3

Judging Form

Region: 2 **Entry #:** 9680

Title: Survival of the Freshest: Preservation of Organic Food

Entry Level:

K-3 **4-6** **7-9** **10-12**

Abstract

In order to more efficiently preserve organic food and detect food contamination, the PACS (Protection Against Contamination and Spoilage) wrap will incorporate four layers that utilize denaturation, biosensors, and electrochromism. This technology will be environmentally friendly, durable, and flexible due to the integration of two layers of nanocellulose, a fibrous substance made from biomass. The second layer will be treated with urea, a denaturant that will prevent food spoilage by destroying the structures of bacterial proteins seeking to enter. The third layer, made of polyaniline, will contain a biosensor chip, which can detect pathogenic bacteria in food and release an electrical charge. This will cause the polyaniline to change color due to its electrochromic properties, notifying consumers of the contamination. Thus, the PACS wrap will serve as an effective method of preserving organic food and detecting food poisoning, paving the way for health, economic, and environmental benefits.

Survival of the Freshest: Preservation of Organic Food

Present Technology

As of today, food preservation can be found in a multitude of forms, with two of the most popular methods being freezing and canning. Freezing preserves food by lowering the temperature in a contained space so as to create a hostile environment for bacteria; as a result, existing bacteria on food becomes dormant and is unable to grow[1]. Because freezing only alters the environment in which food is stored, it maintains food quality relatively well, retaining color, flavor, and nutrients. However, it also requires a substantial amount of energy in order to maintain low temperatures, leading to economic and environmental disadvantages; for instance, 2.3 kilowatt hours are needed to maintain one pound of food at zero degrees Fahrenheit[2].

Canning, on the other hand, works by first heating food to destroy existing bacteria and then storing it in sealed containers in order to prevent further bacterial growth. Although canning is generally a more economical process than freezing, its main disadvantage is that heating food can alter its nutritional value and quality. In addition, canning raises the risk of foodborne botulism poisoning, an illness caused by the bacterium *Clostridium botulinum* that can lead to paralysis, respiratory failure, and, in extreme cases, death. Because the bacterium responsible for botulism poisoning possesses an endosperm coating that is resilient to heat, canning has proven to be ineffective in eradicating it.

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[1] "Food Preservation Methods." Ka Hana 'Imi Na'auao – A Science Careers Curriculum Resource, *Cds.hawaii.edu.* 26 May 2009. Web. 22 Dec. 2014. PDF File. <http://www.cds.hawaii.edu/kahana/downloads/curriculum/SectionII/Unit3/3.C.MeaaiaFoodScience/3.C.3.FoodPreservationMethods.pdf>.

[2] Kendall, P., and L. Payton. "Cost of Preserving and Storing Food." *Colorado State University Extension.* Colorado State University, 05 Aug. 2014. Web. 22 Dec. 2014. <http://www.ext.colostate.edu/pubs/foodnut/08704.html>.

An emerging technology that has the capability to both preserve food and prevent food contamination is irradiation, which treats food with ionizing radiation in order to destroy microorganisms that can cause spoilage and foodborne illnesses[3]. Ionizing radiation is the exposure of materials to ultraviolet rays with high frequencies, which disrupts chemical bonds within the food[4]. Though irradiation can serve a variety of purposes while preserving the nutritional value of food, concerns have been raised over its effects on human health. Despite the fact that the U.S. Food and Drug Administration deems irradiated food safe for human consumption, it is a relatively new technology compared to other methods of food preservation, so long-term effects are still unclear. Furthermore, food treated with irradiation does not satisfy the U.S. Department of Agriculture's definition of organic, a significant disadvantage[5]. Thus, while present technologies used to preserve food raise various health, economic, and environmental concerns, the PACS wrap is able to effectively prevent spoilage and detect food contamination without altering food quality.

History

Thousands of years ago, humans inhabited the Earth in small groups of hunter-gatherers, moving from one area to another in search of a dependable source of food. The need to preserve food arose only when these nomads settled down and began exploring the world of agriculture[6].

Preserving game and crops allowed farmers to become self-sufficient and eliminated the

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[3] "Food Irradiation: What You Need to Know." *U.S. Food and Drug Administration: Protecting and Promoting Your Health*. Food and Drug Administration, 07 Nov. 2014. Web. 22 Dec. 2014. <http://www.fda.gov/Food/ResourcesForYou/Consumers/ucm261680.htm>.

