

Detection of Honey Adulteration By Carbohydrate Analysis

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Thirteen market samples of falsified honey containing invert sirups or conventional corn sirup and 2 labeled mixtures have been analyzed. Results are interpreted in relation to literature values for various carbohydrate constituents of honey and their vulnerability. Published data on composition of United States honey have been refined for this purpose by eliminating samples containing a major portion of honeydew, thus narrowing the compositional ranges for known honey.

Honey, as a natural sweetener, is enjoying an enhanced popularity with today's consumer. Limited availability and increased price have provided major incentives for falsification with other carbohydrate materials. In addition to the traditional adulterants such as invert sirup and conventional corn sirup (CCS), high fructose corn sirup (HFCS) has recently become available and has been used. HFCS represented a major problem until recent research provided a definitive test for its presence in honey (1).

This discussion deals with the effects of CCS and invert sirup adulteration on the carbohydrate composition of honey. The current AOAC test for admixture of CCS with honey (31.134-31.136, 12th Ed.) specifies separation of CCS malto-dextrins by alcohol precipitation, followed by their differentiation from fructose-containing honey oligosaccharides by paper chromatography. Aniline-diphenylamine chromogenic reagent differentiates by color between oligosaccharides with and without fructose. Replacement of the paper chromatographic step by thin layer chromatography greatly expedites the test and the improved technique has been adopted by the AOAC (2).

The only official test for the presence of added invert sirup is the qualitative resorcinol test (31.138-31.139, 12th ed.), which responds to hydroxymethylfurfural (HMF). This test is somewhat ambiguous, because HMF can legitimately be present in honey that has been subjected to heat or abusive storage. Quantitation provides a better understanding; this is discussed in another publication (3).

Knowledge of the carbohydrate composition of a sample is useful in judging its authenticity. Although a large body of compositional data is

available for United States honey (4), its utility is somewhat limited because of the complexity of the analytical procedures heretofore needed to obtain it. Honey is such an extremely variable and complex mixture of sugars and other components (5, 6) that the relatively facile gas-liquid chromatography (GLC) and high performance liquid chromatography (HPLC) have had only limited application in studies of its composition. An HPLC method (7) for glucose, fructose, and sucrose in honey has been adopted as official first action (8), but the other carbohydrates are not well separated. Glucose and fructose may be measured in honey by GLC with lower accuracy. The complexity of honey, which has been reported to contain at least 22 di- and trisaccharides (9), severely limits attempts at quantitation. Doner *et al.* (10) described a GLC procedure in which the ratio of isomaltose to maltose is used to indicate the addition of HFCS.

Because of this complexity, the analytical system developed for an earlier survey of honey composition (2) included a separation of the sugars into monosaccharides, disaccharides, and higher sugars by charcoal column chromatography before use of conventional wet methods for quantitation within each class. The use of hypiodite oxidation and copper reduction yielded values for glucose and fructose; sucrose was analyzed by the increase in reducing value after mild acid hydrolysis. All reducing disaccharides were reported collectively as "maltose," and higher sugars were measured as the reducing value after hydrolysis. This procedure, while entirely suitable for research purposes, is laborious and unsuited for the laboratory that performs only occasional honey analyses.

Analytical data entirely comparable to those of the earlier compositional survey have been obtained in this laboratory by simplified procedures, with only the specific glucose oxidase method used for glucose and the dry weight values of the 3 fractions from the charcoal column. This is accomplished as follows:

Monosaccharide fraction: (1) total monosaccharides by weight; (2) glucose by glucose oxidase; (3) fructose by difference.

Disaccharide fraction: (1) total disaccharides by weight; (2) sucrose by invertase hydrolysis followed by glucose oxidase; (3) all other disaccharides by difference.

Higher sugar fraction: total higher sugars by weight.

In the earlier work, sucrose was measured after mild acid hydrolysis, and the value for sucrose included any melezitose present, most of which is found in the disaccharide fraction. For specific sucrose values, invertase was used. In the procedure described here, melezitose may be estimated, if required, by the difference between values obtained by the 2 hydrolytic procedures applied to the disaccharide fraction. Melezitose is a constituent of honeydew and is found occasionally in small amounts in predominately floral honeys.

