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Best Practices for Food Preservation from Lab to Home Kitchen

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Introduction

Food has the ability to bring people from all walks of life together. There is a need for people to understand how to properly preserve food. This knowledge of food preservation will ensure that what we consume remains edible for as long as possible and will be digested properly by our stomachs. As a person who adores food, I want to bring the ideas and techniques of food preservation and storage into the Chemistry classroom. Food preservation is necessary to ensure the quality and longevity of our food. Techniques vary from early methods of salting, pickling, and dehydration to more recent techniques of pasteurization, food additives, and freeze-drying. The Chemistry of these methods can be explored in the high school classroom setting through labs, demonstrations, and projects. My students constantly ask to do food labs and their mouths salivate when I bring cooking analogies into our discussions on reactions and stoichiometry. Introducing the concept of food preservation to my students will allow me to instill the importance of caring for our food after it has been prepared to avoid being wasteful. My students are really great when it comes to consuming leftovers; however, they may not know the proper storage of their leftovers to ensure their food is still edible after a certain amount of time. Knowing how to preserve food is not only useful, but also economical.

Rationale

In this Information Age, students ask for relevance of atomic structures and interactions to their lifestyles. It is no mystery the abstract ideas of Chemistry are difficult to understand since students do not see them first hand. In my own experiences, I did not fully experience Chemistry until taking my first college course. I want to make understanding this science more accessible to all students at William C. Overfelt High School.

Overfelt is one of 11 high schools of East Side Union High School District in the east side of San Jose, California. San Jose is named the Capital of Silicon Valley due to its central location in a high technology industry and its large population. Being in the heart of continuous technology growth, people living near Overfelt High School struggle with very immediate situations of crime and gang related violence. Some of my students are affiliated with major gangs within this area of San Jose. Many students at Overfelt are bombarded with making difficult life choices not normally experienced by young adults in other areas of San Jose. This often results in their difficulty to focus on academics.

Many families who live in the east side of San Jose is mostly dictated by financial situations. The mean household income is just over $ 60,000 in an area where the cost of single family homes averages around $ 800,000. This results in the majority of families renting homes anywhere from $ 2,000 to 3,000 per month. It is not rare to hear of two and three families living under one roof just to ensure everyone has a roof over their heads and can remain living within this community. Since the majority of families' income goes to renting their houses, I will promote a better understanding of food preservation to relieve any amount of financial burdens on my students' families. Many Overfelt students (over 80%) qualify for free or reduced lunch. Some students rush to the lunch lines to eat their meals since this may be the first or only meal they have that day. Our campus also offers bagged lunch for students who are going on a field trip since they are guaranteed a free or reduced lunch during the school day. There is also an opportunity for students and their families to pick up 20 to 30 pound boxes of groceries once a month for free at Overfelt through a food pantry. Our Nutrition Service Team is passionate about ensuring that our students are fed healthy meals during and after school hours. By incorporating food preservation science and techniques into the Chemistry curriculum, students can take these practical tools to share them with their families and utilize them at home.

Content Understanding

High school students are in the position to make more food choices since they are practicing healthy decision making skills during adolescence. The issues with making appropriate food choices are twofold, regarding student finances and health. For example, I often see students walking into class late with McDonald's bags or Starbucks Frappuccino in their hand. I am concerned with both the financial impact on students who purchase these foods many times each week, and the nutritional value, or lack thereof, from the foods students are choosing to consume. More students need to take advantage of the food provided daily on campus. For many of them, our campus provides the main or sole source of entire meals. The food provided to schools by state funding often arrives frozen, is then heated in the morning, and finally stored in insulated drawers. While our Nutritional Service Team makes every attempt to prepare fresher food to supplement the main part of the meal, a good portion of the food is processed to ensure quick heating time. Whether students receive their food from home, fast food restaurants, or at school, they need to be aware of how to preserve perfectly edible leftovers to avoid foodborne illnesses. This practice of preserving leftovers is also economical since food is not being thrown away due to spoilage.