[4] "Ionizing & Non-Ionizing Radiation." *EPA*. Environmental Protection Agency, n.d. Web. 26 Jan. 2015. <http://www.epa.gov/radiation/understand/ionize_nonionize.html#ionizing>.

[5] "Food Irradiation." *EPA.gov*. United States Environmental Protection Agency, 6 Oct. 2014. Web. 10 Jan. 2015. <http://www.epa.gov/radtown/food-irradiation.html>.

[6] Shephard, Sue. *Pickled, Potted, and Canned: How the Art and Science of Food Preserving Changed the World*. New York: Simon & Schuster, 2000. Print.

need to roam about, constantly looking for their next meal. Early farmers soon discovered that preserving food was a matter of convenience that would allow them to generate a surplus of food, but the prevention of bacterial growth was challenging. Across different time periods, various cultures developed innovative methods of food preservation, and many of these methods are still used in today's society. One of the first methods of preservation was the dehydration, or salting, of foods. Another primitive method included the drying of foods, which was common in the Middle East around 12000 B.C. This technique was developed because the moisture inside of food provides an environment in which bacteria can thrive. Therefore, dehydrating produce, meats, and other foods slows the rate at which these microorganisms grow. In other parts of the world in which sunlight was not abundant, small fires were placed in drying houses, allowing the moisture within the food to evaporate[7].

Later on in history, a French confectioner named Nicolas Appert heated food in glass containers when he wanted to discover a way to preserve food for a long period of time during travel. Although Appert barely understood why his method worked, it was later realized that the method of canning prevented oxygen from entering the container, therefore hindering any bacterial growth on the food inside. Another man named Peter Durand performed the same task using tin cans, since the glass bottles Appert utilized were extremely brittle[8]. Eventually, in the 19th century, Clarence Birdseye made a revolutionary discovery[9]. Birdseye froze foods at low

[7] Nummer, Brian A. "Historical Origins of Food Preservation." *National Center for Home Food Preservation.* University of Georgia, May 2002. Web. 15 Nov. 2014. <http://nchfp.uga.edu/publications/nchfp/factsheets/food_pres_hist.html>.

[8] "Mendel Chapter 4." *Brooklyn.cuny.edu/.* Brooklyn College, n.d. Web. 20 Jan. 2015. <http://www.brooklyn.cuny.edu/bc/ahp/MBG/MBG4/Appert.html>.

[9] "Frozen Foods Research Time-Temperature Tolerance Studies - National Historic Chemical Landmark - American Chemical Society." *Acs.org.* Frozen Foods Research Time-Temperature Tolerance Studies - National Historic Chemical Landmark - American Chemical Society, n.d. Web. 05 Jan. 2015. <http://www.acs.org/content/acs/en/education/whatischemistry/landmarks/frozenfoods.html#early-frozen-

temperatures and realized that, once heated, the food had a "pristine" quality. According to the article "The Science of Freezing Foods" by William Schafer, a food technologist, "Fresh produce contains chemical compounds called enzymes which cause the loss of color, loss of nutrients, flavor changes, and color changes in frozen fruits and vegetables." By being blanched, or heated, and then frozen, these enzymes are "inactivated", thus slowing down the rate at which microorganisms grow on food. Soon, the popularity of frozen food soared, and more companies jumped onto the bandwagon, increasing competition in the market for frozen food. Frozen food continued to be popular in the 20th century, as it still is today.

As different methods of food preservation were created and developed, society continued searching for a method to preserve what is now the food craze: organic food. The lack of additives and preservatives in organic food presents an increasingly difficult challenge to preserve it without changing its quality.

Future Technology

The PACS wrap is composed of four layers that will prevent spoilage and detect contamination in food. In the second layer, we will use urea as a denaturant to prevent bacterial growth. In a standard bacterial cell, the secondary structures take the form of alpha-helices and beta sheets; however, as stated in Elmhurst College's Virtual Chembook, the process of denaturation disrupts these structures and "uncoils them into a random shape." Thus, denaturants can be used to destroy microorganisms by altering the shape of bacterial proteins and preventing them from functioning properly. In turn, because microorganism growth is a major cause of food

foods>.

spoilage, the use of urea as a denaturant in the PACS wrap can slow the rate at which food becomes rancid.

