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Prediction of stevia liking by sucrose liking: Effects of beverage background

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Abstract

Introduction: There is significant concern over the health implications of increased consumption of sugars added to foods and beverages. Understanding the increase in sugar intake, as well as consideration of potential substitutes will require research in multiple domains. Research on hedonic ratings of sucrose suggests that individuals can be classified into two distinct liking profiles: sweet likers and sweet non-likers. However, no known studies have investigated liking for the natural, nonnutritive sweetener, stevia. The present study aimed to investigate the relationship between liking of stevia and sucrose as a function of beverage background.

Methods: Forty young adults, 20 high concentration and 20 moderate concentration stevia likers, gave intensity and pleasantness ratings for stevia blend and sucrose taste solutions that varied in concentration and background.

Results: The results revealed a significant relationship between stevia blend liking and sucrose liking. The majority of stevia high concentration likers were high concentration sucrose likers. Pleasantness ratings also significantly varied as a function of background: the discrepancy in pleasantness ratings between stevia blend high concentration likers and moderate concentration likers observed in distilled water was attenuated in a citric beverage background.

Conclusions: The majority of high concentration stevia likers were sucrose likers; however, pleasantness ratings also significantly varied as a function of stimulus background.

Implications: Limiting sucrose in the modern diet is an important research area for diabetes and other health issues. The results suggest that perception of pleasantness and sweetness at varying sweetener concentrations is not fully generalizable from one beverage background to another.

Keywords

liking; sweet taste; taste; sucrose; stevia

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Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and or national research committee and with the 1964 Helsinki declaration and its later amendments of comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

Motivation to eat is largely influenced by the enjoyment and pleasurable sensory properties of taste, and while sweetness is preferred universally, individuals vary in their degree of liking for sweet tastes (Drewnowski et al. 1997; Mennella et al. 2005). Evidence suggests that humans generally fall into two distinct groups with respect to sweet preference: sweet likers, referring to individuals who prefer highly concentrated sweetness, and sweet non-likers, those who prefer moderately concentrated sweetness. Previous studies using sucrose as a sweet stimulus have characterized high concentration sweet likers as individuals who report higher hedonic ratings with increasing levels of sucrose concentration (Moskowitz et al. 1974; Looy and Weingarten 1992; Drewnowski and Schwartz 1990). Conversely, sweet non-likers, or moderate concentration likers, generally display decreased hedonic ratings for high sucrose concentrations. These individuals may prefer increasing concentrations of sucrose up to a middle-range, followed by a point at which preference decreases with increasing concentration, resembling an inverted U-shaped pattern of response. In other words, sweet likers may find highly concentrated sweet tastes as pleasant, but sweet non-likers may perceive high concentrations of sucrose as overly sweet.

Liking for sweet tastes may in part be explained by genetic factors and taste sensitivity to certain bitter substances. The TAS2R family of taste receptors consists of 25 G-protein coupled receptors that mediate bitter taste detection to a vast collection of compounds (Behrens and Meyerhof 2009). Two particular compounds, 6-*n*-propylthiouracil (PROP) and phenylthiocarbamide (PTC), which are mediated by the TAS2R38 bitter receptor gene (Kim et al. 2003), have been commonly used to assess variations in bitter sensitivity (Bartoshuk et al. 1994), although allelic variation in TAS2R bitter receptor genes has been associated with differences in bitter sensitivity to other compounds as well (Hayes et al. 2011; Roura et al. 2015). Sensitivity to both PROP and PTC also appears to influence perception of sweet taste (Bartoshuk 2000; Drewnowski 2002), in that tasters of these substances have also been reported to show decreased hedonic ratings for sucrose solutions and sweet foods (Looy and Weingarten 1992; Duffy et al 1995). However, this relationship has not been consistently found in all studies, and one study suggested that bitter taste sensitivity to PROP did not predict hedonic responses to either sucrose or saccharin solutions (Drewnowski et al 1997).

Consumption of nonnutritive sweeteners in food and drinks has become a popular strategy of individuals who are interested in decreased sugar intake while maintaining desired sweet taste. A growing consumer interest has developed for foods originating from natural sources, and non-caloric and natural sweeteners made from plant sources have been of interest. Stevia sweeteners are derived from the *Stevia rebaudiana* Bertoni shrub, a plant native to South America, and stevia leaves have been used by the natives of Paraguay to sweeten beverages for centuries (Lewis 1992).

Stevia is 200-300 times more potent than sugar by weight, with a sweetening potential similar to that of aspartame. Therefore, it is important to consider sucrose equivalency (SE) level to determine the appropriate level of desired sweetness potency concentration. Stevia has been noted to exhibit clean sweetness at low SE levels. Additional bitter and black licorice side tastes, that can be addressed by blending with any of a number of non-caloric or caloric sweeteners, have been noted at high SE levels (Prakash et al 2008). Hellfritsch et al.

(2012) reported that higher concentrations of stevia exhibit decreased sweetness. This reduced sweet intensity may be due to a cross-modal suppression effect by the bitter side-tastes found at high concentrations.

Research concerning sweet liking has predominantly investigated psychophysical responses to sucrose, and it is unknown whether sweet liking for sucrose generalizes to liking for stevia. Therefore, the aims of the current study were to investigate the relationship between liking and hedonic ratings for varying concentrations of a stevia sweetener blend in relation to sucrose in different beverage backgrounds. It was hypothesized that stevia liking would not directly map on to sucrose liking. Due to previously reported bitter side-tastes of stevia at higher concentrations, we reasoned that individuals who like high concentrations of the stevia blend might prefer sweetness that is subdued by bitter side-tastes and therefore would not necessarily enjoy the pure sweetness exhibited by sucrose at high concentrations. Furthermore, it was hypothesized that pleasantness ratings given by high concentration stevia blend likers and moderate concentration stevia blend likers would be less discrepant when the sweeteners are placed in a citrus beverage background, due to the sour and bitter-like properties of citrus that may be consonant with any bitter side-tastes associated with stevia. The exploration of hedonic responses and taste perception of stevia may extend the current understanding of sweet liking, as well as contribute to a better understanding of stevia as a sugar substitute.

