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Measurement of Synergistic Effects of Binary Sweetener Mixtures

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Abstract

Some sensory properties of synthetic sweeteners are limiting factors for use in low calorie foods or soft drinks. By combining synthetic sweeteners(Neohesperidin dihydrochacone(NHDC), stevioside) with sucrose, sorbitol or xylitol, these limitations can be overcome. Using trained taste panelists and magnitude estimation methods, synergistic effects were investigated in binary sweetener mixtures. The results showed that synergism, as much as 28% to 69%, was noted at all concentrations in xylitol-stevioside, NHDC-stevioside mixtures. Synergistic effects were found only at high concentration levels in mixtures of sucrose-NHDC, sucrose-stevioside, and sorbitol-stevioside, ranging from 11% to 22%. By taking advantage of synergistic effects, ginseng tea and orange flavored beverages, sweetened with either xylitol-stevioside or NHDC-stevioside, were prepared and the sensory quality was compared with that of sucrose containing beverages. It was found that sensory characteristics were judged to be very similar for all formulations. The result suggests the possibility of using these sweetener mixtures as sugar substitutes in ginseng tea and orange drink.

Key words: stevioside, neohesperidin dihydrochalcone, magnitude estimation, synergism

INTRODUCTION

The increasing demand for reduced-calorie foods and beverages has spurred the development of non-caloric, high intensity sweeteners(1-5). Among them, saccharin, aspartame, stevioside and neohesperidin dihydrochalcone seem to be the promising products. Using these sweeteners as a single sweetener in low-calorie foods often results in poor sensory properties such as bitterness or lingering aftertaste(5-7). In order to improve sensory quality, mixtures of sugars and synthetic combinations have been developed. In these sweetener combinations specific sweetness properties have been detected and synergism has been claimed. Synergism is inferred when the sweetness of a mixture is greater than the sum of the sweetness of its components(8). The existence of synergism has both theoretical and practical importance because it may provide a useful tool for the investigation of multiple receptor sites and valuable information to those who are interested in reducing sweetener levels in foods and beverages.

Various sensory evaluation techniques have been used to measure synergism. We chose 'magnitude estimation' because it provides a direct quantitative estimate of the sweetness intensity of a stimulus, and also minimal amounts of test solutions are required. Synergistic effects for binary mixtures have been studied by many researchers(8-12), but little information has been reported on sweetness intensity of mixtures of simple sugars with neohesperidin dihydrochalcone(NHDC) or stevioside.

Our objectives were to determine the psychophysical sweetness function for selected sweeteners relative to sucrose, to determine the synergistic effects of sweetener mixtures, and to evaluate sensory characteristics of beverages containing sweetener blends relative to sucrose sweetened beverages.

MATERIALS AND METHODS

Sample preparation

Sucrose was the product of Cheiljedang Co.(Seoul, Korea) and neohesperidin dihydrochalone, sorbitol, stevioside, and xylitol were purchased from Sigma Co.(St. Louis, U.S.A.). Ginseng powder was a product of Kookje Food's (Seoul, Korea) and an orange flavored powdered beverage from Koolaid(U.S.A.). Five sweeteners were tested in distilled, filtered water at four concentration steps increasing in weight by a factor of two. Four concentration levels of sucrose and other test sweeteners were presented in Table 1. The concentration ranges for the sweeteners reflected low to moderate sweetness intensity. Samples were prepared fresh on the day of testing and served as follows: sweetener solutions in model system, 20°C; orange drink, 10°C; and ginseng tea, 70°C. Samples of solution were presented to panelists in coded, paper cups.

Table 1. Four concentration levels of sweeteners used in the experiment

Sweetener	Concentration(%, w/v)			
NHDC	0.002	0.004	0.008	0.016
sorbitol	2.0	4.0	8.0	16.0
stevioside	0.011	0.028	0.069	0 172
sucrose	2.0	4 0	8.0	16 0
xylitol	2.0	4.0	8.0	16.0

NHDC : neohesperidin dihydrochalcone

Taste panel

Nine trained panelists(eight females and one male) were used. Subjects were chosen on the basis of performance on screening test assessing their abilities to accurately identify basic tastes, correctly rank solution differing in concentration. Training the panelists was done by magnitude estimation method. Panelists were presented first with a reference solution and this was assigned a sweetness value of 10. They were then presented with the test samples and using a sip and spit procedure, instructed to assign numbers relative to the reference. For example, a score of 50 should indicate a sample 5 × sweeter than the reference. All panelists have been exposed to a variety of sweeteners prior to the study.