In addition, a third layer will utilize biosensors to detect microorganisms that can lead to food poisoning. Biosensors, which consist of a biological component and an electrical component, are able to detect concentrations of specific bacteria and chemicals[10]. Nanoporous silicon sensor arrays will be implemented into the PACS wrap using a "lab-on-a-chip" approach, therefore detecting bacteria and studying its biochemical structure[11]. To detect multiple species of bacteria at once, antibodies will be employed. Any threatening bacteria will then be captured within the biosensor, allowing the bacterial cells to flow into a bead array. To transport the cells to the filter, bacterial suspension must be utilized. These cells will be lysed, or destroyed, and the remnants of the cells will be analyzed by the sensor array[12]. Once the biosensors in the PACS wrap detect the presence of pathogenic bacteria, they will release an electrical charge, sparking a reaction that causes the wrap to change color. This reaction will occur in the same layer, which is composed of polyaniline, a polymer that demonstrates electrochromic properties. In other words, upon being exposed to an electrical charge, polyaniline will exercise a reversible change in color that can alert consumers of contamination.

The final two layers of the PACS wrap, made of nanocellulose, will serve as a protective outer coating, allowing for the wrap to be reusable. Nanocellulose is produced using cellulose

[10] Jacobsen, K. Bruce. "Biosensors and Other Medical and Environmental Probes." *Ornl.gov*. Oak Ridge National Laboratory, n.d. Web. 15 Nov. 2014. <http://web.ornl.gov/info/ornlreview/rev29_3/text/biosens.htm>.

[11] Lu, Chang. "Development of Biosensors for Food Safety Applications Based on Microfluidics and Nanomaterials Food Safety Research Information Office." *Usda.gov*. United States Department of Agriculture, 2009. Web. 07 Jan. 2015. <http://fsrio.nal.usda.gov/nal_web/fsrio/printresults.php?ID=3917>.

[12] Lu, Chang, and Arun Bhunia. "Nanoporous Silicon Based Sensor Array for Bacteria Detection." (n.d.): n. pag. *Http://www.csrees.usda.gov/*. Purdue University, West Lafayette, Indiana, 2008. Web. 19 Jan. 2015. <http://www.csrees.usda.gov/nea/technology/pdfs/Nanoporous_Silicon_Based_Lu.pdf>.

fibers from biomass and is strong and flexible, making the wrap durable so as to be able to be used multiple times without tearage[13]. In addition, nanocellulose is transparent, allowing for color changes in the polyaniline to remain visible to consumers. Therefore, by using the principles of denaturation, biosensing, and electrochromism, the PACS wrap is able to deter food spoilage and detect contamination with minimal environmental impact.

Breakthroughs

The PACS wrap can become a reality by using the concepts of biosensors and electrochromism to warn consumers of contamination in organic food. However, this concept is still a relatively new one, and will require an extensive amount of research to utilize it in our project. Currently, biosensors, also called bioreporters, are used to detect bacteria. There is a potential for biosensors to be used in medical situations, but applying biosensors to food contamination is an area of study that has not yet been researched[14]. We need to discover a method of using biosensors as a catalyst to spur an electric charge that will then cause a change in the wrap's hue. To carry out this process, a conducting polymer, such as polyaniline, must be used.

Since biosensors are just emerging into the field of medical and health sciences, we would need to research and test its capabilities. After researching more on types of biosensors, we would create a biosensor layer in the PACS wrap that will include a chip to detect bacterial activity within the wrap. Although biosensors have been utilized to detect acidity levels and bacteria before, they have not been used on a much smaller scale. To ensure the biosensor chip's

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[13] "Nanocellulose Technology - Purdue NanoForestry." *NanoForestry*. Purdue University, n.d. Web. 10 Jan. 2015. <https://engineering.purdue.edu/nanotrees/cellulose.shtml>.