Materials and Methods

Participants

Seventy individuals were screened for high concentration stevia liking and moderate concentration stevia liking, according to the criteria presented below, in order to identify 20 participants in each category, with 10 males and 10 females in each group (mean age = 19.025, *SD* = 1.577). Participants who reported any recent changes in sense of taste and smell, or diagnosis of diabetes or glucose intolerance were excluded from the study. All participants were naive to the experimental aims and hypotheses and were university students.

Taste Stimuli

Taste stimuli were twenty aqueous solutions of stevia blend and sucrose administered in distilled water and acidified water backgrounds. Sucrose solutions consisted of five concentrations (2%, 4%, 8%, 16%, and 32% weight by volume) based on previous work establishing appropriate sucrose concentrations for examining sweet preference (Drewnowski et al. 1997). Stevia blend solutions were prepared according to sweetness equivalency calculations for the 2%, 4%, 8%, 16%, and 32% sucrose solutions using Truvia sweetener, which contains a combination of stevia leaf extract and erythritol. Sweetness equivalency calculations were based on Truvia product recommendations, which indicate that 1 gram of sucrose is equivalent in sweetness to 0.42 grams of Truvia. These same five concentrations of sucrose and stevia blend were also diluted in an acidified water background, prepared with 0.06% tri-potassium citrate and 0.18% citric acid diluted in distilled water. All taste stimuli in distilled water and acidified water backgrounds appeared as clear liquid samples and were visually indistinguishable. Based on previously established methods for assessing sweet-liking (Moskowitz et al. 1974; Looy and Weingarten 1992; Drewnowski and Schwartz 1990), participants who gave ascending pleasantness ratings to solutions of increasing concentration (i.e., 16% and 32% concentrations were rated as increasingly pleasant) were classified as high concentration likers of a sweetener. Those individuals that displayed either an initial rise in pleasantness ratings followed by a decline, or those who showed descending pleasantness ratings with increasing concentration were classified as moderate concentration likers of a sweetener.

PTC taster status was also explored in relation to psychophysical responses given to stevia solutions. Participants were administered PTC in the form of a filter paper test to determine taster status (taster or non-taster). Individuals who reported a strong bitter or aversive taste were classified as tasters, and all other individuals were classified as non-tasters.

Procedure

During a psychophysical testing session, twenty stevia blend and sucrose solutions of varying concentration and background were administered to participants. Psychophysical ratings of pleasantness for stevia blend and sucrose dissolved in distilled water were assessed to determine liker status. Furthermore, sweetener solutions were also dissolved in a citrus beverage background, intended to taste similarly to a lemon-flavored drink with varying levels of sweetness. These taste stimuli were administered to further assess the relationship between stevia blend and sucrose liking, and also to investigate hedonic ratings of stevia blend in a background that may be complimentary to any existing bitter tastes.

Participants were formally instructed to give numerical ratings of pleasantness and intensity for taste solutions using the general Labeled Magnitude Scale (gLMS) (Bartoshuk et al. 2004). The gLMS is a scale characterized by quasi-logarithmic spacing of verbal labels that has been used to measure sensations including gustatory, olfactory, thermal, and nocioceptive stimuli. The instructions directed participants to compare tastes to all potential and imagined sensory experiences, and to use the verbal descriptors displayed on the scale to guide their responses, and to fine-tune ratings by choosing an exact number (between 0 and 100) to represent their experience. The gLMS for pleasantness is divided by the following labels: ‘strongest unpleasant sensation imaginable,’ ‘very strongly unpleasant,’ ‘strongly unpleasant,’ ‘moderately unpleasant,’ ‘neutral,’ ‘moderately pleasant,’ ‘strongly pleasant,’ ‘very strongly pleasant,’ and ‘strongest pleasant sensation imaginable.’ The gLMS for intensity includes the following labels: ‘no sensation,’ ‘barely detectable,’ ‘weak,’ ‘moderate,’ ‘strong,’ ‘very strong,’ and ‘strongest sensation imaginable.’

Participants were instructed to place randomized 10 ml samples in their mouth, expectorate, and rinse with distilled water after each sample. After receipt of the stimulus, participants reported numerical ratings of pleasantness, as well as ratings of sweetness and bitterness intensity. Between each trial, participants rinsed with distilled water during a 45-second inter-trial interval.

Results

Participant characteristics are summarized in Table 1. High concentration stevia blend likers and moderate concentration stevia blend likers did not significantly differ in BMI, age, or weekly sweetened beverage consumption, *p*s > .50. Additionally, the majority of participants in both high concentration and moderate concentration stevia blend liker groups (75%) were classified as PTC tasters. BMI was not significantly correlated with ratings of pleasantness or sweetness for any concentration, *p*s > .140. A logarithmic transformation was performed on all psychophysical data to correct for non-normality of the variances within the sample (Shapiro Wilk tests revealed *p*s < .05). In addition, the Greenhouse-Geisser correction was applied to data when necessary to correct for violations of sphericity.