Sweetness evaluation experiments

Sensory evaluation involved three parts: determination of relative sweetness of the four sweeteners, and determination of the synergism of sweetener mixtures, and application to real systems. First, the relative sweetness evaluation of four sweeteners was accomplished by magnitude estimation. For these experiments, the panelists were instructed to respond only to sweetness and disregard other taste sensations. Three replicate evaluations of each sweetener solution were completed.

Secondly, synergism between sucrose or sorbitol or xylitol and intense sweeteners(NHDC or stevioside) was investigated using the same method. One concentration of NHDC or stevioside(sweetener B) was combined with four different concentrations of sucrose, sorbitol or xylitol or stevioside(sweetener A). Sweetener mixtures included sucrose-NHDC, sucrose-stevioside, sorbitol-stevioside, xylitol-stevioside, and stevioside-NHDC. The concentration of sweetener B was selected to be equivalent in sweetness to about 4% of the sweetener A. The predicted sweetness of the mixture solution was estimated using the following equation(11,13),

$$T_{a,b}=k_1\left[Ca+\left(\frac{k_2C_b{}^n}{k_1}\right)^{1/m}\right]^m$$

where $T_{a,b}$ = taste intensity of the combination
C_a = concentration of sweetener A
C_b = concentration of sweetener B
k_1, k_2, m, n = constants

Thirdly, ginseng tea(3%) and orange flavored beverages(Koolaid, 0.5%) were prepared and sweetened with stevioside-NHDC or xylitol-stevioside. The purpose of this experiment was to determine whether the replacement of sucrose with sweetener blends affected the sensory properties of the beverages. The original reference beverage was based on 5% sucrose for ginseng tea and 8% sucrose for orange drink. The sweetness of the beverages was theoretically matched to the respective reference drinks by calculation on the basis of the data obtained with model systems. That is, blends of sweeteners were formulated so that individual sweeteners contributed equal sweetness to a blend. Panelists rated the samples for taste attributes using a 9 point scale where 0 meant absence of the attribute and 8 indicated it was extremely intense. The attributes profiled were sweetness, bitterness, sourness, orange or ginseng flavor, astringency and aftertaste. All samples were presented in random order and presented in duplicate.

Data analysis

Data were analyzed using Statistical Analysis System (SAS). Magnitude estimates were converted to logarithms and expressed using the geometric mean. Sweetness curves for each sweetener were then fitted to a power function. Data generated from the quantitative descriptive analysis were evaluated using analysis of variance. Post-hoc comparisons of the group arithmetic means were performed using least significant difference(LSD) procedures(14).

RESULTS AND DISCUSSION

Psychophysical function

The relationship between sweetness intensity and concentration for each sweetener was represented by log-log coordinates(Fig. 1). The exponent values for NHDC and stevioside were lower than 1.0. It means that the sweetness functions of stevioside and NHDC displayed

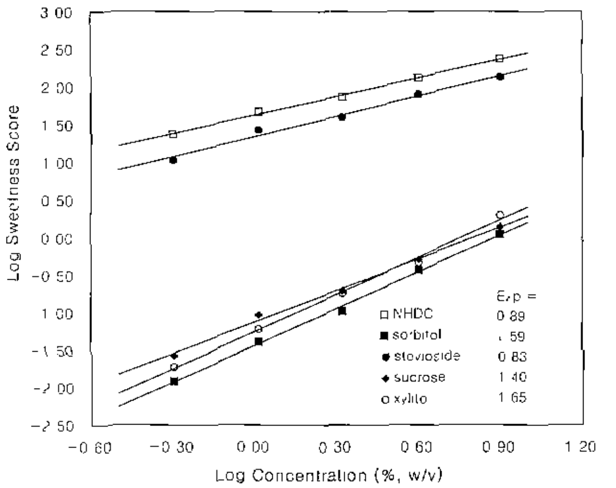

Fig. 1. Sweetness power functions for NHDC, sorbitol, stevioside sucrose and xylitol.

