Bready or Not, Here I Crumb!

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Field(s) of Interest: Chemistry, microbiology, physics, biochemistry, food science

Brief Overview (1-3 sentences):
A popular pastime creating a beloved carb, breadmaking relies on a significant amount of biological, chemical, and physical properties/transformations to craft the ideal loaf. This lesson aims to demonstrate firsthand the processes that breadmakers depend on, exposing to mentees the tasty mechanisms of the molecular world that underlie everything from the ground they walk on to the food they eat.

Agenda:

- Introduction (5 min)
- Module 1: Rise in the Yeast, Set in the West (10-15 min)
- Module 2: The Knead for Speed (15-20 min)
- Module 3: Wake ‘n ___ (10-15 min)
- Conclusion (5 min)

Main Teaching Goals/Key Terms:

- ➔ **Yeast**
- ➔ **Fermentation**
- ➔ **Leavening Reactions**
- ➔ **Water, Flour, Yeast**
- ➔ **Kneading**
- ➔ **Aeration**
- ➔ **Elasticity**
- ➔ **Gluten Development**
- ➔ **Maillard Reaction**
- ➔ **Caramelization**
- ➔ **Melanoidins**

Background for Mentors

Module 1

- **Fermentation**
- **Yeast**
- **Leavening Reactions**

Before bakers put their bread in the oven to bake, they often let the bread dough sit and “rise” or “ferment” for up to *72 hours* – quite a long time to create one bread loaf!

Fig 3 - Visual depiction of the dough-rising process

The rising and fermentation of bread dough is achieved by **yeast** (Saccharomyces cerevisiae), a type of unicellular (living!) fungus that, for the most part, is always used as an ingredient in bread. Being a living organism, yeast needs fuel and energy to survive, which it achieves by the process of **fermentation**. In this process, yeast converts the sugars in the bread dough (in table sugar or flour) to fuel for the yeast to live, producing carbon dioxide gas as a byproduct. This gas is what leads to the dough “rising” before being placed in the oven, as it is trapped like a balloon within the surface of the dough. Not only that, but the production of alcohol as a byproduct also allows the dough to develop a distinct flavor before being baked.

The class of chemical reactions that fermentation belongs to is called **leavening reactions**, where a mixture of molecular compounds expand and become airier by creating and trapping gas bubbles.

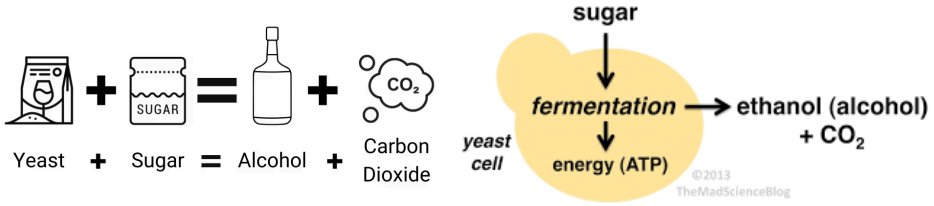

Fig. 1+2 - Biochemical representations of the fermentation process

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Yeast - A type of unicellular fungus used frequently in breadmaking for their ability to facilitate fermentation.
Fermentation - A vital step in the breadmaking process that involves the conversion of sugars into carbon dioxide and alcohol of yeast, enabling the dough to rise and develop flavor.
Leavening Reactions - The class of reactions that fermentation belongs to. In these types of reactions, a mixture of compounds expands and becomes airier by creating and trapping gas bubbles.

Module 2

- **Water, Flour, Yeast**
- **Kneading**
- **Aeration**
- **Elasticity**
- **Gluten Development**
- **Windowpane Test**

To make *the most simple* bread dough (probably won't taste very good...), three ingredients are required:

- **Water** - to hydrate the flour and form bread dough consistency.
- **Flour** - Required for the structure of bread and provides sugars that are food for yeast in fermentation. Also provides amino acids that react with sugars when baked to form the crust (will be covered in next module)
- **Yeast** - required for dough rising and flavor development (leavening agent).

Kneading dough prior to baking it is critical in the dough's structure and workability. Folding the dough end-over-end to knead leads to **aeration** of the dough, trapping even more air molecules in the bread dough and leading to a lighter, fluffier bread texture. Kneading is also critical for increasing the dough's **elasticity**, or the ability for the dough to return to its original shape after being deformed. This elasticity helps the dough retain its shape and resist breaking when stretched. There is an optimal amount of kneading for dough, and over-kneading or overworking the dough may actually decrease the dough's elasticity, leading to a tough dough that resists stretching.