Saccharimetric methods, the bases of earlier honey analyses (11), provided only estimates at best and misleading information at worst. For example, the so-called quantitative estimation procedure (31.137, 12th ed.) for commercial glucose (CCS) will indicate a considerable proportion of CCS when applied to a sample containing a major amount of honeydew. Several recent applications of this test to such materials have resulted in seizures that were not justified. Had the original papers been consulted and had the additional confirming tests recommended (but not included in the AOAC version) been made, these incidents would not have occurred. In a complex mixture, polarimetric analysis is of limited value, although it has been shown to quantitate quite well the glucose and fructose in the monosaccharide fraction of honey from the charcoal column (4).

Honeydew samples have been identified conventionally by polarimetry; the advisory FDA definition for honey requires that it be levorotatory (see ref. 4). Thus a significant (> 5%) amount of melezitose is a confirmatory negative test for a dextrorotatory sample that tests negative for CCS or added sucrose.

Methods for measuring the monosaccharide, disaccharide, and higher sugar content (distribution of sugars) of honey as described above have been adopted by the AOAC (8). Also adopted (8) was a method specific for sucrose which makes use of glucose oxidase to measure glucose liberated from the disaccharide fraction by invertase. The HPLC procedure for glucose, fructose, and sucrose has also been adopted (8). A collaborative test of glucose oxidase determination of glucose in the mono-

saccharide fraction, with fructose measured by difference, did not qualify, although it was satisfactory in the author's laboratory. The fructose value, measured by difference, was strongly affected by column performance.

A simple method that requires no sugar separation can determine true glucose in honey (12) and thus indicates adulteration if values found lie well outside the normal ranges.

Experimental

Methods

1. **Polarization.**—Constant direct polarization was determined by method 31.117, 12th ed., with a 1 dm tube used in a Perkin-Elmer automatic polarimeter. The angular rotation values from the instrument were converted to the International Sugar Scale by multiplying by 2 (ISS values require a 2 dm tube), by 0.26, and dividing by 0.3462 (1° ISS = 0.3462 angular degrees).

2. **Distribution of sugars and determination of sucrose.** These were determined as described (8), with glucose determined by the general glucose oxidase procedure, which is used for determination of glucose in the monosaccharide fraction, and is the same as that described for the sucrose determination.

3. **Glucose and fructose.**—The monosaccharide fraction (5 mL) obtained in the method for distribution of sugars is diluted to 100 mL, and glucose is determined on 2.00 mL aliquots by the glucose oxidase procedure. For the standard glucose tubes, 2.00 mL of a glucose solution containing 100 μ g glucose/mL is used.

Glucose: $(\text{mg glucose}/2 \text{ mL}) \times 2.5 \times 100/\text{g}$
sample on column = per cent glucose.

Fructose: Per cent monosaccharide — per cent
glucose = per cent fructose.

Results and Discussion

Polarization

(Prepared with Walter F. Schmidt and Mary Rodgers, Food and Drug Administration Laboratory, Philadelphia, PA.)

The distribution of polarization values for 468 samples (Fig. 1) closely approaches a normal distribution with some tailing on the side of positive values. When the midpoint of each group is plotted, a remarkably uniform Gaussian curve results which, if idealized on the positive side, intersects the baseline at about -2° S. This implies that the empirical division at 0° S polarization between honeydew and

