Sweetness of α-, β-, and Equilibrium Lactose Relative to Sucrose

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ABSTRACT

The sweetness of α-, β-, and equilibrium lactose, measured by a trained panel using paired comparison with standard reference solutions of sucrose of concentrations from 0.50–6.50%, ranged from 30–35% that of sucrose. The sweetness of β-lactose was 105–122% that of α-lactose. The predicted sweetness of lactose at mutarotation equilibrium, calculated from sweetness values for α- and β-lactose and from the relative amounts present as determined by polarimetry, i.e., 38% α and 62% β, did not differ significantly from the experimentally determined sweetness value, indicating an absence of synergism for sweetness in mixtures of α- and β-lactose. Isosweet sucrose concentrations for three different concentrations of β- and equilibrium lactose and two concentrations of α-lactose are reported.

INTRODUCTION

THE POTENTIAL of α-lactose monohydrate in baking applications has been examined by Ash (1976), and limitations of this form of lactose were its low solubility and its low sweetness compared with sucrose. β-lactose has much greater solubility compared with α-lactose monohydrate (Whittier, 1944), and Goldman and Short (1977) used β-lactose to replace up to 25% of the sucrose in a high-ratio cake formulation without affecting size, tenderness, or sweetness. Sugars are important food ingredients, and the relative sweetness of sugars has been of great interest to food scientists. Few studies have been made on the relative sweetness of α- and β-lactose, although differences in sweetness of anomeric forms of several sugars have long been recognized (Cameron, 1947; Pangborn and Gee, 1961; Pangborn and Chrisp, 1966). Pangborn and Gee (1961) compared the sweetness of α- and β-lactose, and the sweetness of each of these forms relative to lactose solution which had reached mutarotation equilibrium. They found β-lactose to be sweeter than α-lactose at superthreshold concentrations (5% and 7%) but did not measure the magnitude of the relative sweetness. Dahlberg and Penczek (1941) measured the sweetness of β-lactose (6–33%) relative to sucrose (2–20%), but did not test α- or equilibrium lactose. In the present study, the sweetness of α-, β-, and equilibrium lactose relative to sucrose was measured. In addition to establishing the sweetness of β-lactose relative to α-lactose, this study sought to determine from the sweetness of equilibrium lactose whether synergism could be demonstrated for a mixture of lactose anomers as has been shown for mixtures of glucose and fructose, and of glucose and sucrose (Stone and Oliver, 1969).

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EXPERIMENTAL

Materials

α-Lactose monohydrate, free of monosaccharides, was obtained from Sigma Chemical Co., and sucrose from Fisher Scientific Co. β-Lactose was prepared from α-lactose monohydrate by the process of Buma and van der Veen (1974). Distilled water for taste testing was obtained from Lehigh Valley Cooperative Farmers, Allentown, Pa.

Purity of the lactose samples and mutarotation data were determined from optical rotation measurements at 20°C on 2% (w/v) aqueous solutions in a 1 dm tube with a Perkin Elmer Model 141 polarimeter; specific optical rotation data used in the calculation of purity (as total lactose) and of the anomeric composition of the lactose samples were those reported by Buma and van der Veen (1974). Moisture content was determined on 50–500 mg samples by use of a Photovolt Aquatest II instrument, and ash content was measured by the AOAC Method I (1975).

Sensory evaluation

Sensory evaluations were made by a forced choice paired comparison method (Pangborn, 1963) in which the judges were asked to determine the sweeter member of each pair comprising a fixed concentration of lactose (anhydrous basis), and one of three sucrose solutions of differing concentrations. Dissolution of α-lactose monohydrate or β-lactose was achieved in a Waring Blendor in 30 sec and was begun after each observer entered the testing booth. Taste evaluation of each pair was completed within 2 min. Lactose solutions which were to be examined at mutarotation equilibrium were prepared 16 hr before being tasted (Pangborn and Gee, 1961).

The panel consisted of three women and seven men selected on the basis of their ability to detect differences in sweetness and chosen from a group of thirty one experienced sweetness testers (Parrish et al., 1979). All tests were performed in the morning, and three pairs of samples were tested in each session. Serving order was randomized within and between pairs, and the coded samples were served at 22°C in 30 ml amounts in odorless plastic cups.

