In Defense of Food Preservation: Sustainability Benefits Quantified Through a Life Cycle Analysis of Ground Pork Supply Chains

In Defense of Food Preservation: Sustainability Benefits Quantified Through a Life Cycle Analysis of Ground Pork Supply Chains

Brendan T. Rigby

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Abstract

As human population continues to increase, the amount of food needed to support the sum of human life also increases. Unfortunately, getting food onto consumers' plates is an extremely complicated and resource intensive process. Simply producing more food to feed more people is an obvious option, but this solution would increase the environmental impact of our agricultural and food distribution systems. The most logical way to increase the amount of food available for human consumption, without producing more food, is to reduce the amount of unconsumed food that expires, or spoils to a point where it is no longer safe for human consumption. The purpose of this project was to carry out a shelf life study and an associated life cycle analysis, for two versions of the same food product: with and without preservatives. The goal of this study was to develop a framework for decreasing the environmental impact of the food we eat by using food preservatives to reduce food waste. An overarching question, 'can the environmental impact of the pork products that we consume be reduced by food processors and manufacturers using food preservatives?' guided this research. I hypothesized that adding preservatives to unpreserved fresh ground pork products Americans consume (4.7 kg per capita or about 1.5 billion kg total) would reduce the amount of ground pork products that are wasted and go to landfill by 10%. I further hypothesized that preservative use would reduce the greenhouse gas emission for the product system by 5%.

Ground pork was chosen as the model for this study because pork is the most commonly consumed meat product worldwide, and meat products are well documented to have extremely large environmental impacts (USDA FAS, 2016). To carry out the

study, fresh ground pork products were produced with and without preservatives to see how much the product shelf life is extended by preservative use. The preservative blend used was a combination of citric acid and table salt (sodium chloride). Shelf life was quantified through a combination of organoleptic and microbiological tests. Shelf life tests were carried out in real time, not under accelerated conditions. Microbiological testing was limited to aerobic plate counts. Next, LCAs were carried out to determine which product had a smaller environmental impact. LCA models were constructed using openLCA. The models were designed to capture the entire product life cycles, from production and manufacture to distribution and end of life consequences.

I concluded that the reduction of waste will outweigh the environmental impact of producing and using preservatives. The preserved model was determined to have a shelf life of nine days, compared to the conventional model with a six day shelf life. This increased shelf life led to an 8.3% reduction in CO_2 eq throughout the lifespan of the product. Contrary to popular belief, the product with preservatives has a smaller environmental impact, from cradle to grave.

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For Wayne, who would have wanted to celebrate with us.

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Definition of Terms

APC: Aerobic Plate Count. Quantified by diluting a sample and plating it on an appropriate medium. Measured in colony forming units per gram. Gives a broad range of microbial load but does not identify pathogenic strains.

Citric Acid: A naturally occurring component of plant and animal tissues. Anhydrous citric acid can be sourced from lemon or pineapple juice, or through mycological fermentation. Citric Acid has GRAS status with the FDA.

GRAS: Generally Recognized As Safe. GRAS is the FDA's term for a safe food additive. Sometimes associated with a usage rate, i.e., 200 ppm.

Listeria monocytogenes: Dangerous food spoilage pathogen. Especially worrisome because it can grow at refrigeration temperatures, and as low as -4^{o}C

Organoleptic Evaluation: A sensory test to see how the quality of a food product changes over time. Usually includes taste, scent, texture, color and other quantifiably food product attributes.

Pork Butt: The primal cut of a pig that makes up its upper shoulder region. Accounts for about 10% of the total weight of the slaughtering pig, and has a yield of about 86% after deboning and trimming fat.

Picnic Shoulder: The primal cut of a pig that makes up its lower shoulder and front leg region. Accounts for about 11% of the total weight of the slaughtering pig, and has a yield of about 72% after deboning and trimming fat.

Sodium Chloride (Table Salt): A compound composed of sodium and chloride ions. Well documented to be an effective food preservative against certain microbial food pathogens. Sodium Chloride has GRAS status with the FDA.

Shelf Life: A scientific study carried out by food manufacturers to determine the "use-by" date of a product. Usually contains a microbial and organoleptic portion. The microbial portion may target growth of certain organisms if they are known to be present in the food sample, i.e. *Salmonella* in chicken.

Chapter I

Introduction

“When it comes right down to it, food is practically the whole story every time.” - Kurt Vonnegut, Galapagos

As we have become more aware of the environmental impacts of our everyday lives, various organizations, governments and even individuals try to make sustainable choices to reduce their impact and protect the Earth’s natural resources. Unfortunately, it is not always clear which products or services truly have the smallest environmental impact, so oftentimes consumers are left to try to figure out which are the most environmentally friendly for themselves. This is problematic because it leads to consumers comparing or quantifying different marketing claims, despite the fact that the claim may be misleading, or intentionally deceptive. For example, which product is less environmentally detrimental: “locally grown” or “organic” produce? How does the producer define “locally”? Produced within 10 miles? 100 miles? Was this organic produce certified by an accredited audit system like the USDA’s Organic standards? If it is certified organic, how far did it have to travel to get to my plate? Despite being organic, was it responsibly sourced, or did it come from a social hotspot?

Two major factors make these questions critical to answer: growing population and the environmental impact of getting food onto your plate. First, due to continuous worldwide population growth, humans need more and more energy (calories) to survive. Also, scientists believe the Earth is warming at an alarming rate due to climate change induced by greenhouse gasses emitted by human activities. Common agricultural practices are well documented to be a large producer of greenhouse gasses. In order to keep up with the caloric demand of a growing population, conventional knowledge dictates that we should simply produce more food to feed our growing population. Unfortunately, increasing the total amount of food produced would also increase the environmental impact of total food production.

An alternative approach to producing more food to solve the problem of feeding more people would be to decrease the amount of food we produce that goes unconsumed. Unconsumed food, or food waste, is an important factor when we consider the environmental impact of our food system. Not only is wasted food resource intensive to produce, but it also has end of life impacts as it decomposes, all while providing no nutritional benefit to humans. Reducing food waste is not an easy task, because waste happens at every level of manufacturing and processing, as well as at the end users' homes. This means that effective food waste reduction strategies need to consider the total product life cycle, from producer to manufacturer to store owner and customer. If a potential food waste solution is too expensive or complicated, it will not satisfy all parties, and ultimately will not be a viable solution (NRDC, 2012).

A reasonable solution to reduce food waste is through food preservation techniques. Food producers and manufacturers are willing to preserve their food to extend its' useful life so they have more potential customers. A food product with a longer useful life can be shipped to consumers around the world, whereas a product with a shorter useful life probably has to be consumed closer to where it was produced or processed, before it expires. Store owners and consumers are willing to purchase products with preservatives because they have a longer time period to consume them after buying them. Buying foods that will stay fresh for weeks instead of days means fewer trips to the supermarket, and less expiring inventory for store owners (FDA Food Facts, 2018).

Research Significance & Objectives

In this study, I quantify the environmental impact of fresh pork products, and investigate whether the environmental impact of pork consumption could be reduced by adding food preservatives, and thereby, reducing wastage. Reducing wastage of pork and other meat products has far-reaching effects, such as reducing the amount of forest land converted to soybeans, grains or other livestock feeds. As the human population continues to grow, it is imperative to find a way to sustainably feed the world without destroying it.

Pork was chosen to serve as a model food for this study because meat and animal products are known to have a large environmental impact, and pork is the most widely consumed meat product worldwide. According to data gathered in October 2016, 108 billion kg of pork are consumed worldwide annually, compared to 59 billion kg of beef and 88 billion kg of chicken (USDA FAS, 2016). Additionally, the rate of pork consumption is increasing at a greater rate worldwide than rate of consumption of beef or chicken (Ritchie, 2018).

The objectives of my study were:

- To find a methodology to reduce the environmental impact (greenhouse gas emission) from the agricultural sector, despite trying to feed a growing population.
- To outline a method of using preservatives to reduce the overall impact of our food sector. This will be accomplished by using food preservatives to reduce the amount of

food we waste, and modeling product life cycles with and without preservatives in an LCA program.

Background

A recent trend in the food manufacturing industry has been producing more "all natural" foods. Consumers define “all natural” foods, loosely, as food free from artificial colors, flavors and preservatives (Food Product Design, 2011; Imberg, 2015). Unfortunately, the Food and Drug Administration (FDA), the governing body that controls which nutritional claims can be put on labels (such as "no carb", "low sodium" or "reduced fat"), does not define the term "natural.” This has become such a hot button issue that the FDA has turned to food professionals and consumers to ask what "natural" means to them (FDA, 2015).

This consumer-driven push toward "natural" foods compounds another issue in our food system - food waste. Despite researching scholarly articles and food industry publications, it is almost impossible to determine exactly how much food we are wasting at the production, distribution, retail and consumer levels. Research done comparing food production metrics in the United States to average body weight estimated that we waste about 40% of the food we produce (Hall, 2009). Alternatively, the United States Department of Agriculture (USDA) Economic Research Service estimates that we waste about 31% between the consumer and retail levels (USDA ERS, 2013).

Food Waste

Estimates of food waste in the United States usually fall between 30% and 40%, with consumer level food waste alone making up about half of this number, around 20% of our total food supply (Aubrey, 2015; NRDC, 2012). This means that on average, every fifth bag of groceries that U.S. shoppers bring home ends up in their garbage, and ultimately, a landfill. Figure 1 contains a breakdown of the different supply chain levels, and what percentage of our total food waste comes from each level.

Figure 1. Food waste in the value chain.