Stevia Blend and Sucrose Liker Status

A chi-square test of independence was performed to examine the relationship between stevia **blend** liker and sucrose liker status. Individuals classified as high concentration stevia blend likers were also more likely to be classified as high concentration sucrose likers, χ^2 (2, N = 40) = 4.912, p = .027. Of moderate concentration stevia blend likers (n = 20), 14 individuals (70%) were also classified as moderate concentration sucrose likers, and of high concentration stevia blend likers (n = 20), 13 of those individuals (65%) were also classified as high concentration sucrose likers.

Psychophysical Ratings for Stevia Blend and Sucrose by Background

Analyses of Variances with repeated measures were conducted to assess the effect of sweetener (stevia blend vs. sucrose) on pleasantness, sweetness, and bitterness intensity ratings for each concentration and background. Table 2 lists average psychophysical ratings for stevia blend and sucrose in distilled water and citrus beverage across all participants. For the 16% sweetener solutions in distilled water, bitterness intensity was rated as significantly higher for stevia blend (M = 17.925) compared to 16% sucrose (M = 5.225), F(1,39) = 15.260, p < .001, η^2 = .281. However, no other significant differences in overall, average psychophysical ratings were observed between the two sweeteners (*p*s > .100).

Liker Status, Concentration, and Pleasantness

Stevia blend.—There was no main effect of stevia blend liker status on pleasantness ratings when collapsing across all concentrations, F(1,35) = .522, p = .475, partial η^2 = .014. However, as can be expected based on liker status classification methods, there was a significant interaction between stevia blend concentration and stevia blend liker status on pleasantness ratings in the distilled water background, F(2.293,80.255) = 14.717, p < .001, partial η^2 = .296 (Figure 1). Newman Keuls post hoc analyses revealed that high concentration stevia likers rated the highest concentration (32%) significantly more pleasant than moderate concentration stevia blend likers rated all concentrations (2%, 4%, 8%, 16%, and 32%). Conversely, moderate concentration likers rated lower concentrations of stevia blend solutions (2%, 4%, and 8%) significantly more pleasant than high concentration likers rated the lowest concentrations (2%). Within high concentration stevia likers, pleasantness ratings for 16% and 32% stevia blend solutions were significantly greater compared to ratings for the lower concentrations (2% and 4%). Within moderate concentration likers, the average pleasantness rating for the 32% solution was significantly lower than ratings for the 2%, 4%, and 8% concentrations.

Sucrose.—Similarly to that observed for stevia blend, there was no main effect of sucrose liker status on pleasantness ratings when collapsed across concentrations in the distilled water background, $F(1,35) = 2.681$, $p = .111$, partial $\eta^2 = .071$. The interaction between sucrose concentration and sucrose liker status on pleasantness ratings in the distilled water background was significant, $F(2.609,91.318) = 5.852$, $p = .002$, partial $\eta^2 = .143$ (Fig 1). Newman Keuls post hoc analyses suggested that high concentration sucrose likers rated the highest concentration of sucrose (32%) as significantly more pleasant than moderate concentration sucrose likers rated all concentrations (2%, 4%, 8%, 16%, and 32%). High concentration sucrose likers also rated the 16% and 32% concentrations as more pleasant than the lower concentrations. However, there was no significant difference in pleasantness ratings between high concentration sucrose likers and moderate concentration sucrose likers at the lower concentrations (2% and 4%).

Stevia Blend Sweetness Intensity in Distilled Water

The main effect of liker status on sweetness intensity ratings for stevia blend in distilled water collapsed across all concentrations was not significant, $F(1,35) = .083$, $p = .775$, partial $\eta^2 = .002$. However, a significant interaction between stevia blend concentration and stevia blend liker status was observed for sweetness intensity ratings, $F(3.346, 117.121) = 2.991$, $p = .029$, partial $\eta^2 = .079$. Newman Keuls post hoc analyses revealed that higher stevia blend concentrations (16% and 32%) were rated as significantly sweeter than lower concentrations, across both liker groups. In addition, moderate concentration likers specifically rated the 32% concentration as sweeter than all other concentrations. When included as a covariate, sweetness intensity significantly predicted pleasantness ratings at the 32% concentration for moderate concentration likers, $F(1,19) = 3.195$, $p = .049$, $\eta^2 = .762$. Sweetness intensity ratings were also negatively correlated with pleasantness ratings for moderate concentration likers at the 32% concentration $r(18) = -.552$, $p = .012$. Figure 2 displays the relationship between sweetness intensity and pleasantness across liker groups, sweeteners, backgrounds and concentration.

Stevia Blend Bitterness Intensity in Distilled Water

There was no main effect of stevia blend liker status on average bitterness intensity when collapsing across all stevia blend concentrations, $F(1,35) = .476$, $p =.495$, partial $\eta^2 = .013$. Additionally, high concentration and moderate concentration stevia blend likers did not significantly differ in bitterness intensity perception at any of the individual concentrations, $F(4, 140) = .900$, $p = .466$, partial $\eta^2 = .025$. However, higher bitterness intensity ratings were associated with lower pleasantness ratings in the 2% ($r = -.643$, $p = .002$) and 4% concentrations ($r = -.682$, $p = .001$) for moderate concentration stevia blend likers. In high concentration stevia blend likers, bitterness intensity was negatively correlated with pleasantness ratings for 8% ($r = -.524$, $p = .018$) and moderately correlated at the 4% concentration ($r = -.410$, $p = .073$).

PTC Taster Status

PTC taster status was also explored as a potential indicator for the relationship between bitter sensitivity and taste perception of stevia blend. However, PTC taster status was not significantly related to bitterness intensity ratings, sweetness intensity ratings, or pleasantness ratings of stevia blend (*p*s > .5). Therefore, PTC taster status was not included in any additional analyses.

