Physiology and Behavior, Vol. 12, pp. 449–456. Brain Research Publications Inc., 1974. Printed in the U.S.A.

Sweet Taste Induced by Miracle Fruit (*Synsepalum dulcificum*)[1]

LINDA M. BARTOSHUK[2], ROBERT L. GENTILE, HOWARD R. MOSKOWITZ AND HERBERT L. MEISELMAN

Pioneering Research Laboratory, U. S. Army Natick Laboratories, Natick, Massachusetts 01760

(Received 9 August 1973)

BARTOSHUK, L. M., R. L. GENTILE, H. R. MOSKOWITZ AND H. L. MEISELMAN. *Sweet taste induced by miracle fruit* (Synsepalum dulcificum). PHYSIOL. BEHAV. **12**(3) 449–456, 1974.–Topical application of miracle fruit *(Synsepalum dulcificum)* caused subsequently tasted hydrochloric and citric acids to taste less sour than normal and as if they had been sweetened. *Gymnema sylvestre* abolished this sweetness and returned the sourness of both acids to approximately their normal intensities although *Gymnema sylvestre* alone did not significantly affect the taste of the acids. This suggests that miracle fruit adds sweetness to acids without directly blocking sour receptor sites. When sugar was added to citric acid to make it about as sweet as it was after miracle fruit, then the sourness was suppressed in the mixture just as sourness was suppressed by miracle fruit. This suggests that the reduction in sourness after miracle fruit resulted from mixture suppression, i.e., the mutual suppression usually observed between different qualities in a mixture. When several acids were matched in sourness they did not become equally sweet after miracle fruit.

Taste Sweet Miracle fruit *Synsepalum dulcificum* *Gymnema sylvestre* Taste modifier Taste mixtures

---

SYNSEPALUM DULCIFICUM, also known as *Bumelia dulcifica, Sideroxylon dulcificum, Bakeriella dulcifica* and *Richardella dulcifica* [1, 7, 11, 18] was nicknamed miraculous berry by Europeans who experienced its dramatic effects on taste while traveling in tropical West Africa well over 100 years ago [7]. Although the plant is native to tropical West Africa, it has been grown successfully in Florida since 1957 [2]. Exposing the tongue to the flesh of even a single berry sweetens the taste of acid substances and decreases their normal sourness for an hour or more; for example, lemons can be eaten like oranges. In Africa, miracle fruit has been used to sweeten acidulated maize bread (kankies), palm wine, and pito, a beer made from fermented grain [6,7]. Anecdotal reports have made varying claims for miracle fruit: that it sweetens all substances [15,28], only bitter and sour substances [6, 20, 25], or only sour substances [19]. Quantitative psychophysical investigations [3] showed that the tastes of quinine hydrochloride (QHCl), NaCl, and sucrose were not significantly affected by miracle fruit. This supports the contention that miracle fruit sweetens only sour substances. The active principle has been identified as a glycoprotein [5, 18, 19, 23, 24], isolated [5, 18, 23, 24], and named miraculin [5,18].

Two explanations have been offered for the taste modifications induced by miracle fruit. Fairchild [15] suggested that "The effect is to paralyze some of the papillae of the tongue so that many things, even acid ones, taste sweet for some time." Dzendolet [13] proposed a more sophisticated but similar explanation based on his theory that sweet substances are proton-acceptors. He suggested that miracle fruit blocks sour receptor sites preventing the initiation of sour tastes. The perceived taste of an acid would then depend on the taste quality evoked by its anion. Citric acid, for example, would taste sweet after miracle fruit because citrate is a strong proton acceptor.

Kurihara and Beidler [22], Kurihara *et al.* [24], and Bartoshuk *et al.* [3] proposed that miracle fruit causes a sweet taste to be added to normally sour acids. Kurihara and Beidler [22] and Kurihara *et al.* [24] suggested that the sweet taste might be produced by sugar molecules in the following way: the glycoprotein binds to the taste cell membrane such that its sugar groups cannot bind to the receptor sites sensitive to sugars. Acid stimuli cause the conformation of the sweet receptor sites to be altered such that the sugar groups on the glycoprotein can bind to them. Bartoshuk *et al.* [3] suggested that the reduction in sourness might be a consequence of mixture suppression. That is, since moderately intense taste solutions of different qualities are known to suppress one another [4, 14, 21, 29, 30] suppression of sourness after miracle fruit could result from the addition of sweetness rather than direct suppression at the sour receptor sites.

The first mechanism is a subtractive one, i.e., miracle fruit removes sourness while the second mechanism is an

---

[1] Portions of these findings were reported at the Army Research Conference, West Point, 1970.