Food products without preservatives have a shorter useful life, or "shelf life" than their counterparts that contain food preservatives. If more food products are developed without preservatives, it is safe to assume that more food will be wasted, especially at the consumer level. If we waste more food, we will do more damage to the planet because modern agricultural processes use pesticides and herbicides, which have been shown to be environmentally detrimental (NRDC, 2011) (UNEP, 2013). A similar analysis was carried out by Williams and Wikstrom (2011), where they researched whether or not the overall impact of the food system could be reduced by improving food packaging standards. Ultimately, the goal of their analysis was to develop a framework to reduce the overall impact of the food system. In their analysis, they found that increasing the energy use that goes into packaging can potentially be justified due to a decrease in food waste.

Population Growth and the Environmental Footprint of Food Waste

Despite the fact that there are so many unknown variables and undefined terms, this research is extremely important because our population is growing rapidly, and if left unchecked, we may approach a point in human history where we do not have the capacity to produce enough calories and nutrients to feed everybody on earth. The United States Census Bureau estimates that there are about 7.3 billion people currently on earth, and the United Nations expects the world population will reach 9.7 billion by 2050 (US Census, 2017; UN DESA, 2015). Before we reach this point, the research needs to be done to develop a sustainable food production and distribution network to feed as many people as possible while making the smallest possible environmental impact.

Current agricultural practices are extremely environmentally intensive. A single hog weighs about 122 kg at its time of slaughter. Data from Iowa State University shows that it takes about 371 kg of feed to bring a pig to slaughter weight (Lammers, 2007). In order to grow 371 kg of feed (primarily corn and soybeans), it takes almost a tenth of an acre, assuming that the average yield per acre is 168 bushels, or 4,275 kg (25.5 kg/bushel) according to USDA data (USDA NASS, 2016). A single bushel of corn needs about 34,065 liters of water, so in order to grow 371 kg of corn, this will call for almost 500,000 liters (Frankenfield, 2014). According to a USDA survey, the average acre of corn receives about 65 kg nitrogen, 29 kg phosphorous and 37 kg potash (USDA NASS, 2014). This means that the average slaughtering pig necessitates a tenth of an acre worth of corn, 500,000 liters of water and about 13 kg of total fertilizer, before even taking its own living quarters and the water in its diet into account.

Spoilage Organisms

Food spoilage due to microbial contamination has the potential to cause food waste. While microorganisms can play a valuable role in the production of food products such as wine, cheese or yogurt, they can also be toxic and cause sickness or even fatalities. Different microorganisms also come from different sources. Raw pork, for example, is known to carry *Trichinella*, *E. coli*, *Staphylococcus aureus*, *Salmonella spp.* and *Listeria Monocytogenes.* If ingested at a high enough concentration, these microorganisms can cause serious sickness and even death, especially among the immunosuppressed population (USDA FSIS, 2018).

To control against infection by these dangerous microorganisms, the USDA recommends cooking pork to a certain temperature, depending on the preparation method. Whole primal cuts or large tenderloins, for example, can be roasted, broiled, or braised to an internal temperature of 63ºC. Alternatively, ground pork products must be cooked to an internal temperature of 71ºC, regardless of the preparation method. This is due to the fact that microorganisms tend to thrive on the exposed surfaces of large cuts of meat. When large primal cuts are deboned and ground, the microorganisms that were congregated on the surface of the meat are spread throughout the entire ground mass. This is why it’s safe to eat a pork tenderloin or thick porkchop that is still pink in the middle, but not pink ground pork. Ground meats are inherently more difficult to preserve than whole primal cuts, because microorganisms are more evenly distributed throughout, and they have a larger surface area on which to thrive.

Food spoilage can be exacerbated by light, oxygen, heat or humidity, among other factors. When foods spoil, their color, odor, taste and texture may change, but this is not always the case. Some food products are labeled with instructions such as “refrigerate after opening” or “do not consume if seal is broken” to protect against common causes of food spoilage. Due to the risk of injury from ingesting spoilage organisms, their growth, as well as other microbiological and chemical indicators, have an important part in determining the shelf life of a food product (FDA, 2018).

Shelf Life Studies

Shelf life studies are carried out to determine the useful life of a food product, as well as the handling instructions. There is no Federal mandate in the United States that says the useful life of a food product must be printed on the container, but most foods labels contain a “use by” or “best by” date. Handling instructions, however, are required by federal law. These instructions, such as “To prevent illness from bacteria: keep eggs refrigerated, cook eggs until yolks are firm, and cook foods containing eggs thoroughly” advise consumers on how to properly store and cook foods that can cause illness if they are not handled properly (FDA Food Facts, 2018).

Shelf life studies usually contain both microbiological and organoleptic tests. Microbiological tests might be broad spectrum, such as an aerobic plate count (APC), or they could be selective or differential to identify a specific microorganism or species. An APC is a microbiological test to determine the concentration of microorganisms in a food sample. This type of test is often used for precooked, frozen, or refrigerated foods, and it will grow various species, but individual species may not be possible to identify using an APC alone. While an APC can be a valuable tool in determining the quantity of microbiological activity in a sample, it does not necessarily indicate that a food sample is safe to eat. As an example, there are various strains of *E. coli* in your body that contribute to your healthy gut function. Specific strains of *E.coli*, however, can be pathogenic or even fatal if ingested, such as *E. coli* O:157 H:7 (NSW Food Authority, 2010).

APC tests are carried out more frequently than selective or differential tests for shelf life testing because they are generally less complicated and less expensive. Unlike APC's, selective and differential tests do not always grow many different species of microorganisms, and when they do, it is generally easy to identify certain species (FDA, 2017). Selective and differential tests (Figure 2) use different combinations of growth media, food sources, dyes and chemicals to inhibit the growth of certain microorganisms, while allowing others to thrive. They may also carry out chemical reactions so that a color change can signal for certain microorganisms of interest. For example, these tests can be extremely valuable to help microbiologists differentiate between different strains of *E. coli* and *Listeria*, because only certain strains are pathogenic to humans.

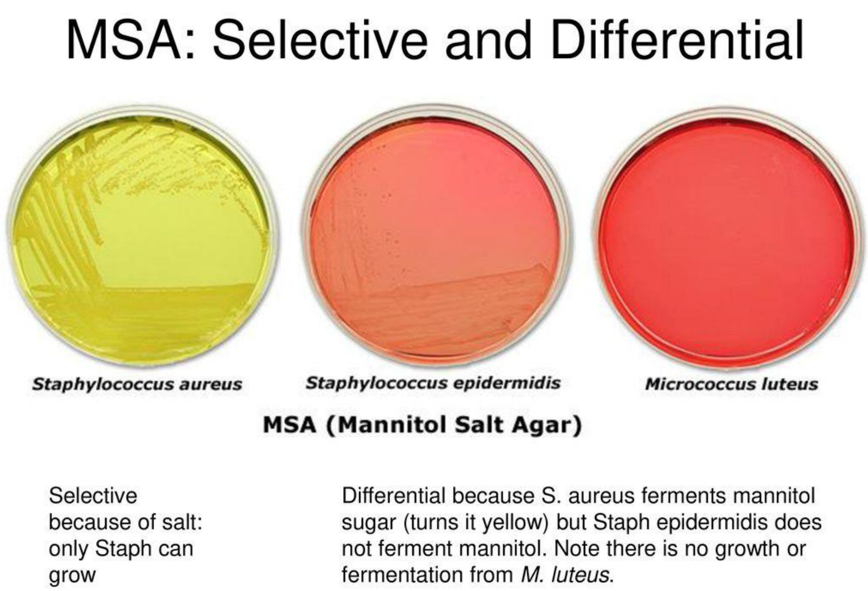


Figure 2. Selective and differential media are used to identify and isolate different strains of *Staphylococcus*.

Unlike objective microbiological tests, organoleptic tests have a level of subjectivity. The purpose of organoleptic tests is to quantify changes in a food product over time using our sensory organs. Organoleptic testing can include tasting a product, looking for color changes or off odors, or even listening for the snap of a potato chip or cracker. Sometimes organoleptic testing can be carried out by an untrained panel, but it can also be carried out by professionals that have been trained to identify various quality indicators for a specific food product. Various organizations develop standards for professional organoleptic or sensory testing. The International Organization for Standardization's (ISO) ISO11036:1994 outlines the methodology for analyzing the texture profile of food or non-food products. The American Society for Testing and Materials International's (ASTM) ASTME1627-11 describes standard practices for evaluation edible oils and fats.

Organoleptic testing can be as simple as determining if a product still meets the quality standards of the manufacturer, but it can also be more complicated. A differential test may ask panelists to taste three samples, two identical and one different, and identify the different sample. This type of forced-choice test is called a Triangle Test. Precise methodology can be found in ISO4120:2004. Another test may ask panelists to taste multiple different samples and stack rank their quality. Sometimes guides such as color charts can be used to increase objectivity and standardize different panelists.

Food Preservatives

Simply put, food preservatives work by making a food product less inhabitable for microorganisms, and less likely to undergo detrimental chemical reactions. Though all microorganism species are different, and require different inputs to thrive, targeted approaches can systematically reduce the speed at which they grow, or their ability to grow at all. Refrigeration, high heat, pH controls and water activity controls can all be used effectively to preserve food and extend its' useful life, but the best preservation methods use a combination of these controls.

Scientists believe that humans may have been preserving foods as early as 3000 BC. Food preservatives were widely in use by 1200 BC, when meats were salted and cured in China (Binkerd & Kolari, 1975). Unbeknownst to these lucky and ingenious early food preservers, many of the salts that they gathered from deserts and mines contained sodium. Sodium, and specifically sodium chloride (or table salt), is well documented to be an effective food preservative, slowing the growth of *Listeria monocytogenes* (Horsch, 2014). L. *monocytogenes* is an especially dangerous food pathogen, because it can grow at temperatures as low as -4°C, which is below the temperature of a refrigerator. Using a combination of high salt content in addition to refrigeration will control organisms that cannot thrive in refrigeration temperatures, as well as controlling *L. monocytogenes* growth, despite the fact that it could potentially grow at this temperature.

