Fermentology • Book

The Biology of the Bread that Bees Make

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Editors note: This publication contains the video of the talk from the Fermentology webinar series, as well as a lightly edited transcript of the lecture. The transcript has been enriched with media, annotations, and links to other material by the digital publication team in order to amplify and extend the content for a reading experience.

Abstract

Margarita López-Urbe is the Lorenzo L. Langstroth Early Career Professor at Pennsylvania State University's Department of Entomology where she studies bees of many kinds. Many bees rely on fermentation in different ways (some ferment nectar, others pollen, others still ferment leaves). Margarita will talk about the fermentation carried out by honeybees. Honeybees make bread out of pollen that they ferment (and then feed to their babies). Margarita and her student Brooke will talk about what goes into making bee bread and what microbes are involved in this process. They will also share preliminary data of an ongoing project about how various biocides shape bee bread microbiome.

Watch the talk

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The Biology of the Bread That Bees Make | Fermentology mini-seminars

Introduction

We want to start by introducing you to honey bees. They probably don't need a lot of introduction – we all know that honey bees are extremely important for pollination and they contribute to agriculture.¹ They are a critical part of the cropping systems in the United States. And you have probably heard of some of the problems that honey bees are having: severe decline in the number of colonies for many years now. But that decline isn't our focus today. Our focus is on the natural history of honey bees, their natural history and the workings of their societies, the center of which is honey bee bread.

Ety/Ento-mology

For many decades, scientists have studied honey bees as model systems to understand how insects that live in these large societies communicate and coordinate behaviors that allow them to be very successful. However, one of the things that many people may not know, or some people may miss is that honey bees are actually very unique and very different compared to other types of bees. When we talk about bees, we are talking about a group of insects with about 20,000 different species in the world. In North America we have about 4,500 species of bees. Honey bees are one species of many, many thousands of species in the world, and these thousands of bees are diverse in every conceivable way. They differ from honey bees (and from each other) in their colors, what they eat, how they fly and especially their sociality.

Table 1. Comparison of bees and their traits.

	<i>Italian</i>	<i>German</i>	<i>Carniolan</i>	<i>Buckfast</i>	<i>Caucasian</i>	<i>Russian</i>
Color	Light	Dark	Black	Medium	Dark	Gray
Disease resistance						
<i>Varroa</i>	-	-	-	-	-	+
<i>Tracheal</i>	-	-	-	+	0	+
<i>AFB*</i>	0	-	+	0	0	0
<i>EFB**</i>	0	0	0	0	0	0
<i>Other</i>	0	0	+	+	-	0
Gentleness	Moderate	Low	High	Low-Mod	High	Low-Mod
Spring buildup	Good	Low	Very good	Low	Very low	OK
Over-wintering ability	Good	Very good	Good	Good	OK	Very good
Excess swarming	OK	OK	High	Low	Low	OK
Honey processing	Very good	OK	Good	Good	Low	OK
Propolis	Low	OK	Low	Low	High	OK
Other traits	Heavy robbing	Short tongue, nice white cappings	Low robbing, good comb builders	Supersedure queens produce defensive colonies	Long tongue	Brood rearing affected by flow, queen cells always present
* AFB = America foulbrood						
** EFB = European foulbrood						

[Different Types of Honey Bees](#), from NC State Extension Apiculturist, David Tarpy.

The majority of bees don't form these large groups with tens of thousands of individuals. Instead, there is only one female in each nest, and that female is the one that is in charge of making the nest, laying the eggs, and doing all the pollen and nectar collection. Hers is a lonely and important job.

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Storiies by [Cogapp](#).

Regardless of whether you are a solitary bee or a social bee, bees make nests, and these nests look different. Honey bees make very organized structures where cells are organized in hexagons, and they are perfectly positioned next to each other. Those are the cavities that honey bees use to store the pollen and the nectar the bees are bringing back to the colony. They go out, they collect pollen and nectar from flowers, and they bring it back to the nest. Those cells are also the places where the queen is going to lay the egg, and all of their larval development is going to take place.

Other bees – for example, bumblebees – are also social, and they also have cells that they use for the same purposes: pollen, nectar storage, and larval development. But the arrangement in the shape of these cells is very different: they are oval in shape and form organized clusters.

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Images from: [Wikimedia](#) and the [National Science Foundation](#)

So, the majority of bees are solitary, and actually about 70 percent of all bees nest underground, so this is the typical way in which bees actually build nests. Usually the one female that is the only one living in that solitary bee nest has to dig a tunnel, and make lateral branches where they excavate cavities that they are going to use as a cell. They put some salivary secretions that are going to protect the pollen and the nectar that they are going to be storing in that cell, and once again this is the place where they're going to lay the eggs and all the larval development is going to take place. Exactly the same thing happens in bees that nest in wood. Bees like carpenter bees for example are wood nesters, and so in those cases the bees also have to make cells. Those are the places where they are collecting the pollen and nectar, and that's where the larvae are going to develop.