Spoiled food is inedible because substances that cause illnesses in the consumer have contaminated it. Food spoils when biological, chemical, or physical interactions occur with external sources. The necessary level of understanding of microbiology and biochemistry for this unit is just past high school level; however, the details provided in this curriculum unit will be more than enough for anyone teaching this unit. An overview on food preservation methods and storage container materials will provide critical background information. The majority of lesson activities will lead students to understand the chemical interactions and reactions involved in food spoilage. Additionally, comparing different storage methods and options will provide students with many opportunities to practice design techniques and engineering practices.

Spoilage of Food

The process of food spoilage is both biological and chemical. The biology of spoilage involves bacteria, yeast, and mold. The chemistry of spoilage includes enzymatic reactions that break down carbohydrates, proteins, and fats into different molecules. Changes in molecules alter the appearance, taste, smell, and texture of food items, making the food less desirable.

Bacterial species vary greatly, but many of them have similar basic needs as humans, including the need for water, oxygen, food, and a warm place to thrive. Other specific environmental needs includes pH above 4.5 to 7 and temperature ranging from 4-60 degrees Celsius (° C).[1] Many of our natural food sources are perfect homes for these single-celled organisms to consume and multiply exponentially. Specific species of bacteria can be found in one food type, but not found in others. Table 1 shows some of the more common bacteria that can spoil food and drinks.

Category	Bacteria s.	Food Affected	Conditions
Gram (-)	Pseudomonas	Red meat Fish Poultry Milk and dairy	Fresh food (aerobically stored food with high water content and natural pH)
Gram (+)	Bacillus and Clostridium	Vacuumed-packed meat (beef, poultry, fish); sous-vide beef	food stored in temperatures < 5° C (freezer temperature)
Lactic acid bacteria	Lactobacillus Streptococcus Leuconostoc Pediococcus	vacuumed-packed meat and poultry	aerobic conditions refrigeration temperature
Other Gram (+)	Micrococcus	meat milk	cured freshly collected; non-pasteurized
--	Enzymes		Mechanism
	Lipase	milk and milk products	hydrolysis of triglycerides → rancid
	Proteinase	milk and milk products	breakdown of peptides → bitterness

Table 1. Common bacteria and enzymes associated with different common foods and drinks. *Compiled from Huis in't Veld, 1996 and references therein.*[2]

The commonality amongst all of these bacteria is that they render our food inedible due to the growth of their colonies. The bacteria with its byproducts are harmful for human consumption. Additionally, the nutrients humans need from the food have been partially or completely consumed by the bacteria.

Enzymes also break down the chemical composition of the nutrients in food that the human body would normally perform during metabolism. Enzymes are proteins that are the "Wreck-It Ralphs" of the biochemical world. An enzyme that helps us in preparing our food is bromelain that is found in pineapple and used in meat tenderizers.[3] Bromelain breaks down meat protein, hence making the meat very tender. This also occurs when humans eat too much pineapple and end up with a raw feeling in their mouths. Enzymes that reduce the quality of food also target specific molecules to break, and the result is organic properties that warn us not to consume the food. A common example is when lipase catalyzes the hydrolysis of triglycerides in milk and milk products to result in rancidity.

Food Preservation Methods

The intention of food preservation is to limit biological, chemical, and physical interactions within food. Only preservation techniques that align to the strategies and activities for this unit will be discussed in detail. The following methods encompass the scope of this unit: dehydration, freeze-drying, pasteurization, and identifying ideal storage temperatures. These methods are mostly commercially done to provide ready-to-eat meals for consumers who would continue the preservation process at home.

Dehydration

This is an umbrella for preservation techniques that remove varying degrees of water from the food source. The atmospheric conditions necessary to achieve dehydration include: temperature, humidity, pressure, portion size, and length of storage intended for the food.[4] Salting, smoking, and hanging in dry air are some common forms of dehydration. Salting dehydrates cells of organisms via the process of osmosis. Cells contain water that is drawn out when the salt concentrations in the environment are greater than the concentration inside the cell.[5]

Freeze-drying

Also known as lyophilization, freeze-drying is under the broader category of dehydration methods. Freeze-drying is an extremely sophisticated way of removing water from food and drinks that not only limits microorganism activities, but also reduces the overall volume of the foodstuff. Temperature and pressure are manipulated to reduce the water content of frozen food resulting in a dry, stable product. Simply stated, three steps accomplish this:

1) Freezing the food/drink;