Citric acid is a weak organic acid that occurs naturally in citrus fruits such as lemons, limes and grapefruits. A 1millimolar (mM) solution of citric acid has the pH of approximately 3.2. This low pH makes microbial growth almost impossible. Adding citric acid to a food matrix will not drop the pH to 3.2, but it will reduce it, depending on the concentration of citric acid in the finished food product, and the pH of other ingredients. Combining a pH reducing compound with increased salt content, as well as temperature controls, make it significantly more difficult for microorganisms to thrive. These hurdles for microbial growth work in conjunction with each other to make the preservation process stronger than the sum of its' parts.

The FDA regulates food additive usage rates, as well as label declarations. In their Code of Federal Regulation (CFR Title 21), the FDA has granted sodium chloride and citric acid GRAS status, meaning that as a food additive, they are generally recognized as safe. Based on previous studies, sodium chloride and citric acid have GRAS status up to levels of 200 parts per million (FDA, 2016). Sodium chloride and citric acid will be used as the preservatives in this study because they naturally occurring, generally recognized as safe by the FDA, and have been used as food preservatives for hundreds of years, especially before a process for canning was developed in the 1800s (FDA, 2016).

Pork as a Model

A useful focus for the environmental effects of meat preservation is United States pork consumption. The average American consumes about 22.5 kg of pork products annually, including a broad range of products like sausage, ham, bacon and ribs (National Pork Board, 2016). Different primal cuts of pork include Butt, Loin, Ham, Picnic Shoulder, Spareribs and Belly (Figure 3). Different pork products and primal cuts undergo vastly different process steps before they arrive on American plates. For example, before it finds a place at the table, picnic shoulder is oftentimes deboned, ground, mixed with a seasoning blend, extruded into a casing, distributed either fresh or frozen, cooked (usually grilled) to an internal temperature of 71°C in order to control microbiological pathogens, and served as sausage. Alternatively, pork belly is usually cured, thinly sliced, distributed either fresh or frozen, cooked (usually pan fried) to an internal temperature of 63°C in order to control microbiological pathogens, and served as bacon.

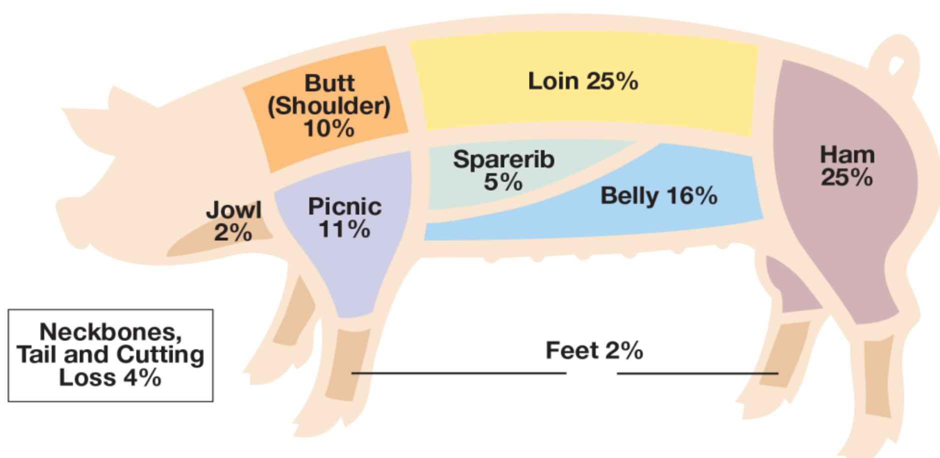


Figure 3. Pork primal cuts.

In order to account for the vast differences in deboning yield, process steps, and distribution of different pork products, a study of the effects of preservatives should focus on ground pork, which makes up 21% of the weight of a pig between the pork butt (10%) and picnic shoulder (11%) (National Pork Board, 2015). Thus, we can assume that 21% of the 22.5 kg of pork that Americans consume annually is ground pork butt or picnic shoulder. Pork butt and picnic shoulder have a significantly lower yield than most other cuts of pork because they have a larger portion of fat and more bones than other cuts. An average American consuming 4.7 kg of ground pork annually will consume about 2.3 kg pork butt and 2.4 kg picnic shoulder. Ground pork that Americans consume has usually already had a significant portion of fat trimmed off, and bones have been removed from the primal cuts. Pork butt has an 86% yield after trimming and deboning, where picnic shoulder has a 72% yield after the same process steps (National Pork Board, 2015). This means that 2.7 kg pork butt and 3.4 kg picnic shoulder, or 6.1 kg total of ground pork needs to be produced annually per American - before taking consumer level food waste into account.

Life Cycle Analysis

Life cycle analysis (LCA) is a technique that is used to quantify the environmental impact that a product has on the environment. Effective LCAs have a focused scope, and consider raw material procurement, manufacture, distribution, use, and end of life product stages. This holistic, cradle to grave approach is the only way to truly quantify a product's environmental impact. LCAs are carried out by looking at the entire product life cycle, and tracking physical inputs, outputs, waste and energy inputs.

The sum of these factors at each product life cycle stage represents the products' entire impact.

An LCA would be an effective strategy, for example, to see how many times a reusable water bottle needs to be refilled to have a smaller impact than disposable bottles. Of course, the reusable bottle has more inputs: it's heavier and contains more plastic, so it probably takes more energy and raw materials to manufacture and distribute. However, because it can be continually reused, eventually there will be a breakeven point, after which the negated impact of the single use water bottles exceeds the impact of the reusable bottle. Without tracking physical inputs, energy inputs, waste and outputs, it would not be possible to find this breakeven point.

It is important to have a focused scope when using LCAs to compare different products. Not clearly defining a scope of an LCA can lead to results that are impossible to interpret. For example, if one product uses a lot of energy to manufacture, but very little water or fertilizer, is it less impactful than a product that uses an exorbitant amount of water, but very little energy or fertilizer? LCAs lose their effectiveness without a defined goal, such as greenhouse gas emission reduction or land use reduction.

A method for assessing environmental impacts of various products is the Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts (TRACI). Impacts such as fossil fuel depletion, land use effects, eutrophication and various other impact categories can be connected in a product system. Once all product stages are connected in a product system, each categorized impact at each product stage can be compared. When done properly, LCAs can give us valuable information about which certain products are more environmentally friendly than others, and why (EPA, 2016).

Research Question, Hypotheses and Specific Aims

An overarching question – can the environmental impact of the pork products that we consume be reduced by food processors and manufacturers using food preservatives? – led to the inception of this project.

I hypothesized that adding preservatives to unpreserved fresh ground pork products Americans consume (4.7 kg per capita or about 1.5 billion kg total) would reduce the amount of ground pork products that are wasted and go to landfill by 10%.

I further hypothesized that this would result in a decrease in greenhouse gas emission for the product system by 5%. I expect this to happen despite the fact that sourcing and distributing preservatives to pork processing plants will add to the impact of the preserved model.

Specific Aims

To complete this research, I:

1. Carried out an organoleptic and microbiological shelf life study to quantify how many more days of useful (shelf) life are obtained by adding 1.5% sodium chloride and 1.0% citric acid by weight to ground pork. The microbiological study will be an APC test with an acceptable limit, and organoleptic testing will be testing for an off odor, color, smell or taste in the product sample over time. Taste attributes will also be tested with an unacceptable/offensive threshold.
2. Estimated how much pork we currently waste, and how this amount would change with preservatives added

3. Quantified the environmental impact of sourcing and distributing enough sodium nitrite to add 1.5% Sodium Chloride and 1.0% Citric Acid to all ground pork in the United States by conducting an LCA, and reviewing previous studies
4. Estimated the greenhouse gas emission reduction using an LCA program modelling preserved and preservative-free ground pork samples

Chapter II

Methods

In order to answer my primary research question, I compared the environmental impact of two different products. Results were measured using an LCA program and a shelf life study with two different models: a model with sodium chloride and citric acid, and a preservative-free model. Pork was chosen to serve as a model food for this study because meat and animal products are known to have a large environmental impact, and pork is the most widely consumed meat product worldwide.

This study took the United States ground pork market and used average data on a per capita basis. Sodium chloride and citric acid were used as the preservative in this study because they are naturally occurring, generally recognized as safe (GRAS) by the FDA and have been used as a food preservative for hundreds of years, especially before a process for canning was developed in the 1800s (FDA, 2016).

Experimental Shelf Life Study

To test my first hypothesis, I procured ten separate and independent samples of raw ground pork. Half of these samples got a preservative blend, 1.5% sodium chloride and 1.0% citric acid by weight added, and the other half did not. The five samples that did not receive the preservative blend represented the control group, while the preserved samples were the test group. Samples were tested on a predetermined schedule and were still tested even if the sample was determined to be expired by previous tests.

Organoleptic samples were not consumed after expiration, but were still inspected for odor, texture and off colors. I received formal training in lab skills while earning my Bachelor of Science in Food Science at the University of Massachusetts Amherst. After this training, 5 years of professional experience working at in-house microbiological labs, as well as working with third party labs to test food samples enabled me to conduct this technical research.

Once an average shelf life difference was determined from the data collected, I could test my first hypothesis, and begin to test my second. The difference in shelf life between the two models (preserved vs. unpreserved pork samples) was used to determine the hypothetical reduction in food waste. Previous research showed that approximately 20% of food is wasted at the consumer level, so this figure was used as the rate of waste in the control model. The preserved pork model made a conservative estimation as to how much more of the product would be consumed due to the additional days of useful life.

The two separate models were calorically balanced, because the preserved model contains less actual pork when compared mass to mass. Per capita ground pork consumption was assumed to be 4.70 kg annually, so the necessary amount of preserved pork product to provide the same caloric density was determined to be 4.82 kg.