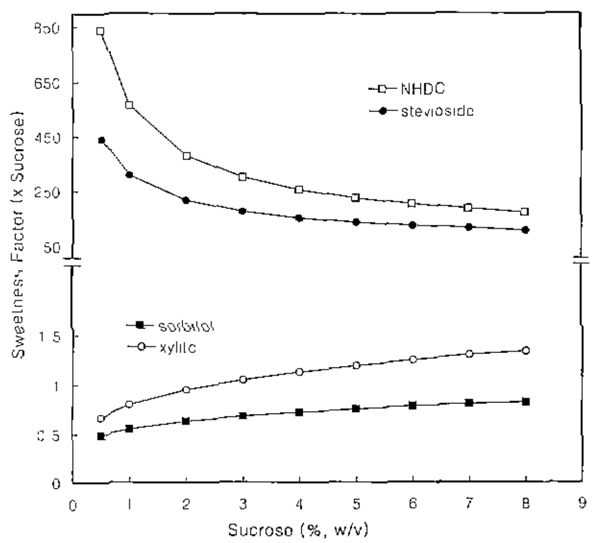

Fig. 2. Relative sweetness of NHDC, sorbitol, stevioside and xylitol over a wide sucrose sweetness equivalency range.

suppression, that is, perceived sweetness growth was slower than concentration growth. Lower exponent values are the characteristic of the sweet taste of artificial sweeteners. Recent studies showed that the exponent values vary considerably across different experiments, partly due to the different method of stimulus application, or the flow rate of the stimulus. This is true in the case of sucrose where reported slope values ranged from 0.6 to 2.0. The exponent values found in the present study were in good agreement with those reported by other investigators(12,13.15-17). The correlation coefficients were greater than 0.97 for all the lines. Schiffman et al.(18) postulated that sweeteners with steep slopes do not saturate receptors as readily as do those with flatter slopes. The power curve slope of a specific sweetener has been reported to be flatter in the elderly population compared to younger subjects, suggesting an age-related decline in taste receptors.

Relative sweetness

Relative sweetness curves were developed for the four sweeteners relative to sucrose(Fig. 2). These were derived from the power curves. Relative sweetness was defined as the number of times sweeter a compound was, on a weight basis, than an isosweet concentration of sucrose(4). Sorbitol and xylitol showed increases in sweetness, while NHDC and stevioside curves exhibited a decrease relative to sucrose as sweetness levels increased. NHDC displayed the greatest potency among the sweeteners. NHDC was about 300 times more sweet than sucrose at a concentration equivalent to 3% sucrose. Relative sweetness of stevioside doubled from 220 to 440, for a decrease in concentration from 3.0% to 0.5%. From these data, one can postulate that the sweetness efficiency of these sweeteners is much higher at low concentrations than it is at high concentrations. This is in line with general affinity kinetics, for example, receptor binding(4). At 8% sucrose equivalency, sorbitol was 0.8 times more sweet and xylitol was 1.4 times more sweet than sucrose. It is not well understood why some sweeteners become more sweet as concentration increases while others become less sweet relative to sucrose. In the artificial sweeteners, it may be assumed that bitter or other side taste become predominant as concentration increases, thus hindering the increase in sweetness.

Synergism

The results of the synergism experiments are presented in Table 2, where theoretical and experimental sweetness values are summarized. Synergism would be suggested if the observed magnitude estimates exceeded the calculated values by 10%(8). Synergism was noted in all sweetener mixture combinations, but not all concentrations. Stevioside showed large synergistic effects as much as 28 to 69% when combined with xylitol or NHDC, but little synergism with sorbitol. Synergistic effects were observed only at the relatively high concentration levels in the blends of sucrose-NHDC, sucrose-stevioside, and sorbitol-stevioside, ranging from 11 to 22%. Previous study reported the existence of synergism for binary mixtures of sorbitol-NHDC and xylitol-NHDC(19). The data

Table 2. Theoretical and experimental mean magnitude estimates and the synergistic effects of selected sweetener mixtures

Mixture composition	Mean ME values		Synergism (%)
	Theoretical	Experimental	
2.0% sorbitol + 0.097% stevioside	0.83	0.83	–
4.0% sorbitol + 0.097% stevioside	1.37	1.23	–
8.0% sorbitol + 0.097% stevioside	2.67	2.42	–
16.0% sorbitol + 0.097% stevioside	5.94	6.61	11
0.011% stevioside + 0.010% NHDC	1.11	1.69	52
0.028% stevioside + 0.010% NHDC	1.37	2.08	52
0.069% stevioside + 0.010% NHDC	1.96	3.00	53
0.172% stevioside + 0.010% NHDC	3.20	5.26	64
2.0% sucrose + 0.005% NHDC	1.03	0.73	–
4.0% sucrose + 0.005% NHDC	1.65	1.52	–
8.0% sucrose + 0.005% NHDC	3.13	3.83	22
16.0% sucrose + 0.005% NHDC	6.85	7.57	11
2.0% sucrose + 0.014% stevioside	1.06	1.05	–
4.0% sucrose + 0.014% stevioside	1.74	1.70	–
8.0% sucrose + 0.014% stevioside	3.47	3.91	13
16.0% sucrose + 0.014% stevioside	8.14	9.05	11
2.0% xylitol + 0.016% stevioside	1.05	1.34	28
4.0% xylitol + 0.016% stevioside	1.60	2.63	64
8.0% xylitol + 0.016% stevioside	2.83	3.80	34
16.0% xylitol + 0.016% stevioside	5.73	9.69	69