Stevia Blend Pleasantness Ratings by Background

There was no main effect of stevia blend liker status in the citrus beverage background across all concentrations, $F(1,35) = .645$, $p = .427$, $\eta^2 = .018$. Furthermore, the interaction between liker status and concentration was only marginally significant in the citrus beverage background, $F(2.484, 86.936) = 2.724$, $p = .059$, $\eta^2 = .059$ (Fig 3).

ANOVAs with repeated measures were conducted to investigate the effects of background (distilled water and citrus beverage) on pleasantness ratings of stevia blend at each of the five concentrations. There was a main effect of liker status in the 4% concentrations, $F(1, 35) = 5.522$, $p = .025$, partial $\eta^2 = .136$, and a marginal effect of liker status in 2% concentrations, $F(1, 35) = 3.875$, $p = .057$, partial $\eta^2 = .100$, suggesting that moderate concentration stevia blend likers reported, on average, significantly higher pleasantness ratings than high concentration stevia blend likers across both backgrounds. As expected, there were main effects of liker status at the higher concentrations such that high concentration likers rated pleasantness of 16%, $F(1, 35) = 8.611$, $p = .006$, partial $\eta^2 = .197$, and 32% concentrations, $F(1, 35) = 25.359$, $p < .001$, partial $\eta^2 =.420$, higher than moderate concentration likers, on average across backgrounds. When collapsing across liker status, pleasantness ratings did not significantly differ by background at any concentration (*p*s > .185). Importantly, there was a significant interaction for background and liker status in the 32% concentration, $F(1,35) = 5.487$, $p = .025$, partial $\eta^2 =.136$. Newman Keuls post hoc analyses revealed that high concentration likers rated 32% distilled water significantly more pleasant ($M = 64.700$) than moderate concentration likers ($M = 34.200$), but ratings did not differ according to liker status in citrus beverage background (*Ms* = 56.350 vs. 42.700).

Stevia Blend Sweetness Ratings by Background

There was a main effect of liker status for the 16% concentrations, $F(1,38) = 4.683$, $p = .037$, partial $\eta^2 =.110$, and a marginal effect of liker status at the 32% concentrations, $F(1,38) = 3.580$, $p = .066$, partial $\eta^2 =.086$, suggesting that high concentration likers tended to perceive greater sweetness intensity compared to moderate concentration likers across both backgrounds. When collapsing across high concentration and moderate concentration likers, the 32% distilled water solution ($M = 60.650$) was rated sweeter than the 32% citrus beverage solution ($M = 44.100$), $F(1,38) = 11.749$, $p = .001$, $\eta^2 = .236$. There were no significant differences in sweetness perception at any other concentrations collapsed across liker status (*p*s > .550) or significant interactions between liker status and background (*p*s > .09). Additionally, sweetness intensity ratings in the citrus beverage background were positively correlated with pleasantness ratings at all concentrations except the 2% concentration, for high concentration likers (*p*s < .021). Sweetness intensity ratings were not related to pleasantness ratings at any concentration for moderate concentration likers (*p*s

> .2). Figure 2 depicts the relationship between sweetness intensity and pleasantness for both liker groups in citrus beverage background.

Stevia Blend Bitterness Ratings by Background

Bitterness intensity ratings were significantly higher in the 2% citrus beverage, $F(1,38) = 72.307$, $p < .001$, partial $\eta^2 = .656$, the 4% citrus beverage, $F(1,38) = 35.322$, $p < .001$, partial $\eta^2 = .482$, the 8% citrus beverage, $F(1,38) = 28.688$, $p < .001$, partial $\eta^2 = .430$, and 32% citrus beverage, $F(1,38) = 12.275$, $p = .001$, partial $\eta^2 = .244$, compared to all corresponding concentrations in the distilled water background. The bitterness effect was not observed in the 16% backgrounds ($p = .178$). There was a main effect of liker status in 4% background, $F(1,38) = 2{,}021$, $p = .013$, partial $\eta^2 = .152$, showing that moderate concentration likers gave greater bitterness ratings compared to high concentration likers. There were no significant effects of liker status on bitterness ratings when collapsed across background at any other concentration, $ps > .170$).

Bitterness intensity was also negatively correlated with pleasantness ratings in the 2% ($r = -.529$, $p = .017$) and 4% ($r = -.599$, $p = .005$) concentrations for moderate concentration likers in the citrus beverage background. For high concentration likers, bitterness intensity ratings were negatively correlated with pleasantness in the 2% concentration ($r = -.485$, $p = .030$), and moderately related in the 4% concentration ($r = -.405$, $p = .076$).

Discussion

Prior research on sucrose liking has traditionally examined psychophysical responses in relation to preference and liking for sucrose in a distilled water background. Considerable effort has been devoted to the understanding of individual variation in liking for other sweeteners (Kamerud and Delwiche 2007); however, we are unaware of any studies that have specifically examined liking for a stevia sweetener as a function of sucrose liker status. The present study provides novel information about liking for stevia sweetener in relation to sucrose, revealing that individuals who were high concentration stevia blend likers were also likely to be high concentration sucrose likers. Importantly, sweeteners with taste profiles similar to that of sucrose may be more readily accepted, and therefore, stevia sweeteners may likely be an acceptable sucrose alternative for the majority of consumers in search of both desired sweetness and nonnutritive, natural sweeteners. At the same time, although the majority of individuals were classified in the same liking group for each sweetener, it is important to note that 35% of high concentration stevia blend likers were found to be moderate concentration sucrose likers, and 30% of moderate concentration stevia blend likers were classified as high concentration sucrose likers. Therefore, it appears that liking for sucrose does not exclusively generalize to liking for stevia blend, and it is likely that other psychophysical properties of stevia also influence taste preference.