[2] Reprint requests should be sent to Linda M. Bartoshuk, John B. Pierce Foundation, 290 Congress Avenue, New Haven, Connecticut 06519.

additive one, i.e., miracle fruit adds sweetness to a normally sour tasting substance. An additional experiment is relevant to these two proposals. *Gymnema sylvestre* has been shown to suppress the sweetness of sucrose without affecting the taste of HCl [3]. Both Bartoshuk *et al.* [3] and Kurihara *et al.* [24] showed that when *Gymnema sylvestre* was used to suppress the miraculin-induced sweetness of citric acid, the sourness of the citric acid increased. Bartoshuk *et al.* [3] quantified this increase and found that the sourness of citric acid went back to approximately its original value. It might seem that this would prove that no sourness suppression had occurred since blocking both sour-sensitive and sweet-sensitive sites should produce a reduction in the taste intensity of acid. However, the simultaneous stimulation of two qualities can lead to inhibition of both [4, 14, 21, 29, 30]. Dzendolet reasoned that citric acid normally stimulates both sweet and sour sites but the sweet taste is inhibited by the greater intensity of sour. Miracle fruit blocks some of the sour sites permitting the sweet taste to be perceived; however, mutual inhibition still exists between sweet and sour. *Gymnema sylvestre* then blocks the sweet sites removing that inhibition and increasing the sour taste. Thus the *Gymnema sylvestre* experiment does not immediately rule out the sourness suppression theory.

The first three experiments test the sourness suppression theory. The fourth experiment tests whether or not the suppression of sourness could result from the addition of sweetness in the absence of any direct block of sour receptor sites. The fifth experiment reveals a previously unreported property of miracle fruit that must be explained by any theory of the action of miracle fruit.

EXPERIMENT 1: MIRACLE FRUIT INDUCED SWEETNESS IN HCl AND CITRIC ACID

This experiment shows the change produced by miracle fruit in the taste qualities of two common acids.

Method

Two of the authors and seven additional employees at the Natick Army Labs served as subjects.

Stimuli were warmed to 34°C and delivered to the extended tongue by a modified McBurney flow system [26]. Each stimulus was preceded by a 40 sec water rinse. Taste stimuli were evaluated by Stevens' method of magnitude estimation with a standard [33] as modified by Smith and McBurney [32]. That is, subjects were given a standard of .13 M NaCl following a water rinse several times at the beginning of a session, and told to call its intensity 100. Other taste intensities were judged relative to the standard. In addition, subjects were asked to break the total intensity of a taste stimulus into the constituent qualities. For example, a complex taste of sweet-sour of total intensity 150 might be 80 sweet and 70 sour. A session consisted of water and four concentrations of a given acid (order randomized), each judged twice before the application of miracle fruit and twice afterwards.

Miracle fruit berries were obtained from Miralin, Co. The pits were removed, the flesh and skin were homogenized with ice in a blender, and the resulting slurry was freeze-dried. The powder obtained was pressed into tablets containing 25 mg each. This amount corresponded to about 1/4–1/2 of one berry. The subject chewed the tablet and moved the fragments across the surface of his tongue for one minute. Since the effect lasted an hour or more, only one application was used per session.

Solutions were made from reagent grade chemicals and water (Hydro Service and Supplies, Inc.) that was organic-free, as near neutral pH as possible, and had a resistance in excess of 18 megohms per cm^3. Citric acid and HCl were scaled in preliminary experiments. Four concentrations of each acid were chosen so that within an acid, intervals between concentrations were psychologically equal and across acids each concentration level was matched for sourness. The resulting molar concentrations were: citric acid, 0.00085, 0.00372, 0.00832, 0.01380 M and HCl, 0.00078, 0.00158, 0.00794, and 0.01288 M.

Results and Discussion

Figures 1 and 2 show the taste of citric acid and HCl before and after miracle fruit. The normal tastes of both acids (sour for citric acid, sour plus some bitter and salty for HCl) are suppressed and a sweet taste is added. These results do not support Dzendolet's sourness suppression mechanism since it predicts that HCl will not be sweetened.

Citric acid appears to be sweetened more than HCl; however, the difference is not statistically significant even at the highest concentrations. This point will be examined again in Experiment 3.

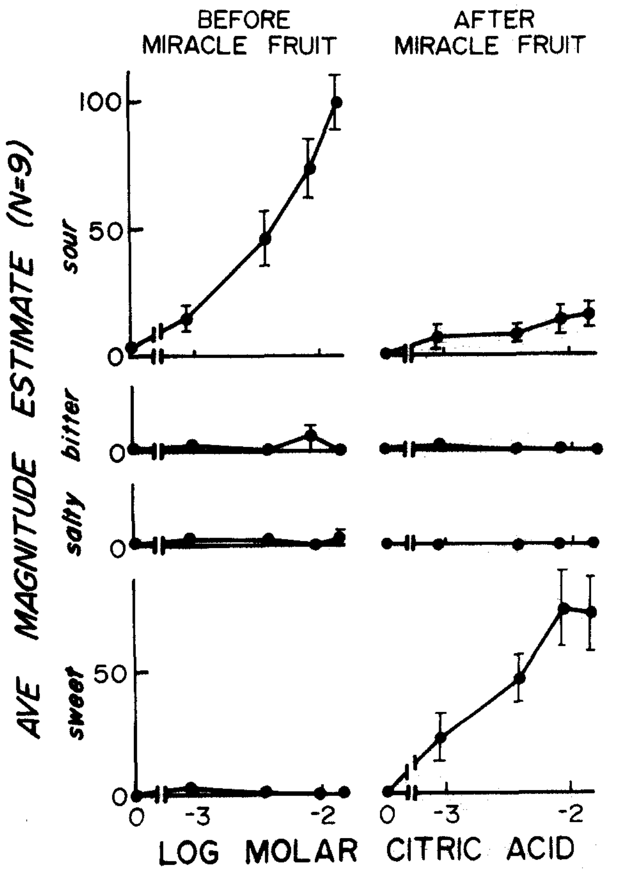

FIG. 1. Effects of miracle fruit on the taste of citric acid. Total taste is divided into sweet, salty, bitter, and sour components. Horizontal lines indicate ± 1 standard error of the mean.