2) Sublimation (solid water directly changed into vapor);

3) Desorption (resulting in a dry, stable product)[6]

All of this is achieved in a vacuum to avoid transitions into the liquid phase. The sophistication of this process exists in the modification of temperature and pressure for each ingredient in the food source. Since the phase change occurs differently in each ingredient, the engineering of vacuum-sealed chambers to achieve sublimation must be taken into consideration for all of these variations. The result leads to very expensive freeze-dry products with shelf lives averaging a decade. Freeze-dried products like meals-ready-to-eat (MRE), from brands like Backpack Country, serve as great emergency rations for natural disasters because of their long shelf lives, or lightening the backpack load on a hiking trip.

Pasteurization

Foods typically pasteurized include milk, liquid eggs, fruit juices, and beer.[7] This mild heat treatment targets specific bacteria species in a two-step process. First, the food item is heated. Secondly, the food is sealed in a hermetic package that includes two processes for packaging. Hot-fill pasteurization involves having the food item at a hot temperature for a short period of time. The inside of the container will be pasteurized during this short span of contact with extremely hot food product. Cold-fill pasteurization typically occurs in frozen foods. The food and container are joined in a very sterile environment during the cold-fill process. This method of pasteurization requires taking extra precautions to avoid microorganism interaction.[8]

The engineering of pasteurizers is dependent on targeting a specific type of bacterial species, while maintaining the foods' flavor and consistency. Milk and creams are common liquid products that are pasteurized to eliminate common bacteria like *Escherichia coli* (abbreviated as *E. coli*), *Salmonella*, and *Listeria*.[9] Even with the intention to create an environment too hot for some bacteria, refrigeration is still necessary to delay the growth of bacterial not killed by the pasteurization process.

Storage Temperature

The intention for storing food and drinks in cold temperatures is to delay bacterial growth. Perishable food like beef, fish, dairy products, and agricultural foods are dependent on cold storage for longer shelf life.[10] Many bacteria will react to hot and cold temperatures just like humans do. If the weather is freezing cold, humans are likely found huddling with many layers of jackets and blankets to keep warm. If the weather mimics the warm shores of Hawaii, humans would be running around soaking up the warmth of the sun. Bacteria act similarly by how they slow down growth and stay huddled in cold temperatures and speed up growth and spread with warm temperatures.

Types of Food Containers

The purpose of food packaging is to protect food against biological and chemical spoilage, while also providing the consumer with a container to store their food according to their preferences. Packaging manufacturers take many factors into consideration when designing and producing these different forms of food containers. Packing considerations include: cost, compatibility with the food, shelf life, modifiable sizing, production speed, impermeability, tamper resistance, and consumer convenience.[11] The materials used for creating food containers vary from metal to edible films. Each type of food container material addresses the form of the containers available, how the materials work in preventing spoilage, and the potential chemical interactions that it may have with food.

Metals

Metal food containers commonly take the shape of cans, trays, bottles, or wraps. It prevents spoilage by creating a barrier from oxygen and light. Two commonly used metal containers are either made of steel or aluminum. Steel is molded into cans and bottles for processed food like fruits, vegetables, and various juices. Aluminum is molded into trays and wraps that are lighter, yet less sturdy compared to steel. Since foods come into direct contact with the metal, chemical reactions may occur. One issue with these metals is its reaction with acids. Over an extent of time, the acid begins to corrode the metal. Packing companies typically coat steel with noncorrosive materials like tin, chromium, or aluminum.[12] These coating materials must be inert to acids, withstand sterilization temperatures, and resist breakage to prevent contamination.[13]

Glass

Glass bottles and jars serve multiple food containment purposes. This material prevents vapor and oxygen loss in food when appropriately sealed. In addition, the thickness of glass can vary to allow for minimal breakage. Since glass is a derivative of metal oxides, like silicon dioxide (commonly known as sand), the modification of thickness is not difficult to achieve; however, the production cost will increase since more material is used. Coatings of silicon or waxes are used to assist with minimizing nicks and scratches on the container. This allows for continued reuse of the container even after the original food item is consumed. Glass and glass coatings are inert and do not react with acids, oxygen, nor bacteria, making this an ideal material for containers aiming to prevent bacterial spoilage by blocking their interaction with material inside the container. However, there are necessary precautions to store glass containers to avoid contamination. Leaving the lid off or loose lids provides an open invitation for bacteria and other contaminants to enter the sacred food space. Extended exposure to air on food products will also create an oxygen-rich environment for bacteria to grow.

