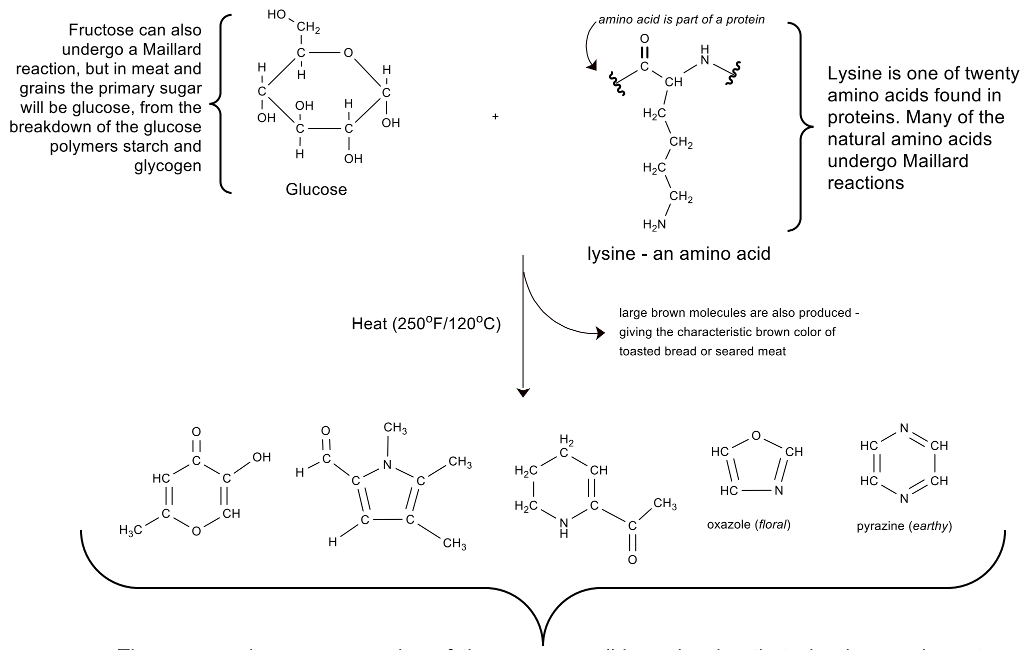
Why Food Browns: Understanding the Maillard Reaction

Introduction:

We have all cooked food and most of us have cooked often enough to understand that the cooking process does more than simply heat the food. The cooking process induces chemical reactions that change both the flavor and appearance of the food. When it comes to cooking meats, heating the food causes the proteins, especially those nearest the surface of the meat, to denature. These denatured proteins become more chemically reactive to other molecules in their environment. One of the primary reactions that occur when browning meats and many other foods is called the Maillard Reaction. The Maillard Reaction is a non-enzymatic chemical reaction between amino acids and reducing sugars that commonly give brown foods their desired flavor. As with many chemical reactions, the outcome of the reaction will depend upon the amino acids and sugars present, but also on the amount of heat and other elements of the reaction environment such at pH.

Background:

The Maillard Reaction is commonly referred to as one of the most important flavor producing reactions in all of cooking. This reaction is also commonly referred to as the browning reaction due to the fact that the products of the chemical reactions have a brown color. As the chemical reaction proceeds, a series of chemical ring structures are formed that reflect brown light, thus providing the color. Of course it is not the change in color that causes the change in flavor, but as you will see in the following experiments, we can take advantage of the color change to evaluate and quantify this reaction. The Maillard reactions literally can produce hundreds to thousands of different chemical compound in small quantities that all contribute to the color and flavor of the food. These compounds include an array of ring structures and the products can be classified based upon these structure. In this series of experiments we will look at the Maillard Reaction and how it impacts the color and flavor of foods.



These are only some examples of the many possible molecules that give browned meat and toasted bread their complex flavors. The products of the Maillard reactions with different amino acids yield flavors ranging from floral and leafy to earthy and meaty. Aroma molecules made from the Maillard reactions include nitrogen atoms and sulfur atoms (not shown) from the amino acids.

Before we start investigating the Maillard Reaction we need to recall a little basic chemistry. The essential chemical reaction in this process occurs between an amino acid and a reducing sugar. As you know, amino acids are biologically important organic molecules containing both an amine ($-NH_2$) and a carboxyl group (-COOH) along with specific side chains that make each of the 20 common amino acids distinct. Amino acids are the monomers used as building blocks to produce proteins. As proteins denature during heating, these amino acids become accessible to chemical reactions. A reducing sugar is any sugar that either has an aldehyde group or can form this group when in solution. Monosaccharides that contain an aldehyde group are known as aldoses. These include the most common monosaccharides glucose and fructose. Some disaccharides such as lactose and maltose are also reducing sugars. The complex chemistries associated with the Maillard Reaction are covered in the textbook.

