A Honey of an Issue

by Dr. Peter Awram

Liquid gold, Nectar of the Gods, Ambrosia -- all terms that have been used to refer to honey throughout history. Honey has held a privileged place in society for thousands of years. If you are a beekeeper, you can't avoid it. Even operations that focus on pollination, or queens and packages can't get away from it and it can feel like a nuisance. But the industry revolves around honey. Without consistent income from honey, most beekeeping operations cannot survive. And that means there is no market for the queens or packages that are produced by others.

As a beekeeper, I'm very aware of all the costs associated with running a business. There are the basics of equipment – vehicles, forklifts, storage buildings etc. The specialty beekeeping equipment such as extracting lines. Pest control is now very significant. All this in a business where weather can be the most significant factor in success. This is not an easy business. I spent a lot of time getting a PhD but running a bee business has proven to be much harder.

What it comes down to though is that the income from honey becomes very significant in the success of the business. Beekeepers need to receive a fair and honest price for their product that reflects the actual costs of running that hive. We're not seeing that.

What has become very obvious over the last 12+ years is that there has been a significant increase of fraud in the honey business. Norberto Garcia has been publishing charts showing massive increases in honey exports without corresponding increases in hives from certain countries[1]. We have had significant scandals erupting from detection of fake honey in many different countries – Australia, the United States, Canada and Europe.[2] [3] [4] [5]

Despite the world's biggest successful food fraud prosecution happening in the US resulting from charges laid in 2008 [3], fraud seems to have increased. There seem to be a number of reasons for this:

- A lack of enforcement coupled with adequate regulations
- A move from corn and cane syrup adulteration to rice syrup which is harder to detect
- Technical sophistication where markers are removed using resin filtration
- A lack of reliable/reproducible testing methods for detection
- Playing catchup – having to generate new methods of fraud detection as new methods of fraud are developed

All this has led to growing frustration among beekeepers like ourselves after working diligently at producing a high quality product to be subject to the whims of the marketplace.

So when I became aware of this new technique for fraud detection it was a revelation that there might be a way to move to a honey market that provides honest returns. The technique uses magnetic resonance something that I understood from my university chemistry classes. A long established method that allows identification of a molecules structure. There were fun puzzles in those classes where you looked at the spectrum to decipher the

structure of the molecule. This is a robust technology that has resulted in no less than 6 Nobel prizes and is used in all sorts of industries including the medical field where MRI (magnetic resonance imaging) is now a major tool in hospitals.

Another factor that made this method stand out is the great leap forward in data processing science. This put another dimension on the method. It was not necessary to tease out the exact details of the complicated spectrum that generated. An algorithm could be designed to compare the spectrum from the test sample and compare it to a set of known honey samples. This would just be like fingerprints in a database being used to identify the criminal. It was a whole new way of looking at not just honey fraud, but food fraud in general.

Methods of Detecting Honey Fraud

There seem to be an endless number of methods for detecting honey fraud. Many found on the internet do not work at all, but a look through the scientific literature provides an abundance of papers where various honeys were examined (Table 1). These range from microscopic analysis of pollen to whole sample analysis with very expensive machines. To evaluate the honey, it's necessary to understand what the different tests look for and their limitations.

There are a number of standard tests that have been developed over the years. One of the most used is just taste. Certainly this has its use, but it is very subjective. Despite the hoopla around wine tasting, systematic testing has shown that it is a pretty poor way to judge wines[6].

Pollen analysis is also prominent. This is simply examining and counting the distinct pollen grains in a microscope, but it is well known that the numbers do not reflect the composition of the honey well and filtration removes pollen. And it is possible to add pollen to the honey from other areas to disguise the origin.

Hydroxymethylfurfural (HMF) increases with heating during processing, but can also be an indicator of HFCS addition. Diastase and other enzyme activities can be measured to indicate the same things. The presence of amylases can suggest that starch syrups have been added.