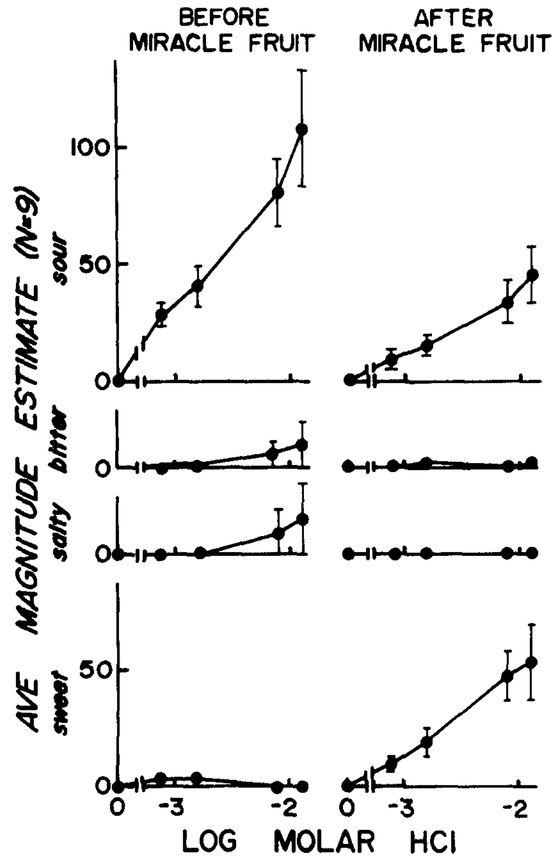

FIG. 2. Effects of miracle fruit on the taste of HCl. Total taste is divided into sweet, salty, bitter, and sour components. Horizontal lines indicate ± 1 standard error of the mean.

EXPERIMENT 2: EFFECTS OF *GYMNEMA SYLVESTRE* ON THE SWEETNESS INDUCED IN HCl AND CITRIC ACID BY MIRACLE FRUIT

This experiment shows what happens to the sour tastes of citric acid and HCl when the sweetness induced by miracle fruit is removed with *Gymnema sylvestre.*

This experiment is in part a replication of Bartoshuk *et al.* [3].

Method

The experiment was run as part of Experiment 1. After each subject completed judging citric acid and HCl before and after miracle fruit, he was given 8 ml of purified *Gymnema sylvestre* extract. He was asked to hold it in his mouth for one minute to insure obtaining maximum suppression [27], spit it out, rinse his tongue for the usual 40 sec in the flow system and then judge an additional stimulus. The stimulus was the highest concentration of the citric acid or HCl used for the earlier scaling experiment. This provided judgments of 0.013 M HCl and 0.014 M citric acid before miracle fruit, after miracle fruit, and after both miracle fruit and *Gymnema sylvestre.* The purified *Gymnema sylvestre* extract was prepared according to the method of Dateo [3, 8, 9] from leaves obtained from the Himalaya Drug Co., Bombay, India. This procedure provided primarily A_1, as designated by Stöcklin *et al.* [34] in powder form, easily soluble in water. The solution used was 0.5 g of powder per liter of water.

Results and Discussion

Table 1 shows the results of this experiment. After miracle fruit the sourness of both acids is greatly diminished; however, after *Gymnema sylvestre* the sourness is back to approximately the normal value. According to Dzendolet the suppression of the sourness of citric acid after miracle fruit is due to inactivation of sour receptors. The return of the sourness of citric acid to approximately its original value after *Gymnema sylvestre* is attributed to a removal of the inhibitory effect of the sweetness produced by the citrate anion. This cannot explain the return of the sourness of HCl after *Gymnema sylvestre* since the chloride ion is not a sweet stimulus according to Dzendolet's theory [12]. In addition, the assumed suppressive capability of the sweetness of the citrate ion would have to be very large. The residual sourness of citric acid was increased by a factor of 4.7 (i.e., from 16.3 to 76.9). If this had been produced by removing the suppressive effects of the sweet citrate ion, then *Gymnema sylvestre* alone should dramatically increase the intensity of citric acid. This is examined in Experiment 3.

TABLE 1

SOURNESS OF CITRIC AND HYDROCHLORIC ACIDS

Experimental Condition	0.014 M Citric Acid	0.013 M HCl
before miracle fruit	100.2 ± 11.7	108.9 ± 25.8
after miracle fruit	16.3 ± 5.6	45.7 ± 12.2
after miracle fruit and *Gymnema sylvestre*	76.9 ± 19.5	117.6 ± 14.7

Sourness values are given ± 1 S.E.M.