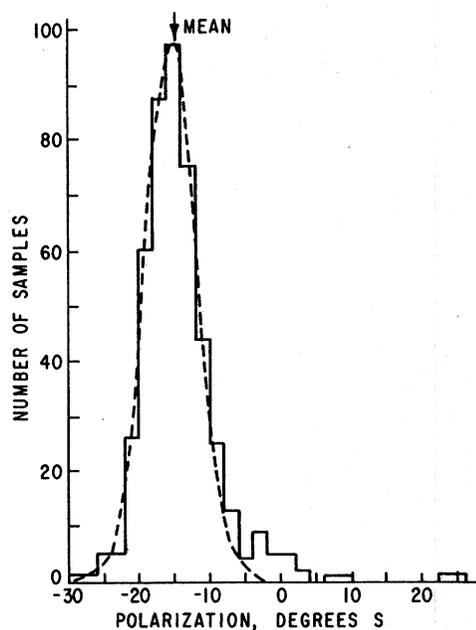


FIG. 1—Distribution of polarization ($^{\circ}$ S) for 468 honey samples, 1974–75 crop.

honey might more properly be at -2° S. In the United States this is only of academic interest, because no account is taken of the presence of honeydew in honey.

The concept that levorotatory samples are honey and dextrorotatory samples are honeydew is largely empirical; no real basis exists for such a division point except that the carbohydrates present in honeydew (melezitose and erlose) are strongly dextrorotatory. We merely attempted to use the polarization data available to indicate, by means of Gaussian symmetry, a possible lower limit of polarization for honey without appreciable honeydew content. The mean value for all 454 levorotatory samples is -14.70° S, standard deviation = 4.37° S, coefficient of variation = 29.77%.

Solids Plus Water

This value, obtained by adding the values for distribution of sugars and the water content (by refractive index, 31.112, 12th ed.) provides insight into the adequacy of the separation and the performance of the charcoal columns. This sum should normally be between 99.0 and 101.0%. Values consistently below 99.0% indicate a defective column that should be re-packed. Some minor honey constituents will

not desorb, and their accumulation limits the number of re-uses of a column to about 10.

Distribution of Sugars

Based on data from the earlier survey (4), the distribution of the three groups of sugars was calculated for the 456 samples for which sugar analyses were reported.

Ranges were wide: monosaccharides, 52.56–79.95%; disaccharides, 3.29–18.16%; and higher sugars, 0.13–8.49%. Examination showed outliers on the low side of the monosaccharide distribution (7 < 56%) and on the high sides of the other 2 groups: 5 with disaccharides > 15% and 16 with higher sugars > 4%. In several cases the same samples had outliers in more than one category.

Many of the samples used in that study had been stored frozen (0° F) since the study. Four of the 7 monosaccharide outliers, 5 of the 5 disaccharide outliers, and 7 of the 16 higher sugar outliers were available. Constant direct polarization was measured according to method 31.117, 12th ed. All 4 of the monosaccharide outliers were honeydews (Sample 138, $+4.5^{\circ}$; Sample 168, $+14.7^{\circ}$; Sample 457, $+3.6^{\circ}$; and Sample 452, $+0.3^{\circ}$ S). In the disaccharide outlier group, 2 of those named above were present; the other 3 were levorotatory. Six of the 7 available higher sugar outliers were honeydews: the 4 above, plus Sample 24, 0.00° ; and Sample 459, $+10.3^{\circ}$ S.

On the basis of these results it is reasonable to assume that all of the 7 monosaccharide and the 16 higher sugar outliers were honeydew, and thus are not properly included in a study of honey variability. Elimination of these outliers from the population results in the distribution shown in Fig. 2 and summarized in Table 1.

The carbohydrate distribution of a number of market samples regarded for various reasons as possibly adulterated (Table 2) shows for 11 of the 15 samples at least one value outside the ranges in Table 1. Thus this analysis is informative and, with other data such as glucose and fructose content, can be conclusive.