Sample Preparation

Ground pork was purchased from a local supermarket for this study. The pork was purchased on the same day that it was ground, and the sell by date on the container was two days after the purchase/grind date. The first test for each lot was carried out on the sell by date (Figure 4), "day 0". Each lot was tested again every third day after the sell by date, until day 12. Tests were carried out on day 0 (sell by date), day 3, day 6, day 9 and day 12. Each testing sample was labeled with a lab ID, and the date it should be tested on. The ID would be the test number, followed by C or T for control or test, followed by M or O for microbiological test or organoleptic test. Sample 01-C-M-7/28/17 was the first lot of control samples, and it was prepared for a microbiological test, carried out on 7/28/17.

Figure 4. Example of a single lot of ground pork for sale at a supermarket in November, 2018. The Sell By date has been circled in red. The sell by date was the date of the first test for each lot. Handling instructions are highlighted in blue.

To prepare samples for testing, a 3' x 4' table was cleaned, washed and sanitized. First, sterile whirl-pack lab sample bags were labeled with proper sample code and testing dates.

Next, the package of pork was opened with a sanitized knife by a trained technician wearing sanitized gloves. First, the pork would be carefully placed into a cleaned washed and sanitized bowl. At this point, the appropriate amount of sodium chloride and citric acid was added to the test lots, and it would be mixed for one minute. If it was a control test, it was simply be mixed for one minute. Using a sterile scoop, the pork would be portioned into the ten labeled sample bags, two for each of the testing days, one for microbiological testing, and one for organoleptic testing. Samples were stored at refrigeration temperatures with minimal exposure to light or air until they were tested.

Microbiological Test Scheme

Once basic testing plans were in place, a microbiological laboratory to carry out my testing scheme was identified. The laboratory that tested these microbiological samples was Advanced Food Labs (AFL), recommended by food industry colleagues. AFL was used because they have a good reputation as a reliable laboratory within the industry, and were available to do testing seven days a week. Availability for testing on Saturday and Sunday was important, because the test schedule was predetermined to be every third day, which would occasionally be a weekend day. When microbiological samples were prepared to be sent out, AFL would be contacted and told how much testing was needed, the dates that samples should be tested on, and the handling instructions for samples. This information was prepared in an Analysis Request Form (Figure 5) and sent to the laboratory.

Advanced Food Labs, Inc.

31-B Foodmart Road. Boston, MA 02118
Tel: (617) 269-6424 • (617) 268-0971 • Fax: (617) 268-1635 • Email: aflabs@aol.com
www.advancedfoodlabs.com

ANALYSIS REQUEST FORM

COMPANY NAME: _B.T. STUDIES____________________ **DATE:** _7/19/17_______________ **Time:** _10 am___________
ADDRESS: ____99 Crescent Avenue____________________ **CONTACT:** ___BRENDAN RIGBY____________________
Chelsea, MA, 02150 **EMAIL:** ___RIGBY1090@yahoo.com________________________
PHONE: ___781-718-7122_________ **FAX:** ________________
MOBILE: ________________________________ **Authorizing Signature:** ____________________

SAMPLES DESCRIPTION:	AFL # (for lab only)	SAMPLES DESCRIPTION:	AFL # (for lab only)
01-C-M (7/19)			
01-C-M (7/22)			
01-C-M (7/25)			
01-C-M (7/28)			
01-C-M (7/31)			

MICROBIOLOGICAL ANALYSES
____X____ Total (Aerobic) Plate Count
________ Anaerobic Plate Count
________ Bacillus cereus
________ Campylobacter
________ Clostridium perfringens
________ Coliform
________ E. coli
________ E. coli, O157:H7
________ Lactic Acid Bacteria
________ Listeria
________ Listeria monocytogenes
________ Salmonella
________ Staphylococcus. aureus (coagulase+)
________ Yeast and Mold
________ Water Potability (USDA plants)
________ Shelf Life
Other: ____________________

ALLERGENS
________ Wheat
________ Soy
________ Gluten
________ Dairy
________ Egg
________ Nuts
________ Fish & Shellfish
________ Histamine
Other: ____________________

PROXIMATE ANALYSES:
________ Moisture
________ Protein
________ Fat
________ Omega 3
________ Omega 6
________ Fatty Acid Profile
________ Ash
________ Calories
________ Carbohydrates
________ Fiber, total dietary
Other: ____________________

ENVIRONMENTAL
________ Water/Soil/Solids organic
________ PCB
________ Heavy Metals
________ Methyl Bromide
________ Pesticides
________ Insecticides
Other: ____________________

VITAMINS & MINERALS
_____ Potassium _____ Vit.A
_____ Copper _____ Vit. B
_____ Magnesium _____ Vit. C
_____ Zinc _____ Vit.D
_____ Iron _____ Vit.E
_____ Calcium _____ Vit. K
Other: ____________________

GENERAL CHEMISTRY
________ Chloramphenicol
________ Cholesterol
________ Decomposition
________ Fatty Acid Profile
________ Histamine
________ Methyl Mercury
________ Total Mercury
________ pH
________ Phosphate
________ Salt
________ Sodium
________ Sulfites
________ Nitrites
________ Carbohydrates
________ Sugar Profile
________ TBA (Rancidity)
________ Trans Fatty Acid
________ Water Activity (aw)
Other: ____________________
Other: ____________________
Other: ____________________

NUTRITIONAL LABEL
________ Nutritional Label
Other: ____________________

ENTOMOLOGY
________ Filth Analysis
________ Foreign matter
Other: ____________________

Have a representative contact us with results: [ ] Call [ ] Fax [ ] Email [ ] Rush (50% surcharge)

FOR LABORATORY USE ONLY
SAMPLES RECEIVED: Frozen ______°___ Refrigerated ______°___ Ambient _____°___
SAMPLES STORED IN LAB: Frozen ______°___ Refrigerated ______°___ Ambient _____°___
Thermometer Used: E1________ Other________

Notes / Comments ______________________________
How did you hear about us? ______________________________

If you are interested in a test that is not listed above, please contact us.

Form # 166 Issued: NA Rev. 4-16-15 P1 of 1

Figure 5. Advanced Food Labs Analysis Request Form.

When AFL was contacted, they provided a time when their courier would pick up the samples, and this information was entered into the Analysis Request Form and sent to AFL. On pick up day, the courier took the samples from a refrigerator and put them in a cooler with ice packs to transport them to the laboratory. When the lab received the samples, they stored them at refrigeration temperatures and tested on the predetermined schedule as instructed.

AFL tested samples for an APC. An AFL employee, certified by the American Society of Microbiology, carried these tests out in accordance with Association of Analytical Communities (AOAC) standards. At a high level, an APC is carried out by diluting a sample using a serial dilution scheme from the original sample, 1:1 to a 1:10 dilution to a 1:100, etc. (Figure 6). Next, each of these diluted samples was plated by depositing one gram onto appropriate media. Depending on the growth medium, APC samples are usually incubated at approximately 35^{o}C for two days. After two days of growth, the plates can be removed from the incubator to be counted.

Results were reported as colony forming units per gram (CFU/g). A colony forming unit is a distinct spot of growth on the growth medium. If, for example, a sample has 10^6 CFU/g, it will overgrow the 1:10 and 1:100 plates. They will be unable to be read, because they will have 10000 and 1000 colonies on them, respectively. They will be reported as too numerous to count (TNTC). On the 1:1000 plate, there will be approximately 100 colonies, and the 1:10000 plate there will be approximately 10 colonies, and the 1:100000 plate, there will be approximately one colony. These results were weighed and complied by the AFL team, and were supplied to me about two weeks after samples were submitted. It was predetermined that an acceptable microbial concentration would be less than 2,000,000 CFU/g. While this is a conservatively high threshold, it should be remembered that ground pork is not ready to eat, and must go through a heat treatment kill step before consumption.

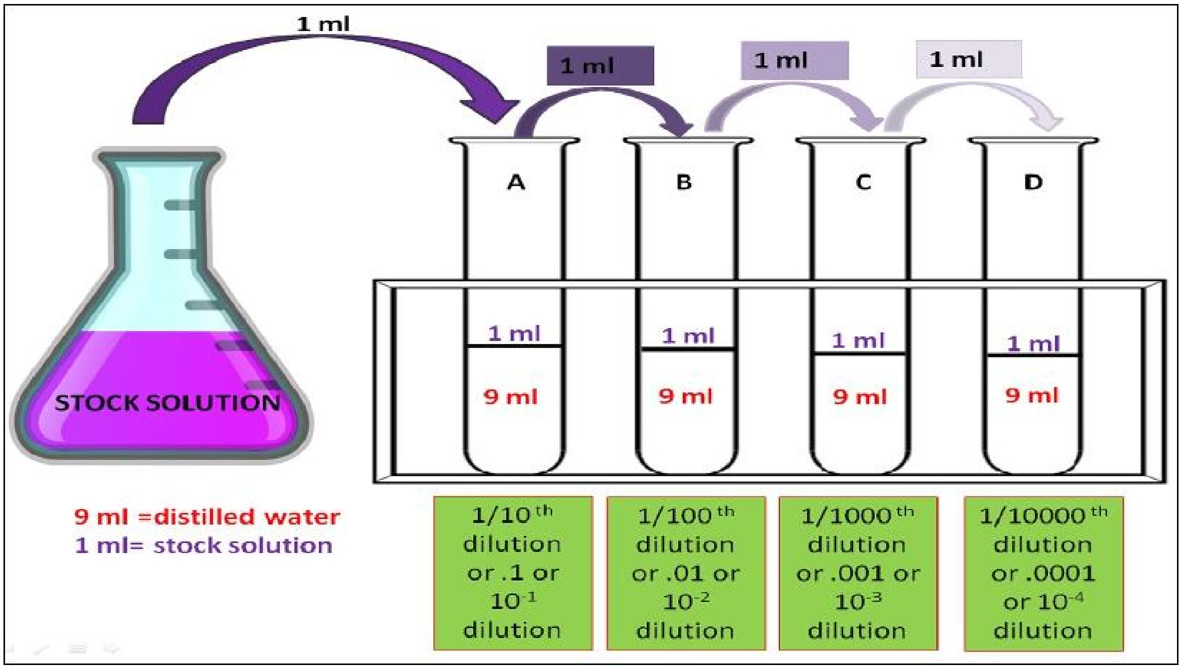


Figure 6. Basic serial dilution scheme.