Paper

Depending on the thickness and type, paper containers include bags, wraps, or carton form. Paper containers are often coated with laminates, plastics, resins, and waxes to prevent leakage, bursts, rips, vapor loss, and to block contaminants. Paper of minimal thickness is good for bagging or wrapping baked goods. The next type of paper container is thicker than the previous and is appropriate for holding drinks, like milk and juices. Paper with limited thickness and coating allows for permeability of gases, which is useful when paper containers are used in cooking. For instance, wrapping a slab of sea bass in parchment paper with some shitake mushroom, ginger, and soy sauce, then broiling it in an oven produces a wonderfully steamed meal. Some of the gases permeate through the paper while letting heat through to cook the food products. These containers are sophisticated with the addition of susceptors to allow for more versatility beyond storage and extend into the cooking process. Susceptors are found in microwavable popcorn bags and Hot Pocket wrappers.

Plastics

Plastics provide the most diverse forms of containers since they are flexible, stretchable, lightweight, resistant to breakage, heat sealable, and form almost all shapes. Different forms of plastic serve purposes for specific types of storage. For example, polyethylene with ethyl vinyl acetate is in frozen food containers, while polystyrene is Styrofoam for to-go containers.[14] Other forms of plastics include bottles, jars, closures, films, pouches, bags, tubes, and trays. The plastic material is good for creating a barrier to oxygen, light, and moisture. Like glass, plastic is inert to bacterial and chemical spoilage hence making it an appropriate container for many different food sources. The limitations with plastic are its inability to withstand high temperature and its permeability to certain liquids and gases.

Edible Film

This innovative form of storing food is edible! Edible films are made of food products in combination with additional sugar, starches, casein, or gelatin. Prime examples of edible films are the candy coating on M&Ms and casing on sausages. The film provides a minimal barrier to the food from spoilage, analogous to the tortilla of a burrito. Since the barrier is also a food product, the risk of spoilage is the highest in this form of container material. Edible films are mainly for the purposes of consumer’s convenience and preferences.

Refrigerators

Temperature plays an important role in regulating spoilage of food and drinks. In general, hot temperatures speed up chemical reactions and cold temperatures slow down reactions. Since the process of spoilage is biochemical, placing food items in a regulated cold environment delays or hinders bacteria from reacting with the food. Examples of cold storage used by individuals domestically include refrigerators, water coolers, chillers, and deep freezers. Most households around the world have some variations of sophistications in refrigeration techniques. A refrigerant removes the heat from the food, resulting in a lower temperature.[15] Refrigerators and other cold storage equipment provide space for cold temperature to extract energy from food. This is the process of latent heat of vaporization. If a system is placed on a very cold surface, eventually the system and surface will reach equilibrium between the two original temperatures. Refrigerators have mechanisms to ensure that energy is constantly removed from the system to prevent the temperature from reaching equilibrium with the outside of the refrigerator.

Settings

Studies about the knowledge and understanding of refrigerator settings show that very few people know the appropriate temperature to prevent food spoilage and cross-contamination. There are still discrepancies with optimal temperatures for cold and freezer compartments. The recommended temperatures for refrigerators housing perishable food is less than 4.4° C (40.0° F). A survey of 200 refrigerator owners showed that less than 18% have a visible thermometer to read the exact temperature in fridges.[16] Even with highly intelligent refrigerators that display everything from temperature to listing dates of when items were placed inside, we still try to hide a slice of cake behind the low-fat Greek yogurt. Different sources recommend getting a visible refrigerator thermometer to accurately monitor temperature throughout the fridge,[17,18] as there are suggested temperatures for the three different compartments of the refrigerator.