Stable Isotope Ratio Analysis (SIRA) is a method developed for identifying C4 contamination and works well unless C3 sugars (e.g. rice syrup) is used. The two major constituents of honey are glucose and fructose. Unfortunately, these components are very easy to reproduce. When the US started producing excess corn and developed methods of producing high-fructose corn syrup from starch, the resemblance to honey made it an easy adulterant. HFCS does have an Achilles heel. Because of the way the plant processes CO_2, it is easy to identify C4 plant derived sugars – corn and sugar cane being the ones most relevant here.

Testing methods are continually under development. There has been something like an arms race in honey for decades now. A new method of testing would identify fraud and then the scammers would find a way around it. Analytical techniques have been playing catchup for some time and considering the massive increase in adulterated honey that has occurred the battle has not been going well. However, over the last decade a number of very advanced analytical

equipment has been used to look at the problem of honey fraud and a new generation of techniques are in the process of development. Call it Honey Testing version 2.0.

These rely on the use of a database of authentic honey as well as known adulterated samples. The most well-developed of these is Magnetic Resonance (MR). A number of different methods have been used, but the Bruker Honey Screener is the most well developed and has the largest database. This technique looks at the entire sample of the honey. Think of it as hitting a whole bunch of bells at once with a mallet. The sound or resonance that comes back tells you about each bell. There are bells with low tones and others with high notes. You can compare this with a database of known samples and determine what is there. The system developed by Bruker is very reproducible. Machines around the world use a standardized protocol that allows for excellent reproducibility between machines and a standard report is issued with

Magnetic Resonance can measure specific components like the older tests and is very good at identifying sugar composition, which is very characteristic of floral source. Currently MR directly measures 36 compounds including sugars, amino acids, fermentation products and this will likely increase in the future as the composition of honey is better understood. But what sets MR apart from older techniques is the "fingerprinting" database. When a sample is analysed with MR the data creates a "fingerprint" of the sample. Then using the latest techniques in data handling, it is possible to compare it to a database of known authentic and fraudulent samples. When a similar fingerprint is found in the database it is possible to determine floral source and geographic region of the honey. Or to match it to known samples. If the sample is labelled as a specific floral type or country of origin, it is possible to say if it matches the other samples from that flower or country to determine if there is mislabelling. Mismatches or no match indicate problems. Using the reference database, a number of tests are performed that have been correlated with syrup adulteration. The major advantage of this technique is that a specific marker or adulterant need not be identified. It is the deviation from the known samples that is examined. The usefulness of the technique increases with more samples in the database and the more specific the labelling of the of the sample. For example, by identifying the honey as from Mesquite from Arizona, there is much less variation in the sample database for comparison. It is only necessary to check if it is consistent with the Arizona Mesquite honey samples. Although as it stands now there are no Mesquite honey samples from Arizona in the database. It is these absences from the database that need to be fixed.

It is possible to take this principle and using a "fingerprint" and compare it to a known database to identify honey and screen out fakes or blends. Mass spectrometry is the next most advanced instrument in this category of second-generation techniques. While both magnetic resonance and MS are capable of identifying specific compounds, it is the fingerprinting technique that holds the promise to cutting out the adulteration in the marketplace. But these require very large databases. Currently the Bruker database is 18000+ samples and a new release is expected before the end of the year with a considerable increase in the number of samples, but it is the creation of this database that is of utmost importance.

At True Honey Buzz, our company has been working on grabbing authentic samples directly from hives to minimize the issues with authenticating the honey. Issues of feed making its way

into honey supers are always present, but we can minimize this through timing of sample collection and most importantly large numbers of samples.

Data processing and manipulation techniques developed by Google and Amazon are filtering down to where you can use them to look at what is found in honey. Bad samples where there is adulteration or bee feeding can be identified by clustering algorithms. By comparing samples from wildly different regions that have some similar plants but not others it becomes possible to tease out what traces are specific to a specific flower. Or to specific minerals in the soil allowing geographic distinctions. Weather patterns from year to year are expressed in data.

A number of similar methods are being developed using other machines that look at the entire sample using various different methods. Raman Spectrophotometry, Near-IR and a number of different mass spectrometry (MS) methods. MS covers a lot of different methods and some of the most developed involve using LC (liquid chromatography) which will separate compounds before the MS step. HRMS (High resolution-MS) is also gaining traction. But these methods are still under development.

