

# The Chemical Composition of Honey

David W. Ball

Department of Chemistry, Cleveland State University, Cleveland, OH 44115; [d.ball@csuohio.edu](mailto:d.ball@csuohio.edu)

Honey is nature's original sweetener. It has been used as a food for at least six thousand years and for much of that time was the sole source of sweet for much of the world's population (1). Honey is produced by six to eleven of the approximately 20,000 species of bees (2), with the exact number depending on the authority consulted. Collectively, however, these species produced over 174 million pounds of honey in the United States in 2005 (3). In addition to producing honey, a variety of crops are dependent on honeybees for pollination: apples, avocados, blueberries, cherries, cranberries, sunflowers, alfalfa, cucumbers, kiwi fruit, melons, and vegetables. Interestingly, without honeybees, there would be virtually no almond crop (3).

At first approximation, honey is a supersaturated sugar solution. However, honey is much more than that. Its unique (though variable) combination of components makes honey a prized addition to the diet. In this article, we will consider the chemical composition of honey.

## Nectar

Virtually all honey derives from nectar, a derivative of phloem sap that is expressed from specialized cell groups called *nectaries* (2). Nectaries are termed *floral* if they occur as part of a flower or *extrafloral* if they occur elsewhere on a plant. Nectar is an aqueous solution of sugars, amino and other acids, proteins, lipids, minerals, and other components. The exact composition of nectar varies tremendously, depend-

ing on the plant species and the environmental conditions. For example, the total sugar content can range from 5 to 80 percent of the nectar (1). The types of sugars can also vary; typical sugars are shown in Figure 1. In many nectars, sucrose is the main or exclusive sugar, while in some nectars sucrose, glucose, and fructose are present in roughly equal quantities. For example, in the families Lamiaceae (mints) and Ranunculaceae (buttercups and clematis) sucrose is the dominant sugar. Some nectars have very little sucrose but varying proportions of glucose and fructose as it is in the families Brassicaceae (mustard and cabbage) and Asteraceae (asters, daisies, and sunflowers) (4). Only rarely are other sugars found. Raffinose, galactose, and sorbitol have been found in a few plant nectars, but they are not widely found (1). Phloem sap contains mainly sucrose, so a chemical change must occur to produce glucose and fructose in the nectar. These chemical changes are mediated by transglucosidases and transfructosidases that are found in the nectaries.

Amino acids are found in nectar, but at low quantities, typically 0.002–4.8% of the total solids in the nectar (1). This is usually too low to be considered a viable source of amino acids for honeybee dietary needs; bees typically meet their protein needs from pollen. In a survey of 395 tropical and temperate floral nectars, Baker and Baker (5) found a variety of amino acids in a varying proportion of samples, as listed in Table 1. Other components of nectar include lipids, organic acids (including ascorbic acid, vitamin C), and minerals (6).

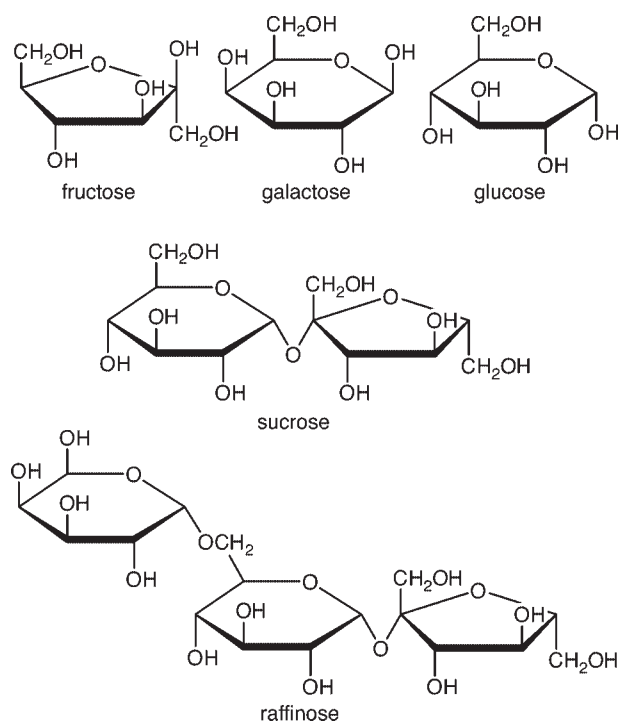


Figure 1. Structures of some of the common sugars found in nectar and honey.