In this experiment we will do two simple activities. First, we will run the Maillard Reaction with a series of amino acids and sugars in neutral (water), acidic (acetic acid buffer) and basic/alkali (bicarbonate buffer) conditions to determine their reactivity and gain a greater understanding of how the reaction works. In the second exercise, we will apply this knowledge to cooking, by dipping foods into various solutions and evaluate them on the length of time it takes for the food to brown. This exercise we will also allow us to evaluate the impact of pH in the browning process

1. ***Alkali Solution***: 0.02 M Sodium Bicarbonate Buffer, pH = 9.5
2. ***Acetic Solution***: 0.2 M Sodium Acetic Acid Buffer, pH = 5.5
3. ***Neutral Solution***: deionized water, pH = 7.1
4. ***Amino Acids in Water*** (Neutral Solution).
5. ***Carbohydrates in Water*** (Neutral Solution).
6. ***Amino Acid in Bicarbonate Buffer*** (Alkali Solution).
7. ***Carbohydrates in Bicarbonate Buffer*** (Alkali Solution).
8. ***Amino Acid in Acetic Acid Buffer*** (Acetic Solution)
9. ***Carbohydrates in Acetic Acid Buffer*** (Acetic Solutio

Exercise 5.1: The Maillard Reactions with Amino Acids & Carbohydrates

There will be four groups of 4-5 students per group. Group one will work on reactions in water, group two will work on reactions in acetic conditions, group three and four will work on reactions in alkali conditions. In this exercise we will be comparing the level of browning due to the Maillard Reaction in solutions of carbohydrates and amino acids alone and in combination. Each reaction will be measured at neutral, acidic and alkali conditions. Thus you can compare the reactivity of the sugars, amino acids and the impact of pH on the reaction kinetics.

Amino Acid	Amino Acid	Draw "R" Group Identify any amine or amino groups	Sugar Letter	Sugar	Draw the Structure of the sugar – Circle any anomeric carbons.
1	Lysine		A	Arabinose	
2	Leucine		B	Fructose	
3	Glutamate		C	Xylose	
4	Glycine		D	Ribose	
			E	Glucose	
			F	Sucrose	

Procedure 5.1.1. Browning of Amino Acids and Carbohydrates in Solution

1. In this exercise we will observe the browning of amino acids and sugars alone and in combination in water, acidic or basic conditions.
2. Indicate your assigned condition for 5.1.1 (NEUTRAL, ACIDIC or ALKALI). Use this condition for this portion of the experiment.
3. Obtain 35 test tubes in a test tube rack.
4. Label the test tubes with a number or letter for the amino acid or carbohydrate indicated in the table below.

	Buffer only	**Arabinose**	**Fructose**	**Xylose**	**Ribose**	**Glucose**	**Sucrose**
Buffer only	X	A	B	C	D	E	F
Lysine	1	1+A	1+B	1+C	1+D	1+E	1+F
Leucine	2	2+A	2+B	2+C	2+D	2+E	2+F
Glutamate	3	3+A	3+B	3+C	3+D	3+E	3+F
Glycine	4	4+A	4+B	4+C	4+D	4+E	4+F

5. For test tubes 1, 2, 3, 4 add 1 mL of the appropriate amino acid solution.
6. For test tubes A, B, C, D, E, F add 1 mL of the appropriate sugar solution.
7. For test tubes labeled buffer only add 2 ml of the buffer assigned to your group
8. Mix the solutions thoroughly using the vortexter. (your instructor will show you how to use this)
9. Prepare two water baths each large enough to hold 35 test tubes.
   A. A 90-100 °C water bath *HOT be careful*!!!
   B. An ice water bath
10. Place the test tubes into the hot water bath for 30 minutes.
11. Transfer the test tubes from the hot water bath to the ice water bath to stop the chemical reaction.
12. As a group, evaluate the intensity of color formation (how much of the reactants have been converted to product). As an entire classroom – identify the test tube with the reaction that has produce the most product (is the darkest). Compare that to a tube without any color formation. The darkest colored tube for the entire class is not arbitrarily set at “10”. A tube without any color will be arbitrarily set at “0”.
13. Record the reaction completion for each tube for ALL conditions by recreating the table above in the results section in Data Table 5.1.1.

Exercise 5.2: The Maillard Reaction in Action

Procedure 5.2.1. Browning Times of Foods Treated at Different pHs.