[14] Jacobsen, K. Bruce. "Biosensors and Other Medical and Environmental Probes." *Ornl.gov*. Oak Ridge National Laboratory, n.d. Web. 15 Nov. 2014. <http://web.ornl.gov/info/ornlreview/rev29_3/text/biosens.htm>.

ability to detect several types of bacteria at first and alert consumers of contamination by changing color, a controlled experiment will be conducted. Three different experimental groups and one control group will be tested, with twelve apples about the same size in each group. The independent variable will be the type of wrap utilized to cover each apple, and the dependent variable will be the change in each wrapped apple's appearance. In the experimental groups, the apples will be wrapped with standard plastic (cling) wrap, a resealable plastic bag, and the PACS wrap. The control group will consist of an apple that will remain uncovered throughout the experiment's length of thirty days. One type of nocuous bacteria, such as *Escherichia coli*, a common contaminant, will inhabit the apples in each test group. To ensure the accuracy of the data collected, several conditions must remain constant, such as the type of apple used and the room in which the apples are stored. Over the testing period of thirty days, qualitative data regarding changes in the apple's appearance and whether the polyaniline in the PACS wrap fluctuates in color or not will be recorded by the observer. According to the research conducted, upon detecting a change in the protein content within the wrap, the biosensor chip will trigger an electric charge, spurring an electrochromic reaction from the polyaniline. By conducting this investigation, the biosensor's ability to operate on a much smaller scale will be tested. Comparing the other wraps' abilities to alert consumers of contamination to the abilities of the PACS wrap will offer valuable information about the wrap's efficacy.

Experimenting with biosensors and electrochromic polymers will also provide information about the wrap's ability to detect contamination. Although both components of the PACS wrap exist today, they have not been used in collaboration. Overall, utilizing biosensors and polyaniline as an electrochromic conductor will achieve the goal of warning consumers of food contamination in their own homes, reducing the risk of food-related illnesses.

Design Process

In order to create the most effective design possible for the wrap, we had to evaluate the various possibilities associated with conditions such as the method utilized to make the PACS wrap environmentally-friendly, the denaturant used, and the type of chromism incorporated. Because one of our major concerns was making the wrap eco-friendly, we first considered using entirely biodegradable or compostable materials. However, certain crucial components of the wrap, such as the biosensor chip, are not biodegradable, making this an unfeasible idea. As a result, we chose to instead make the PACS wrap reusable, which would also allow for it to be more cost-effective for consumers. In order to do this, we needed a durable yet also flexible material, and after investigating various plastics, aerogels, and other substances, we came across nanocellulose. Not only is nanocellulose strong, flexible, and transparent, making it extremely suitable for use in a wrap, it is manufactured using biomass, an additional environmental benefit.

Upon learning that protein denaturation can disrupt vital structures inside of a bacterial cell, thus destroying it, we decided to utilize a denaturant in the wrap so as to prevent bacteria from entering. Initially, we considered using ethanol for this purpose, as it is currently used as a way of pickling and preserving certain foods as well as in various disinfecting products, such as hand sanitizer. However, the main concern with ethanol is the fact that it has an extremely low freezing point and takes the form of a liquid at room temperature, making it difficult to work with. In addition, we feared that ethanol could potentially contaminate the food being preserved, leading to safety issues. As a result, we researched a variety of other denaturants, eventually finding urea. Similar to ethanol, urea is a chaotropic denaturant; however, it is nontoxic, even found in a number of bodily processes. Furthermore, urea takes the form of a white crystalline solid at room temperature and thus can be more easily incorporated into the wrap[15].

We also researched numerous ways for the PACS wrap to alert consumers of contamination detected in food. While we discovered chromism, a quality of certain substances that causes them to change color in response to various stimuli, early on, we still had to evaluate the different variations of chromism in order to determine which one would be most practical to use in our technology. Eventually, we decided on electrochromism, a reversible change in color as a result of exposure to an electrical charge, since it is most suitable for the project design. Because biosensors contain an electrical component, they can serve as a catalyst upon detecting contamination, causing the electrochromic material — polyaniline — to change color. Therefore, by evaluating various choices and possibilities while developing our technology, we were able to create the most effective design possible for the PACS wrap.

Consequences

Preserving organic food with this new technology will have an immense impact on consumers and even introduce new potential for the technologies incorporated in the PACS wrap. Therefore, combining several concepts and technologies in the wrap to preserve organic food will have numerous benefits, but also disadvantages.

The negative consequences of the PACS wrap includes its applications and overall cost for production. The wrap is targeted specifically to organic foods, but non-organic foods will not be able to be preserved. In addition, the expense to create the PACS wrap will be costly.

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[15] Bennion, Brian J., and Valerie Daggett. "The Molecular Basis for the Chemical Denaturation of Proteins by Urea." *Pnas.org*. Proceedings of the National Academy of Sciences of the United States of America, 7 Mar. 2003. Web. 10 Jan. 2015. <http://www.pnas.org/content/100/9/5142.full>.

