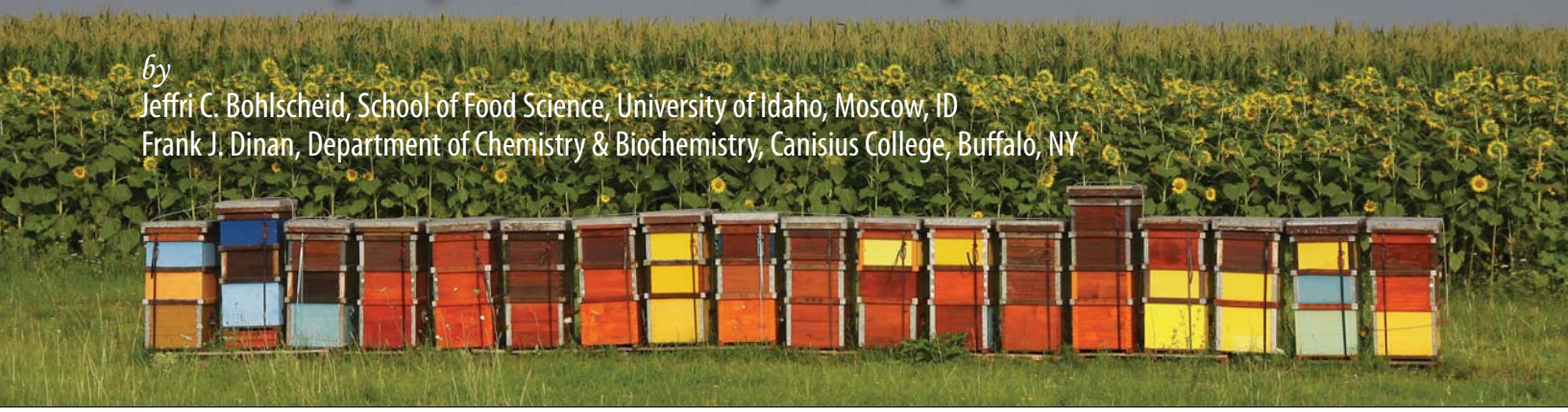
The Case of the Missing Bees: High Fructose Corn Syrup and Colony Collapse Disorder



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Part I – Changes in the Lives of Bees

Almond butter is a delicious, upscale alternative to peanut butter and we love it. But its price has increased nearly three-fold over the last two years while that of peanut butter has changed very little. The reason for this is surprising: almonds are much more dependent on honeybees for pollination than are peanuts. The California almond crop, by far the world's largest, used an unbelievable 40 billion honeybees to pollinate it in 2005 and about a third of that number of bees is no longer available (Benjamin and McCallum, 2009).

Since 2007, nearly a third of the honeybees in North America, Europe, and South America have died for unknown reasons. How important is this to our lives? A U.S. Department of Agriculture/Cornell University study estimates that honeybees pollinate nearly a third of everything that we eat (beeculture.com, 2000). If these bees disappear, fruits, vegetables, and nuts will go with them, meat production will severely decline, and we will be in very bad shape, indeed.

Two significant changes have occurred in the world of honeybees in the United States since the mid1970s: (1) there has been a steady increase in the amount of high fructose corn syrup (HFCS) consumed by honeybees, and (2) about one third of the honeybee colonies in the U.S. have "collapsed" and are no longer available. The latter phenomenon is called colony collapse disorder (CCD) (Kaplan, 2009). It must be noted, however, that while these phenomena correlate, correlation can exist without causation. This case study will consider whether recent research establishes a causal link between these two observations.

Many things, ranging from pesticides to cell phone use to virus infestations, have been blamed for CCD and it is likely that there may be multiple causes for this phenomenon (Millus, 2009). In this case study, however, our focus will be limited to recently disclosed problems that reportedly arise when HFCS is used to feed honeybees.