EXPERIMENT 3: EFFECTS OF *GYMNEMA SYLVESTRE* ON THE TASTES OF HCl AND CITRIC ACID

This experiment provides a necessary control for Experiment 2 by showing that *Gymnema sylvestre* alone does not enhance the sourness of citric acid nor that of HCl. The latter point is a confirmation of the same conclusion from Bartoshuk *et al.* [3].

Method

The stimulating procedure and apparatus were basically the same as in Experiment 1. In the first half of the session, water and 5 concentrations of HCl or citric acid were each judged twice following the 40 sec water rinse. In the second half, these stimuli were judged again but each trial (i.e., water rinse followed by test stimulus) was preceded by the 1 min exposure of the tongue to 8 ml of *Gymnema sylvestre* extract described above.

Results and Discussion

Figure 3 shows the total intensity functions for citric acid and HCl before and after *Gymnema sylvestre.* The breakdown into component qualities is not shown since the judgments were predominantly sour before and after *Gymnema sylvestre*. Neither citric acid nor HCl was significantly enhanced by *Gymnema sylvestre*. Thus Dzendolet's proposed mechanism cannot explain the sweetness induced by miracle fruit.

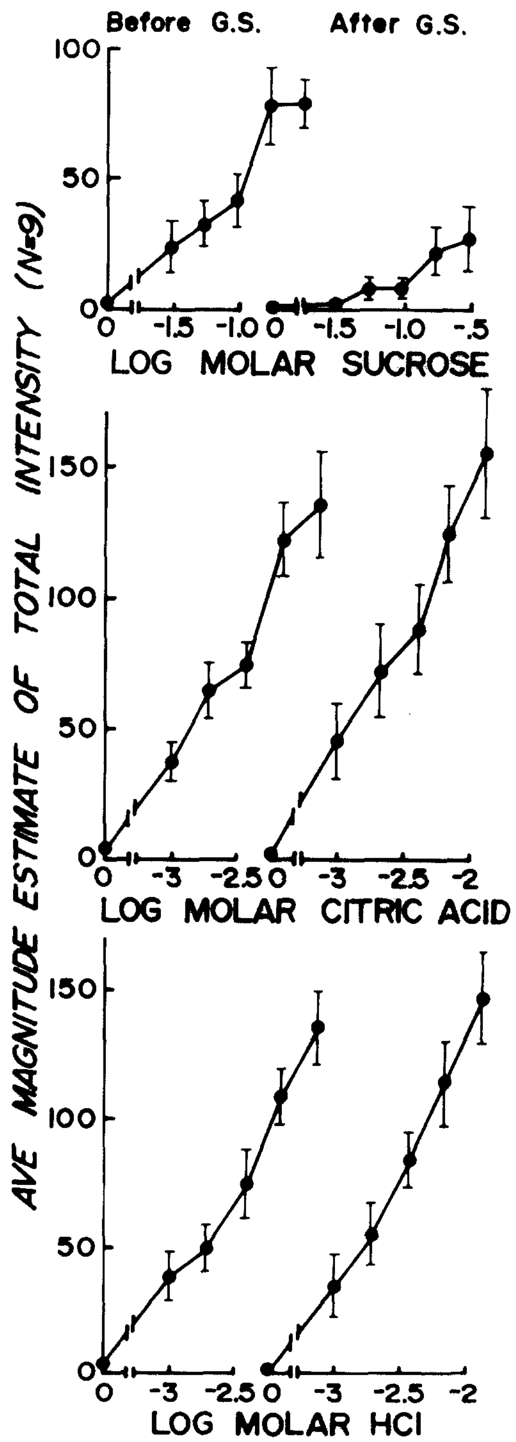

FIG. 3. Effects of *Gymnema sylvestre* (G.S.) on the taste intensity of citric acid and HCl. The suppression of sucrose taste by G.S. is shown to demonstrate the efficacy of the G.S. Horizontal lines indicate ± 1 standard error of the mean.

EXPERIMENT 4: THE SUPPRESSION OF THE SOURNESS OF CITRIC ACID BY THE ADDITION OF MIRACLE FRUIT INDUCED SWEETNESS

Kurihara *et al.* [24], Kurihara and Beidler [22], and Bartoshuk *et al.* [3] argued that miracle fruit does not inhibit sour receptor sites but simply adds a sweet stimulus to the normal taste of acids. Bartoshuk *et al.* [3] suggested that this added sweetness is responsible for the suppression of sourness. This can be tested by comparing the sour suppression produced by miracle fruit to sour suppression produced by other sweeteners.

Method

Two of the authors and 8 other employees of the U. S. Army Natick Labs served as subjects.

Stimuli were presented in cups at room temperature and sipped by the subjects. Each test stimulus was preceded by a distilled water rinse. The stimuli were mixtures of acid and sugar, constructed as follows: Each stimulus had the same amount of acid (0.009 M or 1.891 g per liter of mixture). The concentration of sugar varied from 0.03 M (10.27 g per liter of mixture) to 1 M (342.3 g per liter of mixture). Subjects estimated the intensity of sweetness and sourness of each mixture relative to a standard. Three sugars were used. L-arabinose and D-xylose were chosen because they were identified as components of the miracle fruit glycoprotein and were suggested by Kurihara *et al.* [24] as responsible for producing the sweet taste induced by miracle fruit. Sucrose was also used to test the generality of sour suppression produced by sweetness. After judging the mixtures, subjects exposed their tongues to miracle fruit (as in Experiments 1 and 3) and then judged the sweetness and sourness of the 0.009 M citric acid alone.