Table 1. Occurrence of Individual Amino Acids in 395 Floral Nectars

Amino Acid	Number of Nectars	Percentage of Nectars
Alanine	380	96
Arginine	356	90
Serine	352	89
Proline	344	87
Glycine	332	84
Isoleucine	287	73
Threonine	263	67
Valine	260	66
Leucine	255	66
Glutamic acid	245	62
Cysteine	218	55
Phenylalanine	216	55
Tyrosine	204	52
Tryptophan	189	48
Lysine	162	41
Glutamine	162	41
Aspartic acid	128	32
Asparagine	106	27
Methionine	80	20
Histidine	77	19

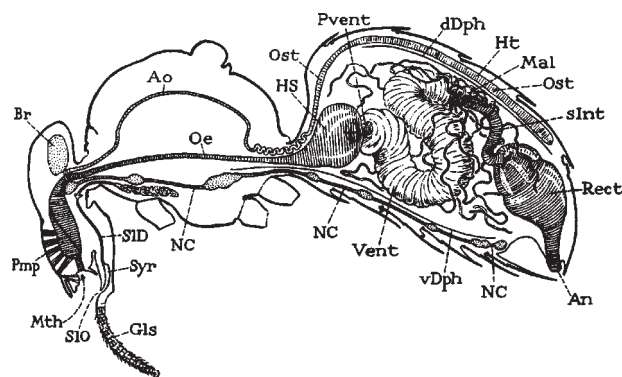


Figure 2. Some general anatomy of a worker bee. Only the relevant parts are defined: Gls—tongue; SIO—salivary orifice; Syr—salivary syringe; SID—salivary duct; Oe—oesophagus; HS—honey stomach; and Vent—ventriculus (intestine) (diagram from ref 1).

The exact composition of the nectar has a definite impact on the flavor and quality of the finished honey. Although it is impossible to force bees to visit a particular nectar source, it is not uncommon to locate beehives near a large quantity of one type of flowering plant, such as a clover patch, orange grove, pumpkin patch, or other substantial acreage devoted to one plant. Since it would be likely that most of the nectar would derive from that source, the honey produced can legitimately be called “clover honey” or “orange blossom honey” or “pumpkin blossom honey”, and these “single-source” honeys have a distinctive and sometimes recognizable smell and flavor.

Bees may also collect honeydew, a liquid secreted by insects of the order Hemiptera, the most common example being aphids (7). Although similar to honey and considered a delicacy by some cultures, it is generally considered inferior to real honey and will not be considered here further.

## Nectar into Honey

Bees have a complex anatomy that is used to collect nectar from plants. A diagram of some relevant bee anatomy is shown in Figure 2. When a worker bee drinks nectar from a flower, a maximum of about 25 mg of nectar is stored at the bottom of the esophagus in a widened region called the honey stomach or honey sac (1). During the course of this process, the nectar is mixed with the secretions of two glands, the salivary and the hypopharyngeal. It is the secretions of the latter glands, which contain enzymes, that begin to chemically alter the nectar. These enzymes include diastase and invertase, both of which break down larger saccharides, especially sucrose, into monosaccharides. Glucose oxidase is also present. Thus, chemical transformation of the nectar into honey begins almost immediately (7).

In the hive, the forager bee disgorges the nectar and transfers it to a house bee. The house bee drinks the nectar through her proboscis and may regurgitate and redrink the nectar additional times over a period of 15–20 minutes. In doing so, more enzyme-containing secretions are mixed with the nectar. The nectar may also be passed to another house bee for additional processing. Eventually, the nectar droplet is deposited into the honeycomb.