Fructose Content

The mean fructose content of the 439 samples remaining after removal of honeydew outliers (Table 1) is 38.38%; the 17 outliers averaged only 33.36% fructose. The spread between extremes is decreased from the earlier value of 17.01% fructose to 13.35%; s is decreased from 2.07 to 1.77; and the corresponding coefficient

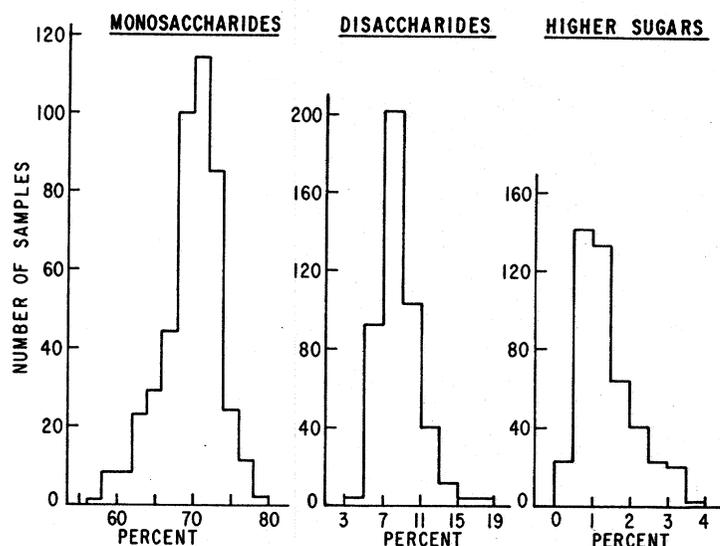


FIG. 2.—Distribution of saccharides in 439 honey samples, data of 1962 (4) with honeydew outliers removed.

 Table 1. Carbohydrate analysis of honey^a

Sugar	Mean, %	s, %	CV, %	Range, %
Monosaccharides	69.71	4.13	5.92	58.00–79.95
Disaccharides	8.62	2.08	24.1	3.29–18.16
Glucose	30.31	3.04	10.03	22.89–40.75
Fructose	38.38	1.77	4.61	30.91–44.26
Fructose/glucose	1.229	0.126	10.2	0.76–1.86
Sucrose	1.31	0.87	66.4	0.25–7.57
Higher sugars	1.36	1.11	81.6	0.13–3.85

^a For 439 samples from (4), honeydew outliers removed (see text).

of variation is decreased from 5.42 to 4.61%. The coefficient of variation for fructose content was the smallest known for a honey constituent or property until that for the ¹²C/¹³C isotope ratio was determined to be 3.73% (1). Three of the samples in Table 2 are below this lower limit for fructose.

Glucose Content

Removal of the 17 honeydews from the sample population decreased the average glucose content from 31.28 to 30.31% and reduced the range between limits from 18.97% glucose¹ to 17.86, but had little effect on *s* and the coefficient of variation. Three of the samples in Table 2 exceed the upper limit.

Thirteen of the 456 samples analyzed earlier

¹ The value of 22.03% in Table 1 (4) given for the lowest glucose content is in error; Sample 168 had 21.78%.

(4) contained more than 36.0% glucose. Two were described as from the athel tree (*Tamarix aphylla*), 6 from cotton (*Gossypium hirsutum*), 1 each from dandelion (*Taraxacum officinale*), heartsease (*Polygonum* spp.), blue curls (*Trichostema lanceolatum*), and manzanita (*Arctostaphylos* spp.), and 1 was an autumn desert blend. Four of these exceeded 38% glucose: 1 each from athel tree, cotton, blue curls, and manzanita. Rapeseed honey, known to granulate rapidly, would also be expected to be high in glucose. Because no samples from this source were included in the 1962 study, 10 samples of this type of honey were obtained from a Canadian source and analyzed for glucose by the direct glucose oxidase procedure (12). The average was 36.27%, range 34.54–37.15%, *s* = 0.75. A glucose content >38% in a sample may be considered as contributory evidence of its falsification in the absence of pollen from the 4 sources listed above.