Results and Discussion

Figure 4 shows the effects on the taste of citric acid produced by adding sucrose. As the concentration of sugar increases, the perceived sweetness of the mixture increases and the perceived sourness decreases. This agrees with other reports of the effects of sucrose on the sourness of citric acid [14, 21, 30, 31]. The suppression of sourness produced by the sweetness of sugars is compared to the suppression of sourness produced by the sweetness of miracle fruit in Fig. 5.

Sourness of citric acid appears to be suppressed as a function of the sweetness perceived in the mixture. That is, the suppression of sourness of acids by miracle fruit can be explained as an example of the general taste phenomenon of mixture suppression and need not be attributed to a direct suppressive effect on sour receptor sites.

EXPERIMENT 5: EFFECTS OF MIRACLE FRUIT ON EQUALLY SOUR ACIDS

The relation between the sourness of several acids and their sweetness after miracle fruit has been examined with a matching procedure [22,24]. This procedure required the subject to select a citric acid solution equal in sourness to a given test acid solution before miracle fruit and to select a citric acid solution equal in sweetness to a given test solution after miracle fruit. The resulting sourness and sweetness functions were similar apparently suggesting that the sourness of an acid predicts its sweetness after miracle fruit. However, in Experiment 1 equally sour citric acid and HCl did not appear to be equally sweet after miracle fruit although the difference was not statistically significant

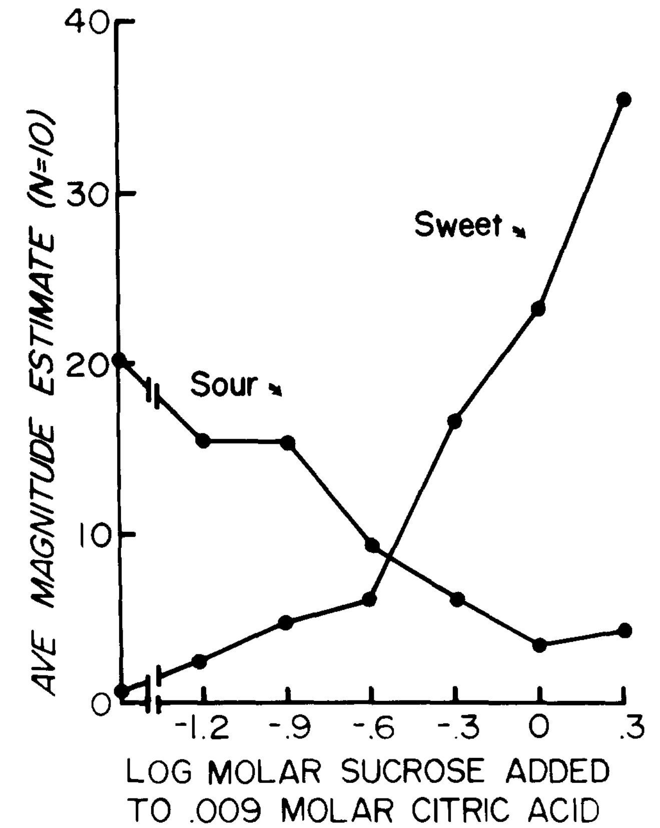

FIG. 4. Suppression of sourness of 0.009 M citric acid produced by adding sweetness of sucrose.

($p>0.05$) for the highest concentration. Experiment 3 was intended to provide a more sensitive test by initially equating acids for sourness for each subject.

Method

The authors and 10 additional employees of the U. S. Army Natick Labs served as subjects. The experiment was done in two parts. In the first, each subject was given a cup containing a standard HCl solution (0.01 M). Concentration series (21 steps separated by 0.1 log units) were prepared of seven additional acids: acetic, ascorbic, citric, gluconic, malic, sulfuric, and tartaric acids. Each subject tasted these acids by sipping them from cups and then selected the concentration of test acid that best matched the sourness of the standard. Sampling was unlimited but the subject was required to rinse his mouth with distilled water for 10 sec before tasting either the standard or the test acid. In the second part of the experiment, each subject was first given miracle fruit and then asked to evaluate pairs of acid stimuli for their relative sweetness. Each pair consisted of the standard HCl and the concentration of a test acid that subject had selected as equal in sourness to the standard. The subject was asked to indicate the sweeter of the two stimuli and to give a number reflecting how many times as sweet it was. Each pair was presented twice, the order being reversed on the second presentation and an HCl-HCl pair was included as a control.

Results and Discussion

Table 2 shows that both citric and tartaric acids were significantly sweeter than HCl after miracle fruit. These results do not agree with the conclusion of Kurihara *et al.* [24] and Kurihara and Beidler [22] that equally sour acids are equally sweetened after miracle fruit. One possible explanation for the discrepancy is that their matching procedure may not be as sensitive as the direct comparison method used in the present study. In their procedure the citric acid concentrations to which other acids were matched were unevenly spaced with respect to both concentration and initial sourness. This would be expected to increase variability.