Organization

Most fridges have three compartments, each with separate optimal temperature ranges to allow for differentiated food and drink storage. The fresh food storage compartment is for unfrozen food at a temperature of 0 to 8° C, the chill compartment is for very perishable food at a temperature of -2 to 3° C, and the cellular compartment is for all food and drinks at temperature warmer than the previous two compartments.[19] When Americans were surveyed, there were few who knew how to separate different food items onto the many shelving options available depending on fridge design. Refrigeration storage has become more reflective of personal style of the users rather than the functionality of the fridge. Although instructional manuals recommend food locations within the compartments, there are no real consequences to misuse. People tend to place food and drinks where it is convenient, based on categories of food items, or because it looks more organized one way than another. Food placement variations result in a high chance of cross-contamination.

Food Safety

When food items are stored improperly, the likelihood of cross-contamination is increased and provides opportunities for bacterial and chemical spoilage. Foodborne illnesses are defined as:

"…[I]nfections or irritations of the gastrointestinal (GI) tract caused by food or beverages that contain harmful bacteria, parasites, viruses, or chemicals."[20] The lack of knowledge about appropriate food storage contributes to the rise in illness due to spoilage of food and drinks.

Statistics Of Foodborne Illness

Though not all foodborne illnesses are reported to the public health department, an estimated 1 in 6 Americans experience foodborne illnesses.[21] The Center of Disease Control (CDC) places foodborne illnesses into one of two categories: known pathogens and unspecified agents. There are numerous hurdles in obtaining data on foodborne illnesses since the mechanism of infection differs in each individual. We eat and metabolize food slightly different from one person to the next. Unfortunately, medical records from doctor and hospital visits, as well as autopsy reports can only provide a rough number of occurrences related to foodborne illnesses. The CDC estimates that 48 million sicknesses, 128,000 hospitalizations, and 3,000 deaths occur each year from foodborne illnesses.[22] To aid in the reduction of these numbers, local and national public health departments created informational flyers and pamphlets to better understand the causes and recognize the symptoms of these illnesses.

Teaching Strategies

Design and Engineering Practices

As part of the adoption of Next Generation Science Standards (NGSS), students are asked to apply these standards to designing and building systems that explain science concepts. These may be modeling, creating a pathway that leads to quantifiable results, or modifying a previous design. The intention of this unit is to allow teachers many opportunities to create meaningful lessons involving this aspect of science. The unit allows teachers and students to test these ideas and questions. For instance, food preservation is an avenue for students to design the “best” brand of plastic container or to test different types of iceboxes for cold retention. Food storage materials can be compared in different environments and situations to determine the most appropriate form for storing different food or drink items. Furthermore, teachers can have students test the different compartments and settings of a refrigerator to devise a fact sheet of best practices in storing food.

Inquiry-Based

The level of curiosity in students seems dependent on their interest in what they observe. When a phenomenon is presented, curiosity seems higher than usual. A lesson involving food science excites many students because there is the anticipation of getting to eat the food afterwards. This unit provides ideas for inquiry-based learning by having students test these concepts for accuracy and precision. The underlying chemistry of the results is the teacher’s avenue to teach these complex reactions and interactions between substances. Classification of matter, cause-effect determinations, and reaction pathways are just a few of the applications for inquiry-based learning.

Classroom Activities: Design and Engineering

The intent of this unit is to inform students about the best practices in food preservation and storage. In class, students will use this understanding to design and build appropriate storage units in order to reduce bacterial or enzymatic activity in food and drinks. Even though this will be a unit for Chemistry, there is a lot of microbiology involved in understanding food spoilage due to bacterial, yeast, and mold. Food preservation techniques such as pasteurization and freeze-drying limit these interactions.

The activities noted below are modifiable to address different scientific content in a science class. The major themes of these activities are to expand upon the NGSS and our district's aim to incorporate activities for students to demonstrate depth of knowledge (DOK) level 3 and 4. DOK levels are explained in "Implementing District Standards." These standards are achieved when students demonstrate their understanding by designing a model or experiment to gather data that supports the physical science content.

Activity 1 – Writing Claims and Identifying Variables

The activity will require students to explore the interaction between ketchup (food item) and spoons made from different materials. As with all labs, students will begin by writing a claim. I moved away from using the word hypothesis to eliminate the first person reference. An example is provided to help students feel more comfortable with writing claims (e.g. The plastic and wooden spoons will not react with the ketchup). The protocol only presents a graphic of what the setup should look like but no instructions (Figure 1). This is to have students explore more openly with the material, thus pushing cognitive limits and encourage students to think and work beyond their comfort zone.