As expected based on classification methods, pleasantness ratings for both stevia blend and sucrose followed similar patterns according to respective sweetener liker status. Both high concentration stevia blend and sucrose likers rated higher concentrations of the respective sweetener significantly more pleasant than all other concentrations. An important distinction for moderate concentration likers was observed for stevia blend, in that moderate concentration likers rated lower concentrations of stevia blend (2% and 4%) as more pleasant than high concentration likers rated these low concentrations. Interestingly, a similar phenomenon was not observed in the sucrose distilled water background for high concentration and moderate concentration sucrose likers. Differences in ratings according to sucrose liker status only became prominent at higher concentrations; however, the disparity in pleasantness ratings according to stevia blend liker status became apparent beginning at the lowest concentration. This may suggest that individuals experience a wider discrepancy in perceived pleasantness of stevia blend solutions compared to that of sucrose solutions. At the same time, high concentration and moderate concentration stevia blend likers did not differ in pleasantness ratings given for the 8% solution, which may suggest that medium-level stevia blend concentrations could appeal to a wider variety of individuals when being used as a sugar replacement.

The perception of sweetness seemed to play a role in hedonic experience at the highest concentrations of stevia blend. Sweetness intensity ratings were negatively correlated with pleasantness ratings given by moderate concentration likers, but only at the highest concentration of stevia blend in distilled water. Therefore, individuals who rated tastes high in sweetness did not necessarily rate the same tastes high in pleasantness. In fact, high sweetness intensity ratings were found to be predictive of lowered pleasantness ratings for the 32% concentration in moderate concentration likers, which may imply that the perception of highly concentrated sweetness may be found aversive by moderate concentration likers. Other work has suggested attenuated sweetness of steviol glycosides (stevioside, rebaudioside A, and rubusoside), at maximal concentrations, which may be due to suppression of sweetness by the bitter side-tastes (Hellfritch et al. 2012). Therefore, it is possible that some individuals may detect subtle changes in the quality of sweetness at higher concentrations without explicitly perceiving changes in sweetness and bitterness, and that certain higher concentrations of stevia may be more appealing than others.

Sweetness intensity ratings were positively correlated with pleasantness ratings in the citrus beverage background, but not in distilled water, for high concentration stevia blend likers. Therefore, the presence of sweetness in combination with citrus may be of particular interest when evaluating pleasantness for high concentration likers. Other research investigating factors that drive consumer preferences of fruit has also identified sweetness as a key factor influencing liking of pears (Steyn et al. 2011), strawberries (Colquhoun et al. 2012), kiwifruit (Jaeger et al. 2003), and raspberries (Villamor et al. 2013). The combination of citrus flavor and sweetness may also induce a mixture suppression effect, in which components of a taste mixture have been found to either suppress or enhance the intensity of individual tastes in the mixture (Bartoshuk and Cleveland 1977). This is supported by the lowered sweetness intensity ratings observed in the citrus beverage background compared to distilled water at the 32% concentration, for both high concentration and moderate concentration likers. Thus, citrus qualities may actually suppress sweetness at this concentration. Importantly, sweetness ratings were not related to pleasantness for moderate concentration likers in the citrus beverage background, as was observed for distilled water. Because moderate concentration likers prefer less concentrated sweetness, the citrus background may offer sweet tastes that appeal to a wider variety of liking preferences.

While previous work has suggested that bitter sensitivity to PROP and PTC influences sweet liking (Hayes and Duffy 2008; Kamerud and Delwiche 2007; Lawless 1979; Looy and Weingarten 1992), and that stevia may exhibit bitter side-tastes at highly concentrated levels (Prakash et al. 2008), the findings of the current study suggest that explicit bitterness intensity ratings reported by participants did not differ based on liker status. However when included as a covariate, bitterness intensity significantly predicted pleasantness ratings at low stevia blend concentrations (2% and 4%) for moderate concentration likers, and medium stevia blend concentrations (8%) for high concentration likers, in that higher bitterness ratings were associated with lowered pleasantness ratings. Thus, bitterness may have contributed to pleasantness for moderate concentration likers at low concentrations, and for high concentration likers at the medium concentration, which may indicate different thresholds for which bitterness influences pleasantness perception according to liker status. We speculate that bitterness may be more salient to moderate concentration likers, resulting in the observed effects of bitterness that occurred at the lowest concentrations.

When comparing reported bitterness ratings for stevia blend and sucrose, there was a significant difference in ratings at the 16% concentration, in which the 16% stevia blend solution was rated as significantly more bitter than sucrose. This difference suggests that participants might have detected bitter side-tastes of stevia at the 16% level, although perceived bitterness did not appear to influence hedonic ratings, as there were no observed differences in reported pleasantness or sweet intensity ratings for stevia blend and sucrose. In addition, this difference in bitterness intensity ratings did not occur at the highest concentration (32%). It is possible that the higher sweetness intensity of the 32% concentration masked the bitterness previously detected at the 16% concentration. Increased perception of bitterness may occur at high sweetness concentrations such as the 16% stevia blend used in the current study, but only up to a certain threshold of sweetness. As perceived sweetness intensity increases (i.e., 32% and beyond), sweet and bitter taste perception at these concentrations may interact or offset each other. It may be worthwhile for future research to assess perception of sweet and bitter taste at greater concentrations of stevia blend to better understand this relationship. Interestingly, when comparing backgrounds, bitterness intensities were higher for all concentrations in citrus beverage compared to distilled water, except for the 16% concentration. Therefore, a citrus beverage background may be especially complimentary to concentrations with existing bitter side-tastes.