Fructose/Glucose Ratio

The dispersion of the fructose and glucose values for the samples included in Table 1 is shown in Fig. 3, and the distribution of fructose/glucose values is shown in Fig. 4. Two of the 439 samples have fructose/glucose <1.00. One, preserved since the earlier work, was re-analyzed, verifying the value. The other was from blue curls, a honey earlier reported (13) to have fructose/glucose <1. Two samples of

Table 2. Carbohydrates in questioned samples

No.	Monosaccharides			F/G	Disaccharides		Higher sugars total, %	HMF, mg/100 g	Probable additive
	Total, %	Fructose, %	Glucose, %		Total, %	Sucrose, %			
1	69.1	34.6	34.5	1.00	13.8	9.7	1.65	97.5	invert sirup
2	48.7	23.2	25.5	0.91	9.4		17.6	16.7	corn sirup
3	81.2	39.9	41.3	0.97	1.8	0.3	0.3	1.4	invert sirup ^a
4	46.5	21.4	25.1	0.85	17.3	2.6	13.5	17.5	corn sirup
5	80.7	40.5	40.2	1.01	1.9		0.4		invert sirup ^a
6	63.6	33.4	30.2	1.11	16.0	13.2	6.0	46.3	invert sirup
7	75.0	37.1	37.9	0.98	7.5	0.7	1.3	45.8	invert sirup ^a
8	68.8	30.4	38.4	0.79	8.0	4.6	5.5	87.5	invert sirup
9	76.9	38.8	38.1	1.02	5.2		0.9	4.3	invert sirup
10	69.7	34.2	35.5	0.96	11.5	4.7	1.5	25.6	invert sirup
11	60.8	36.0	24.8	1.45	18.3	12.6	2.4	4.9	
12	76.9	33.4	43.5	0.77	2.0	0.3	0.3	1.9	invert sirup ^b
13	71.4	33.7	37.7	0.89	6.5		1.4	36.3	invert sirup ^a
14	84.2	37.7	26.0	1.45	17.6	13.1	2.1	14.0	
15	80.5	39.3	41.2	0.95	2.7	0.4	0.5	2.8	invert sirup ^a

^a Apparently contained no honey.

^b Honey substitute, labeled as containing invert sirup, not a questioned sample.

blue curls honey from California (1975 crop) were analyzed by the method described above. The reported preponderance of glucose over fructose characteristic of this honey type is confirmed (Table 3). The effect on fructose/glucose of adding invert sirup, which normally has fructose/glucose <1, or of adding CCS, is also apparent in Table 2.

Sucrose

(Prepared with A. P. Hoban, Eastern Regional Research Center, Philadelphia, PA.) The sucrose content of honey is normally rather low; White *et al.* (4) gave for 490 samples a mean of 1.31%, *s* = 0.95, range 0.25–7.57%. This included 7 samples >5.0%; one of these was eliminated when outliers were removed. Of the

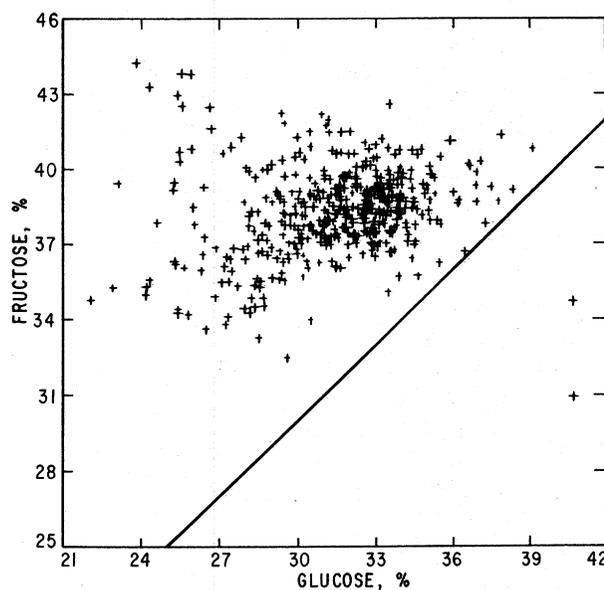


FIG. 3—Fructose and glucose relationship for 439 honey samples. Line indicates F/G = 1.