The overall structure and ability for bread dough to stretch and trap air comes from its **gluten development.** The proteins glutenin and gliadin in flour combine to make gluten, which creates a spider web-like structure that traps gases and stretches when pulled. Kneading aligns and strengthens gluten strands.

But how do bakers know when they have kneaded the perfect amount? The **windowpane test** is a visual test that bakers use to determine if the time they have spent kneading is optimal. To perform the test, the dough is stretched between the fingers until you can see through a thin transparent layer of dough without it breaking. If this can be successfully done, the dough has been kneaded to the perfect amount.

Fig. 4+5 - The windowpane test (left) and gluten strands in kneaded bread dough (right)

	Water, Flour, Yeast - The three ingredients required to make the most simple bread dough. Yeast - required for dough rising (leavening agent) Flour - required for the structure of bread (contains gluten-forming proteins) and is food for yeast. Water - required to hydrate flour and form dough. **Kneading** - The process of folding/working bread dough in order to develop the ideal structure and texture. **Aeration** - The process of physically trapping air molecules within the bread dough, leading to a fluffier and lighter bread texture. **Elasticity** - The ability of a material to return to its original shape and size after being deformed. Kneading dough increases its elasticity, making it easier to mold and shape. Over-kneading dough can actually decrease elasticity, leading to a tough dough. **Gluten Development** - The activation of the proteins glutenin and gliadin in flour. These proteins combine to make gluten, which organizes itself into strands to make a matrix that traps gases and enables aeration. **Windowpane Test** - A visual test often used by bakers to determine the perfect amount of kneading/gluten formation. Performed by stretching until you can see through a thin transparent layer of dough without it breaking.

Module 3

- **Amino Acids**
- **Sugars**
- **Maillard Reaction**
- **Caramelization**
- **Melanoidins**

Flour provides bread dough with two essential molecules – sugar and amino acids. **Amino acids** are tiny building blocks that make up long chains called proteins. **Sugars** are sweet molecules that react with amino acids in the maillard reaction and are caramelized in high heat.

In the **Maillard Reaction**, which only happens at high heat (140-200℃ = 284-392℉), amino acids and sugars combine and create large chains of molecules that each contribute to the baked bread's flavor. These large chains are developed and located on the outer perimeter of the bread dough, creating what will become the hard, crispy bread crust. The chain-like products of the Maillard Reaction, called **Melanoidins** are also brown in color, resulting in the characteristic golden-brown color of the crust when adequately baked.

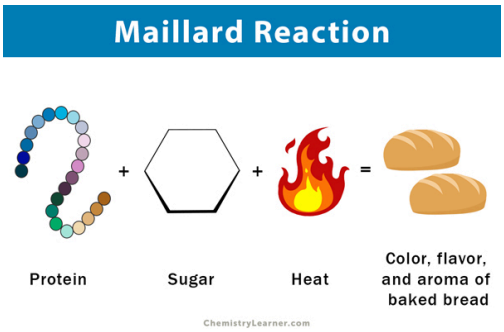

Fig 6 - Chemical representation of the Maillard Reaction

In addition to the Maillard Reaction, **caramelization** is also crucial in developing bread's brown color in the oven and adding more flavor elements to the finished product. Caramelization occurs in sugars alone when they are heated to high temperatures (think caramel!)

Fig. 7 - Color development with increasing exposure to caramelization

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Amino Acids - Tiny building blocks, in this case coming from flour, that make up protein that you might find in muscle, food, and hair.
Sugars - Sweet molecules that interact with amino acids in the maillard reaction and are caramelized when in high heat.
Maillard Reaction - A chemical reaction that occurs within the proteins and sugars of bread when heated, facilitating the browning and structure of the

	crust. Also adds to the flavor of cooked dough. **Caramelization** - A browning process that occurs when sugars are heated to high temperatures (think caramel!). Works in conjunction with the maillard reaction to further brown and complicate the flavors of the crust. **Melanoidins** - The polymers, or long chains of molecules, that form after maillard reactions that give bread its flavor and brown color after being in the oven.