Bitter side tastes associated with stevia blend did not appear to be mediated by the genetic status for perception of the bitterness of PTC in the current study. Other studies (Hayes and Duffy 2008; Lawless 1979; Looy and Weingarten 1992) have reported that individuals who are sensitive to bitter compounds such as PROP, PTC, and quinine (super-tasters), are more likely to prefer low concentrations of sucrose, and that non-tasters of these bitter substances are more likely to prefer high concentrations of sucrose. However, not all studies have replicated this proposed relationship between taster status and sweet liking (Drewnowski et al 1997; Ly and Drewnowski 2001; Kamerud and Delwiche 2007). Kamerud and Delwiche (2007) investigated a large number of iso-sweet compounds and reported that, although individual differences in the perception of bitterness of the sweeteners was important for liking, this was not due to PROP sensitivity. Furthermore, the TAS2R38 bitter taste receptor has been found to be specifically implicated in taste detection for PTC and PROP (Kim et al.

2003), but other bitter taste receptors, TAS2R4 and TAS2R14, have been identified as mediating bitter tastes associated with stevia (Allen et al. 2013; Hellfritsch et al. 2012). Therefore, it might be expected that PTC taster status would not be related to taste perception of stevia, and perhaps sensitivity to other bitter substances may better predict psychophysical ratings of stevia solutions.

Sweeteners are known to exhibit particular qualities in different types of foods and beverages. Based on known bitter-side tastes associated with stevia, it was posited that the sour and bitter-like properties of a citrus beverage would be consonant with bitter tastes associated with stevia, and potentially mitigate the relationship between liker status and pleasantness ratings. In the citrus beverage background, the interaction between stevia blend liker status and concentration was only marginally significant. Although the results point to a trend in which high concentration stevia likers tended to show increased pleasantness ratings along with increasing concentration like that observed in distilled water, the relationship between pleasantness ratings and concentration for moderate concentration likers was less defined. Moderate concentration likers did not necessarily rate higher concentrations of stevia blend as less pleasant than low concentrations of stevia blend in the citrus beverage background. Therefore, the differences between pleasantness ratings as a function of liker status appear to become attenuated when stevia blend is placed in a citrus beverage background. Importantly, both moderate concentration likers and high concentration likers tended to rate citrus beverage solutions of both sweeteners at low concentrations as slightly below neutral pleasantness. In the future, it may be important to determine optimal sweetness concentrations that offset the acidity of this background to make similar beverages optimally palatable.

The altered relationship between pleasantness ratings and stevia blend concentration in the citrus beverage background suggest that properties specific to citrus flavor, and their interaction with stevia, may moderate perception of pleasantness. Higher bitterness ratings were associated with decreased pleasantness at low concentrations for both high concentration and moderate concentration likers in the citrus beverage background, which may have been due to the perception of lowered sweetness in a sour or astringent background. Although not reported in the current study, sourness or astringency intensity ratings may be useful for understanding this relationship. Other work has found that differences in chemosensory perception of sour tastes might partly be due to genetic variability (Knaapila et al. 2012; Rawal et al. 2013). Furthermore, preference for sour taste may be particularly relevant to dietary choices, with important implications for populations drawn to consume nonnutritive sweeteners with the intention of compliance with a diabetic diet, weight loss, or maintenance. Naturally bitter and sour products such as fruits, berries, and vegetables are known for health benefits such as prevention of coronary heart diseases and some types of cancer (Van Duyn and Pivonka 2000). Therefore, the acceptance of these foods, or products with similar taste properties, may be important to consider for potential dietary and weight loss interventions.

Conclusions

The present study provides novel information regarding the relationship between stevia blend liking and sucrose liking. While sucrose liking was significantly related to stevia blend liking, it appears that psychophysical ratings of pleasantness, sweetness, and intensity do not generalize completely across the two sweeteners. Hedonic responses of pleasantness and sweetness for stevia blend and sucrose tended to follow similar profiles in distilled water, which may be expected of two sweeteners matched on sweetness equivalency. Although stevia blend was rated as more bitter than sucrose at the second highest concentration, this effect was not observed in the highest concentration, nor was it accompanied by any differences in pleasantness ratings. Importantly, beverage background appeared to moderate the relationship between sweetness, pleasantness, and liker status. The findings suggest that citrus taste may provide an advantageous background for stevia. However, future studies may wish to determine optimal stevia and citrus concentrations in which acidity does not suppress the perception of sweetness.