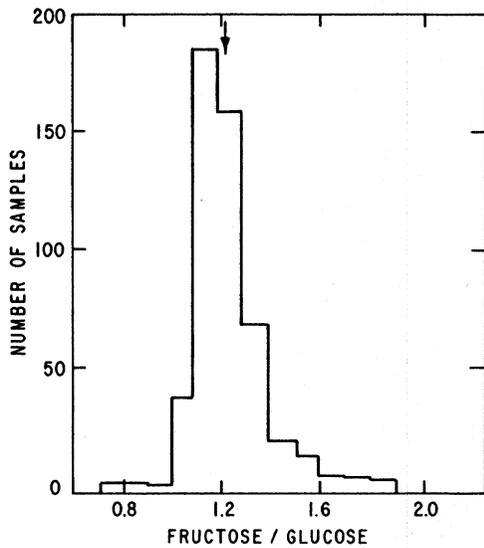


FIG. 4—Distribution of fructose/glucose ratio in 439 honey samples, data of 1962 (4) with honeydew outliers removed.

6 remaining, 3 were alfalfa or alfalfa-sweet clover, 1 citrus, 1 star thistle (*Centaurea solistialis*), and 1 hairy vetch (*Vicia villosa*).

A collection of 481 honey samples of the 1974–1975 crops, certified authentic by their producers, had been obtained for a project to develop means to detect the addition to honey of high fructose corn sirup. These were analyzed for sucrose by the procedure described elsewhere (8). The distribution of values is shown in Fig. 5. It resembles that in the earlier work (4), but a much greater proportion is found in the 0–0.5% group, possibly because of the greater sensitivity of the method used. The mean was 1.21%, $s = 1.30$, and range 0.03–9.74%. Thirteen of these samples exceeded 5%; only one (a California orange honey) was higher than the 8% cited in the FDA advisory definition. Floral types of these 13 samples were 1 citrus, 1 locust (*Robinia* spp.), 7 alfalfa alone or mixed with sweet clover, 1 macademia nut, 1 unknown.

Table 3. Analysis of honey from blue curls (*Trichostema lanceolatum*)

Sample	Fructose, %	Glucose, %	Ratio, F/G
149 (1962)	30.91	40.75	0.76
402 (1975)	31.91	38.15	0.84
428 (1975)	34.04	37.52	0.91

The data from these 2 analytical studies showed that 19 of 919 samples of United States honey had sucrose contents greater than 5%; citrus (4 samples), alfalfa, and alfalfa-sweet clover (10 samples) were the types most frequently high in sucrose. Most of these types cited are known to be deficient in natural invertase and are slow to ripen. The sucrose content of all natural unheated United States honeys will decrease to <5% in a few months at room temperature; a high sucrose adulterated product is more stable. The time may be reduced to a few weeks by diluting the sample (if necessary) to 18.6% moisture and holding it at 37°C.

The sucrose contents of 41 additional samples received in the comb also are shown in Fig. 5. For these samples, obtained directly from the hive and refrigerated upon receipt, the mean sucrose content is 2.78%, appreciably higher than that for the extracted samples. This may be ascribed to their having less storage time during which to ripen by action of the natural invertase.

The advisory FDA definition of honey allows a maximum of 8% sucrose. The Codex Alimentarius limit (14) for apparent sucrose (increase

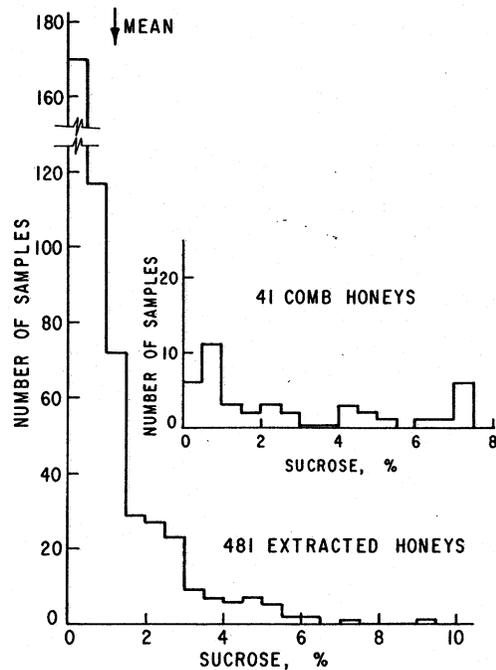


FIG. 5—Distribution of sucrose content of 481 extracted honey samples and 41 comb honey samples, crop years 1974–75.

in reducing sugars after mild acid hydrolysis) is 5%; but 10% is permitted for specified floral types known frequently to be high in sucrose (Banksia, lavender, Robinia). The high sucrose values for several samples in Table 2 is contributory evidence of their falsification.

