total taste intensity of sucrose, NaCl and sucrose/NaCl mixtures. Chem. Senses. 14(1):81.

Dever, M.C., Beveridge, H.J.T., Cumming, D.B., and MacGregor, D.R. 1986. Measurement and stability of aspartame in a fruit spread. Can Ins. Food Sci. Technol. J. 19(2):86.

Dubose, C.N., Cardello, A.V., and Maller, O. 1980. Effects of colorants, and flavorants on identification, perceived flavor intensity, and hedonic quality of fruit-flavored beverages and cake. J. Food Sci. 45:1393.

Duxbury, D.D. 1990. High-intensity sweetener blends provide synergistic enhancement. Food Processing. 4:36.

Dwivedi, B.K. 1978. Low calorie and Special Dietary Foods, CRC Press, Inc. West Palm Beach, Florida.

Enns, M.P., and Hornung, D. 1985. Contributions of smell and taste to overall intensity. Chem. Senses. 10:357.

Ebeler, S.E., Pangborn, R.M., and Jennings, W.G. 1988. Influence of dispersion medium on aroma intensity and headspace concentration of methone and isoamyl acetate. J. Agric. Food Chem. 36(4):791.

FDA. 1981. Aspartame: Commissioner's final decision. Food and Drug. Admin., Fed. Reg. 46:38285.

FDA. 1983. Food additives permitted for direct addition to food for human consumption: Aspartame. Food and Drug Admin., Fed. Reg. 48:31376.

Frank, R.A., and Archambo, G. 1986. Intensity and hedonic judgements of taste mixtures: an information integration analysis. Chem Senses 11(4):427.

Frank, R.A., and Byram, J. 1988. Taste-smell interactions are tastant and odorant dependent. Chem. Senses. 13(3):445.

Frank, R.A., Ducheny, K., and Mize, S.J.S. 1989. Strawberry odor, but not red color, enhances the sweetness of sucrose solutions. Chem. Senses. 14(3):371.

Frank, R.A., Mize, S.J.S., and Carter, R. 1989b. An assessment of binary mixture interactions for nine sweeteners. Chem. Senses. 14(5):621.

Frijters, J.E.R., and Oude Ophuis, P.A.M. 1983. The construction and prediction of psychophysical power functions for the sweetness of equiratio sugar mixtures. Perception. 12:753-767.

Frijters, J.E.R., deGraaf, C., and Koolen, H.C.M. 1984. The validity of the equiratio taste mixture model investigated with sorbitol-sucrose mixtures. Chem. Senses. 9(3):241.

Garcia-Medina, M.R. 1981. Flavor-odor taste interactions in solutions of acetic acid and coffee. Chem. Senses. 6:13.

Gelardi, R.C. 1987. The multiple sweetener approach and new sweeteners on the horizon. Food Technol. 41(1):123.

Gillan, D.J. 1983. Taste-taste, odor-odor and taste-odor mixtures: Greater suppression within than between modalities in Percept. Psychophys. 33:183.

Giovanni, M.E., and Pangborn, R.M. 1983. Measurement of Taste Intensity and Degree of Liking of Beverages by Graphic Scales and Magnitude Estimation. J. Food Sci. 48:1175.

Hoechst Celanese Corp. 1988. Newly approved U.S. sweetener used in a variety of products worldwide. Food Eng. 10:42.

Holmer, B.E. 1984a. Aspartame: Implications for the food scientist. In *Aspartame. Physiology and Biochemistry*, p. 247. Marcel Dekker, New York.

Holmer, B.E. 1984b. Properties and Stability of Aspartame. Food Tech. 7:50.

Hornung, D.E., and Enns, M.P. 1984. The independence and integration of olfaction and taste. Chem. Senses.9:97.

Hyman, A. 1983. The influence of color on the taste perception of carbonated water preparations. Bull.Psychonom. Soc. 2:.

Hyvonen, L., Kurkela, R., Koivistoinen, P., and Ratilainen, A. 1978. Fructose-saccharin and xylitol-saccharin synergism. J. Food Sci. 43:251.

Hyvonen, L., Koivistoinen, P., and Ratilainen, A. 1978. Sweetening of soft drinks with mixtures of sugars and saccharine. J. Food Sci. 43(5):1580.

Jakinovich, W., Jr. 1982. Stimulation of the gerbil's gustatory receptors by saccharin. J. Neurosci., 2: 49.

Johnson, J., and Clydesdale, F.M. 1982. Perceived sweetness and redness in colored sucrose solutions. J. Food. Sci. 947:747.

Kamen, J. 1959. Interaction of sucrose and calcium cyclamate on perceived intensity of sweetness. Food Res., 110:505.

Kuznicki, J.T., and Ashbaugh, N. 1979. Taste quality differences within the sweet and salty taste categories. Sensory Process. 3:157.

Kuznicki, J.T., and Ashbaugh, N. 1982. Space and time separation of taste mixture components. Chem. Senses. 7:39.