Instead of looking for specific markers, which can be removed or added to evade detection, now there are hundreds of compounds that are being checked in a single test. And in many cases the exact compound is unknown it is just the signals from compounds that are being recorded by the technique. It becomes a much harder task to replace a compound if its identity isn't even known.

What is honey?

This is a harder question than it seems as first. The Codex Alimentarius developed by the United Nations has a definition of honey[7]. That definition defines a number of exceptions based on floral type and not all the possible honeys are well defined. But it acts as guidance only and has not been consistently adopted in the laws of all countries preventing a consistent front to fraud.

Honey is a natural product which means it varies depending on the flower, the year, the geography and the weather. There is a huge amount of variation in what is called honey and as a result it is not always clear what meets regulations and what doesn't. Apimondia has tried to clarify this point by releasing a statement on honey fraud [8]. The US Pharmacopeia just released their statement on the identity of honey for comment[9].

The general thrust of these documents is that honey consists only of what bees collect from plants and then fully process. Nothing can be added or removed including water. The problem is that honey is so varied and rich that it is not always clear what those components are.

The Commodification of Honey

Despite the long history of honey as a delicacy and privilege, honey is generally marketed as "Honey." This is a great disservice to the industry. It has turned honey into a commodity, meaning that brokers and packers can use honey from anywhere in the world to fulfill their needs. This puts beekeepers at a disadvantage. Inspite of having a unique product, beekeepers have to compete on price with beekeepers around the world that have very different costs of

production and standards of quality. This also devalues the unique and individual properties of honey in the mind of most consumers. There are a few standout examples of distinct honey such as Manuka and Buckwheat, but compare what the average consumer has to say about wine vs honey and it becomes obvious that much of the uniqueness provided by different floral and geographic regions is being lost.

This is starting to change as local food movements gain strength. The marketing of specialty honey by region and floral type is getting more attention. Selling a specialty product can result in a significant increase in price to the beekeeper. This needs to be emphasized by labelling honey by floral type and origin and legislation that ensures that these claims are accurate. As well as allowing higher prices for specialty honey, it makes the identification of fraud considerably easier as the variations that have to be accounted for are smaller.

This marketing need not be only by unfloral type. It is possible to refer to geographic regions and times such as Summer North Dakota honey. These claims can be verified using a number of different techniques that have been developed and have high reliability and reproducibility. It takes away the commodity aspect and provides a unique selling point. One day a consumer may want to try Summer North Dakota and another day a British Columbian Blueberry honey. In this way you are able to market honey as a premium product as seen with wine. It prevents retailers from imposing pressure on packers to lower prices by threatening to stock cheap imported honey.

The cost imposed by label changes are negligible. There is considerable technology that allows for printing portions of labels after application. Efficient and small sized packing machinery is easily obtained. The added value from marketing honey as a premium product far outstrips the associated cost.

Honey is already a premium product in the mind of the consumer. It is not necessary to change the customers perception of honey significantly to market in this manner. If consumers were only looking for a cheap sweetener, honey would not sell at all. There are already many of these at considerably lower cost on the supermarket shelves. Consumers already pay more for honey and they will pay more and buy more when the added value is clearly outlined.

Australia has shown that this is true. The Australian Honey Bee Industry Council Annual Report stated in 2019

> "The media has driven the public to review their purchase decisions and this has driven opportunities for beekeeper owned brands. Supermarkets now report that consumers rank the importance of 100% Australian honey higher than price. To have price rank below 100% Australian origin demonstrates the value that consumers place in the quality of Australian honey and gives a strong position from which to improve market outcomes for beekeepers into the future." [10]

The same report mentions that a poor honey crop in 2004 which resulted in a doubling of retail honey prices had only a 19% drop in sales. Price was not the major factor in honey buying

decisions. It is also reasonable to assume that as consumers adjusted to the new prices that the sales volume would return.

What Really is Honey Fraud?