support the concept that there seems to be optimal mixture combinations with respect to the extent of synergism(12).

In addition to a higher sweetness efficiency, combining synthetic sweeteners with other sweeteners resulted in a more acceptable taste profile. Possible off- and aftertastes were decreased because of the much lower concentrations of each sweetener needed. The present experiments were carried out in an aqueous model system and some of the most promising mixtures suggest further study in a variety of foods.

Table 3. Sweetener mixture composition of ginseng tea and orange flavored drinks

Sweetener mixture
Ginseng tea(reference = 5% sucrose)
2.50% xylitol + 0.007% stevioside
0.002% NHDC + 0.007% stevioside
Orange flavored drink(reference = 8% sucrose)
3.72% xylitol + 0.014% stevioside
0.005% NHDC + 0.014% stevioside

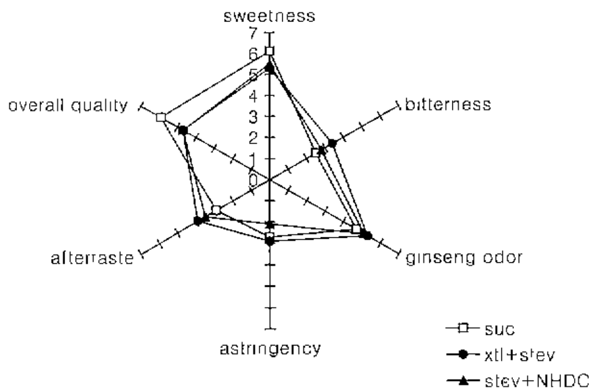

Fig. 3. Comparison of QDA profiles of mixture-sweetened ginseng tea with the reference based on sucrose at 70°C.
suc: sucrose, xtl: xylitol, stev: stevioside, NHDC: neohesperidine dihydrochalcone.

Applications

Ginseng tea and orange flavored drink containing xylitol-stevioside or NHDC-stevioside mixtures were prepared and their sensory properties were compared with those of original drinks containing sucrose. Table 3 illustrates the mixture compositions of drinks of which were based on the results obtained in the synergistic experiments(Table 2). Results showed that ginseng tea

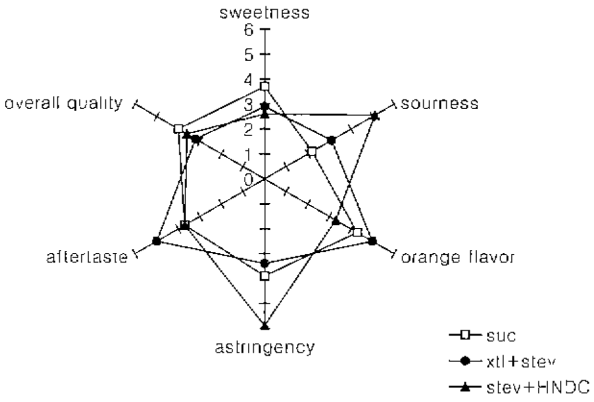

Fig. 4. Comparison of QDA profiles of mixture-sweetened orange flavored drinks with the reference based on sucrose at 10°C.
suc: sucrose, xtl: xylitol, stev: stevioside, NHDC: neohesperidine dihydrochalcone.

sweetened with either xylitol-stevioside or NHDC-stevioside mixtures could not be distinguished sensorially from traditional sucrose drink(Fig. 3). Sensory characteristics of orange drink containing xylitol-stevioside were not significantly different from those of orange drink sweetened with sucrose(Fig. 4). For the NHDC-stevioside mixture, some panel members complained of increased astringency($p<0.05$) and sourness($p<0.01$), but the overall sensory quality was found to be indistinguishable.

From the results, we can conclude that a calorie reduction would be achieved without significantly changing the sensorial properties of the beverages in this case, if a compromise is to be made between different factors such as sweetness, quality, calorie content, price, and so on.

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