Other Disaccharides

The analytical procedures described herein will not permit quantitation of other individual disaccharides. Although several GLC procedures for honey analysis have been reported (15-18), rigorous evidence of complete separation of the reported disaccharides has not been forthcoming. Doner *et al.* (10) described a GLC procedure for measuring isomaltose/maltose ratio for use in selecting samples for isotope ratio analysis for HFCS; this procedure can provide information useful for distinguishing synthetic mixtures sold as honey, because all honeys examined contained these sugars. The total absence of maltose and isomaltose from several of the samples listed in Table 2 (Nos. 5, 12, 15) when analyzed by the GLC procedure confirmed that they contained no honey.

Higher Sugars

The distribution of higher sugars found in the earlier study, after the correction for honeydew noted above, is shown in Fig. 2 and Table 1 for levorotatory honeys. The finding of more than 4.0% higher sugars in a levorotatory sample may be considered contributory evidence of falsification (Table 2).

Hydroxymethylfurfural

This compound is present in nearly all honey; its content depends on the storage and heating history of the specific sample. The use of HMF analysis for detection of adulteration is discussed in another paper, as is the analysis of samples from the 1974-75 crops (3).

Other Carbohydrates

The minor di- and trisaccharides of honey are considered to originate largely from the transglucosylation accompanying the inversion of nectar sucrose by honeybee invertase and from acid reversion.

Saccharides produced by glucose transfer during honey ripening are known to differ from

those resulting from the fructose transfer characteristic of yeast invertase inversion of sucrose (5). The sugars obtained from Sample 3 in Table 2 were examined by paper chromatography. Migrations on paper of these sugars was typical of those reported by Bacon and Edelman (19) for yeast transfructosylation intermediates, differing from those known for the transglucosylation typical of honey invertase (20). This, together with low HMF levels and other considerations, is consistent with the product's identity as an invert sirup produced by enzyme inversion.

The wide variability in honey composition requires for demonstration of adulteration that a number of parameters be outside expected norms. In addition to the carbohydrate components discussed here, such factors as acidity (free, lactone, and total), ash, proline (21), and protein (22) may be included.

Carbohydrate analysis as described here is of little or no value in detecting the addition of HFCS to honey; the material sufficiently resembles honey in its major constituents and is so purified that its addition does not change composition sufficiently for reliable detection. The use of $^{13}\text{C}/^{12}\text{C}$ ratio (1) does provide an absolute method for this purpose. In addition, Kushnir (23) has developed a thin layer chromatographic procedure that, when applied to a suitably prepared concentrate of trace higher sugars, will detect the addition of 5% or more HFCS to honey. This has been successfully tested collaboratively (2). A suggested order of procedure is shown below for the analyses of a questioned sample. A wider and more definitive set of analytical guidelines is in preparation which will differentiate in more detail between genuine and adulterated honey, based on data from this and other sources.

Detection of Honey Adulteration: Recommended Order of Procedure

Perform test A and/or B below:

A. *Determine $\delta^{13}\text{C}$ (1)*: Values less negative than -21.5‰ are conclusive for adulteration with corn or cane sirups. Values between -21.5‰ and -23.4‰ are inconclusive and require testing by the TLC method. Values more negative than -23.4‰ characterize pure honey.

B. *Apply TLC test (23)*: Positive test demonstrates presence of about 5% or more of high fructose or conventional corn sirups, which can be differentiated by determining distribution of sugars, glucose content, and fructose/glucose

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ratio. If TLC test is negative, carry out HMF test.