There is a reasonable consensus on what defines fraud in honey:

- The addition of cheap syrups
- The use of resin technology to remove toxic or undesirable compounds.
- Extraction of immature or unripen honey with high moisture
- Force feeding of sugar syrups to bees to bulk up production
- Mislabelling of the floral or geographic origin

The addition of cheap syrups is what most people think of as honey fraud. Yet these are all considered forms of fraud and each presents different problems for analysis and as a result there is no single test that can check for each possibility. The available testing methods have all shown to be better at detecting some forms of fraud than others.

Stricter labelling rules make the process of identifying fake much easier. There are fewer variables to consider and deviations are easier to identify. While these newer techniques are already having an effect on the market of fraudulent honey, by greatly expanding the databases, significant inroads into removing honey fraud from the marketplace are possible.

How second-generation techniques are already tackling the issue of honey fraud.

Bulking out with cheap syrups

The addition of sugars and syrups to bulk out honey has a long history. But it is the process of turning starch into monosaccharides that resemble honey that has contributed greatly to honey fraud. HFCS (High Fructose Corn Syrup) is the best known of these, but because there is an established test to detect it and invert sugar derived from sugar cane, its use has declined substantially over the last decade. This test goes by several terms C4-test, SIRA (stable isotope ratio analysis, IRMS (isotope ratio mass spectrophotometry) or AOAC 998.12. It requires considerable technical skill and specialized equipment to perform and has a limit of detection of 7%. This is the only method of testing honey recognized by the international analytical testing organization AOAC. The ease of detection of these C4-containing syrups has caused a significant move to syrups derived from rice starch. These syrups have proven to be cheaper than HFCS and are undetectable by SIRA. This has actually proven useful to the fraudsters by showing that their so-called “honey” passes the official SIRA test. They can claim they are not doing anything wrong. A modification of this method using liquid chromatography (LC) has been developed, but results are not easily replicated among labs. Which has resulted in shopping for labs that give the answers desired.

Currently SIRA, LC/EA-IRMS and Magnetic Resonance are the most common ways of detecting sugar adulteration. Some of the cleaner syrups are presenting a bit of a problem to Magnetic Resonance at the moment. The limit of detection of MR is about 2% although this varies depending on the region of the spectrum that is being examined. In our own lab, we have been able to detect syrup adulteration down to 1% but that is under lab conditions with specific syrups. Real world detection rates will vary greatly depending on the quality of the syrup and how much is added. Improvements in the algorithm will allow identification of the dilution of real components in relation to the glucose/fructose ratio showing the value of a large database, but also increased labelling of honey by geographic and floral origins greatly enhances the effectiveness of the "fingerprinting" methodology. Generic honey encompasses a much larger range of values so dilution of valid markers by clean syrups is harder to spot. (Need figure) But this technique allows constant evolution in the algorithms and size of the database to improve detection.