Introduction

Being a staple food item in the diets of many around the world, bread and breadmaking serves not only as a popular snack, but also as a symbol for the universality of small, molecular interactions that uphold the world as we know and see it.

Concepts to Introduce ● The role of a living, breathing organism in creating bread. ○ Yeast ○ Fermentation ● The ingredients in the basic, most simple bread dough recipe and why each is important. ○ Water ○ Flour ○ Yeast ● Why bread/pizza/pretzel/bagelmakers and bakers knead dough ○ Kneading ○ Aeration ○ Elasticity ● The role of the oven in baking beyond just being hot. ○ Maillard Reaction ○ Caramelization	**Questions to Pique Interest** ● Think about the best piece of bread you've ever had. What were your favorite parts of the bread? ● Did you know that bread uses living, breathing tiny microbes to rise? ● Imagine you are trying to make a bread dough without water or flour or yeast – what would the dough look like?
Scientists, Current and Past Events **Louis Pasteur** - contributed significantly to understanding yeast fermentation and the biochemical processes involved in breadmaking. **Antonie van Leeuwenhoek** - In the 17th century, Leeuwenhoek identified yeast as a living organism. **Joseph Lee** - An African American inventor who revolutionized bread production with his invention of the automatic bread-making machine in 1894. **Ancient Egyptians (c. 3000 BCE) -** The Egyptians were the first to bake leavened bread using fermentation, likely discovered accidentally when dough was left out to rise naturally.	**Careers and Applications** ● **Baker (pastry chef, breadmaker, pizza maker, etc.)** ● **Microbiologist** ● **Molecular Gastronomist** ● **Biochemist**

Module 1: Rise in the Yeast, Set in the West

Mentees in groups will perform the classic balloon-yeast experiment to demonstrate the role of yeast in rising bread dough.

Teaching Goals

1. **Yeast** - A type of microscopic (unicellular) fungus used frequently in breadmaking for their ability to release gases via fermentation and rise bread dough.
2. **Fermentation** - An important step in the breadmaking process that converts sugars in flour/sugar into carbon dioxide gas and alcohol, enabling the dough to rise and develop flavor.
3. **Leavening Reactions** - The production of gases that causes bread dough to rise via leavening agents like yeast and baking powder/soda. Fermentation is a leavening reaction and yeast is a leavening agent.

Materials

- 1 balloon per group
- 1 packet of active dry yeast per group
- 1 clear, clean plastic bottle per group
- 1 bottle/thermos of **warm** water per site
- 1 small ziploc bag of sugar per site
- 1 Teaspoon to measure out sugar per site

Different Methods for Teaching

1. **Living Organisms** - One of the points of emphasis for this lesson is the fact that yeast is a living, breathing organism that is used as an ingredient in bread without as much as a second thought. Perhaps have the mentees first observe the yeast alone to demonstrate that even the most unassuming of ingredients can have significant biological origins and impacts on the final product.
    a. You may also prompt mentees to consider what similarities they have with yeast in terms of energetic demand, respiration, etc.
2. **Preach patience!** Though 20-30 minutes is recommended for this experiment, different conditions will yield different experimental results. If your balloons are not inflated by the end of this period, encourage your mentees to remain patient and continue to check in on their bottles.

Procedure

1. Pass out one clear, empty plastic bottle to each group of mentees.
2. Have a mentor come around and fill the plastic bottles up about an inch full of warm water.
3. Hand each group a packet of active dry yeast. Have mentees slowly pour the yeast into the water with another mentee gently swirling the bottle as the yeast is poured.
4. Designate a mentor to go around with a bag of

Figure 1: *Fill bottle with water, about an inch full*

sugar and a teaspoon, having the mentees scoop one teaspoon of sugar into the bottle and swirl some more.

5. Pass out a balloon to each group, having the mentees blow it up a few times just enough to stretch it out.
6. Place the neck of the balloon onto the neck of the bottle. Swirl the bottle gently one more time
7. Place the bottle in a warm place (likely in direct sunlight if you can) for about 20 minutes, proceed with the following modules.
8. After ~20 minutes or at the end of site, check back in on the balloons – they should be somewhat inflated.
    a. Connect the inflating of the balloon to the rising of bread dough due to leavening reactions/fermentation.