Organoleptic Test Scheme

Organoleptic testing was scheduled to be carried out on the same day as microbiological testing. Samples were first removed from the refrigerator and inspected while still in their lab bag. The color of the sample, as well as any moisture were noted. A color change can be an indicator for chemical reactions in the sample, such as oxidation. Moisture being drawn out of the sample and pooling in the sample bag can be a risk for yeast and mold growth. Next, the sample was opened, and the odor was quantified. Off odors can be a sign of spoilage organism growth. Last, the sample was prepared to be consumed.

To safely eat the sample without imparting too many texture or flavor changes, a six inch pan was heated with one tablespoon of neutral oil. After heating the oil in the pan for two minutes on medium-high heat, the sample was added. The sample was cooked for approximately five minutes, until it was no longer visibly pink. While cooking, the pork was stirred and flipped carefully with a rubber spatula, to impart the smallest possible texture changes during the cooking process.

Once it was cooked, the pork was cooled at room temperature for about five minutes before consumption. Finally, the sample was consumed, and its' texture and overall flavor were recorded. Data gathered during organoleptic testing was recorded on the Organoleptic Test Form. One test form was used for all five samples of each lot. Each sample attribute, color, odor, moisture before cooking, texture and flavor was quantified on a one-to-five scale, with five being the highest possible quality, and one being unacceptable. These scores were combined for each sample, and if a sample had a sum of 11 or less attribute points, it was considered expired.

LCA Data Gathering

To compare the two different product supply chains, LCA models were constructed using openLCA (openLCA, 2018). In openLCA, product lifecycles can be built using processes and raw material flows. Each raw material or process flow has upstream and downstream effects attached to it. These flows can be connected together so that the sum of their effects represent the entire product lifecycle. Data used in these

LCAs was gathered from industry publications, scholarly articles and some educated assumptions. For both models, it was assumed that the hog was raised in Iowa, because they produce more pork than any other state in the United States. Both models were also designed to be consumed in Cambridge, Massachusetts.

To build the models, flows were divided into four categories: raw material inputs, energy inputs, waste, and outputs. Models were also broken into three lifecycle stages: processing, manufacturing and distribution/retail/use. At the processing level, inputs were a certain mass of whole hog, and energy required to slaughter. Outputs were the picnic shoulder and pork butt primal cuts. Waste at this level was neck bones, tail and other losses during cutting. At the manufacturing level, in addition to the picnic shoulder and pork butt, there was also corrugated cardboard and plastic wrap to transport the product from Iowa to a supermarket in Cambridge, Massachusetts. Energy input at this level was a cold chain transport, approximately 2,060 kilometers from Iowa to Cambridge. While trimming primal cuts off of their bones, and removing fat to grind them, there is a significant yield loss or 72% for the picnic shoulder and 86% for the pork butt. This was recorded as waste at the manufacturing level.

Finally, the output of the manufacturing level is ground pork on the supermarket shelf. At the distribution/retail/use level, there is an energy input to keep the ground pork refrigerated at the supermarket to slow microbial growth. The waste at the consumer level was variable, 20% for the conventional model and 10% for the preserved model. This was due to the fact that the preserved model has a longer useful life, so more can be consumed before it expires.

Model Inputs and Outputs

The models were similar, but values were adjusted due to the extension of shelf life and decrease in food waste for the preserved pork model. The amount of swine at slaughtering weight needed in each model varied, because while the net amount of ground pork consumed in the end was calorically identical, the amount of waste throughout the process life cycle varied. Because both models started with different amounts of swine at slaughtering weight, they also needed different amounts of electricity to process, and cardboard and plastic wrap to pack for transport. Industry publications show that the average slaughtering weight of a hog is 122 kg, and it takes about 9.34 KWH of energy to slaughter. To be compatible with openLCA, 9.34 KWH was converted to 33.62 MJ of electricity. This translates to 0.28 MJ per kg of hog primal cuts. Next, it was assumed that hog primal cuts were packaged in 0.025 kg plastic wrap per kg of hog, and they were packed in 10kg boxes that weigh about 0.5 kg, or 0.05 kg corrugated box per kg hog primal cut. Industry publications show that 4% of swine is wasted at the processing level, and this was recorded as kilograms of slaughterhouse waste. At this point in the process lifecycle, the swine has been grown to slaughtering weight, slaughtered, divided into primal cuts, wrapped in film and boxed to be shipped.

Models started at a hog farm in Iowa, because Iowa is the largest producer of hogs in the Unites States. This means that to continue to the manufacturing level, the picnic shoulder and pork butt primal cuts need to be transported from to a supermarket in Cambridge, Massachusetts. This trip is about 2060 kilometers, and the primal cuts need to be refrigerated the entire time. It was determined that a single refrigerated truck could carry about 17,550 kilograms of boxed primal cuts. This means that the pork for the study made up about 0.00035% of the entire load of the truck. OpenLCA considers the distance of the trip, as well as the weight of the cargo, so the entire truck input would have been 36,153,000 kg*km, but the input of the small amount of pork in this study which was added to openLCA was a small fraction of this. Also, at the manufacturing level, fat and bones were removed from primal cuts. Picnic shoulder has a 72% deboning, trimming and grinding yield, while pork butt has an 86% yield. Waste at the manufacturing level was considered municipal solid waste in openLCA, because it is thrown in the trash, and added to solid waste trash streams. At this level, the preservatives are added to the preserved model.

At the distribution level, ground pork is added to the supermarket shelf. It was assumed that the ground pork took up about 0.09 square meters on a supermarket shelf. Based on supermarket industry publications, I assumed it takes 580 KWH to refrigerate a square meter for an entire year, or 1.59 KWH to refrigerate a square meter for a day. Next, it was assumed that the average ground pork product was on the shelf for three days before it was purchased, which coincides with the "sell by" date after grinding. The amount of energy needed to refrigerate 0.09 meters^2 for three days was determined to be 0.43 KWH, or 1.51 MJ. At the retail or consumer level, it was determined that 20% of pork is wasted based on industry publications, whereas only 10% the preserved pork with an extended shelf life was wasted. Waste at the consumer level was also considered municipal solid waste. See Tables 1 and 2 for LCA models.

Table 1. Control pork model inputs and outputs.

Flow	Amount	Unit	Life Cycle Stage
Swine at Slaughtering weight	7.84	kg	Processing Input
Medium Voltage Electricity	2.20	MJ	Processing Input
Packaging Film	0.19	kg	Processing Input
Corrugated Box	0.38	kg	Processing Input
Slaughterhouse Waste	0.31	kg	Processing Output
Transport, truck with refrigeration	15509	kg*km	Manufacturing Input
Municipal solid waste	1.65	kg	Manufacturing Output
Cooling Energy	1.51	MJ	Retail Input
Ground Pork Consumed	4.70	kg	Retail Output
Municipal solid waste	1.18	kg	Retail Output

Table 2. Preserved pork model, 10% waste inputs and outputs.

Flow	Amount	Unit	Life Cycle Stage
Swine at Slaughtering weight	7.15	kg	Processing Input
Medium Voltage Electricity	2.00	MJ	Processing Input
Packaging Film	0.17	kg	Processing Input
Corrugated Box	0.34	kg	Processing Input
Slaughterhouse Waste	0.29	kg	Processing Output
Citric Acid	0.05	kg	Manufacturing Input
Sodium Chloride	0.08	kg	Manufacturing Input
Transport, truck with refrigeration	14137	kg*km	Manufacturing Input
Municipal solid waste	1.50	kg	Manufacturing Output
Cooling Energy	1.51	MJ	Retail Input
Preserved Pork Product Consumed	4.82	kg	Retail Output
Municipal solid waste	0.54	kg	Retail Output

Chapter III

Results

The organoleptic and microbiological studies that made up the shelf life study were carried out simultaneously. Organoleptic data was gathered gradually after each test, while microbiological data was returned from AFL after each set of samples, not each individual test.

Shelf Life Study

From an organoleptic standpoint, the control samples were confirmed to be expired after approximately 8 days, because two samples failed on the sixth day, and three samples failed on the ninth day. The preserved samples were confirmed to be expired after approximately 11 days, because two samples failed on the ninth day, and three samples failed on the twelfth day (Table 3). From a purely organoleptic standpoint, without taking microbiological testing into account, the preserved samples were confirmed to expire approximately three days later than the control samples.

Table 3. Organoleptic data, total scores of all five sample attributes combined. An asterisk (*) denotes an expired sample based on the combination of attribute scores.

Sample ID	**Day 0**	**Day 3**	**Day 6**	**Day 9**	**Day 12**
01-C-O	25	19	12	9*	6*
02-C-O	25	21	13	10*	6*
03-C-O	25	20	11*	10*	7*
04-C-O	25	21	12	8*	5*
05-C-O	25	19	10*	9*	6*
01-T-O	24	22	16	12	9*
02-T-O	24	23	17	14	10*
03-T-O	24	21	15	11*	8*
04-T-O	24	22	15	12	8*
05-T-O	24	23	14	11*	6*
CONTROL AVERAGE	**25.0**	**20.0**	**11.6***	**9.2***	**6.0***
TEST AVERAGE	**24.0**	**22.2**	**15.4**	**12.0**	**8.2***

As can be observed in Figure 7 a-e, all samples lost their color very quickly. The control samples oxidized rapidly and turned a deep red color. The preserved sample, while not oxidizing, underwent a graying color change reaction. The preserved sample probably did not oxidize as quickly because citric acid is known to be an antioxidant.

Figure 7a. Control (Left) and Preserved (Right) Pork on day 0 of shelf life testing.

Figure 7b. Control (Left) and Preserved (Right) Pork on day 3 of shelf life testing.