Although Dzendolet's sourness suppression mechanism for miracle fruit can be ruled out because it cannot explain the sweetness induced with HCl, some of his arguments are relevant here just as in Experiment 3. Acids do not all taste alike. Taste qualities other than sour are present and these may influence the sweetness induced by miracle fruit independent of the nature of the mechanism of miracle fruit. For example, let us accept Dzendolet's contention that citric acid is a mixture of sour and sweet with the greater sourness overwhelming the lesser sweetness through mixture suppression. If additional sweetness is added via miracle fruit, then perhaps the normal sourness might be additionally suppressed and some of the previously suppressed sweetness of the acid itself might become perceptible and add to the sweetness induced by miracle fruit. The present experiments do not test this possibility. If the anions of some acids like citric acid are not contributing an important sweet taste, then the differences across acids in the degree of sweetness induced by miracle fruit reflects an important property of miracle fruit that must be explained by any acceptable theory of its function.

GENERAL DISCUSSION

If miracle fruit is topically applied to the tongue and acids are subsequently tasted, then acids taste less sour than normal and as if a sweet taste had been added. The two theories proposed to explain the effects of miracle fruit try to account for these two phenomena. One theory [13] treats the sourness suppression as the primary effect and considers the sweetness addition to be secondary while the other [3, 22, 24] treats the sweetness addition as the primary effect and considers the sourness suppression to be secondary. The present series of experiments were designed to test these two positions. The results support the second position, namely, that miracle fruit causes a sweet taste to be added to acids and that this sweet taste suppresses the sourness of acids through mixture suppression. These experiments do not suggest how the sweet taste is produced.

Although the sourness suppression mechanism cannot account for the major effects of miracle fruit, Dzendolet's suggestion concerning anion sweetness has not been eliminated as the source of another observation, namely, the differential sweetening observed across acids of equal sourness. That is, those acids that are most effectively sweetened by miracle fruit might be those whose anions are capable of evoking a sweet taste that adds to the sweetness induced by miracle fruit. If this is not the case, then the differential sweetening phenomenon would deserve closer attention since it would reflect a previously unreported property of miracle fruit itself rather than a property of the acid stimuli.

Miracle fruit has been investigated electrophysiologically in four species: man, monkey, rat and hamster [10,17]. In