Each class is divided into teams based on the amount of materials available. Teams of three or four are ideal. If additional teams are needed, then each team may choose two different material spoons until all spoons run out. I would assign a few teams to setup the control to ensure there are enough containers to use for each team.

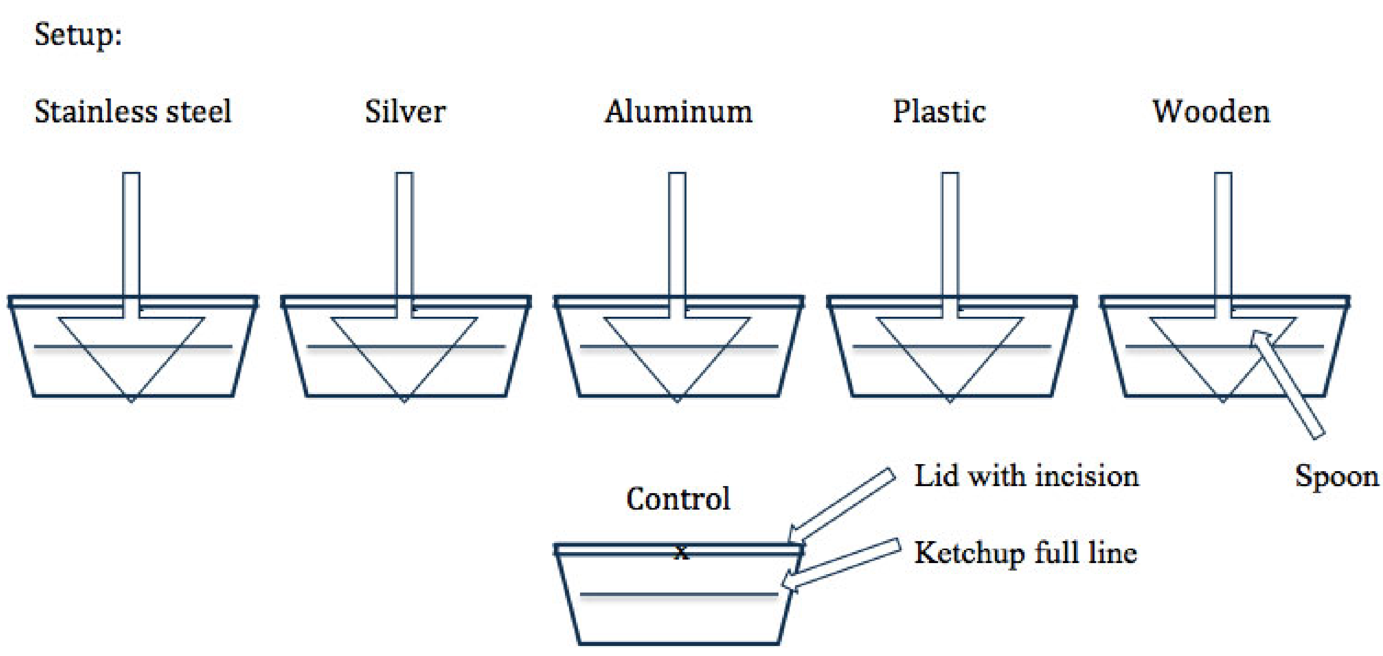

Figure 1. Setup provided to students during the beginning of the Ketchup Lab.

Some likely questions to arise during the activity:

1. Should a line be drawn on the containers to show the initial amount of ketchup?
2. Do we need to close all containers as they are done being used or all at the end?
3. Does the spoon need to be fully immersed in the ketchup?
4. When will we check the results?

All teams are instructed to place their setups in a location in the room so as not to be disturbed. A paper towel can be used to label each team's setup. The best results occur when the containers are placed in a warm space of the room with some direct sunlight. The activity can also be done in a cool room with little direct sunlight, which may result in obvious tarnish of the silver spoons; however, no result will occur with the aluminum covered spoon. The other material spoons are inert and will result in no reaction with the ketchup.

I would then discuss the data tables and the two types of observations: qualitative and quantitative. Thereafter, the discussion questions are adaptable to one or more of the following topics: interactions between matter (physical and chemical changes) and chemical reaction/stoichiometry.

