EFFECT OF LEAF STORAGE METHODS ON BREWED TEA

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ABSTRACT
Tea leaves are most commonly stored in one of two materials: paper or plastic. Currently, no research exists on which is better, but there exists a lot of evidence suggesting that continued use of plastic is detrimental to environmental health. To determine the relevance of either casing material on selected properties of brewed tea, tea leaves were stored in either paper or plastic casings for a week, over a range of storage temperatures. The pH, electrical conductivity, and turbidity of the tea was then measured. The results showed no significant difference between paper and plastic casings, or between turbidity and electrical conductivity with the storage temperature of the tea leaves. However, a correlation can be seen between the pH of brewed tea leaves and the storage temperature. Thus, although the casing of tea leaves has little impact on the properties of brewed tea, storage temperature has a significant effect on the pH.

1. INTRODUCTION
Tea is generally sold either as loose leaf tea, or as tea bags in tea sleeves. Both of these forms of tea leaves are then stored in a variety of ways, ranging from a paper-based enclosure housing tea leaves in filtering sleeves, to a plastic sleeve encasing every individually packaged tea bag. From observation, there seems to be no correlation between the quality of tea and the choice of casing material; more expensive tea brands do not tend to use one casing over the other. Furthermore, plastic usage continues to have environmental concerns, from macro-scale pollution to micro plastics rapidly spreading across the globe. Single-use plastic, especially, is a growing concern, as it cannot be recycled and is a large source of pollution; this is the plastic used in tea bag casings. A lack of difference between the two storage methods would suggest that companies could use paper packaging without affecting the quality of their product, and simultaneously reduce plastic usage, thus also having a positive environmental impact.

To determine the relevance of tea leaf casing material, Vadham Darjeeling and Assam Black Tea leaves, originally stored in a plastic shipping-friendly bag, were used. A measured amount of tea leaves was then placed in either a paper envelope, to replicate paper casings, or a Ziploc bag, to replicate plastic casings. The packaged tea leaves were then incubated in the freezer (-17.8 ºC), in the refrigerator (2.8 ºC), at room temperature (23.3 ºC), in a toaster oven at a low temperature (32.2 ºC), and in a toaster oven at a high temperature (43.3 ºC) for a week. This was done to mimic the possible storage temperatures of tea leaves in industry, as well as provide a sufficient duration over which either the casing material or the storage temperature could have an effect on the tea leaves. The leaves were then used to brew tea in distilled water. The properties measured were the pH of the brewed tea, to compare the acidity, the turbidity of the brewed tea, to compare the smoothness and strength of the tea, and the electrical conductivity, to compare the ionic concentration. A statistical analysis was then used to determine the impact of the casing material on the measured properties, as well as the effect of the storage temperature on the measured properties.

2. BACKGROUND

I. Plastic vs. Paper Packaging

A recent study states that single-use plastic, such as the plastic used in the individual casing of tea bags, is very detrimental to environmental health since it cannot be recycled and makes up much of the world's trash [1]. Different governing bodies, from national governments, such as Canada, to municipalities, such as the city of Seattle, are looking to implement single-use plastic bans. Additionally, plastic packaging of tea expels millions of micro and nanoparticles into the brewed tea [2]. While the full effect of these tiny particles has not yet been determined, it is safe to assume that they are better avoided. Plastic is not the only means to store tea; many tea companies choose to store and sell their leaves in paper sleeves instead. Paper packaging also can produce micro and nanoparticles, however, these are mostly assumed to be nontoxic. To date, there is no research examining the difference between the two casings of tea leaves on the various properties of tea, once brewed. However, there has been previous research indicating a correlation between storage temperature of tea leaves and the taste of tea, which guided this experimental process.