So, in summary, whether you're solitary or social, bees make nests. And the other thing that is interesting biologically about bees is that they prepare the food for the larvae. When the bees go out of the nest and they're foraging on flowers, they're choosing the right pollen and nectar and they're going to bring it back and mix it in a way that is going to be perfect for the developing larvae. This is not trivial; this is very different from other types of insects. If we think about other pollinators, like monarch butterflies for example, the life cycle of the monarch butterfly is very different. When

adults emerge, they mate and then the females are going to look for a plant where they will lay the eggs. When the egg hatches, the caterpillar is going to be by itself looking for leaves and other plant tissues to use, so mom is not preparing food in any way throughout their development.

Being Bee Bread

We have talked about pollen and nectar, but what is bee bread?²

Bee bread is the mixture of that pollen and nectar that the bees are bringing back to the nest, but it also involves microbial activity of bacteria and yeast.

In the cells, the bee bread is not a homogeneous mixture of pollen; it is made up of pollen loads that the bees are bringing back to the nest. Once these pollen loads are packed in the cells, they are covered with honey, and this is when the process of producing the bee bread begins. The bee bread production process involves two steps: one is bacterial fermentation, and the second one is fermentation by yeast. The first step that is led by bacteria usually involves bacteria in the genus *Lactobacillus*³, particularly the species *Lactobacillus kunkeei* is very common in bee bread.^[1] This species thrives in environments where there is a lot of fructose; these bacteria metabolize the fructose present in the mixture of pollen and nectar, and produce lactic acid. The production of lactic acid decreases the pH of that bee bread and creates the perfect environment for the next step of the fermentation process, which is led by yeast.

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Royal College of Surgeons of England. A modern elixir of life. (1908) Retrieved from the Digital Public Library of America, <http://www.archive.org/details/b22429827>.

Saccharomyces is a key genus of yeasts that is involved in the fermentation of many foods made by humans such as beer and sourdough bread, for example. This type of yeast is also involved in the fermentation of bee bread. At this point in time, after the first fermentation step by bacteria and when the yeasts are growing, the total bacterial activity of the bee bread decreases. The bee bread comes to be dominated by these beneficial yeasts. The yeasts help to preserve the bee bread and to stop pathogenic yeasts or “bad yeast” from growing and spoiling the bee bread.

The bee bread is not only pollen and nectar; there is a process that is driven by bacterial activity that transforms that raw pollen into bee bread through a process of fermentation. What happens is that nutritionally, bee bread is different from raw pollen. There is an increase in lactic acid due to the action of *Lactobacillus*, and there is less starch because that is part of what is being used for the fermentation. One interesting aspect of bee bread and bee bread production is that in honey bees, the developing larvae are not directly consuming the bee bread. In honey bee colonies, the queen lays egg in the cells. Once these eggs hatch and become larvae they spend the first few days of their lives eating something called royal jelly. Royal jelly is a secretion that nurse bees produce from their mandibular glands and give to these very young larvae. After day three, when the larvae are, in essence, weaned, the nurse bees start bringing in bee bread. All of the consumption of bee bread is always mediated by the presence of nurse bees. Nurse bees are the bearers of bread to the developing larvae.

Why do Bees Ferment?

But why are bees going to all the trouble of fermenting bee bread? Fermentation is thought to be important for the long-term preservation of the food in the colony. It is a food, like beer or wine or even cheese, that can be produced in the fall and stored up all winter, to be consumed in lean times. This is particularly important for honey bees because honey bees, unlike many other bees, are perennial organisms. The colony overwinters, and there are hundreds to thousands of individuals in the colony during the winter. They need to have access to bee bread to start producing the next generation when the spring comes. They also need the bee bread during hard times during the rest of the year; there are periods even during summer, for example, where pollen may not be as available. Having this stored pollen in the colony is

Photo from Margarita López-Urbe

critical to keep producing more workers, so the process of preserving the bee bread is critical for bee health.

This is where the problems come. We have observed for many decades now that honey bees are having a hard time overwintering successfully, and there are many colonies that die every year. Part of the problem is exposure to pesticides; they're feeding on plants that are exposed to pesticides because they're usually used for pollination of agricultural crops. While the pesticides can have direct impacts on bees, they can also have indirect impacts in other ways - for example, it can impact the microbiome of the bee bread. This has been receiving a lot of attention recently. For example, studies have shown that when colonies are foraging on areas where the plants have been exposed to fungicides and they bring in the pollen to the colony and they culture this bee bread, the diversity of yeast in the bee bread is significantly lower than the diversity of yeast in colonies that have had no exposure to do fungicides.