Figure 7c. Control (Left) and Preserved (Right) Pork on day 6 of shelf life testing.

Figure 7d. Control (Left) and Preserved (Right) Pork on day 9 of shelf life testing.

Figure 7e. Control (Left) and Preserved (Right) Pork on day 12 of shelf life testing.

From a microbiological standpoint, there was one control sample that was confirmed to be expired on the third day after the sell-by date, three samples confirmed to be expired on the sixth day, and one sample confirmed to be expired on the ninth day (Table 4). On the sixth day, APC counts ranged from 1,600,000-4,400,000, and on the ninth day, from 2,000,000 to 36,000,000

In contrast, the preserved samples had not yet expired after twelve days (Table 5). The APC counts were only 300, 300, 7200, 34000 and 130,000.

Table 4. Microbiological results, control samples.

Control Sample ID	Sell By	Sample Date	Days Past Sell-By Date	APC/10^3
01-C	7/19/2017	7/19/2017	0	160
01-C	7/19/2017	7/22/2017	3	130
01-C	7/19/2017	7/25/2017	6	2200*
01-C	7/19/2017	7/28/2017	9	16000*
01-C	7/19/2017	7/31/2017	12	14000*
02-C	11/1/2017	11/1/2017	0	630
02-C	11/1/2017	11/4/2017	3	1300
02-C	11/1/2017	11/7/2017	6	3800*
02-C	11/1/2017	11/10/2017	9	13000*
02-C	11/1/2017	11/13/2017	12	12000*
03-C	11/16/2017	11/16/2017	0	880
03-C	11/16/2017	11/19/2017	3	2100*
03-C	11/16/2017	11/22/2017	6	3700*
03-C	11/16/2017	11/25/2017	9	2100*
03-C	11/16/2017	11/28/2017	12	1700*
04-C	11/29/2017	11/29/2017	0	100
04-C	11/29/2017	12/2/2017	3	170
04-C	11/29/2017	12/5/2017	6	1600
04-C	11/29/2017	12/8/2017	9	2000*
04-C	11/29/2017	12/11/2017	12	11000*
05-C	1/18/2018	1/18/2018	0	480
05-C	1/18/2018	1/21/2018	3	1500
05-C	1/18/2018	1/24/2018	6	4400*
05-C	1/18/2018	1/27/2018	9	36000*
05-C	1/18/2018	1/30/2018	12	34000*

* Denotes an expired sample.

Table 5. Microbiological results, preserved samples.

Control Sample ID	Sell By	Sample Date	Days Past Sell-By Date	APC/10^3
01-T	8/17/2017	8/17/2017	0	83
01-T	8/17/2017	8/20/2017	3	58
01-T	8/17/2017	8/23/2017	6	230
01-T	8/17/2017	8/26/2017	9	180
01-T	8/17/2017	8/29/2017	12	130
02-T	1/23/2018	1/23/2018	0	5.3
02-T	1/23/2018	1/26/2018	3	7
02-T	1/23/2018	1/29/2018	6	9
02-T	1/23/2018	2/1/2018	9	16
02-T	1/23/2018	2/4/2018	12	34
03-T	1/30/2018	1/30/2018	0	0.6
03-T	1/30/2018	2/2/2018	3	0.9
03-T	1/30/2018	2/5/2018	6	0.8
03-T	1/30/2018	2/8/2018	9	0.3
03-T	1/30/2018	2/11/2018	12	0.3
04-T	2/7/2018	2/7/2018	0	1.5
04-T	2/7/2018	2/10/2018	3	1
04-T	2/7/2018	2/13/2018	6	0.3
04-T	2/7/2018	2/16/2018	9	0.2
04-T	2/7/2018	2/19/2018	12	0.3
05-T	2/14/2018	2/14/2018	0	7.7
05-T	2/14/2018	2/17/2018	3	3
05-T	2/14/2018	2/20/2018	6	3.9
05-T	2/14/2018	2/23/2018	9	4.8
05-T	2/14/2018	2/26/2018	12	7.2

A Framework to Combine the Tests

From an organoleptic standpoint, preserving samples resulted in a three day extension of shelf life, from approximately 8 days to 11 days. From a microbiological standpoint, preserving samples resulted in a six day extension of shelf life, from approximately 6 days to 12 days. These results had to be weighed to define a reasonable shelf life extension. While the preserved sample did not expire from a microbiological standpoint, it did fail organoleptic tests. This means that the quality diminished, with excessive odor and loss of flavor and texture, but it would still be suitable to eat from a food safety standpoint. Despite this factor, it was determined that a three day shelf life extension, from six days after the sell by date for the control product to nine days for the preserved product was a reasonable shelf life. This determination was made because after six days, two of five control samples failed the organoleptic test. Meanwhile, after nine days, two of five preserved samples failed the organoleptic test. Also, one control sample expired from a microbiological standpoint before six days had passed from the sell-by date, so a three day extension was an intentionally conservative estimate.

A shelf life extension of three days has various business and consumer behavior implications that had to be considered. If consumption were uniform throughout the entire duration of the shelf life, consumers would eat about 13.3% of the fresh ground pork products that they buy for approximately six days, until the product reaches its' expiration date. At this point, 80% of the product had hypothetically been consumed. However, according to research done by Farr-Wharton, Foth and Choi (2014), many consumers lose their desire to continually consume the same leftovers. This means that more consumption generally happens closer to the purchase date, and a diminishing amount is consumed each day, until product expiration. Also, according to research done by Lebersorger and Schneider (2014), more than a quarter of discarded food products did not show any signs of spoilage, but were disposed of due to the passing of the expiration date.

Business practices of supermarkets also had to be taken into account. As perishable products approach the end of their shelf life, supermarkets will often reduce their cost as a "manager's special." While this reduces the amount of product wasted by the supermarket, there is not necessarily evidence to show that it reduces the amount of product wasted throughout the entire supply chain. Research done by Aschemann et.al. shows that selling price reduced items will impact the perception of the product, or even the store as a whole. If consumers perceive the product to be less valuable, it may be more likely to go unconsumed, because the financial loss of wasting the product is not as large.

It is generally assumed that 20% of food in the United States is wasted at the consumer level, so this was accepted as the rate of waste for the control sample. With the shelf life extension of three days, from six days to nine days, it was determined that it is reasonable to assume that an additional 10% of food will be consumed. In case this assumption was inaccurate due to a miscalculation in the aforementioned considerations, a sensitivity analysis was also included. Preserved models with 15% and 5% of product wastage were also included.

LCA Study

Once it was determined that the rate of food waste at the consumer level could be reduced from 20% to 10% using preservatives, LCA models could be made. First, the control product was modeled without preservatives, with 20% waste at the consumer level (Figure 8). Next, the preserved product was modeled with only 10% waste at the consumer level (Figure 9).

Process: 4.70 kg Ground Pork Consumed in Cambridge MA (20% MODEL)

Inputs

Flow	Category	Amount	Unit
cooling energy	353:Steam and air conditioning supply/3530:Steam and air con...	1.51000	MJ
corrugated board box	170:Manufacture of paper and paper products/1702:Manufactu...	0.38000	kg
electricity, medium voltage	351:Electric power generation, transmission and distribution/35...	2.20000	MJ
packaging film, low density polyethylene	222:Manufacture of plastics products/2220:Manufacture of plas...	0.19000	kg
swine for slaughtering, live weight	014:Animal production/0145:Raising of swine/pigs	7.84000	kg
transport, freight, lorry with reefer, cooling	492:Other land transport/4923:Freight transport by road	1.55090E4	kg*km

Outputs

Flow	Category	Amount	Unit
4.70 kg Ground Pork Consumed in Cambridge MA (2...		4.70000	kg
municipal solid waste	382:Waste treatment and disposal/3821:Treatment and disposal ...	2.68000	kg
slaughterhouse waste	101:Processing and preserving of meat/1010:Processing and pre...	0.31000	kg

Figure 8. Control version, 20% waste LCA model.

Process: 4.82 kg Preserved Pork Product Consumed in Cambridge MA (10% MODEL)

Inputs

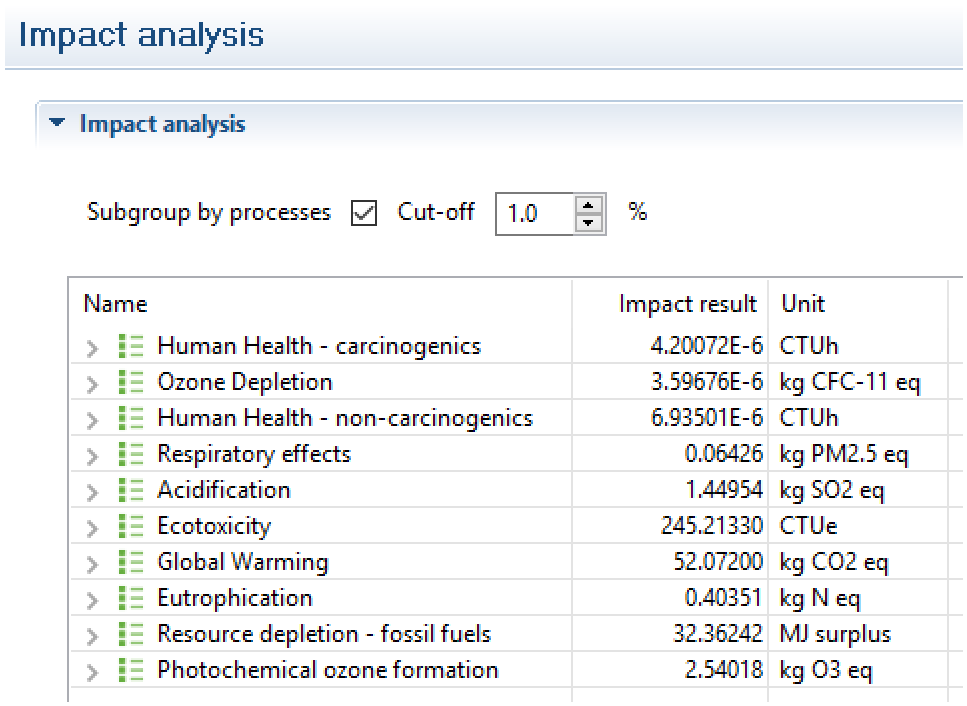
Flow	Category	Amount	Unit
citric acid	201:Manufacture of basic chemicals, fertil...	0.05000	kg
cooling energy	353:Steam and air conditioning supply/35...	1.51000	MJ
corrugated board box	170:Manufacture of paper and paper pro...	0.34000	kg
electricity, medium voltage	351:Electric power generation, transmissi...	2.00000	MJ
packaging film, low density polyethylene	222:Manufacture of plastics products/222...	0.17000	kg
sodium chloride, powder	089:Mining and quarrying n.e.c./0893:Extr...	0.08000	kg
swine for slaughtering, live weight	014:Animal production/0145:Raising of s...	7.15000	kg
transport, freight, lorry with reefer, cooling	492:Other land transport/4923:Freight tra...	1.41370E4	kg*km