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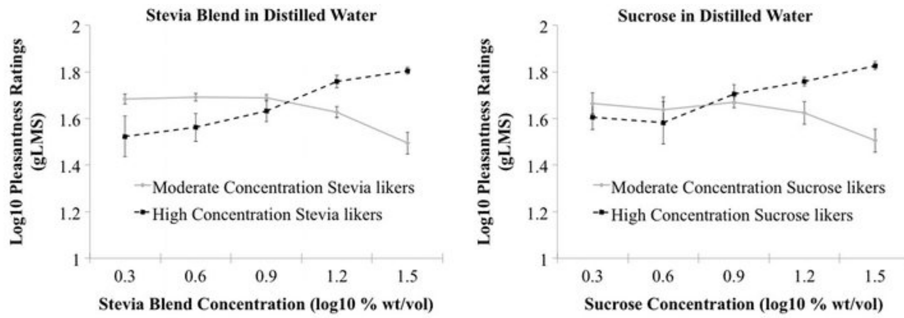
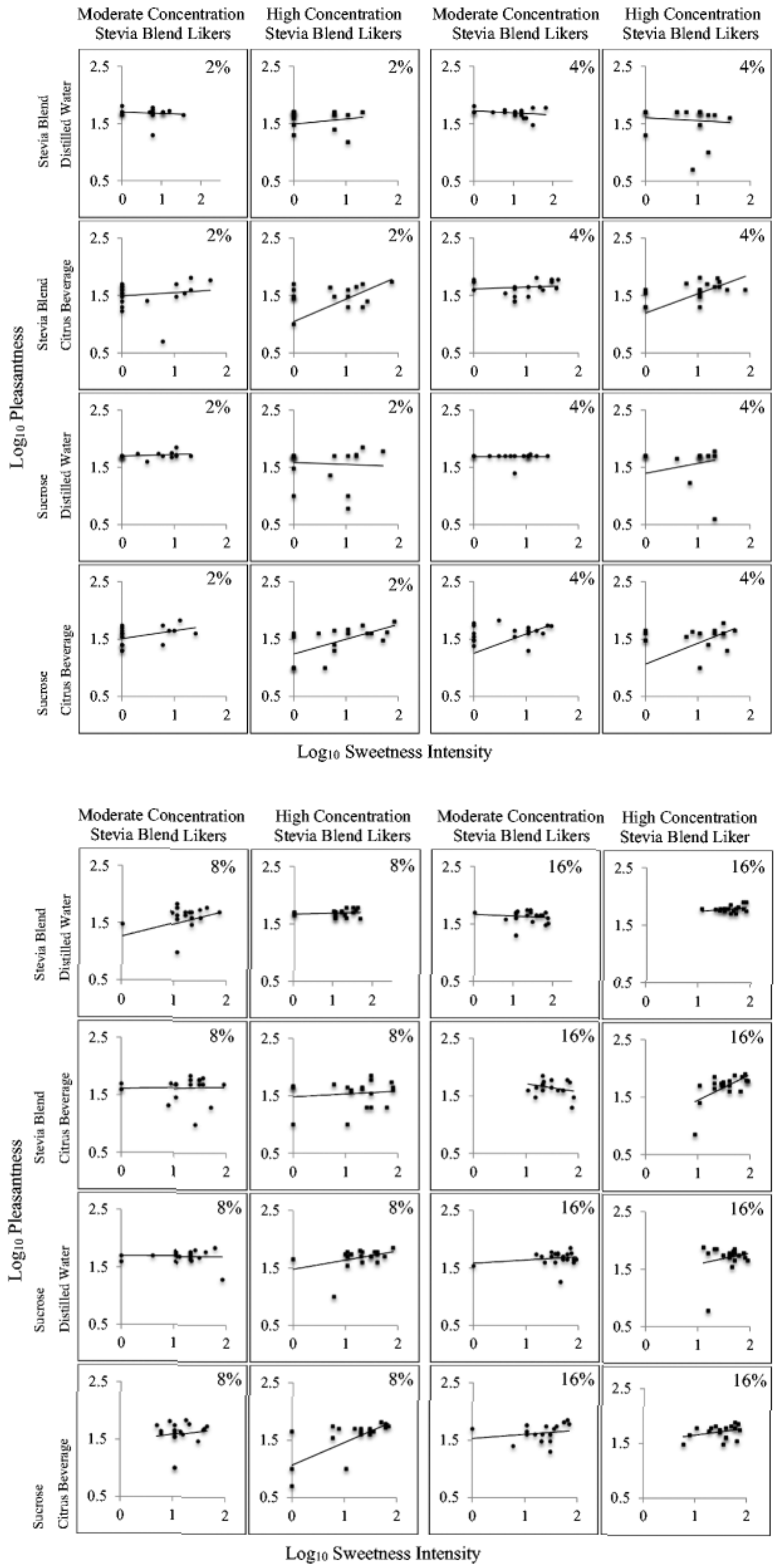


Fig. 1.

Pleasantness ratings by concentration and liker status for stevia blend and sucrose in distilled water.


Moderate Concentration Stevia Blend Likers
High Concentration Stevia Blend Likers
Moderate Concentration Stevia Blend Likers
High Concentration Stevia Blend Likers
2%
4%
8%
16%
Stevia Blend Distilled Water
Stevia Blend Citrus Beverage
Sucrose Distilled Water
Sucrose Citrus Beverage
Log₁₀ Pleasantness
Log₁₀ Sweetness Intensity
High Concentration Stevia Blend Liker

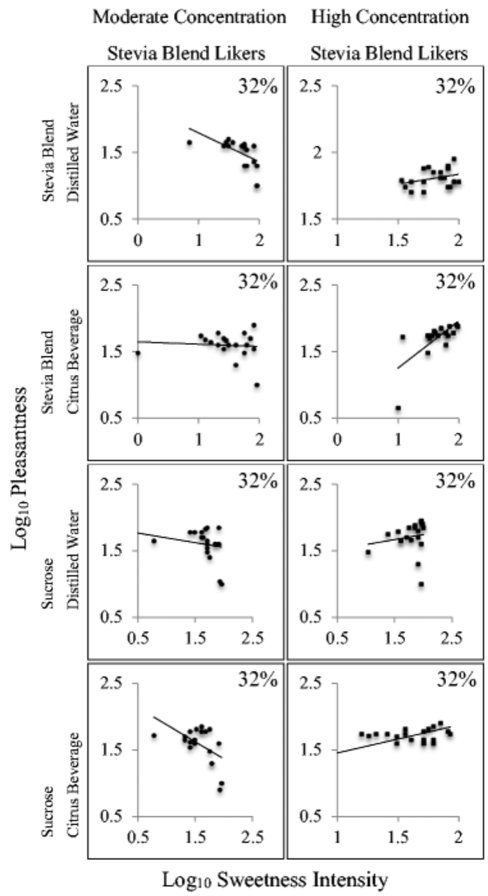


Fig. 2.