Figure 2: *Add yeast + sugar, stretch a balloon over the neck of the bottle.*

Figure 3: *Different stages of balloon inflation following successful fermentation*

Classroom Notes

Warm water may not be necessary in this module if you or your site does not have access to it. The time period for inflation may be significantly slower or may require a warmer temperature. If no inflation is observed by the end of your site's allotted time, show an image of the final result.

Module 2: The Knead for Speed

Each mentee will create their own dough, then compare kneaded vs. unkneaded dough to establish the role of kneading in creating a workable, elastic dough.

Teaching Goals

1. **Water, Flour, Yeast** - The three ingredients required to make the most simple bread dough. Yeast - required for dough rising (leavening agent) Flour - required for the structure of bread (contains gluten-forming proteins) and is food for yeast. Water - required to hydrate flour and form dough.
2. **Kneading** - The process of folding/working bread dough in order to develop the ideal structure and texture.
3. **Aeration** - The process of trapping air molecules within the bread dough, allowing for yeast activation and fermentation. Aeration leads to a fluffier and lighter bread texture.
4. **Elasticity** - The ability of a material to return to its original shape and size after being deformed (stretchiness). Kneading dough increases its elasticity, making it easier to mold and shape. Over-kneading dough can actually decrease elasticity, leading to a tough dough.
5. **Windowpane Test** - A visual test often used by bakers to determine the perfect amount of kneading/gluten formation. Performed by stretching until you can see through a thin transparent layer of dough without it breaking.
6. **Gluten Development** - The activation of the proteins glutenin and gliadin in flour. These proteins combine to make gluten, which organizes itself into strands to make a matrix that traps gases and enables aeration.

Materials

- 1 mixing bowl per group
- 1 spatula/mixing stick per group
- 1 cup of flour per group
- ½ cup warm water per group
- 1 packet of active dry yeast
- 1 sheet Parchment paper/aluminum foil per mentee
- 1 ziploc bag per mentee to knead in/take home dough
- Optional - pair of plastic gloves for mentees with gluten concerns

Different Methods for Teaching

1. **Elasticity vs. Stretchiness** - these are not the same thing! A very stretchy dough can be likened to play-doh (which is not what bread dough should feel like). Bread dough balances elasticity and stretchiness to make a dough that is somewhat stretchy, but can still return to its original shape.
2. **Gluten Development and Spiderwebs** - gluten is an advanced teaching goal here, but can be likened to spiderwebs in a much more digestible manner.
3. **The Role of Yeast** - since this was covered in the previous module, have mentees respond to the question of why yeast is important in bread dough.

Procedure

1. Lay out a sheet of parchment paper per mentee to act as a work/knead station for the dough.
2. After having a mentor distribute yeast and flour, have mentees combine the two together in the bowl, mixing them together evenly.
3. Have a mentor slowly pour in water into each group's bowl as they mix.
    a. Water should be preferably warm, but room temp should be fine.
4. When the dough is shaggy (not sticky, but still workable), divide the dough up per mentee in the group, then lay dough on paper,
    a. If too sticky – add more flour
5. Have the mentees split off a piece of their dough that will NOT be kneaded.
6. With the remaining dough, have mentees knead end-over-end for about 5 minutes, adding more flour per request.
    a. *Mentees with gluten allergie*s/concerns may want to use plastic gloves, but coordinate with your site to determine the necessary precautions (i.e. if they should be doing this module at all)
    b. Younger sites/sites concerned about mess can knead their dough through a Ziploc bag or with plastic gloves. Since no end-over-end kneading can be achieved with a Ziploc bag, sites using this option should skip step (7).
    c. To add an additional challenge element - have mentees see if they can successfully perform the windowpane test!
7. Compare the kneaded vs. unkneaded dough, then discuss the value of kneading dough prior to shaping and baking it.
8. **Mentees can bag their dough and take it home! Encourage them to try and either pan-fry or bake their dough if they so desire.**

Figure 1: *Example of a shaggy dough*

Figure 2: *Shaggy (unkneaded) dough vs. kneaded dough ball*

Figure 3: *Successful windowpane test (6c)*

Classroom Notes

This module has potential to become very messy! Be very wary of this and potentially allocate some time for cleanup.

Module 3: Wake ‘n __

The mentees will play a classwide game of a rendition of Sharks and Minnows to demonstrate the baking process and reactions involved in developing the crust and flavor of the bread in the oven.