Determine HMF content (3): The following conclusions can be drawn from the amount of HMF found in the sample:

20 mg/100 g or more: Adulteration with invert sirup is strongly implied. Confirm with distribution of sugars, glucose, sucrose, and fructose contents.

10–20 mg/100 g: Sample may be heat- or storage-abused honey. Carbohydrate analysis should differentiate between such honey and adulterated honey.

<10 mg/100 g: Determine glucose content. If >40%, sample is not genuine; if between 38–40%, absence of specific pollens indicates adulteration; if <38%, sample is probably genuine.

Acknowledgments

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REFERENCES

- (1) White, J. W., Jr, & Doner, L. W. (1978) *J. Assoc. Off. Anal. Chem.* **61**, 746–750
- (2) White, J. W., Jr, Kushnir, I., & Doner, L. W. (1979) *J. Assoc. Off. Anal. Chem.* **62**, 921–927
- (3) White, J. W., Jr, & Siciliano, J. (1980) *J. Assoc. Off. Anal. Chem.* **63**, 7–10
- (4) White, J. W., Jr, Riethof, M. L., Subers, M. H., & Kushnir, I. (1962) *Composition of American Honeys*, Tech. Bull. 1261, Agric. Res. Serv., U.S. Dept. of Agric., Washington, DC
- (5) White, J. W., Jr, (1975) in *Honey: A Comprehensive Survey*, E. Crane (Ed.), Heinemann, London, UK, pp. 157–206
- (6) White, J. W., Jr (1978) in *Advances in Food Research*, C. O. Chichester, E. Mrak, & G. F. Stewart (Eds.), Vol. 24, Academic Press, Inc., New York, NY, pp. 287–374
- (7) Thean, J. E., & Funderburk, W. C., Jr (1977) *J. Assoc. Off. Anal. Chem.* **60**, 838–841
- (8) White, J. W., Jr (1979) *J. Assoc. Off. Anal. Chem.* **62**, 515–526
- (9) Doner, L. W. (1977) *J. Sci. Food Agric.* **28**, 443–456
- (10) Doner, L. W., Phillips, J. G., & White, J. W., Jr (1979) *J. Assoc. Off. Anal. Chem.* **62**, 186–189
- (11) Browne, C. A. (1908) *Chemical Analysis and Composition of American Honeys*, U.S. Bur. Chem. Bull. 110, Washington, DC
- (12) White, J. W., Jr (1964) *J. Assoc. Off. Agric. Chem.* **47**, 488–491
- (13) Eckert, J. E., & Allinger, H. W. (1939) *Physical and Chemical Properties of California Honeys*, Calif. Agric. Expt. Sta. Bull. 631
- (14) Codex Alimentarius Commission (1969) *Recommended European Standard for Honey*, CAC/RS-12-1969, Joint FAO/WHO Food Std Program, Rome, Italy
- (15) Hadorn, H., Zürcher, K., & Strack, C. (1974) *Mitt. Geb. Lebensm. Hyg.* **65**, 198–208
- (16) Battaglini, M. B., & Bossi, G. (1972) *Apiacta* **7**, 5–8
- (17) Echigo, T. (1970) *Bull. Fac. Agr. Tamagawa Univ.* **10**, 3–12
- (18) Wood, P. J., Siddiqui, I., & Weisz, J. (1975) *J. Apic. Res.* **14**, 41–45
- (19) Bacon, J. S. D., & Edelman, J. (1950) *Arch. Biochem.* **28**, 467–468
- (20) White, J. W., Jr, & Maher, J. (1953) *Arch. Biochem. Biophys.* **42**, 360–367
- (21) White, J. W., Jr, & Rudyj, O. N. (1978) *J. Apic. Res.* **17**, 89–93
- (22) White, J. W., Jr, & Rudyj, O. N. (1979) *J. Apic. Res.* **17**, 234–238
- (23) Kushnir, I. (1979) *J. Assoc. Off. Anal. Chem.* **62**, 917–920