Outputs

Flow	Category	Amount	Unit
4.82 kg Preserved Pork Product Consumed in Camb...		4.82000	kg
municipal solid waste	382:Waste treatment and disposal/3821:Tr...	2.04000	kg
slaughterhouse waste	101:Processing and preserving of meat/1...	0.29000	kg

Figure 9. Preserved version, 10% waste LCA model.

The impact analysis of these product systems yielded an 8.3% difference of kilograms of CO_2 equivalent emissions into the atmosphere. The control model showed 52.07 kg CO_2 eq emitted (Figure 10), while the preservative model resulted in 47.73 kg CO_2 eq (Figure 11).



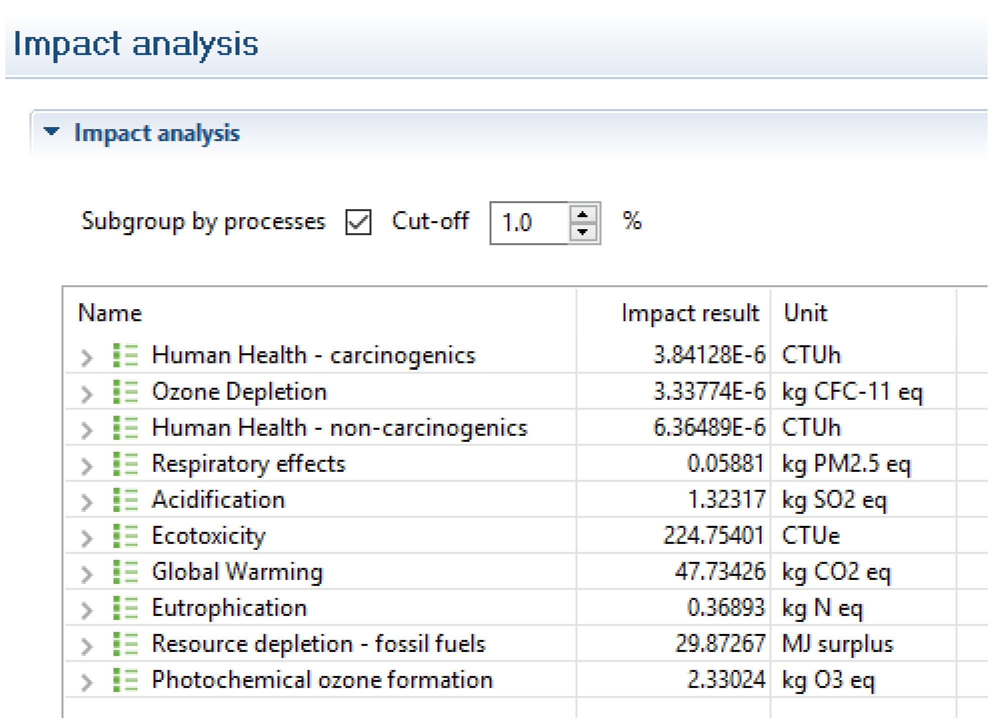
Impact analysis

Impact analysis

Subgroup by processes ☑ Cut-off 1.0 %

Name	Impact result	Unit
Human Health - carcinogenics	4.20072E-6	CTUh
Ozone Depletion	3.59676E-6	kg CFC-11 eq
Human Health - non-carcinogenics	6.93501E-6	CTUh
Respiratory effects	0.06426	kg PM2.5 eq
Acidification	1.44954	kg SO2 eq
Ecotoxicity	245.21330	CTUe
Global Warming	52.07200	kg CO2 eq
Eutrophication	0.40351	kg N eq
Resource depletion - fossil fuels	32.36242	MJ surplus
Photochemical ozone formation	2.54018	kg O3 eq

Figure 10. Control model, 20% waste impact analysis.



Impact analysis

Impact analysis

Subgroup by processes ☑ Cut-off 1.0 %

Name	Impact result	Unit
Human Health - carcinogenics	3.84128E-6	CTUh
Ozone Depletion	3.33774E-6	kg CFC-11 eq
Human Health - non-carcinogenics	6.36489E-6	CTUh
Respiratory effects	0.05881	kg PM2.5 eq
Acidification	1.32317	kg SO2 eq
Ecotoxicity	224.75401	CTUe
Global Warming	47.73426	kg CO2 eq
Eutrophication	0.36893	kg N eq
Resource depletion - fossil fuels	29.87267	MJ surplus
Photochemical ozone formation	2.33024	kg O3 eq

Figure 11. Preserved model, 10% waste impact analysis.

Sensitivity Analysis

In case the assumption that a three day shelf life extension would lead to a 10% decrease in waste was too optimistic, a preserved product with 15% waste was also modeled (Figure 12). Alternatively, if this assumption was too conservative, a preserved product with 5% waste was also modeled (Figure 13).

Process: 4.82 kg Preserved Pork Product Consumed in Cambridge MA (15% MODEL)

Inputs

Flow	Category	Amount	Unit
citric acid	201:Manufacture of basic chemical...	0.06000	kg
cooling energy	353:Steam and air conditioning sup...	1.51000	MJ
corrugated board box	170:Manufacture of paper and pape...	0.36000	kg
electricity, medium voltage	351:Electric power generation, trans...	2.12000	MJ
packaging film, low density polyethylene	222:Manufacture of plastics produc...	0.18000	kg
sodium chloride, powder	089:Mining and quarrying n.e.c./08...	0.09000	kg
swine for slaughtering, live weight	014:Animal production/0145:Raisin...	7.56000	kg
transport, freight, lorry with reefer, cooling	492:Other land transport/4923:Freig...	1.49550E4	kg*km

Outputs

Flow	Category	Amount	Unit
4.82 kg Preserved Pork Product Consumed in Cambr...		4.82000	kg
municipal solid waste	382:Waste treatment and disposal/38...	2.44000	kg
slaughterhouse waste	101:Processing and preserving of me...	0.30000	kg

Figure 12. Preserved version, 15% waste LCA model.

Process: 4.82 kg Preserved Pork Product Consumed in Cambridge MA (5% MODEL)

Inputs

Flow	Category	Amount	Unit
citric acid	201:Manufacture of basic chemicals, f...	0.05000	kg
cooling energy	353:Steam and air conditioning suppl...	1.51000	MJ
corrugated board box	170:Manufacture of paper and paper ...	0.32000	kg
electricity, medium voltage	351:Electric power generation, transm...	1.89000	MJ
packaging film, low density polyethylene	222:Manufacture of plastics products/...	0.16000	kg
sodium chloride, powder	089:Mining and quarrying n.e.c./0893:...	0.08000	kg
swine for slaughtering, live weight	014:Animal production/0145:Raising ...	6.76000	kg
transport, freight, lorry with reefer, cooling	492:Other land transport/4923:Freight ...	1.33720E4	kg*km

Outputs

Flow	Category	Amount	Unit
4.82 kg Preserved Pork Product Consumed in Camb...		4.82000	kg
municipal solid waste	382:Waste treatment and disposal/382...	1.67000	kg
slaughterhouse waste	101:Processing and preserving of mea...	0.27000	kg

Figure 13. Preserved version, 5% waste LCA model.

The impact analysis of these product systems yielded a 3.0% decrease in kilograms of CO_2 equivalent emissions into the atmosphere for the 15% waste model and 13.3% decrease for the 5% waste model, compared to the control model. The 15% waste model showed 50.49 kg CO_2 eq emitted (Figure 14), while the 5% waste model resulted in 45.15 kg CO_2 eq (Figure 15).

Impact analysis

Impact analysis

Subgroup by processes ☑ Cut-off 1.0 %

Name	Impact result	Unit
Human Health - carcinogenics	4.06280E-6	CTUh
Ozone Depletion	3.53581E-6	kg CFC-11 eq
Human Health - non-carcinogenics	6.73366E-6	CTUh
Respiratory effects	0.06221	kg PM2.5 eq
Acidification	1.39921	kg SO2 eq
Ecotoxicity	237.76486	CTUe
Global Warming	50.49882	kg CO2 eq
Eutrophication	0.39022	kg N eq
Resource depletion - fossil fuels	31.62240	MJ surplus
Photochemical ozone formation	2.46589	kg O3 eq

Figure 14. Preserved model, 15% waste impact analysis.

Impact analysis

Impact analysis

Subgroup by processes ☑ Cut-off 1.0 %

Name	Impact result	Unit
Human Health - carcinogenics	3.63244E-6	CTUh
Ozone Depletion	3.16027E-6	kg CFC-11 eq
Human Health - non-carcinogenics	6.02086E-6	CTUh
Respiratory effects	0.05561	kg PM2.5 eq
Acidification	1.25107	kg SO2 eq
Ecotoxicity	212.57438	CTUe
Global Warming	45.15019	kg CO2 eq
Eutrophication	0.34886	kg N eq
Resource depletion - fossil fuels	28.27543	MJ surplus
Photochemical ozone formation	2.20396	kg O3 eq

Figure 15. Preserved model, 5% waste impact analysis.