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Bees and the Need for Research. This graphic summarizes the main themes from "Honey Bee Research in the US: Current State and Solutions to Beekeeping Problems" by Margarita M. López-Urbe and Michael Simone-Finstrom (2019).

As this article and chapter both emphasize, much research on bees is driven by the dangers bees face. Because of this, research, and the sharing of such, is vital for not only the field of study, but also the health of hives and to support beekeepers in their efforts to sustain colonies.

What does this mean? What it means is that when the colonies have no exposure to fungicides, all the good yeasts help with the fermentation and the preservation of the pollen and to some extent the protection of the bee bread from getting spoiled by pathogenic microbes. But when you have fungicides, those yeasts may get eliminated, and then we have an increase in pathogenic microbes that can actually lead to spoilage of the bee bread and potentially even the demise of the colony. We have been very interested in this question of how these chemicals that are present in the environment are impacting the health of honey bees through changes in the microbiome.

The Science of the Bread that Bees Make

With this in mind, we started this project last year, for which we are specifically interested in how the chemicals that beekeepers themselves add to the colonies may be impacting the microbiome of the hive environment. You may be wondering: why would beekeepers need to add chemicals to their colonies or put pesticides in their colonies? Pesticides, or miticides in this case, are a very important management tool that beekeepers use to control the population of *Varroa* mites. *Varroa* mites are a parasitic mite that can spread diseases within the honey bee colony, and keeping the population of *Varroa* mites low is very important for ensuring the long-term survival of that colony. One of the miticides that we decided to look at that's quite commonly used is Formic Pro, which is developed from formic acid. We have mentioned the importance of pH and the pH conditions for some of those key bacterial and yeast species that are present in the microbiome, so we wanted to see how adding this intense acid to the colony might change the balance of the microbiome in the bee bread.

We collected samples of bee bread from the colonies both before and after a 20-day treatment with Formic Pro. We used sterile tubes to collect all those layers of bee bread, and then brought that back to the lab to extract the DNA. We then characterized the microbiome found in that beer bread.

We were looking at the relative abundance of the bacterial species in the bee bread. For the colonies that received no treatment, we collected samples before that 20-day period and then after. The microbes in the bee bread were relatively comparable between the two time points, and particularly of note, the *Lactobacillus kunkeei* stayed pretty much consistent in its abundance in the bee bread. But when looking at formic acid treated colonies, there was a much more dramatic change. The microbes were less comparable, and that relative abundance of *Lactobacillus kunkeei* decreased through time.

These data are still fairly preliminary data, so we're still trying to understand what these changes mean, and we also still need to analyze the fungal data so that we know how the fungi were affected by exposure to formic acid. But it's pretty clear from what we've found that the miticides are capable of causing a shift in the balance of the microbes in the bee bread and that shift could potentially lead to impacts on the value of the bee bread to the bees. We are excited to keep exploring this data and to learn more so that we know how these changes affect the bees themselves.

Meanwhile, nearly all of the foods that are important to honey bees are also consumed by humans. We humans eat the honey made by bees. We rely on (and even sometimes eat) the wax made by bees. We eat royal jelly and we even eat bee bread. We have included here some recipes that feature the pleasures of the hive, a reminder of our dependence on honeybees in particular and the wild diversity of bees more generally.

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Bees, Honey, and People. Images from the [NC State University Libraries' Rare and Unique Digital Collections](#).

If you are interested in learning more about this project or other work in our lab, you can visit our [lab website](#).

More [current research on bee bread can be found](#) in the **Directory of Open Access Journals**, where academic knowledge is available to anyone with an internet connection.

For more research on bees, please explore MIT Mediated Matter Group's Research on Bees with [Maiden Flight](#) and [Synthetic Apiary](#) projects, as well as Elsa Youngsteadt's [Urban Ecology Lab](#).

Footnotes

1. For more on how honey bees contribute to North Carolina agriculture specifically, [visit NC State Extension's resources](#). ↵
2. The term [“bee pollen” on Wikidata](#) links this idea to more related concepts. ↵
3. Referred to as "A modern elixir of life" in the British Medical Journal (1908). See the document below. ↵

Citations

1. Edwards CG, Haag KM, Collins MD, Hutson RA, Huang YC. **Lactobacillus kunkeei sp. nov.**: a spoilage organism associated with grape juice fermentations. J Appl Microbiol. 1998 May;84(5):698-702. doi: 10.1046/j.1365-2672.1998.00399.x. <https://pubmed.ncbi.nlm.nih.gov/9674120/> ↵