1. Obtain potatoes, carrots, and chicken
2. Cut or slice the food items into ½ to 1 inch pieces.
3. Obtain three container and label them Distilled water, Acetic Acid Buffer, and Bicarbonate Buffer.
4. You will be cooking three different samples of each of the four foods listed and recording the amount of time it takes the majority of the food items in the pan to brown.
5. Work with ONE food type at a time.
6. Dip 3-5 food item per solution and cook immediately after each piece of that item is dipped.
7. Evenly coat a frying pan with canola oil and heat to 325°F as you are dipping each food item.
8. The frying pan will need to be cleaned between each cooking event.
9. Preparing food samples and browning.
    A. Distilled Water Dip
        a. Dip several (3 – 5) pieces of potato into distilled water
        b. Add to the warmed frying pan
        c. Brown the potatoes stirring regularly
        d. Record the amount of time from when the potatoes are added to the frying pan to when the majority of the potato pieces are browned
        e. Repeat the cooking exercise for the carrots, onions and chicken
        f. Record you data in Data Table 5.2.1.
    B. Acetic Acid Dip
        a. Dip several (3 – 5) pieces of potato into the acetic acid solution
        b. Add to the warmed frying pan
        c. Brown the potatoes stirring regularly
        d. Record the amount of time from when the potatoes are added to the frying pan to when the majority of the potato pieces are browned
        e. Repeat the cooking exercise for the carrots, onions and chicken
        f. Record you data in Data Table 5.2.1.
    C. Bicarbonate Buffer Dip
        a. Dip several (3 – 5) pieces of potato into bicarbonate buffer
        b. Add to the warmed frying pan
        c. Brown the potatoes stirring regularly
        d. Record the amount of time from when the potatoes are added to the frying pan to when the majority of the potato pieces are browned
        e. Repeat the cooking exercise for the carrots, onions and chicken
        f. Record you data in Data Table 5.2.1.

Exercise 5.3: Experimenting with the Maillard Reaction

5.3.1 Enter the results from your first two experiments into the results section below (including the other groups for 5.1), review the structure of the amino acids and the sugars and make a few observations of any trends below.

5.3.2 Design an experiment to increase the rate of browning of a food using this trend. Use the process of science to design and carry out your experiment:

1. A key question being investigated in each of the exercises below.

2. A hypothesis or proposed answer to the question asked.

3. A prediction for the outcome of the experiment based upon your hypotheses you developed: The prediction should written as an if/then statement and be specific to the measurements being made.

4. An explanation of your reasoning for each of your hypotheses and predictions.

5.3.3 Describe your experiment including controls, perform the results and then explain/conclude upon your results. Ensure to explain your results in terms of your hypothesis.

Results:

Data Table 5.1.1. Maillard Reaction in Amino Acids and Carbohydrate Solutions in **Water**

	Buffer only	**Arabinose**	**Fructose**	**Xylose**	**Ribose**	**Glucose**	**Sucrose**
Buffer only							
Lysine							
Leucine							
Glutamate							
Glycine							

Data Table 5.1.1. Maillard Reaction in Amino Acids and Carbohydrate Solutions in **Acidic Soln**

	Buffer only	**Arabinose**	**Fructose**	**Xylose**	**Ribose**	**Glucose**	**Sucrose**
Buffer only							
Lysine							
Leucine							
Glutamate							
Glycine							

Data Table 5.1.1. Maillard Reaction in Amino Acids and Carbohydrate Solutions in **Alkali Soln**

	Buffer only	Arabinose	Fructose	Xylose	Ribose	Glucose	Sucrose
Buffer only							
Lysine							
Leucine							
Glutamate							
Glycine							

Exercise 5.2: The Maillard Reaction in Action

Data Table 5.2.1. Browning Time of Foods in Different pH Solutions

	Water Times	Avg	Acetic Acid Time	Avg	Bicarbonate Time	Avg
Potato						
Carrot						
Chicken						

Conclusions and Discussion:

1. In Exercise 5.1.1 we compared the level of browning due the Maillard Reaction in different amino acid and carbohydrate solutions in water alone and in combination.
    A. Which single carbohydrate gave the greatest level of browning?
    B. Which single amino acid gave the greatest level of browning?
    C. Which combination of carbohydrate and amino acid gave the greatest level of browning?

2. In Exercise 5.1.2 we compared the level of browning due the Maillard Reaction in different amino acid and carbohydrate solutions in bicarbonate buffer alone and in combination.
    A. Which single carbohydrate gave the greatest level of browning?
    B. Which single amino acid gave the greatest level of browning?
    C. Which combination of carbohydrate and amino acid gave the greatest level of browning?
    D. How did the level of browning for these combinations compare to the results in section 5.1.1?

3. In section 5.2.1 food was browned after dipping in water, acetic acid buffer, or bicarbonate buffer.
    A. What was the main difference between these three solutions?
    B. How did the browning times compare for the different food items in each of the three solutions?
    C. For each of the different food items, which solution gave the fastest browning time? Which gave the slowest browning time?
    D. Using your data, how does changing pH impact browning times for the different food items?

Process of Science Questions and Conclusions: Earlier you created a key questions, hypotheses, predictions, and explanations for this prediction for each of the experiments in this laboratory exercise.

Based upon your data and the questions you have answered related to this exercise you should be able to complete the process of science questions and conclusions.

Answer the following questions.
1. Did your data support or falsify your hypothesis?
2. How did you come to this conclusion?
3. Did these results change your thinking about this topic? How?
4. What changes would you make to your hypothesis based on this new data?
5. What changes would you make to the experiments to better clarify your results?

Each person is responsible to maintain notes and records on their own AND to collect results from the other groups throughout the experiment. Each person will submit their own report for the entire laboratory experience.