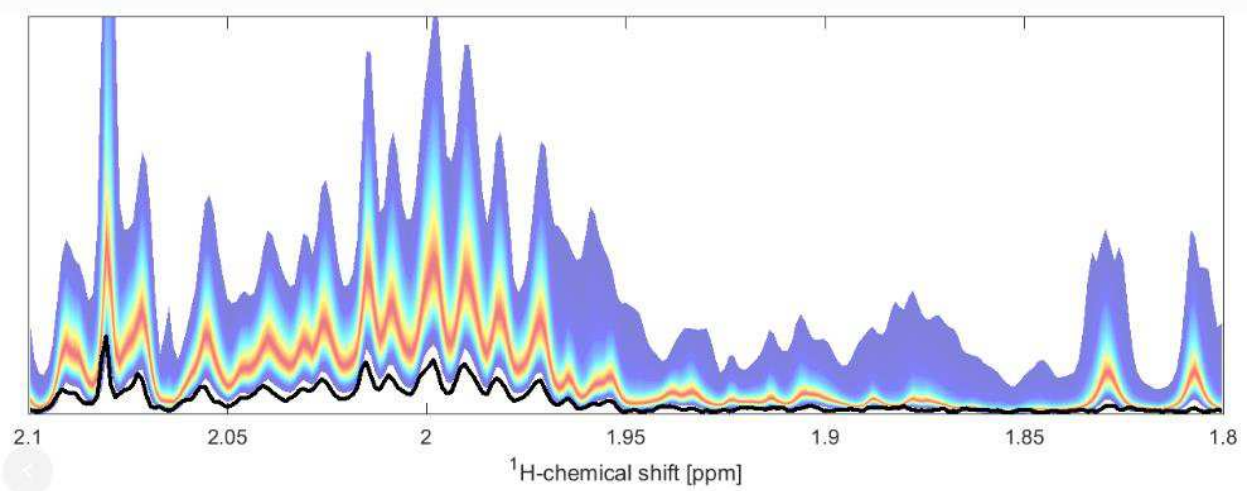
The Rise of Resin technology

Older tests have generally looked at specific markers in syrups. While many of them work well, the scammers have learnt how to bypass the test. Usually it's just a matter of finding a way to remove a component that shouldn't be there or adding one that should. For example, rice syrup can be identified by the presence of arsenic (also referred to as TMR – trace marker rice) yet a number of ways have been developed to remove this from the syrup. One of the major methods for removing contaminants involves the use of resin columns. This involves increasing the water content to allow passage through the columns and then drying down to an acceptable moisture content under 18%. In addition, these columns will remove unwanted tastes, flavours and colors that help disguise the origin of the honey by stripping out many other components that are supposed to be present. Sellers on places like Alibaba actually brag about the ability to pass tests

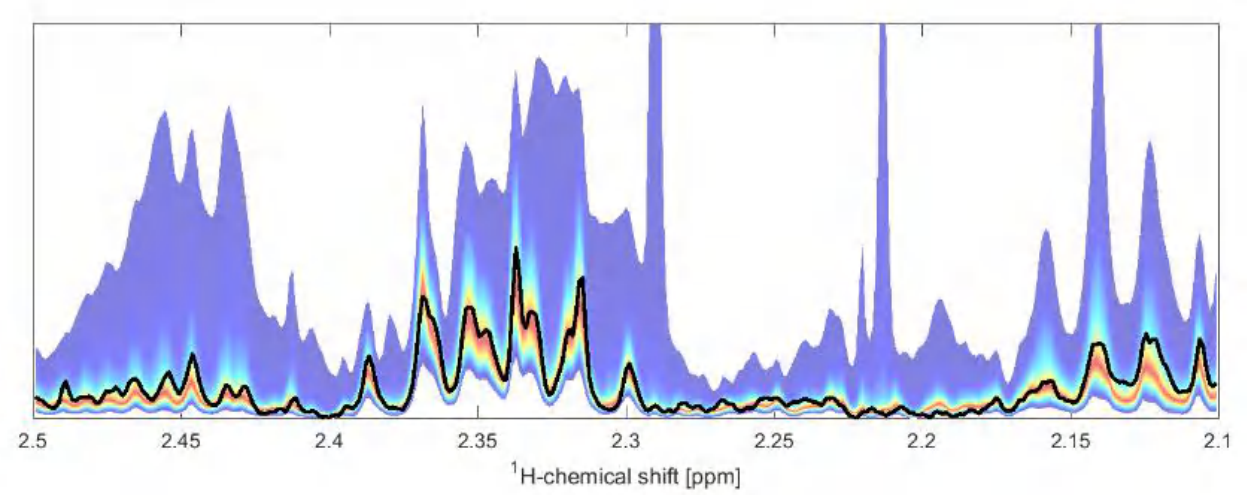
The product you see above claims it is able to pass C3C4C13 tests that are common in North America to verify honey authenticity. At $0.61 US, these syrups can easily be purchased by any producer. Often, pictures on the advertisements show large factories with specialized lab

facilities that focus on testing their products with honey so that they pass standard honey screening tests. These advertisements are commonly found on many selling platforms online.

