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On the Calculation of Sugar Concentration in Flower Nectar

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Summary. There are several sources of potential error in calculating the concentration or energy value of floral nectar. Errors resulting from confusing data become substantial with increasing concentration. The different methods of expressing sugar concentration are here clarified, and the correct methods of converting from one to the other are provided. Refractometers in use in field studies usually read on a weight per total weight basis; this is recommended as the mode of statement. The perils of oversimplifying conversions from this mode, as is often done, are pointed out.

There is an increasing number of studies concerned with the energetics of plant-pollinator interactions. Often these studies involve measurements of sugar concentration, volume, and total energy value of the nectar secreted by individual flowers. Our purpose is to discuss sources of confusion and error in these calculations, and to suggest a standardized method for reporting these data.

There are several common methods for expressing the concentration of a solution in "per cent." The first source of confusion involves converting between these different methods, which is further complicated when researchers fail to identify their units of measurement. The following methods are most commonly used:

i. Per cent solution as g solute per 100 g SOLUTION. This is frequently termed per cent solution on a "weight to weight" basis or "weight to total weight" basis.

ii. Per cent solution as g solute per 100 ml SOLUTION. Sometimes this is converted to molarity (M), the number of gram molecular weights per liter solution.

iii. Per cent solution as g solute per 100 ml SOLVENT. Sometimes this is converted to molality (m), the number of gram molecular weights per liter solvent. It is a "weight per volume" measure.

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Table 1. Comparisons between different methods of expressing concentration using values for sucrose obtained from Table 88 (page D-308) in CRC Handbook (1978–1979). Values in brackets are per cent error from column (i), which is used as a standard (see text)

i g solute per 100 g solution	ii g solute per 100 ml solution	iii g solute per 100 ml solvent	Molarity (M)	Molality (m)
0.50	0.50 (0)	0.50 (0)	0.015	0.015
1.00	1.00 (0)	1.01 (1.0)	0.029	0.029
10.00	10.38 (3.8)	11.11 (11.1)	0.303	0.324
20.00	21.62 (8.1)	25.00 (25.0)	0.632	0.731
30.00	33.81 (12.7)	42.86 (42.9)	0.988	1.252
40.00	47.06 (17.7)	66.67 (66.7)	1.375	1.948
50.00	61.48 (23.0)	100.00 (100.0)	1.796	2.921
60.00	77.19 (28.7)	150.00 (150.0)	2.255	4.382
70.00	94.31 (34.7)	233.33 (233.3)	2.755	6.816
80.00	112.94 (53.7)	400.07 (400.1)	3.299	11.686

The distinction between (i), (ii), and (iii) above is often overlooked, especially when concentrations are reported as per cent solution without the units specified. Literature on nectar-feedings birds, for instance, contains examples of all three: Stiles (1976) uses (iii); elsewhere, Stiles (1975) and Hainsworth and Wolf (1972) use molarity (ii); Baker (1975) and Feinsinger (1978) use (i). Using values obtained from the Handbook of Chemistry and Physics (1978–1979), Table 1 shows that the error resulting from confusing these different methods becomes substantial with increasing concentration. To convert correctly between these different methods of determining per cent solution of sucrose or other sugars expressed as "sucrose equivalence," we suggest using Table 88 (page D-308) in the 59th (1978–1979) edition of the Handbook of Chemistry and Physics. Using this table, which goes by 0.5%, 1.0%, or 2.0% (i) increments, will require interpolations. Nevertheless, the error introduced by these interpolations should be minimal relative to the precision and accuracy of refractometer measurements. For those studies requiring greater accuracy, we recommend Table 15 in Hoynak and Bollenback (1966), which goes by 0.1% (i) increments but which does not use metric units.

The importance of these conversions is that measurements of nectar concentration are often taken as g solute per 100 g solution (i above), whereas measurements in g solute per 100 ml solution (ii above) are necessary for conversion to energy values (see below). That is, most refractometers commonly used for measuring nectar sugar solutions in sucrose equivalence, such as those made by American Optical, Bellingham and Stanley, Bausch and Lomb, and National, read directly in g solute per 100 g solution (i) or ° Brix. ° Brix, a standard used in the sugar industry, is equivalent to (i) above. Other refractometers read concentration as refractive index and supply tables for conversion to (i); however, we caution users of these tables to check units of measurement when making the calculations, since some manufacturers do not specify the "per cent" used in their conversions. Because g solute per 100 g solution (i) is the most commonly obtained and easily interpreted measure, we suggest that it be used as a standard when sugar concentrations of nectar are reported. We realize that confusion may occur when researchers prepare their own sugar solutions, where for ease of preparation molarity (from ii) or molality (from iii) are often used (e.g. Hainsworth and Wolf, 1976; Stiles, 1976). Nevertheless, if appropriate units of measurement are reported the reader should have little problem with interpretation.

To calculate energy values for nectar (calories or, preferably, joules), total mg sugar per flower must be determined. Total mg sugar is of course the product of nectar volume (e.g. ml) and concentration per unit volume (e.g. mg per ml). Therefore, mg sugar cannot be calculated directly from measurements in g solute per 100 g solution (i). Values in (i) must first be converted to g per l or mg per ml with the table in the Handbook of Chemistry and Physics (1978–1979) as specified above, then multiplied by nectar volume (ml). The significance of neglecting the conversion from (i) to (ii) is shown by Table 1 or by the following example: 100 g of a sucrose solution that is 40% on a g solute per 100 g solution basis contains 40 g sucrose and occupies only 85 ml, whereas 100 ml of the same solution contains 47.06 g sucrose and would be a 47.06% solution by (ii). Thus, not converting from (i) to (ii) above before calculating mg sugar, or joules, in a given volume of the solution would result in substantial error.

Incomplete reporting of data can further complicate comparisons between nectar studies. Some authors (e.g. Heinrich, 1976) report only total mg sucrose equivalence. Data on volumes of nectar are important, however, because crop volume limits nectar intake in both hummingbirds (DeBenedictis et al., 1978) and bees. Furthermore, recent studies (Feinsinger, 1978; Bolten and Feinsinger, 1978) demonstrate the importance of concentration with respect to volume in nectar solutions. Therefore, reports on nectar investigations should include both concentration and total volume of nectar secreted, from which mg sucrose equivalence or total energy value can easily be calculated if appropriate.

After one of us (HGB) first noticed the problem, a perusal of the literature showed us that many workers have fallen into error when using refractometer readings to estimate the caloric content of nectars and when making "artificial nectars" to replace natural nectars in experimental studies on the foraging patterns of flower visitors. We hope that this note may help authors of papers already published to make corrections, and all of us to avoid future problems. Reporting data in complete and standardized fashion will legitimize comparisons between the results of independent studies.

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