HFCS is produced using an enzyme (alpha-amylase) to break down cornstarch, a high molecular weight glucose polymer, into smaller, approximately eight glucose unit fragments. These units are then treated with a second enzyme (amyloglucosidase) that breaks them into individual glucose molecules (Crabb, 1999). Glucose isomerase, a third enzyme, then converts the glucose molecules into fructose. A blend of 45% glucose and 55% fructose, called HFCS-55, has been found to closely approximate the taste of sucrose (table sugar) and is the most widely used form of HFCS in the U.S. It has become ubiquitous in our diets. A U.S. Department of Agriculture (USDA) report demonstrates how dramatically the use of HFCS has increased. It indicates that the per capita consumption of HFCS has increased from 318 grams to 18 kilograms over the period 1970 to 2006 (LeBlanc, 2009).

Questions

1. Sucrose is a disaccharide that undergoes hydrolysis to form two monosaccharides, glucose and fructose, when it is consumed. Why then should there be any significant difference between consuming sucrose and HFCS-55?
2. Can HFCS-55 be considered a natural substance? Explain your reasoning, specifically listing the criteria by which you believe a substance may be considered "natural" as opposed to "unnatural."
3. Both "natural" and genetically modified (GM) forms of corn are available in the United States. Based on the criteria that you have listed for Question 2, does your answer to the previous question depend on whether the HFCS-55 is made from "natural" or GM corn? Explain your reasoning.

Commercial beekeepers, called apiarists, keep hundreds or even thousands of honeybee colonies. They rent their colonies to farmers who need bees to pollinate their crops. At appropriate times, these colonies must be moved from one location to another in response to farmers' needs. To do this, the bee hives are covered with nets, stacked four levels deep on trailer trucks, and shipped hundreds or even thousands of miles to locations where their services are needed. For instance, colonies of bees may spend their summer in the Dakotas where pollen is abundant, be trucked to California in the winter to pollinate the almond crop, then be moved to Florida to service citrus crops and later to Maine to meet the needs of berry farmers. The typical commercial bee colony is reported to travel an average of 5,500 miles per year (Benjamin, 2009). In a sense, honeybees are now being used as if they were inanimate pollination machines.

While being transported, the bees have no access to pollen and must be fed. Prior to the mid-1970s, apiarists used concentrated syrup made from sucrose dissolved in water to feed the bees while they were in transit. After that time, HFCS-55 has largely replaced sucrose as the bees supplementary feed because it is cheaper and easier to handle than sucrose, and it is acidic, making it fermentation-resistant and capable of being stored for long times (LeBlanc, 2009). This practice continues today.

Question

4. It has been argued that just the process of transporting honeybees from one crop location to another over long distances may contribute to CCD regardless of what the colonies are fed. Is there evidence to support or refute this argument? Explain your reasoning.

The structures of the chemicals discussed in this case study are shown in Figures 2, 3 and 4 on the next page.

Figure 1. Moving spring bees from South Carolina to Maine for blueberry pollination.

Figure 2. Sugar

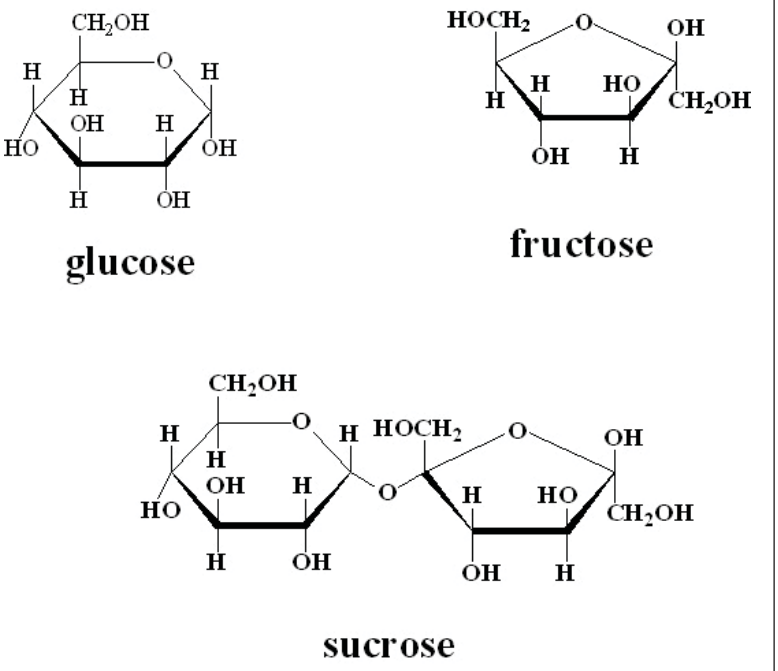


Figure 3. Starch (amylose form)