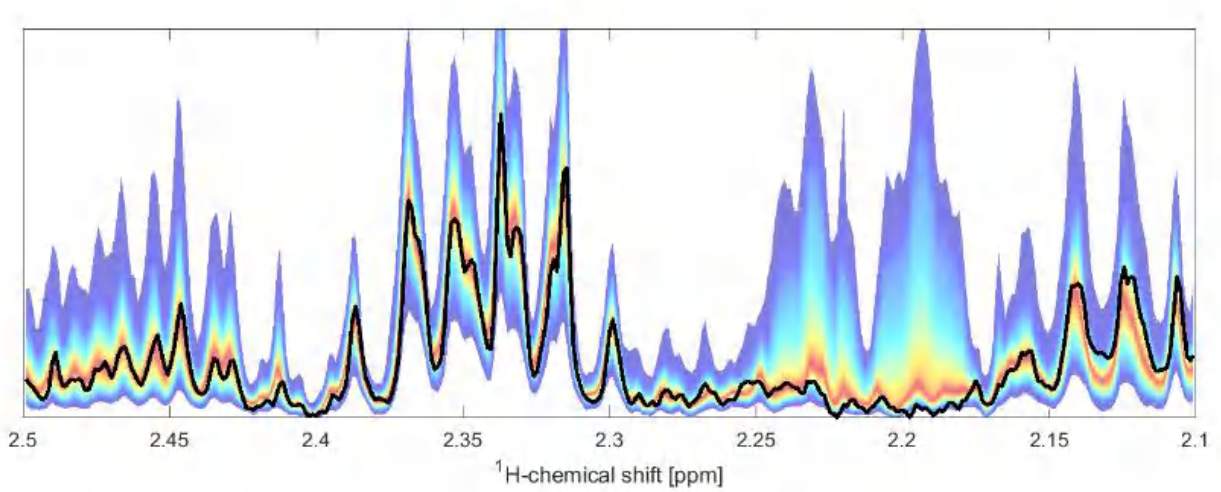
Resin columns remove significant numbers of compounds from the honey beyond the offending substance and you tend to get something that is basically sugar syrup. Colourants may be added to darken the clear syrup, and these can sometimes be detected by liquid chromatography, but Magnetic Resonance is excellent at showing that there are missing compounds in the honey cause by resin filtration. MS will work as well since they can produce similar results if it is used in conjunction with a fingerprint database.



Shows a honey that was diluted with sucrose syrup (black) against a database of honey samples (multi-colored). The region within this Magnetic Resonance spectra is identifying the proline molecule. A The drop along the entire spectra except in the glucose and fructose regions clearly indicated dilution of honey with sugar syrups. The more specific the database (e.g. a monofloral database) the sample is compared against the easier this uniform drop is to identify allowing identification of smaller amount of added syrup.



A. Coffee blossom honey profile (black) against generalized Bruker database of all honey sample blossom fingerprints (13212 Samples)



B. Coffee blossom honey profile (black) against specialized database for all Coffee Blossom honey (648 Samples). This shows how the deviation from the more specific database makes fraud easier to identify. There is less variation that must be accounted for.

More sensitive equipment is being used to detect smaller amounts of contaminants that are missed by resin filtration. High resolution mass spectrometry (HRMS) is one of the methods that some analysis laboratories have adopted. This equipment is also used to detect drug residues and is very sensitive. Each lab has their own technique and there are no standardised methods with this technology yet. It also relies on knowing what the contaminants are so if the composition of the syrups changes this is really just a more sensitive method of the older techniques and is open to evasion by cleaning up the syrups further.

Harvesting of Immature Honey to increase yields

Bees process nectar into honey by adding a number of enzymes and compounds to the honey while removing most of the water. This process transforms the nectar significantly and it becomes quite different and requires considerable effort from the bee. The bees are freed up to go and collect more nectar. This method involves removing honey at least once per day before the bees have an opportunity to ripen the honey and remove the moisture. The unripen nectar is transported to huge factories for processing. Travel can take days where fermentation becomes an issue and inhibitors may need to be added. Resin columns may be used remove undesirable degradation products such as acids and ethanol before drying to acceptable moisture levels.