Teaching Goals	**Materials**
1. **Amino Acids** - Tiny building blocks, in this case coming from flour, that make up protein that you might find in muscle, food, and hair. 2. **Sugars** - Sweet molecules that interact with amino acids in the maillard reaction and are caramelized when in high heat. 3. **Maillard Reaction** - A chemical reaction that occurs within the proteins and sugars of bread when heated, facilitating the browning and structure of the crust. Also adds to the flavor of cooked dough. Amino acids and sugars come together to react with each other, and other amino acids linked with sugars, eventually forming large chains of molecules (polymers) that give bread its color and flavor after being in the oven. 4. **Caramelization** - A browning process that occurs when sugars are heated to high temperatures (think caramel!). Works in conjunction with the maillard reaction to further brown and complicate the flavors of the crust. 5. **Melanoidins** - The polymers, or long chains of molecules, that form after maillard reactions that give bread its flavor and brown color after being in the oven.	None!

Different Methods for Teaching

1. **Retention despite activity** - the activity for this module uses the mentees as a representation of the workings of the Maillard Reaction. Because it is so game-centric, retention of teaching goals may be difficult while the game is being played. To counteract this, be sure to use as much teaching goal-related language/vocabulary during the game to reinforce its ultimate applications to the reactions involved with baking,
2. **Self-explanatory teaching goals** - some of the teaching goals in this lesson, namely aeration and caramelization, sound similar to other words (i.e. air, caramel) that could be used to more easily explain complex teaching goals.
3. **Proteins (amino acids) + Sugars** - there is *no need* to be going into complex biochemical discussions of these classes of macromolecules. Explain the concepts so that the mentees can understand the activity + module at the very least.

Procedure

Sharks & Minnows, but Amino Acids & Sugars

1. Start with 1-3 “Amino Acids” to act as sharks in the center of the play area. All other sugars will line up on one edge of the play area.
2. A mentor will shout “heat!” to prompt the sugars to try and run to the other side without being tagged by the proteins.
3. If tagged, the sugars will link arms with the amino acid who tagged them, modeling the reaction between sugars and amino acids in the maillard reaction.
4. These linked individuals will then try and cover as much ground as possible, tagging more sugars to recruit them to their chain.
5. With each round, the mentors will shout “heat!” at gradually decreasing intervals, modeling how heat prompts the maillard reaction to speed up.
6. Game ends when all sugars have been consumed/tagged (or after a set amount of rounds – sites decide).
    - Doing this activity outside is preferable, being sure to take the yeast balloons with the site.

Alternate activity for sites that cannot go outside

Rock, paper, scissor chain

1. Designate one mentee to begin as the sole amino acid. All other mentees are sugars and should stand in a line facing the amino acid.
2. When a mentor shouts heat!, the amino acid and sugar facing each other play a game of rock, paper scissors.
    a. If the amino acid wins, the sugar will link arms with the amino acid and kick off the next game of rock, paper, scissors with the next sugar in line.
    b. If the sugar wins, the sugar is unused in the reaction and runs back to the end of the line. The next rock, paper, scissors battle between the amino acid and next sugar in line can *only happen when the previous sugar makes it back to the very end of the line.*
        i. This represents how the

Figure 1: *the “sharks,” or the growing amino acid-sugar chain in the outdoor rendition of the activity*

Figure 2: *circle of linked arms at the end of indoor rendition of activity = finalized crust*

Maillard reaction speeds up with heat + time (more sugars linking arms = less in line = less distance the winning sugar has to travel to get to the end of the line = less time to kick off next rock, paper, scissors) 3. The aim of the game is to create a circle of linked arms with no more sugars in line. This circle will represent the hard outside crust of the bread that is formed through the maillard reaction.	

Classroom Notes

Be sure to check back in on the fermentation bottles!

Conclusion

As mentioned in module 2, mentees can take their bread dough home! If they were to leave the bread in the bag for some time, their dough would rise. Encourage them to bake the bread or continue kneading the dough if needed at home, paying attention to each step and the molecular interactions that are involved (maybe even explaining to their parents the science behind each step).

References

- Playingwithrain, Yeast Balloon Experiment: https://playingwithrain.com/yeast-balloon-experiment/
- Seriouseats, *An Introduction to the Maillard Reaction: the Science of Browning, Aroma, and Flavor*: https://www.seriouseats.com/what-is-maillard-reaction-cooking-science