The equal sweetness point, obtained from the plot of the sucrose concentration vs. the percentage of judges who selected the lactose solution as sweeter than the sucrose solution (Pangborn, 1963), is the sucrose concentration for which 50% of the judges selected the lactose solution.

RESULTS & DISCUSSION

THE PURITY of both α-lactose monohydrate and β-lactose was >99.8%, based on specific optical rotation data at equilibrium (Buma and van der Veen, 1974). Ash content was <0.09%, and moisture content, excluding water of crystallization of the α-lactose monohydrate, was <0.12%. No fruity flavor or other off-flavor was found with any of the lactose solutions which we tested, unlike some batches of lactose examined by other workers (Pangborn, 1963).

The concentrations of the three sucrose solutions used for measuring the sweetness of each lactose solution are shown in Table 1. Rapid dissolution of α-lactose monohydrate was not possible at the 15% (w/v) concentration level; by the time solution was attained and its sweetness determined, the anomeric ratio of α/β lactose had changed to approximately 80/20. Consequently, at the 15% (w/v) concentration, the study was restricted to β-lactose and equilibrated lactose (α:β ratio of 38:62) (Buma and van der Veen, 1974). We considered using anhydrous α-lactose instead of the monohydrate because of its greater ease of dissolution in order to obtain rapid dissolution at 15% (w/v), but the procedures for dehydration of the monohydrate involving alcohols (Nickerson and Lim, 1974) or heating (Sharp, 1943; Herrington, 1948) all gave products with off-flavors which masked sweetness. Sensory evaluation of lactose solutions below 3.75% (w/v) at the next level of twofold dilution, i.e., 1.875% (w/v) concentration, was not attempted because experience in a previous study of the relative sweetness of sugars (Parrish et al., 1979) showed the extreme difficulty of making sweetness comparisons near the recognition (for sweetness) thresholds.

Extrapolation of the data of Table 2 indicated that the equal sweetness concentration for 1.875% (w/v) lactose could be expected to be about 0.5% (w/v) sucrose; the latter value is close to the values of 0.582% (Pfaffman, 1959) and 0.53% (Parrish et al., 1979) reported for the recognition (for sweetness) threshold for sucrose.

Results for the sweetness comparison of solutions of α-, β-, and equilibrium lactose with sucrose are shown in Table 2. The mutarotation of α- and β-lactose follows a first-order equation (Hudson, 1903), and from optical rotation measurements (Buma and van der Veen, 1974) it was calculated that the α-lactose monohydrate contained 2.2% β-lactose. During the time involved in dissolution and in sweetness evaluation of α-lactose monohydrate, the amount of β-lactose present would increase by mutarotation to 5.7%, assuming that the rate of mutarotation of lactose in water is not changed significantly by contact with the mouth and its contents. Similarly, the β-lactose was calculated to contain 1.4% α-lactose, and the amount of α-lactose present would increase during testing to 3.9%. The sucrose concentrations for equal sweetness for α- or β-lactose shown in Table 2 can be corrected to make allowance for the contribution to sweetness by the small amount of other anomer present. When this calculation is made, the largest correction is found with 7.50% α-lactose; however, the difference between the measured sucrose concentration for equal sweetness (2.15%) and the corrected value (2.12%) amounts only to a 1.5% decrease. This difference is small compared to the differences in sweetness observed from one evaluation session to another. Consequently, the sweetness values reported for α- and β-lactose (Table 2) have not been corrected for the contribution by the other anomer present. The data show no significant differences between the three kinds of lactose solution at 3.75% concentration. The greater sweetness at 7.50% concentration of β-lactose compared to equilibrium or α-lactose is significant at $p = 0.01$ and in agreement with Pangborn and Gee's (1961) observation, but no significant difference exists between α-lactose and equilibrium lactose. At 15% concentration β-lactose is sweeter than equilibrium lactose ($p = 0.07$). In studies of relative sweetness of α- or β-lactose compared to equilibrium lactose, Pangborn and Gee (1961) found that equilibrium lactose is sweeter ($p = 0.001$) than α-lactose at 7.00% concentration. Our data for 7.50% solutions of α-lactose and equilibrium lactose, tested by comparison with sucrose, did not show a statistically significant difference in sweetness. Thus, Pangborn and Gee's (1961) direct comparison procedure for β-lactose and equilibrium lactose is more sensitive than our indirect comparison of these lactose forms with sucrose solutions used as reference standards. This finding is reinforced by the fact that Pangborn and Gee (1961) found with 0.3% solutions of lactose, a concentration which is near threshold, that α-lactose is sweeter than equilibrium lactose ($p = 0.01$), and that equilibrium lactose is sweeter than β-lactose ($p = 0.01$). These unexpected results did not receive comment by Pangborn and Gee (1961).