Table 2. Chemical Composition of U.S. Honeys

Component	Average (%)	Range (%)
Water	17.2	12.2–22.9
Fructose	38.4	30.9–44.3
Glucose	30.3	22.9–40.7
Sucrose	1.3	0.2–7.6
Other disaccharides	7.3	2.7–16.0
Higher sugars	1.4	0.1–3.8
Gluconic acid	0.57	0.17–1.17
Acids (not including gluconic)	0.43	0.13–0.92
Lactones	0.14	0.0–0.37
Minerals	0.17	0.02–1.03
Nitrogen	0.04	0.0–0.13

NOTE: Data are from ref 1. The pH of honey is ~3.9 and ranges from 3.4 to 6.

The ripening of nectar into honey is a combination of two processes: the conversion of sucrose into glucose and fructose and the evaporation of excess water. Honey is less than 20% water, so as much as 80% of the total nectar must be evaporated. Bees are constantly fanning the honeycomb with their wings, hastening water evaporation. In fact, excess humidity can be detrimental to honey production, and beehives are typically slightly tilted to prevent pooling of water inside the hive. The actual conversion process from salivated nectar to honey takes 1–3 days. Bees continue to add nectar to individual honeycomb cells until the chamber is full, after which the bees will cap the cell with newly produced beeswax (7).

## Honey

Depending on the source(s) of nectar, honey can have a variable composition. The average composition of a sampling of 490 honey samples from around the United States (1, p 871) is listed in Table 2. The wide range of some components is due to the equally wide range of nectar sources. Single-source honeys will have a lower range of values because of the greater consistency in the composition of the nectar.

One of the defining characteristics of honey is its low moisture content. Folklore has it that honey is the only food that will not spoil. This is due to its low moisture content; bacteria, for example, cannot survive in a medium with such a high osmotic pressure (8). However, this is not to say that honey cannot be unsafe. It can be made from nectar that is not palatable or even poisonous (such as that of rhododendron) or may contain spores of mold or other organisms that can act as allergens or toxins, which is the reason not to feed honey to babies less than one year old (8). Honey that is harvested before it is completely ripe has a higher moisture content and may be vulnerable to spoilage. Also, honey is hygroscopic and will absorb water from the atmosphere if it is not kept in a well-sealed container.

Honey is typically about 83 degrees Brix or about 83% sugar. (The “degrees Brix” unit, abbreviated °Bx, indicates how many grams of sucrose are dissolved in 100 grams of solution; it is a common unit used to describe honey, maple syrup, fermenting grape juice, and frozen concentrated or-

**Table 3. Mineral Content of Light-Colored Honey**

Mineral	Average (ppm)	Range (ppm)
Potassium	205	100–588
Sulfur	58	36–108
Chlorine	52	23–75
Calcium	49	23–68
Phosphorus	35	23–50
Magnesium	19	11–56
Sodium	18	6–35
Iron	2.4	1.2–4.8
Copper	0.3	0.14–0.70
Manganese	0.3	0.17–0.44

NOTE: Data are from ref 1.

**Table 4. Vitamin Content of Honey**

Vitamin	Concentration (ppm)
Riboflavin	0.63
Pantothenic acid	0.96
Niacin	3.2
Thiamin	0.06
Pyridoxin	3.2
Ascorbic acid	22

NOTE: Data taken for U.S. samples only from ref 1.

ange juice; ref 9.) Although the typical *individual* concentrations of sugars are below the individual saturation limit (about 69 g/100 g H<sub>2</sub>O for glucose and 380 g/100 g H<sub>2</sub>O for fructose; ref 10), the *total* sugar concentration is high enough to consider honey a supersaturated solution. Indeed, over time, glucose will precipitate from solution, as many a long-time keeper of honey will confirm. Honey stored at cool temperatures is also prone to glucose precipitation.