Laffort, P., Etcheto, M., Patte, F. ,and Marfaing. 1989. Implications of power law exponent in synergy and inhibition of olfactory mixtures. Chem Senses. 14(1):11.

Labell, F. 1988. FDA grants approval of calorie-free sweetener for dry product use. Food Processing. 10:48.

Larson-Powers, N. and Pangborn, R.M. 1978a. Paired comparisons and time-intensity measurements of the sensory properties of beverages and gelatins containing sucrose or synthetic sweeteners. J. Food Sci. 43:41.

Larson-Powers, N. and Pangborn, R.M. 1978b. Descriptive analysis of the sensory properties of beverages and gelatins containing sucrose or synthetic sweeteners. J. Food Sci. 43:47.

Lawless, H.T., and Skinner, E.Z. 1979. The duration and percieved intensity of sucrose taste. Percept. & Psych. 25(3): 180.

Lawless, H. 1982a. Adapting efficiency of salt-sucrose mixtures. Percept. & Psych. 32(5):419.

Lawless, H.T. 1982b. Paradoxical Adaptation to Taste Mixtures. Physiol. & Behav. 25:149.

Lawless, H.T., and Malone, G.J. 1986. The discriminative efficiency of common scaling methods. J. Sensory Studies. 1:85.

Maga, J.A. 1974. Influence of color on taste thresholds. Chem. Senses. Flav. 1:115.

Matysiak, N.L., and Noble, A.C. 1991. Comparison of Temporal Perception of Fruitiness in Model Systems Sweetened with Aspartame, an Aspartame + Acesulfame K Blend or Sucrose. J. Food Sci. 56(3):823.

Mazur, R.H. 1976. Aspartame a Sweet Surprise. J. Toxicol. Environ. Health. 2:243.

McBride, R.L. 1986. Sweetness of binary mixtures of sucrose, fructose and glucose. J. Exp. Psy: Human Percept. & Perform. 12:584.

McBride, R.L. 1987a. Taste psychophysics and the Beidler equation. Chem. Senses. 12(2):323.

McBride, R.L. 1987b. Psychophysics as measurement science, sensory science, food science. Chem. and Ind. 1(5):30.

McBride, R.L. 1988. Taste reception of binary sugar mixtures: Psychophysical comparison of two models. Percept. & Psych. 44(2):167.

McBurney, D.H. 1974. Are there primary tastes for man? Chem. Sens. Flav.1:17.

McBurney, D.H., and Gent, J.F. 1979. On the nature of taste qualities. Psychol. Bull. 86:151.

McCormick, R.D. 1975. Aspartame: A new dimension for controlling product sweetness. Food Product Dev. 9(1):22.

McDaniel, M.R., and Sawyer, F.M. 1981. Descriptive analysis of whiskey sour formulations: magnitude estimation vs a 9-point category scale. J. Food Sci. 46:178.

McPherson, B.A., McGill, L.A., and Bodyfelt, F.W. 1978. Effect of stabilizing agents and aspartame on the sensory properties of orange sherbet. J. Food Sci.43:935.

Meiselman, H.L. 1971. Effect of presentation procedure on taste intensity functions. Percept.& Psych. 10:15.

Morris, C. 1983. New option for soft drinks: Aspartame. Food Eng. 9:51.

Moskowitz, H.R. 1970a. Ratio scales of sugar sweetness. Percept. Psychophys. 7 (5):315.

Moskowitz, H.R. 1970b. Sweetness intensity of artificial sweeteners. Percept. Psychophys. 8 (1):40.

Moskowitz, H.R. 1971a. Intensity scales for pure tastes and taste mixtures. Percept. Phychophys. 9(1A):51.

Moskowitz, H.R. 1971b. The sweetness and pleasantness of sugars. Am. J. of Psy. 84(3):387.

Moskowitz, H.R., and Wehrly, T. 1972. Economic applications of sweetness scales. J. Food Sci. 37:411.

Moskowitz, H.R. 1972. Perceptual changes in taste mixtures. Percept. & Psychophys. 11(4):257.

Moskowitz, H.R. 1974. Sensory Evaluation by magnitude estimation. Food Tech. 11:16.

Moskowitz, H.R. 1977. Magnitude estimation: Notes on what, how, when and why to use it. J. Food Quality., 3:195.

Murphy, C., Cain, W.S., and Bartoshuk, L.M. 1977. Mutual interaction of taste and olfaction. Sens. Processes. 1:204.

Murphy, C., and Cain, W.S. 1980. Taste and Olfaction: Independence vs interaction. Physiol. & Behav. 24:601.

Nawar, W.W. 1971. Some variables affecting composition of headspace aroma. J. Agric. Food Chem. 19(6):1057.

Nolan, A.L. 1984. Aspartame: too good to be true? Food Eng. 3:16.

Pangborn, R.M. 1960. Influence of color on the discrimination of sweetness. Am. J. Psychol. 73:229.