Associations between $\log_{10}$ sweetness intensity and pleasantness ratings for moderate concentration and high concentration stevia blend likers for stevia blend and sucrose in distilled water and citrus beverage backgrounds.

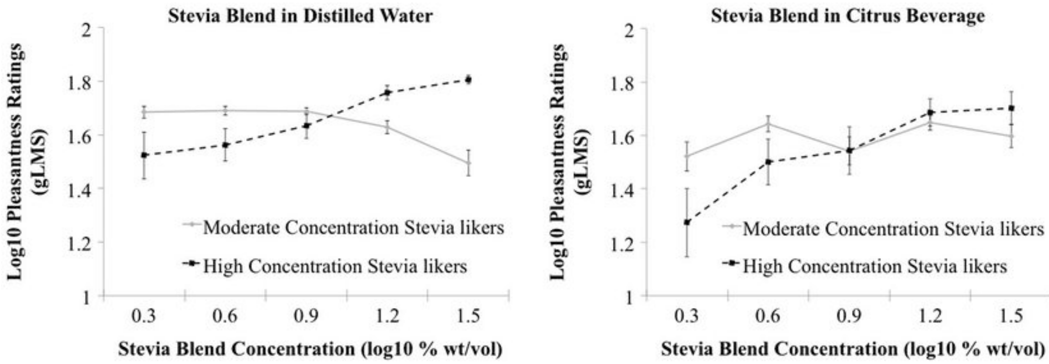


Fig. 3.

Pleasantness ratings by stevia blend concentration and liker status, in distilled water and citrus beverage backgrounds.

Table 1

Mean age, weight, height, BMI, and artificially sweetened beverage consumption, and frequency of sucrose likers and non-likers

	Moderate concentration stevia blend likers (n = 20)		High concentration stevia blend likers (n = 20)	
Variable	***M***	***SEM***	***M***	***SEM***
Age (years)	19.20	0.34	18.85	0.36
Weight (pounds)	146.35	5.68	141.05	10.16
Height (inches)	66.93	0.81	67.1	0.98
BMI	22.89	0.69	22.80	0.69
Artificially sweetened beverage consumption (per week)	1.05	1.473	0.8	1.356
Variable	**N**	**%**	**n**	**%**
Sucrose Liker Status				
Sucrose Liker Status Moderate concentration sucrose likers	14	70	7	35
High concentration sucrose likers	6	30	13	65
Gender				
Male	10	50	10	50
Female	10	50	10	50
PTC Taster Status				
Taster	15	75%	15	75%
Non-taster	5	25%	5	25%

Table 2

Pleasantness and Intensity Ratings for Stevia and Sucrose by Background

Average Sweetness Intensity Ratings *(SEM)*			
		Stevia Blend	**Sucrose**
Distilled Water	2%	44.6 *(1.8)*	47.2 *(2.0)*
	4%	44.5 *(1.8)*	46.4 *(1.9)*
	8%	48.0 *(1.9)*	50.7 *(1.9)*
	16%	51.3 *(1.7)*	51.8 *(2.0)*
	32%	49.5 *(1.8)*	51.0 *(3.1)*
Citrus Beverage	2%	33.0 *(2.5)*	33.2 *(2.7)*
	4%	42.0 *(2.2)*	36.0 *(2.6)*
	8%	40.8 *(2.5)*	42.2 *(2.7)*
	16%	49.6 *(2.3)*	48.7 *(2.1)*
	32%	49.5 *(2.5)*	47.9 *(2.7)*
Average Sweetness Intensity Ratings *(SEM)*			
		Stevia Blend	**Sucrose**
Distilled Water	2%	4.7 *(1.1)*	5.4 *(1.5)*
	4%	11.4 *(2.0)*	8.2 *(1.1)*
	8%	20.0 *(2.8)*	23.2 *(3.1)*
	16%	36.8 *(3.4)*	45.6 *(3.7)*
	32%	60.7 *(3.6)**	58.7 *(4.0)*
Citrus Beverage	2%	8.1 *(2.4)*	9.3 *(2.7)*
	4%	14.1 *(2.5)*	11.1 *(2.0)*
	8%	23.1 *(3.4)*	19.8 *(2.8)*
	16%	38.4 *(4.0)*	33.0 *(3.2)*
	32%	44.1 *(3.9)**	43.4 *(3.6)*
Average Bitterness Intensity Ratings *(SEM)*			
		Stevia Blend	**Sucrose**
Distilled Water	2%	4.9 *(1.7)*	3.8 *(1.3)*
	4%	8.5 *(2.6)*	5.5 *(2.0)*
	8%	7.2 *(1.8)*	5.7 *(1.4)*
	16%	17.9 *(3.5)***	5.2 *(1.2)***
	32%	8.5 *(2.4)*	4.6 *(1.3)*
Citrus Beverage	2%	44.0 *(4.5)*	41.9 *(4.4)*
	4%	32.6 *(3.6)*	39.1 *(4.0)*
	8%	28.0 *(3.9)*	24.4 *(3.0)*
	16%	17.9 *(3.5)*	21.2 *(3.3)*
	32%	18.5 *(3.3)*	15.0 *(2.6)*

[*] Sweetness intensity ratings for stevia blend significantly differ for background ($p = .001$).

[**] Bitterness intensity ratings for stevia blend and sucrose significantly differ ($p = .001$).