Producing nanocellulose fibers utilizing a process called electrospinning, in which fibers are drawn from a liquid polymer, is a relatively new concept and will require more research in laboratories before it can be integrated into the wrap. Also, the biosensor chip in the middle layer has only recently been introduced for its potential to detect contamination and can only be mass-produced multiple years from now. These negative consequences, however, are far outweighed by the positive impact that the wrap will have.

Organic food is quickly emerging as a healthier alternative to processed foods, since it is brought fresh from farm to table, eliminating the use of chemical agents and pesticides. Although consuming organic food is a new trend, it spoils extremely easily, and the PACS wrap provides an innovative way to prevent organic food spoilage. Most of the food we consume is genetically altered and processed with flavorings, chemicals that attempt to slow bacterial growth, and numerous other additives. Many of these additives are not tested, and not surprisingly, they threaten human health[16]. Utilizing the PACS wrap to preserve organic food will leave its quality untouched, decreasing any health risks associated with preservatives, such as the increased risk of reactions to allergens. Also, when organic food spoils, retailers cannot sell it, nor can consumers eat it when food spoils in their own homes. The U.S. spent more than 1 billion last year to dispose of food waste, and by decreasing the amount of food waste in landfills by preservation, these expenses can be cut down significantly.

Incorporating biosensors and polyaniline in the PACS wrap will positively impact the number of foodborne illnesses in the United States and even around the world. According to the Centers for Disease Control and Prevention, "Every year, about 48 million of us, roughly one in

[16] "Additives." *Sustainabletable.org*. GRACE Communications Foundation, n.d. Web. 10 Jan. 2015. <http://www.sustainabletable.org/385/additives>.

six people in the United States, get sick from eating contaminated food." In the daily news, cases of food contamination are abundant, ranging from school cafeterias to restaurants. By noticing the four-layered wrap changing colors consistently after biosensors detect invading bacteria, consumers will be alerted to refrain from eating the food inside of the wrap. If the PACS wrap is widely used, the number of foodborne illnesses and deaths today can be decreased.

Including two layers of nanocellulose into the wrap will have a positive impact on the environment as well. Nanocellulose is a newly introduced material produced from biomass, which has massive potential for packaging foods. As a natural material that is extremely durable and flexible, nanocellulose can protect the wrap from being torn easily, prevent urea from leakage, and reduce the production cost of the wrap, since it is relatively inexpensive[17]. In addition, another benefit of integrating nanocellulose in the PACS wrap is that it will make the wrap reusable, eliminating any cost to dispose of the product.

Creating a multi-layered wrap that can preserve organic food, detect contaminants and warn consumers will significantly reduce food waste. Overall, the PACS wrap will be able to protect consumers from contaminated food, substantially cut down the cost of food waste disposal, and will provide others with an efficient way to preserve organic food without using additives.

[17] "Nanocellulose Technology - Purdue NanoForestry." *NanoForestry*. Purdue University, n.d. Web. 10 Jan. 2015. <https://engineering.purdue.edu/nanotrees/cellulose.shtml>.

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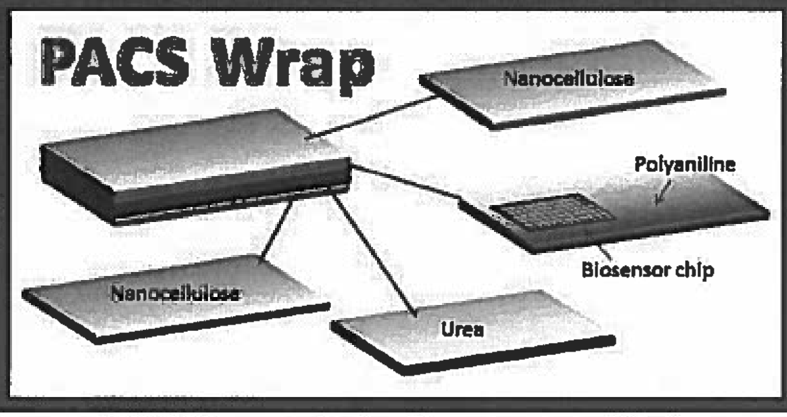
Survival of the Freshest: Preservation of Organic Food

The future of fresh food

- Home
- Past and Present Technology
- PACS Wrap
- Consequences
- Breakthroughs



PACS: Protection Against Contamination and Spoilage
A multi-layered, eco-friendly wrap that preserves organic food and detects and warns consumers of contamination

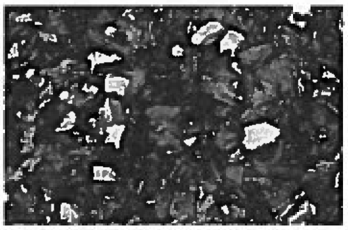
Note: The diagram of the PACS Wrap is magnified. The actual product will be paper-thin.