Most of the carbohydrates in honey are monosaccharides, with more fructose than glucose. At a distant third place is sucrose; other disaccharides present in honey, albeit in very small quantities, are maltose, isomaltose, nigerose, turanose, and maltulose. At about 1% or less of the total sugars, a small quantity of higher sugars, oligosaccharides, and dextrans are also present in honey (7). Interestingly, the so-called sugar spectrum of finished honey is not static. Rather, it does change with time. A slight (<15%) decrease in the quantity of fructose and glucose occurs over time owing to the acid-catalyzed formation of maltose and other reducing disaccharides (1).

Honey is deceptively acidic, as the high sugar content tends to mask the acidity in the taste. The average pH of honey is 3.9, which is equivalent to an ~0.0001 M aqueous solution of a strong monoprotic acid. It was originally thought that formic and citric acids were the dominant acids in honeys. However, it is now understood that gluconic acid (2,3,4,5,6-pentahydroxyhexanoic acid) is the predominating acid in honey. It is produced by glucose oxidase from bee secretions acting on glucose. Gluconic acid has a  $pK_a$  of 3.7 (compared to the  $pK_a$  of acetic acid of 4.75) and is also a good chelating agent. Other acids that have been identified in honey include acetic, butyric, citric, formic, lactic, malic, malic, oxalic, and succinic acids (1).

The mineral content of honey has a 50-fold range of values, the largest of any component. The minerals found in honey, their average values, and their ranges are listed in Table 3. Note that by US FDA standards, most honey can be classified as a low-sodium or sodium-free food! Trace elements found in honey include chromium, lithium, nickel, lead, tin, and zinc (1).

In addition to diastase, invertase, and glucose oxidase, other enzymes found in honey include catalase and an acid

phosphatase. There is only a small quantity of protein in finished honey as indicated by the low nitrogen content in Table 2. There are also free amino acids in honey, with proline being the dominant amino acid present. It is generally agreed that most of the amino acid content derives from the bees, not the nectar or the pollen. Total amino acid rarely exceeds 300 ppm (7).

Honey contains small but detectable quantities of vitamins, as listed in Table 4. However, honey should not be considered good sources of vitamins, as the concentrations of many are best described in the parts per million range (1).

The chemical composition of honey affects several of its physical characteristics. As a concentrated sugar solution, honey has a high refractive index (about 1.49) and viscosity (typical clover honey has a viscosity of about 120 poise at room temperature, compared to 0.0089 poise for water). The specific gravity of honey is about 1.4, and the specific heat of honey is about 40% less than that of pure water (1).

The aroma and flavor of honey are attributed to the sugars, the acids, and other volatile components in honey. These volatile components include a variety of C<sub>1</sub>–C<sub>5</sub> aldehydes and alcohols. Methyl and ethyl formate have also been identified in honey. It has been noted that many phenylacetic esters have a honey-like taste and aroma (11).

One obvious characteristic of honey is its color. Mass-produced honey is a blend made from many honey sources, and so may be uniform in color. But individually harvested honey can have a range of colors depending on the season, the nectar source, the time between nectar collection and honey harvest, and production details (heating having the most obvious color impact). The author's experience with his own beehive indicates that the color of the honey in the combs changes suddenly from light to dark in the middle of the summer without a gradual transition, obviously caused by a change in available nectar sources. Curiously, the chemicals most responsible for the color of honey remain largely unknown. Some researchers suggest that the color is due to the presence or absence of carotenoids; others suggest that polyphenols are responsible. Another possibility is a chemical caramelization of the saccharides in honey, catalyzed by the acids present. Others suggest a Maillard reaction between the sugars and amino acids. Whatever the source of the color,

it is generally true that the darker the honey, the more intense the flavor (1, 5).

## Conclusion

Honey is a fascinating food. Although it can be characterized as an impure, supersaturated sugar solution, the chemistry of honey is more than just that. Their variability in color, aroma, and flavor make sampling different honeys an educational and tasty—and potentially sticky—experience.

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