Activity 2 – Permeability of Plastic Wraps

Different types of plastic wrap have varied permeability. This activity allows students to determine what type of plastic wrap will prevent browning or oxidation of sliced fruits. To start this activity, students should observe and briefly explain the chemical reaction between oxygen gas and phenol compounds in fruit. Taking a sliced apple and leaving it unwrapped will provide a good visual for students to provide claims as to how or why the color changed from white to brown. Students are then tasked with determining which type of plastic wrap will slow down this oxidation process the most. With the inspiration from ScienceBuddies.org, students should design their own experiment of testing different fruits that are known to brown and different plastic wraps (e.g. low density polyethylene (LDPE), polyvinyl chloride (PVC), and polyvinylidene chloride (PVdC)).[23]

I have students make predictions on which type of plastic wrap and under what specific conditions would create the least amount of oxidation of the fruit. Their research includes some information about different types of plastics and which fruits brown due to oxidation. Students would write their own list of materials, procedures, and data table prior to being able to conduct their experiment. Their procedures should include how to prepare their fruit samples, the conditions in which the fruit is stored, and the length of time for observations. Once their experiment is completed, students need to analyze the results and updates to the original procedure with rationales as to how these updates improve the experiment.

Possible variations in setup may include:

1. Placing plastic wrap directly on the fruit's open surface.
2. Using a vacuum seal method to remove oxygen between the fruit and plastic wrap.
3. Placing food in a plastic container and then using plastic wrap to cover the container.

To promote creativity in the ways plastic wrap is used, I limit only two teams using the same setup or procedures. A third team with a similar setup would be asked to use the plastic wrap in a different way. Their final submitted team assignment is a portfolio including all revisions of their procedures and data.

Activity 3 – Designing an Energy Efficient Icebox

One major method of food storage is refrigeration. In an emergency or natural disaster, electricity may be out for long periods of time and our perishable food may spoil at a quicker rate. This activity is for students to design and build an icebox that can keep highly perishable foods, like fresh herbs and dairy products, from spoiling without the use of electricity. Understanding the first and second laws of thermodynamics will help students choose their materials and strategize how to limit heat energy from moving to and through the food.

The icebox design should include materials not already made to be used as a cooler (e.g. foam box). Students should use materials found in and outside their home when designing their iceboxes. The determination of the efficiency of their iceboxes will mainly be qualitative. Although calculating the efficiency in energy retention by the icebox is possible, a straightforward qualitative analysis is sufficient in determining the effectiveness of their icebox design. Each team of students would store the same perishable food in their icebox and compare the freshness of their food to ones stored in a refrigerator. Students may also use data gathered from other teams' iceboxes to see the similarities and differences in efficiencies in preventing spoilage of their food.

Resources

Teacher Section

"Polymer Permeability: Which Plastic Wrap Prevents Oxidation Best?" Science Buddies. Accessed August 01, 2017. https://www.sciencebuddies.org/science-fair-projects/project-ideas/Chem_p033/materials-science/which-plastic-wrap-prevents-oxidation-best#summary. This is a premade lab protocol to use if teachers do not want their students to design their own experiments. If you would like students to create their own set of procedures, use the link in the Student Section of resources.

Cheynier, Véronique. "Phenolic compounds: from plants to foods." *Phytochemistry Reviews*11, no. 2-3 (2012): 153-77. doi:10.1007/s11101-012-9242-8. This research article's abstract provides additional information on why fruits brown. The remainder of the article is in depth biochemical information that is beyond the scope of high school Chemistry.

Cooke, Lacy. "7 ways to keep food cool without a refrigerator." Inhabitat Green Design Innovation Architecture Green Building. April 23, 2016. Accessed August 02, 2017. http://inhabitat.com/7-ways-to-keep-food-cool-without-a-refrigerator/. If you would like to provide students with some ideas for Activity 3, this online article provides different types of homemade coolers.

Student Section

"pH Values of Common Foods and Ingredients." PDF. Madison: University of Wisconsin. Accessed May 25, 2017. https://foodsafety.wisc.edu/business_food/files/approximate_ph.pdf This list of common foods and their pH values for students to reference. Foods acidic or basic nature can interact with different materials in their storage containers.