Past and Present Technology

- Home
- Past and Present Technology
- PACS Wrap
- Consequences
- Breakthroughs

Past

- Drying
  - Uses smoke or sunlight to dry food and prevent spoilage
- Curing
  - Treats food with salt to extract moisture and deter bacteria growth

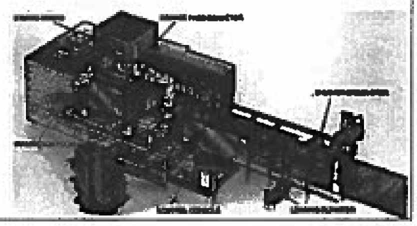


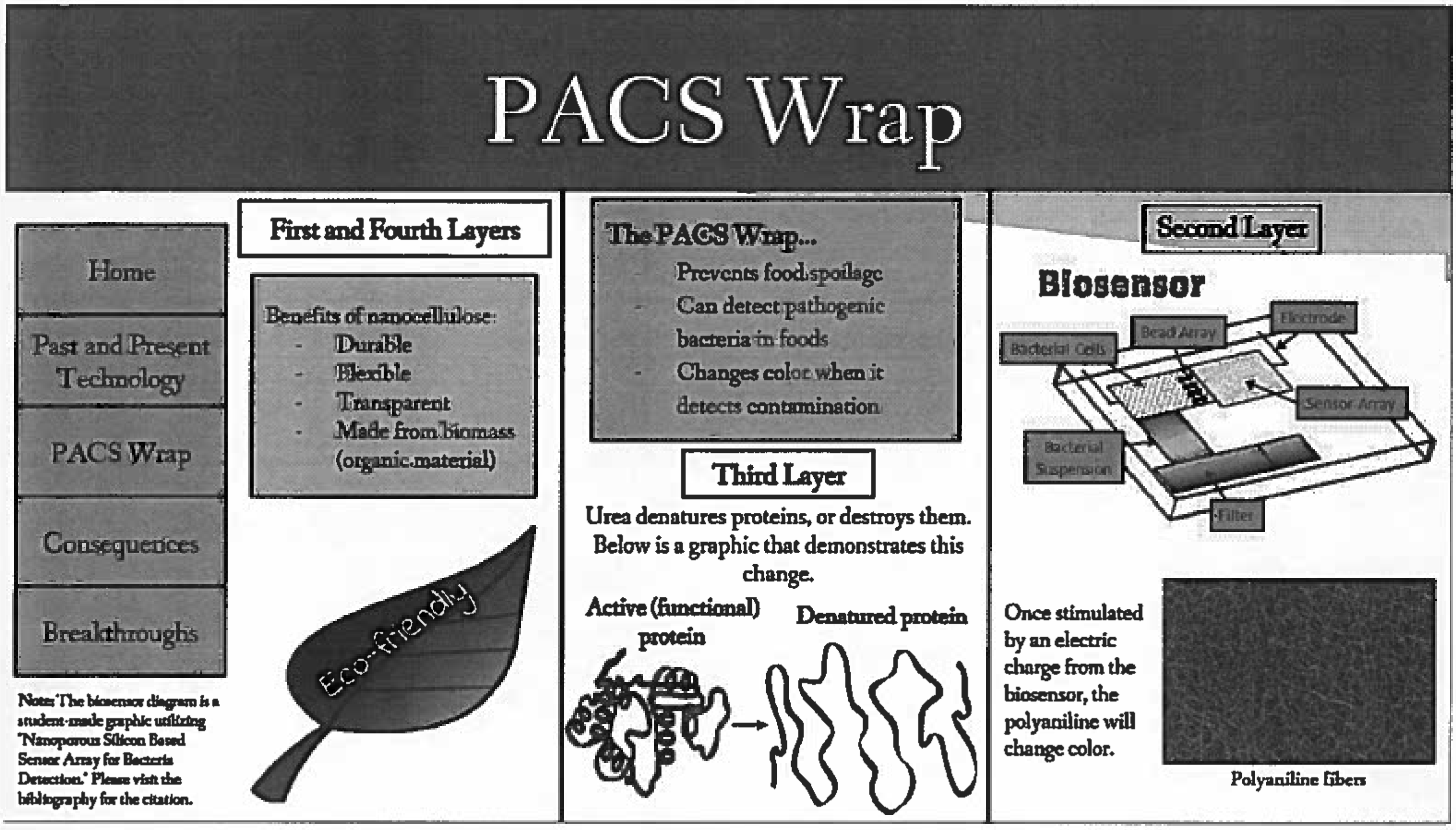
Disadvantages of current food preservation methods include:
- Altered food quality
- Safety/health concerns
- Energy wastage