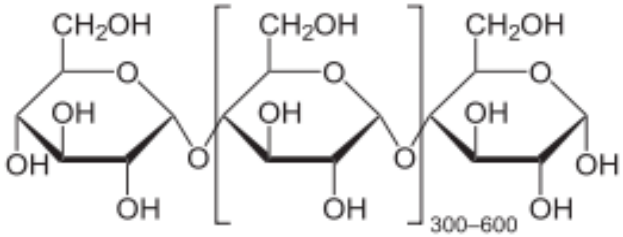
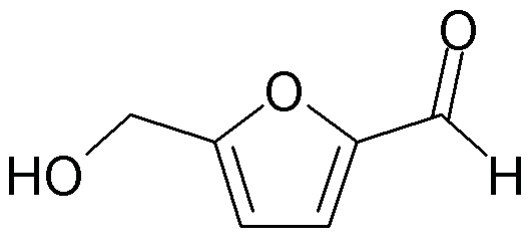


Figure 4. 5- hydroxymethylfurfural (HMF)



Part II – High Fructose Corn Syrup and 5-Hydoxymethylfurfural (HMF)

A recent study has demonstrated that fructose can be readily dehydrated under acidic conditions to form HMF in high yield (Huber, 2006). This observation, together with the fact that HFCS-55 with its potentially elevated level of fructose is fed to bees while they are being transported and cannot feed themselves, has led to concerns about the toxicity of HMF to bees. A USDA initiated study was conducted to investigate these concerns (LeBlanc, 2009).

The LeBlanc study established that commercial HFCS-55 supplies are acidic, having an average pH of 4.6, and contain metal ions, particularly manganese, that catalyzes the dehydration of fructose to HMF. The study conclusively demonstrated that HMF levels in HFCS-55 increase when it is stored at high temperatures. The study also demonstrated that commercially supplied HFCS-55 samples that had initial HMF levels of approximately 20 ppm increased to 70 ppm and 240 ppm HMF, respectively, when the samples were stored at 104° and 120° F for 36 days.

Mortality data for bees fed on HFCS-55 containing various concentrations of HMF established HMF's toxicity: bees fed on HFCS-55 containing 57, 100, 150, and 200 ppm of HMF all had approximately 20% survival rates after 26 days—and this survival rate dropped to 10% when the bees were fed on HFCS-55 containing 250 ppm HMF. The normal life expectancy of worker bees ranges from 28 to 36 days for workers (females) and from 40 to 50 days for drones (males) (Wiki.answers.com, 2010).

Questions

5. Trace metals such as manganese that catalyze the formation of HMF were found to be present in all of the commercial HFCS samples that were studied by LeBlanc. How can this observation be explained?
6. Four reaction steps must occur for fructose to be converted into HMF. What are these?

Part III – The Other Side of the Story

The Corn Refiners Association (CRA) has challenged the results obtained in the LeBlanc study (Halliday, 2009). They point out that their members have numerous safety measures in place for producing high quality HFCS, and that it has been used safely as a food supply for both humans and honeybees for decades. They further argue that HMF has been found in all sweeteners, including honey itself. Honey is largely a mixture of fructose (~38%), glucose (~32%), and water (~18%) together with pollen and other relatively minor ingredients (Bogdanov, 2009).