The resulting product is not honey. It is missing many of the components that bees put into honey. Deviation from the sugar profile and the absence of major components can be seen with Magnetic Resonance. Many of the older methods such as HPLC and GC and the Phadebas test for diastase (an enzyme added by the bees) also provide useful information. Traces of fermentation may also be present.

Force feeding of sugar syrup to bulk up production.

The extent of this form of adulteration is not clear. During a nectar flow this is a difficult method to implement as honey bees are attracted to nectar much more than syrup. However reports of

directly depositing the feed in the brood nest suggest that it would be possible. Feeding with C4 sugars such as sugar cane or HFCS is detectable with IRMS. MS and LC/EA-IRMS are probably better measures of syrup feeding than Magnetic Resonance unless the fed sugars make up a significant portion.

Mislabelling of floral and geographic origin

The damage caused by this is most obvious in areas of specialty honey where beekeepers have been able to avoid the commoditization of honey. The Manuka market is the best example. Because of the significant increase in price premium for Manuka, significant adulteration occurs. There are reports that 70%+ of labelled Manuka honey is fraudulent. This decreases the value to honest beekeepers and devalues honey in general when reports expose the fraud.

Classically, pollen analysis has been used to determine origin. However, it is well known that pollen is not collected evenly by bees. For example, blueberry and alfalfa pollens are well known to be under-represented in honey samples. In addition, we have seen that pollen from previous crops carries over year to year. Magnetic resonance is currently the best technique for determining origins. In our research we have seen clear markers from specific floral varieties that correlate to blooming period. While these kinds of marker are not well integrated into the Bruker database, they present excellent targets for the identification of specific floral types in the future.

Non-targeted testing methods are improving constantly

Bruker is currently working on version 3 of the database which will greatly expand the database from the current 18,000+ sample. It should be released at the time this article is published. We have been working with Bruker to increase the number of North American samples included in the database. It is important to authenticate samples properly for the database. As beekeepers we have been pulling authentic samples directly from the hive during flow. By collecting fresh samples in new comb we minimize contamination with other honey and bee feed traces. This allows the collection of high quality samples. Then with large numbers of samples it is possible to eliminate outliers so that even if a bad sample is accidentally introduced into the database it can be identified and removed. Generally 100+ samples are adequate to identify a floral or geographic region although that can vary greatly depending on the kind of honey.

The great sensitivity allowed by MS suggests that it may be better than Magnetic Resonance for detecting trace components remaining in artificial syrups. MS can be sensitive enough to detect traces of the packaging in the honey. This may assist in determining origin, if the contaminants can be associated with particular areas.

In the future it is expected that the high sensitivity of MS will be very complimentary to the broad specificity of MR to provide a very sensitive methodology for detecting the majority of fraud using new and old methods. But this level of certainty is still in the future.

The current Covid-19 pandemic has had a significant affect on the availability of fraudulent honey-like products. Factories have shut down and transportation routes have been severely

curtailed. Honey consumption has increased in this period possibly due to hoarding and the perceived health benefits by consumers. As a result, beekeepers are seeing an increase in price for the 2020 crop. However, this is not a time to become complacent. As the world reopens we can expect the factories and shipping routes to open up. With the resulting world chaos, governments do not have the ability to properly address issues of fraud. There will be pressure to divert enforcement budgets to pandemic needs. It can be expected that scammers will take advantage of the confusion.

One thing to remember when thinking about how to stop honey fraud is that it will always be possible to defeat tests. The real question is how much does it to cost to defeat the test. If it's not possible for the scammers to make money or the risks of getting caught are too great then there is no reason to for scammers to do this. They will move on to other areas where there is money to be made. These new methods are evolving rapidly and are being shown to be very effective. Bigger databases and refined algorithms will strengthen them quickly. What is needed most now is a push to implement these techniques on a broad basis and to ensure that the regulations are strong and the enforcement effective. It is important that beekeepers and consumers make it clear that this is what they want. Talking to your government officials, newspapers and just the people buying your honey so they understand what is at stake will have a dramatic effect on the industry.

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