Table 1—Concentrations of sucrose solutions used in paired-comparison test of sweetness of lactose solutions

Concentration % (w/v)			
Lactose	Sucrose		
3.75	0.50	1.00	1.50
7.50[a]	1.50	2.00	2.50
	2.00	2.50	3.00
15.00[a]	4.00	5.00	6.00
	4.50	5.50	6.50

[a] The lower set of sucrose concentrations was used for comparison with β-lactose solutions.

Table 2—Equal sweetness concentration values for α-, equilibrium and β-lactose compared to sucrose

Concentration % (w/v)						
	Sucrose for equal sweetness compared to					
Lactose	α-Lactose		Equilibrium lactose		β-Lactose	
3.75	1.09	(10)[a]	1.09	(9)	1.09	(9)
	1.04	(11)	0.91	(9)	1.21	(10)
	1.11	(10)	1.25	(8)	1.10	(8)
	1.08	(0.03)[b]	1.08	(0.17)	1.13	(0.06)
7.50	2.27	(7)	2.16	(11)	2.70	(10)
	2.08	(10)	2.23	(8)	2.52	(10)
	2.14	(10)	2.29	(10)	2.65	(10)
	2.16	(0.10)	2.23	(0.07)	2.62	(0.09)
15.00	—		4.93	(9)	5.11	(9)
			4.89	(10)	5.36	(9)
			4.91	(0.03)	5.24	(0.18)

[a] Value in parentheses is number of judges involved in sweetness evaluation in each session.
[b] Mean (standard deviation) of replicate analyses.

Table 3—Comparison of data from studies on sweetness of lactose

Concentration % (w/v)					
	Sucrose for equal sweetness compared to lactose				
	α-Lactose	Equilibrium lactose		β-Lactose	
Lactose	This study	This study	Pangborn (1963)[a]	This study	Dahlberg & Penczek (1941)[a]
3.75	1.08	1.06	1.1	1.13	1.33
7.50	2.15	2.22	2.32	2.62	2.77
15.00	—	4.91	4.76	5.23	5.65

[a] Values interpolated from published data cited.

Table 4—Sucrose concentration for equal sweetness of equilibrium lactose; comparison of experimental value with that calculated from values for anomers

Concentration % (w/v)		
	Sucrose for equal sweetness	
Equilibrium lactose	Experimental	Calculated[a]
3.75	1.06	1.12
7.50	2.22	2.44

[a] Calculation based on anomeric ratio at equilibrium as determined by polarimetry, i.e., 38% α and 62% β, and sweetness value for lactose anomers from Table 3.

Interpolated values from studies of sucrose with equilibrium lactose (Pangborn, 1963) or with β-lactose (Dahlberg and Penczek, 1941), for lactose concentrations up to 15%, are shown in comparison with values obtained in this study (Table 3). The agreement between corresponding values in the three studies is good considering the variables inherent in sweetness testing, e.g., differences between panels and sources of lactose.

Synergistic effects on sweetness in mixtures of sugars are well known (Stone and Oliver, 1969). An objective of this study of the sweetness of the anomeric forms of lactose relative to sucrose was to determine if a synergistic effect could be shown for mixtures of the anomeric forms of lactose. To test this possibility we calculated the relative sweetness of equilibrium lactose from the values for α- and β-lactose (Table 2) using polarimetric data (Buma and van der Veen, 1974) for the relative amounts of the two forms at equilibrium, i.e., 38% α-lactose and 62% β-lactose. Comparison of these calculated values with those determined experimentally at concentrations of 3.75% and 7.50% are shown in Table 4. The limited data show no indication of a synergistic effect of sweetness between α- and β-lactose.

The data on relative sweetness of lactose (Table 2) shows β-lactose to be only 1.05–1.22 times as sweet as α-lactose. This small difference in sweetness would be of no practical value in food applications when choosing between α-lactose and β-lactose, e.g., as a coating sugar in baking applications.

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Ms received 8/8/80; revised 12/17/80; accepted 12/17/80.

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