Question

7. Suggest a way by which HMF could be formed in honey.

The CRA argues that the case for HMF as a cause for CCD is dubious because the USDA study used highly unusual conditions—extreme temperatures, prolonged storage times, or non-standard storage containers, which were aimed at maximizing HMF formation. The CRA-recommended storage standard for HFCS-55 is between 75° and 86° F. Moreover the CRA specifies that the sweetener be stored in stainless steel or stainless steel coated vessels (Halliday, 2009). While these criteria may be adequate, they may not always be met by those using HFCS in actual field conditions.

Question

8. In your judgment, were the conditions used in the USDA study unreasonable or reasonable reflections of possible actual field conditions? Explain your reasoning.

The CRA points out that a paper published in 2000 states that HMF occurs in many foods in high concentrations, sometimes at one part per thousand in dried fruits (Janzowski, 2000). This paper reports that a variety of tests of HMF's toxicity conducted on mammalian cells indicated that it does not pose a serious health risk over the range of concentrations tested.

Question

9. Is the data reported in the Janzowski paper relevant to the question of HMF's potential toxicity to honeybees? Explain your reasoning.

Sales of HFCS in the U.S. are very substantial; it is a major item of commerce. The U.S. Food and Drug Administration (FDA) first awarded Generally Recognized as Safe (GRAS) status to it in 1983 and that status was reaffirmed in 1996 (Schorin, 2005). In view of these facts, it is seems unlikely that the commercial use of HFCS in the U.S. would be restricted easily.

Question

10. This case gives two very different views on the safe use of HFCS-55 to feed honeybees: that presented in the LeBlanc paper and the alternative put forth by the CRA in their press release (Halliday, 2009). You are to critically evaluate these opposing arguments and clearly list the facts that support the view that you favor.

References

http://www.beeculture.com/beeculture/pollination2000/pg14.htm. (Last accessed 9/14/2010.)

Benjamin, A., and B. McCallum. 2009. *A World Without Bees*. New York: Pegasus Books.

Bogdanov, S. 2009. *Bogdanov's Book of Bees.* New Brunswick, Canada: Central Beekeepers Alliance.

Corn Refiners Association. 2009. Press Release: Study on HMF and High Fructose Corn Syrup Flawed. http://www.sweetsurprise.com/news-and-press/press-releases/hmf-honeybees-hfcs. Last accessed Sept. 18, 2010.

Crabb, W.D., and J.K. Shetty. 1999. Commodity scale production of sugars from starches. *Current Opinions in Microbiology* 2(3): 252–6.

Halliday, Jess. 2009. Humans, bees not at risk from heated HFCS, says CRA. FoodNavigator-USA.com. http://www.foodnavigator-usa.com/Science-Nutrition/Humans-bees-not-at-risk-from-heated-HFCS-says-CRA. Last accessed January 28, 2011.

Huber, G.W., et al. 2006. Synthesis of transportation fuels from biomass: Chemistry, catalysts and engineering. *Chemical Reviews* 106(9): 4044–4098.

Janzowski, C., et al. 2000. 5-Hydroxymethylfurfural: Assessment of mutagenicity, DNA damaging potential and reactivity toward cellular glutathione. *Food and Chemical Toxicology* 38(9): 801–9.

Kaplan, K. 2009. Survey reports latest honey bee losses. USDA/ARS.

LeBlanc, B.W., et al. 2009. Formation of hydroxymethylfurfural in domestic high-fructose corn syrup and its toxicity to the honeybee *(Apis mellifera). Journal of Agricultural and Food Chemistry* 57(16): 9369–9376. (Added issue).

Millus, S. 2009. No one villain behind honeybee collapse. *Science News Web Edition.* (Dec. 25).

Schorin, M. D. 2005. High fructose corn syrups, Part 1: composition, consumption and metabolism. *Nutrition Today* 40(6): 248–252.

USDA Agricultural Research Service. 2009. Honeybee Colony Losses in U.S. Almost 30%. (May 29).

Wiki.answers.com. 2010. Last accessed Sept. 18, 2010.

Wilson, W.T., and D.M. Menapace. 1977. Disappearing disease of honey bees: a survey of the United States. *American Bee Journal* 116(11): 520–521.