"Polymer Permeability: Which Plastic Wrap Prevents Oxidation Best?" Science Buddies. Accessed August 01, 2017. https://www.sciencebuddies.org/science-fair-projects/project-ideas/Chem_p033/materials-science/which-plastic-wrap-prevents-oxidation-best#summary. This site poses the question for Activity 2 without giving students precise directions on how to design their test for which type of plastic works best.

Seltzer, Howard. "Keeping food safe when the power goes out." Keeping food safe when the power goes out | FoodSafety.gov. March

17, 2014. Accessed August 02, 2017. https://www.foodsafety.gov/blog/poweroutage.html. This online article is a great introduction for Activity 3. Students should be made aware of the many hazards that come when the electricity goes out and their refrigerator is out for hours.

Classroom Section

Wolke, Robert L., and Marlene Parrish. *What Einstein told his cook: kitchen science explained*. New York: W.W. Norton & Co., 2008. 112-13. This chapter was the inspiration for Activity 1. An excerpt from the box can be posed as a problem for students to understand and then solve through scientific exploration.

Materials for Activities

Activity 1: To-go sauce containers with lids, a precision knife, ketchup with high fructose corn syrup (for better results compared to organic ketchup), small sample-size spoons of made of plastic, stainless steel, and silver, and aluminum foil. Alternatively, different material wires or string can be used in place of spoons.

Activity 2: LDPE (e.g., Handiwrap or Glad Wrap), PVC (e.g., Reynolds PVC Foodservice Wrap or Boardwalk PVC Food Wrap Film) and PVdC (e.g., Saran Wrap, which is almost 90% polyvinylidene chloride),[24] sliced apples or avocado, and a refrigerator to keep samples. Alternatively, use a cooler with ice if a refrigerator is unavailable or ask that students conduct this experiment at home.

Activity 3: Fresh herbs, small cartons of whole milk, household items such as cardboard, foam, wax paper, aluminum foil, clay pots, plastic containers or pipes, etc. This activity allows students to gather materials they think would make the most effective icebox.

Implementing District Standards

Next Generation Science Standards

HS-ETS1-1. Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

HS-ETS1-2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

Depth of Knowledge

DOK level 3: Strategic Thinking is evident in student work when they design an investigation to respond to a scientific problem, provide rational with citation of evidences, or develop a model to explain complex ideas.

DOK level 4: Extended Thinking is demonstrated when students carry observations of a phenomenon to the development of an in depth conclusion that explains the science behind the phenomenon.[25]

Endnotes

1. Vaclavik, Vickie A., and Elizabeth W. Christian. *Essentials of Food Science*. New York, NY: Springer New York, 2008. 384.
2. Veld, Jos H.j. Huis Int. "Microbial and biochemical spoilage of foods: an overview." *International Journal of Food Microbiology* 33, no. 1 (1996). 8-10.
3. Vaclavik, Vickie A., and Elizabeth W. Christian, *Essentials of Food Science*, 110.
4. Vaclavik, Vickie A., and Elizabeth W. Christian, *Essentials of Food Science*, 438.
5. Wolke, Robert L., and Marlene Parrish. *What Einstein told his cook: kitchen science explained*. New York: W.W. Norton & Co., 2008. 138-39.
6. Ahmed, Jasim, and Shafiur Rahman. *Handbook of food process design*. Hoboken, NJ: Wiley-Blackwell, 2012. 622-23.
7. Vaclavik, Vickie A., and Elizabeth W. Christian, *Essentials of Food Science*, 426.
8. Ahmed, Jasim, and Shafiur Rahman, *Handbook of Food Process Design*, 338.
9. *The Dangers of Raw Milk: Unpasteurized Milk Can Pose a Serious Health Risk*. PDF. The U.S. Food and Drug Administration Center for Food Safety and Applied Nutrition Food Information, August 2012. 2.
10. Ahmed, Jasim, and Shafiur Rahman, *Handbook of Food Process Design*, 410.
11. Vaclavik, Vickie A., and Elizabeth W. Christian, *Essentials of Food Science*, 472.
12. Vaclavik, Vickie A., and Elizabeth W. Christian, *Essentials of Food Science*, 473.
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