Chapter IV

Discussion

After carrying out shelf life tests and an LCA for two different product systems, the results supported my first hypothesis. Preservatives can be used to reduce food waste because the preserved model performed better on both the organoleptic and microbiological tests than the control version. An increase in shelf life from approximately six days to nine days would justify a reduction in waste from 20% to 10%. In case this justification was not warranted, a sensitivity analysis was carried out to see what would happen if waste was only reduced to 15%, or if waste was reduced more than expected to only 5%.

My second hypothesis, which stated that this reduction in waste would lead to a reduction in greenhouse gas emission for the product system, was also supported by the results. The preserved model was shown to have an 8.3% reduction in CO_2 eq throughout the lifespan of the product in the 10% waste model. If waste was only reduced to 15% with the use of preservatives, only a 5% decrease in waste from the control scenario, the model shows a 3.0% reduction in CO_2 eq throughout the lifespan of the product. Alternatively, if waste was reduced much more with the use of preservatives, to only 5%, the model shows a 13.3% reduction in CO_2 eq throughout the lifespan of the product.

In one way, it seems extremely intuitive that this would be the case. Food manufacturers are in business to make money. Many of them would not be increasing their operating cost by adding preservatives to their products if they were not getting value out of the added preservatives, such as an extended shelf life. Alternatively, to look at this issue from the consumer point of view, most “high quality” or expensive foods are marketed as “preservative free” and the preserved model technically has more inputs due to the preservatives. It would be logical for a consumer to compare the price and ingredient lists of prepared food products and make the assumption that the preservative free version is more expensive, and therefore higher quality. This is not a correct assumption to make, because the entire product system, and waste streams are not being taken into account. Consumers, perhaps with the assistance of misleading marketing claims, are falling for the appeal to nature fallacy.

The Naturalistic, or Appeal to Nature Fallacy

Simply put, the appeal to nature fallacy is the logical misstep that humans make when assuming that “a thing is good because it is ‘natural’, or it is bad because it is ‘unnatural’” (Moore, 1903). There are various examples of people using an “appeal to nature” fallacy to strengthen their argument, such as anti-vaccination movements, herbal healers or chefs. Herbal healers, for example, might say that their medication is more effective or safe than western medicine because it is natural or naturally derived, but this is not necessarily the case. Chlorine and *E. coli* O157:H7 are both naturally occurring, but it would not be advisable or safe to ingest either. Philosopher Steven Pinker has made valid arguments against the appeal to nature, or naturalistic fallacy:

> The naturalistic fallacy is the idea that what is found in nature is good. It was the basis for social Darwinism, the belief that helping the poor and sick would get in the way of evolution, which depends on the survival of the fittest. Today, biologists denounce the naturalistic fallacy because they want to describe the natural world honestly, without people deriving morals about how we ought to behave (as in: If birds and beasts engage in adultery, infanticide, cannibalism, it must be OK) (Pinker; Sailer 2002)

While the control, preservative free, version is closer to "natural" or "unprocessed" ground pork, this does not mean it is necessarily better for the environment or for human health.

Conclusions

This study alone was not designed to rebuild the entire food production, manufacturing and distribution sectors, but instead provide a framework for future testing. Depending on the pH, water activity, refrigeration needs and microbes of concern in a given food product, a different preservative blend can be designed to maximize shelf life, with the goal of environmental impact reduction. These preservative blends would not be universal, but instead unique, tailored to control the specific factors that makes an individual food product spoil. If, for example, a food product already has low water activity, but a neutral pH, it might not need any preservatives to bind free water, but only to reduce the pH. Next, the blends would also have to take into account if the product is ready-to-eat (RTE), or needs to be cooked prior to consumption. A non-RTE product that will be cooked will have a large reduction in microbial activity during the cooking process, so the acceptability limit of an APC might be higher.

Future studies along this vein should focus on other high impact food items, such as beef, chicken, milk and cheese. Preservative use does not have to be the only solution for food sector environmental impact reduction. Other ways to reduce the environmental impact of foods without changing their formulation would be to reduce shipping distance, improvements in food packaging (Williams and Wikstrom, 2010), increase efficiency of refrigeration units in trucks and at supermarkets. Focusing on high impact food items, and high impact processes within their distribution systems will make the largest reductions in environmental impact.

Preservative End of Life & Residence Time

Preservatives are effective because they make a food product less inhabitable for microorganisms, and less likely to undergo detrimental chemical reactions. But what else do they do? What happens to preservatives inside your body? If they are inert inside your body, what happens when they inevitably end up in out wastewater streams? How long do they stick around in the environment before they break down?

While various preservatives and preservative blends have received GRAS status from the FDA, research regarding the environmental impact of preservative use is scarce. Before more studies are done to make high-tech, food specific preservative blends, research ought to be done to define the end of life effects and environmental residence time for common preservatives. Without this knowledge, we may successfully extend the shelf life of our food products while doing irreparable harm to local water supplies or wildlife.

Vegan Interlude

It is no secret that meat and meat products tend to be the most environmentally intensive food products. This is because energy is lost as it travels up trophic levels, from plants that get their energy from sunlight, to animals that eat those plants to animals that eat the animals that eat plants. If our end goal as a society is to reduce the environmental impact of our food system by any means necessary, the most effective way to do this would probably be to follow a strict vegan diet, while limiting resource intensive foods such as almonds, which despite being vegan, are water intensive. From this viewpoint, food is strictly fuel, and should not be consumed for any reason other than sustaining our bodies. For better or for worse, this is not the goal of our society. Instead, food is intrinsically tied to our culture in every imaginable way. Holidays, days of the week and seasons all have certain foods that are essential to make the human experience what it is.

This study attempted to account for the cultural implications of our diets. While efforts like “meatless Mondays” can have a positive impact, completely removing meat from our diet would, without much exaggeration, fundamentally change what it means to be human. Furthermore, it’s not easy to get people to change their activities or actions. In this sense, an approach to improve food preservation is a relatively soft approach, whereas trying to get people to change what they put in their bodies is a significantly harder approach. While the hard approach might be more logical from a mathematical standpoint, the soft approach has a better chance for success in the long run, because it doesn’t require individuals to change their current behavior.

Public Policy

With the information gathered from the aforementioned studies, public policy needs to be informed. Every facet of public policy from farm subsidies to school lunches to use by/best by dates should be reviewed through the lens of the massive environmental impact of the food supply chain. It is probably safe to assume that these programs were designed with financial, cultural and ethical factors in mind, but environmental factors must also be weighed. For example, a “best-by” date does not refer to food safety, but instead to food quality, whereas a "use-by" date is based on food safety. Shelf stable crackers, for example, have an extremely low water activity that makes microbial growth almost impossible. The crackers will, however, go stale eventually. This is why they are labeled with a "best-by" date. A food past its' best-by date is not at peak freshness, but it is also not necessarily unsafe to eat, or expired in the traditional sense. This information is not clear to consumers, and it likely leads to more food waste. If these statements were federally regulated – which they currently are not – food waste could be reduced without increasing risk of harm to consumers.

Appendix

Data Forms for Organoleptic and Microbial Results

ORGANOLEPTIC REVIEW

SAMPLE VERSION: 02-C-0 SELL BY DATE: 11/1/17

DATE:	DAYS PAST SELL BY:	TEMPERATURE (°C):	COLOR:	ODOR:	MOISTURE:	TEXTURE:	TASTE:	TOTAL SCORE	OBSERVATIONS:
11/1/17	0	34.2	5	5	5	5	5	25	ACCEPTABLE
11/4/17	3	34.6	3	4	4	5	5	21	ACCEPTABLE
11/7/17	6	34.6	2	2	3	3	3	13	BOARDERLINE ACCEPTABLE
11/10/17	9	34.4	1	1	3	3	2	10	EXPIRED
11/13/17	12	34.6	1	1	2	1*	1*	6	

CONCLUSION: PRODUCT HAS 6-8 DAY SHELF LIFE FROM ORGANOLEPTIC STANDPOINT

NOTES: * = PRODUCT NOT TASTED BECAUSE IT WAS DETERMINED TO BE EXPIRED BY PREVIOUS TESTS

Figure 16. An example of a completed organoleptic evaluation.

31- B Foodmart Road • Boston, MA 02118
Tel: 617-269-6424 • 617-268-0971 • Fax: 617-268-1635

Certificate of Analysis

September 1, 2017

B. T. STUDIES
99 Crescent Avenue
Chelsea, Massachusetts **0 2 1 5 0**
Attn: Brendan Rigby

Report # 10461
Samples Received: August 17, 2017

Refrigerated Shelf - Life Study

All test performed on product held at 35 °F.

AFL # 23586					
Sample Description: Raw Ground Pork Code: 01-T					
Duration Time of Shelf Life	***8/17/2017***	***8/20/2017***	***8/23/2017***	***8/26/2017***	***8/29/2017***
Sample Test Procedure(s):	**Results:**	**Results:**	**Results:**	**Results:**	**Results:**
Aerobic Plate Count/g	83,000	58,000	230,000	180,000	130,000

Methods: FDA - Bacteriological Analytical Manual; USDA – FSIS; SMEDP; AOAC.

Sulenna Aguilar
Sulenna Aguilar.
Laboratory Analyst

Advanced Food Labs maintains accreditation in accordance to ISO/IEC 17025:2005 for the specific tests listed in PJLA Certificate # L16-474.

The data and other information contained on this document represent only the samples analyzed and are rendered upon the condition that they are not to be reproduced wholly or in part for advertising or other purposes without written permission from the laboratory.

Figure 17. Completed AFL Certificate of Analysis

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