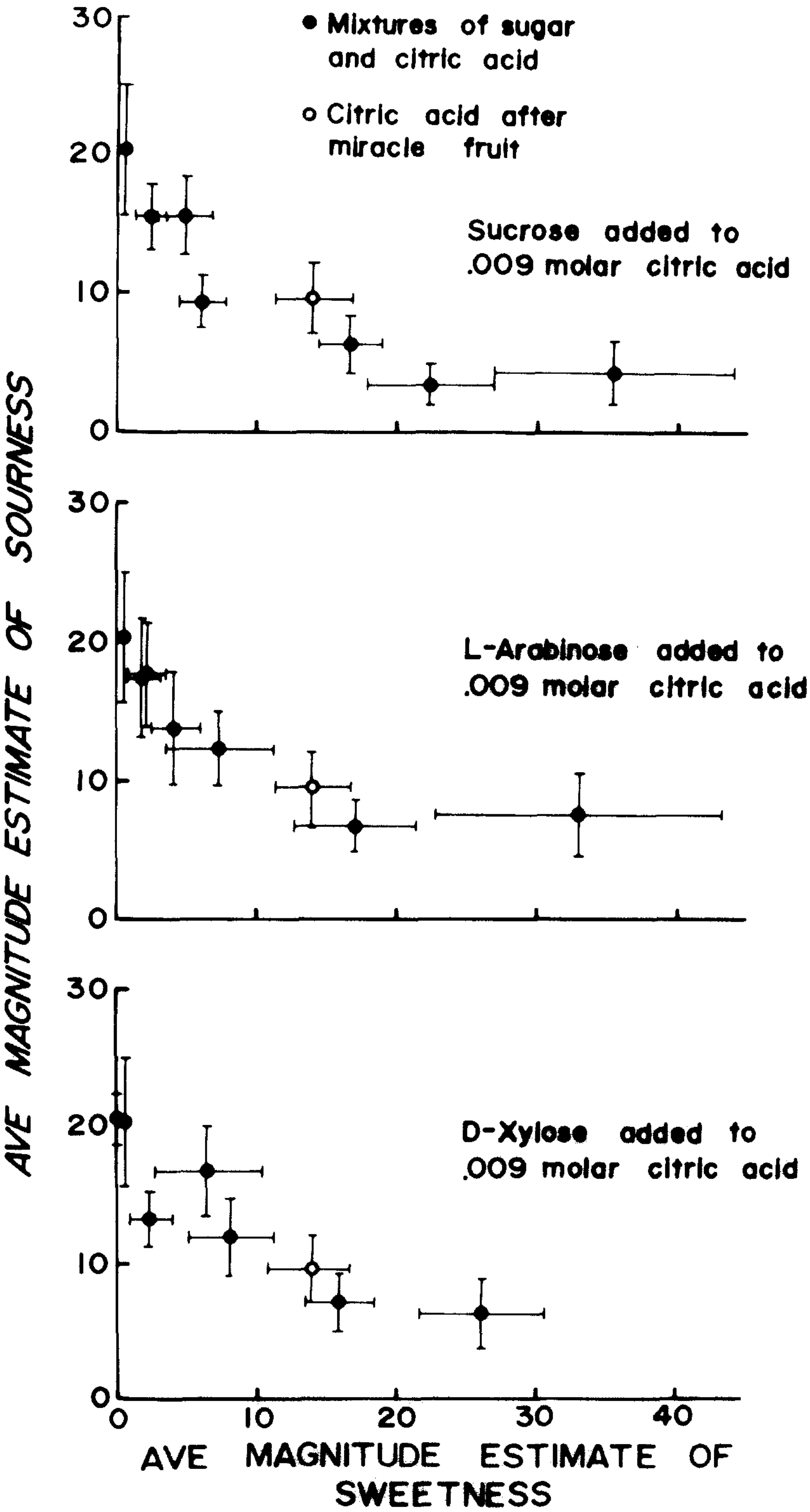

FIG. 5. Suppression of the sourness of 0.009 M citric acid as a function of adding the sweetness of sucrose, L-arabinose, or D-xylose (•) compared to the suppression of the sourness of 0.009 M citric acid by the sweetness induced by miracle fruit (○). Horizontal and vertical lines indicate ± 1 standard error of the sourness and sweetness means.

man and monkey, acids produced greater whole nerve chorda tympani responses after miracle fruit than before. In man, application of *Gymnema sylvestre* abolished this increased neural response to acid [10]. Diamant, *et al.* [10] interpreted these results to mean that after miracle fruit, the application of acid to the tongue caused both sweet and sour receptor sites to fire. That is, the increase in whole nerve response was caused by the addition of impulses from

TABLE 2

SWEETNESS OF EQUALLY SOUR ACIDS

Test Acid	G.M. Ratio of Sweetness of Test Acid to HCl	*t*-test Results*
citric	2.43	sweeter than all acids except tartaric
tartaric	1.86	sweeter than gluconic and hydrochloric acids
malic	1.48	
sulfuric	1.41	
ascorbic	1.33	not significantly different from one another
acetic	1.23	
gluconic	1.08	
HCl	1.05	

*Treatments by subjects analysis of variance gave F = 4.268, df = 7,13 for the log transforms of the ratio scores (significant, $p<0.05$). *T*-tests showed that any ratio 1.65 times another is significant, ($p<0.01$). This is summarized in the right hand column.

sweet receptor sites. This is a particularly exciting result for the following reasons. In Experiment 1, the total intensity of the taste of citric acid did not increase after miracle fruit (see Fig. 2 and also Reference 3). The decrease in sourness balanced the added sweetness leaving the total intensity virtually unchanged. We have explained the decreased sourness as primarily due to mixture suppression. The fact that the whole nerve response to acid in Diamant, *et al.* was actually increased after miracle fruit suggests that this mixture suppression occurs in the central nervous system in man. This possibility is supported by electrophysiological recordings from rat. Halpern [16] showed that mixtures appear to produce a simple sum of their components in the chorda tympani of the rat but produce less than the simple sum in the medulla. That is, mixture suppression appears to be central not peripheral in that species. In rat and hamster, miracle fruit did not increase the response to acid. Rather, the response may have actually decreased [10,17]. Single fiber recordings are needed to determine what if any effects miracle fruit has in these species.

Taste modifiers are of theorectical interest since they can provide tools for the study of sensory coding. They are of potential use in the laboratory since they offer the unusual possibility of changing taste cues without changing the nutritive properties of diets. In addition, a taste modifier like miracle fruit can be used to increase the palatability of food. Temporarily modifying the tongue rather than using taste additives sweet in themselves offers an alternative to conventional nonnutritive sweeteners like saccharin and cyclamate.