Dried Vegetables | Irradiation Plant

Present

- Canning
  - Stores heated food in sealed containers to prevent bacteria growth
- Freezing
  - Creates a hostile environment for bacteria by lowering temperatures
- Irradiation
  - Uses ionizing radiation to preserve food and destroy pathogenic bacteria




PACS Wrap
Home
Past and Present Technology
PACS Wrap
Consequences
Breakthroughs
Note: The biosensor diagram is a student-made graphic utilizing "Nanoporous Silicon Based Sensor Array for Bacteria Detection." Please visit the bibliography for the citation.
First and Fourth Layers
Benefits of nanocellulose:
- Durable
- Flexible
- Transparent
- Made from biomass (organic material)
Eco-friendly
The PACS Wrap...
- Prevents food spoilage
- Can detect pathogenic bacteria in foods
- Changes color when it detects contamination
Third Layer
Urea denatures proteins, or destroys them. Below is a graphic that demonstrates this change.
Active (functional) protein
Denatured protein
Second Layer
Biosensor
Electrode
Bead Array
Bacterial Cells
Sensor Array
Bacterial Suspension
Filter
Once stimulated by an electric charge from the biosensor, the polyaniline will change color.
Polyaniline fibers

Consequences

Home

Past and Present Technology

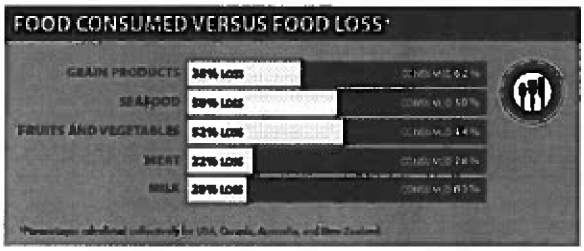
PACS Wrap

Consequences

Breakthroughs

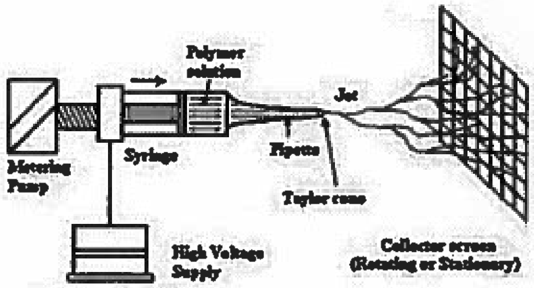
Positive:

- Decreased cost for food waste disposal
- Less risk of receiving foodborne illnesses
- Eco-friendly due to integration of nanocellulose



Negative:

- Large production cost
  - Can be cut down significantly once technique of electrospinning is perfected



Process of Electrospinning

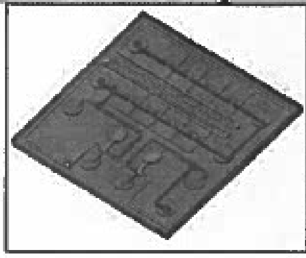
Breakthroughs

- Home
- Past and Present Technology
- PACS Wrap
- Consequences
- Breakthroughs

In order to make PACS wrap a reality...

- Biosensors, which are utilized to detect contamination within the wrap, need to be applied as a small chip
- A controlled experiment that tests the PACS Wrap's ability to detect harmful bacteria and change color must be carried out

Biosensor Chip



Elements of the Controlled Experiment

Independent Variable	Dependent Variable	Control Group	Experimental Groups	Constants
Type of wrap utilized to cover apples	Change in wrapped apple's appearance	Unwrapped apple	Apples wrapped in plastic wrap, plastic bag, and PACS Wrap	Type and size of apple, all room conditions (temperature, moisture, etc.)