Pangborn, R.M., and Hansen, B. 1963. The influence of color on discrimination of sweetness and sourness in pear-nectar. Am. J. Psychol. 36:315.

Poulton, E.C. 1968. The new psychophysics: six models for magnitude estimation. Psychol. Bul. 69(1):1.

Powers, J.J., Ware, G.O., and Shinholser, K. 1990. Magnitude estimation with and without re-scaling. J. Sensory Studies. 5:105.

Redlinger, P.A., and Setser, C.S. 1987. Sensory Quality of Selected Sweeteners: Aqueous and Lipid Model Systems. J. Food Sci. 52(2):451.

Rifkin, B., and Bartoshuk, L.M. 1980. Taste synergism Between Monosodium Glutamate and Disodium 5'-Guanylate. Physiol. & Behav. 24:1169.

Ripper, A., Holmer, B.E., and Miller, G.A.. 1986. Aspartame. In *Alternative Sweeteners*. L.O. Nabors and R.C. Gelardi (Eds.), Marcel Dekker, Inc., New York.

Roth, H.A., Radle, S.R., Gifford, S.R., and Clydesdale, F.M. 1988. Psychophysical Relationship Between Perceived Sweetness and

Color in Lemon- and Lime-Flavored Drinks. J.Food Sci. 53(4):1117.

Rozin, P. 1982. Taste-smell confusion and the duality of the olfactory sense. Percept. Psychophysics. 31:397.

Schifferstein, H.N.J., and Frijters, J.E.R. 1990. Sensory integration in citric acid/ sucrose mixtures. Chem Senses. 15:87.

Schifferstein, H.N.J., and Frijters, J.E.R. 1991. The effectiveness of different sweeteners in suppressing citric acid sourness. Percept. & Psychophys. 49(1):1.

Schiffman, S.S., and Erikson, R.P. 1971. A theoretical review: a psychophysical model for gustatory quality. Physiol. Behav. 7:617.

Schiffman, S.S., and Erikson, R.P. 1980. The issue of primary taste versus a taste continuum. Neurosci. Behav. Rev. 4:109.

Schiffman, S.S. 1984. Comparison of taste properties of aspartame with other sweeteners. In. "Aspartame. Physiology and Biochemistry". L.D. Stegnik and L.J. Filer. Jr. (Eds.), p. 207, Marcel Dekker, Inc. New York.

Schiffman, S.S., Crofton, V.A., and Beeker, T.G. 1985. Sensory Evaluation of Soft Drinks With Various Sweeteners. Physil. & Behav. 34:367.

Stevens, S.S., and Galanter, E.H. 1957. Ratio scales and category scales for a dozen perceptual continua. J. Exp. Psy. 54:377.

Stevens, S.S. 1969. Sensory scales of taste intensity. Percpet. & Psychophys. 6(5):302.

Stevens, S.S. 1975. Psychophysics: An introduction to its perceptual, neural, and social prospects. John Wiley, New York.

Stone, H., and Oliver, S.M.. 1969. Measurement of the relative sweetness of selected sweeteners and sweetener mixtures. J. Food Sci., 34:215.

Stone, H., Oliver, S.M., and Kloehn, J. 1969. Temperature and ph effects on relative sweetness of suprathreshold mixtures of dextrose fructose. Percept. & Psych. 5:257.

Swain, R.L. 1951. The effect on the flavor of strawberry preserves caused by partial replacement of sucrose with other sweeteners. Food. Technol. 5:291.

Thomson, D.M.H., Tunaley, A., and Van Trijp, H.C.M. 1987. A reappraisal of the use of multidemensional scaling to investigate the sensory characteristics of sweeteners. J. Sensory Studies. 2:215.

Valdes, R.M., Simone, M.J., and Hinreiner, E.H. 1956a. Effect of sucrose and organic acids on apparent flavor intensity. I. Aqueous solutions. Food Tech. 6:282.

Valdes, R.M., Simone, M.J., Hinreiner, E.H. 1956b. Effect of sucrose and organic acids on apparent flavor intensity. II. Fruit nectars. Food Tech. 8:387.

van der Heijden, A., Brussel, L.B.P., Heidema, J., Kosmeijer, and Peer, H.G. 1983. Interrelationships Among Synergism, Potentiation, Enhancement and Expanded Perceived Intensity Vs Concentration. J.Food Sci. 48:1192.

von Rymon Lipinsky, G.W. 1982. AcesulfameK-'new and interesting prospects'. Soft Drinks. 10:92.

von Rymon Lipinsky, G.W., and Huddart, B.E. 1983. Acesulfame K. Paper presented at SCI Food Safety Panel Symposium, Jan 5, London.

von Rymon Lipinsky, G.W., and Luck, E. 1983. The future of Acesulfame-K. Food Manu. 3:35.

Wientjes, A.G. 1968. The influence of sugar concentrations on the vapor pressure of food odor volatiles in aqueous solutions. J. Food Sci. 33:1.