REFERENCES

1. Baehni, C. Mémoire sur les Sapotacées III. Inventaire des genres. *Boissiera* **11:** 1–262, 1965.
2. Bartoshuk, L. M. Alteration of taste qualities through natural products. Presented at the Army Research Conference, West Point, New York, 1970.
3. Bartoshuk, L. M., G. P. Dateo, D. J. Vandenbelt, R. L. Buttrick and L. Long. Effects of *Gymnema sylvestre* and *Synsepalum dulcificum.* In: *Olfaction and Taste III,* edited by C. Pfaffmann. New York: Rockefeller University Press, 1969, pp. 436–444.
4. Beebe-Center, J. G., M. S. Rogers, W. H. Atkinson and P. N. O'Connell. Sweetness and saltiness of compound solutions of sucrose and NaCl as a function of concentration of solutes. *J. exp. Psychol.* **57:** 231–234, 1959.
5. Brouwer, J. N., H. V. D. Well, A. Francke and G. J. Henning. Miraculin, the sweetness-inducing protein from miracle fruit. *Nature* **220:** 373–374, 1968.
6. Dalzeil, J. M. *The Useful Plants of West Tropical Africa.* London: Crown Agents for the Colonies, 1948.
7. Daniell, W. F. On the Synsepalum dulcificum, *De Cand.*; or, miraculous berry of Western Africa. *Pharmac. J.* **11:** 445–448, 1852.
8. Dateo, G. P. and L. Long. Gymnemic acid, the antisaccharine principle of *Gymnema sylvestre* leaves: studies on the isolation and heterogeneity of gymnemic acid A_1. Presented at 161st ACS Meeting, AGFD 2, Los Angeles, California, Spring, 1971.
9. Dateo, G. P. and L. Long. Gymnemic acid, the antisaccharine principle of *Gymnema sylvestre*: studies on the isolation and heterogeneity of gymnemic acid A_1. *J. agric. Fd. Chem.* **21:** in press.
10. Diamant, H., G. Hellekant and Y. Zotterman. The effect of miraculin on the taste buds of man, monkey, and rat. In: *Olfaction and Taste IV,* edited by D. Schneider. Stuttgart: Wissenschaftliche Verlagsgesellschaft, 1972, pp. 241–244.
11. Dubard, M. Les Sapotacées du groupe des Sidéroxylénées. *Ann. Musée Colonies Marseille.* **10:** 28, 1912.
12. Dzendolet, E. A structure common to sweet-evoking compounds. *Percept. Psychophys.* **3:** 65–68, 1968.
13. Dzendolet, E. Theory for the mechanism of action of "miracle fruit." *Percept. Psychophys.* **6:** 187–188, 1969.
14. Fabian, F. M. and H. B. Blum. Relative taste potency of some basic food constituents and their competitive and compensatory action. *Food Res.* **8:** 179–193, 1943.
15. Fairchild, D. *Exploring for Plants.* New York: MacMillan, 1931.
16. Halpern, B. P. Some relationships between electrophysiology and behavior in taste. In: *The Chemical Senses and Nutrition,* edited by M. R. Kare and O. Maller. Baltimore: Johns Hopkins Press, 1967, pp. 213–241.
17. Harvey, R. J. Gustatory studies relating to *Synsepalum dulcificum* (miracle fruit) and neural coding. Unpublished Ph.D. Thesis, Worcester Polytechnic Institute (WTD-53), 1970.
18. Henning, G. J., J. N. Brouwer, H. U. D. Wel and A. Francke. Miraculin, the sweetness-inducing principle from miracle fruit. In: *Olfaciton and Taste IV,* edited by C. Pfaffmann. New York: Rockefeller University Press, 1969, pp. 445–449.
19. Inglett, G. E., B. Dowling, J. J. Albrecht and F. A. Haglan. Taste-modifying properties of miracle fruit *(Synsepalum Dulcificum). agric. food Chem.* **13:** 284–287, 1965.
20. Irvine, F. R. *Th e Woody Plants of Ghana.* London: Oxford University Press, 1961.
21. Kamen, J. M., F. L. Pilgrim, N. J. Gutman and B. J. Kroll. Interaction of suprathreshold taste stimuli. *J. exp. Psychol.* **62:** 348–356, 1961.
22. Kurihara, K. and L. M. Beidler. Mechanism of the action of taste-modifying protein. *Nature* **222:** 1176–1179, 1969.
23. Kurihara, K. and L. M. Beidler. Taste-modifying protein from miracle fruit. *Science* **161:** 1241–1243, 1968.

24. Kurihara, K., Y. Kurihara and L. M. Beidler. Isolation and mechanism of taste modifiers; taste modifying protein and gymnemic acids. In: *Olfaction and Taste III*, edited by C. Pfaffmann. New York: Rockefeller University Press, 1969, pp. 450–469.
25. Labat. R. P. *Voyage du Chevalier des Marchais.* Paris: Saugrain, Quay de Gefvres, à la Croix Blanche, 1730.
26. McBurney, D. H. and C. Pfaffmann. Gustatory adaptation to saliva and sodium chloride. *J. exp. Psychol.* **65:** 523–529, 1963.
27. Meiselman, H. L. and B. P. Halpern. Human judgements of *Gymnema sylvestre* and sucrose mixtures. *Physiol. Behav.* **5:** 945–948, 1970.
28. Menninger, E. A. *Fantastic Trees.* New York: Viking Press, 1967.
29. Moskowitz, H. R. Perceptual changes in taste mixtures. *Percept. Psychophys.* **11:** 257–262, 1972.
30. Pangborn, R. M. Taste interrelationships. *Food Res.* **25:** 245–256, 1960.
31. Pangborn, R. M. Taste interrelationships, II. Suprathreshold solutions of sucrose and citric acid. *J. Food Sci.* **26:** 648–655, 1961.
32. Smith, D. V. and D. H. McBurney. Gustatory cross adaptation: does a single mechanism code the salty taste? *J. exp. Psychol.* **80:** 101–105, 1969.
33. Stevens, S. S. Issues in Psychophysical Measurement. *Psychol. Rev.* **78:** 426–450, 1971.
34. Stöcklin, W., E. Weiss and T. Reichstein. Gymnemsäure, das anti-saccharine Prinzip von *Gymnema sylvestre* R. Br. *Helv. Chem. Acta.* **50:** 474–490, 1967.