Another study states that the main factors that impact the storage of tea leaves and produce significant variations in brewed tea are moisture, temperature, oxidation, and light exposure [3]. Temperature seemed most relevant: as tea is increasingly shipped around the world, storage temperatures can vary a lot. In addition, tea bags can be stored at a variety of temperatures in homes, depending on where people store their tea. The impact of storage varying temperature of tea leaves was used as a means to further examine the difference between plastic and paper casings. It has been found that lower storage temperatures have little effect on the freshness and flavor of tea, as measured by pH and other chemical tests [4]. It was also found that higher storage temperatures tend to dehydrate tea leaves and lessen the acidity of brewed tea. Thus, a difference between the brewed tea from tea leaves stored at colder and warmer temperatures can be expected. However, the researchers experimented with green tea leaves, which tend to release a bitter acidic taste if brewed for too long. Black tea leaves, such as those used in this experiment, are much more robust, and therefore may produce different results.

II. Acidity

The first property of brewed tea that was measured was the pH of the tea, as measured by a pH sensor. The pH affects the acidity of tea, which impacts the taste. Tea that is more acidic has a tangier and bitter taste, which is usually less desirable in tea. Figure 1 below describes how a pH sensor calculates the pH of liquids. The average pH of black tea ranges between 4.9 – 5.5 [5].

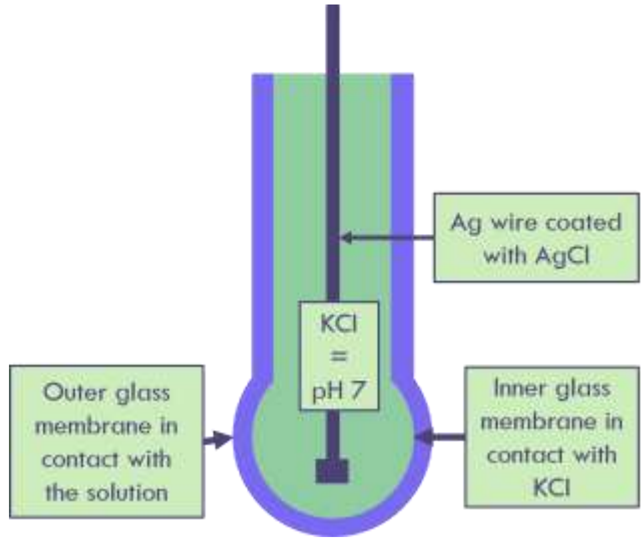

Figure 1: A pH sensor measures the concentration of hydrogen ions (acidity) in brewed tea, with units of pH, a scale that measures the moles of hydrogen in a liquid. The inner solution, Potassium Chloride, is a liquid with a known pH of 7. The glass membrane then comparatively measures the number of hydrogen ions in the sample solution by measuring the difference in voltage produced by hydrogen ions inside and outside the tube, by measuring the ion exchange on both sides of the glass membrane. Since the inner concentration of hydrogen ions is known, the concentration of hydrogen ions in the sample solution can be computed [6].

II. Turbidity

Turbidity, which measures the concentration of undissolved particles in tea, affects the smoothness of tea. The less turbid a liquid is, the better dissolved the solvent is, and thus the less particulate the taste. Turbidity also correlates to the strength of the tea flavor, since the more the dissolved particles, the stronger the tea flavor. Figure 2 below describes how a turbidity sensor measures the turbidity of a liquid.

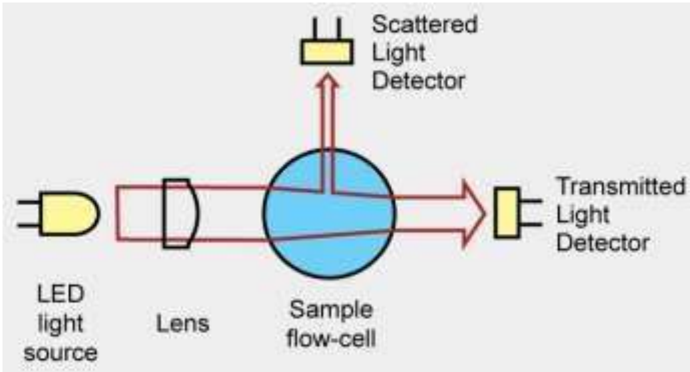

Figure 2 [7]: A turbidity sensor measures the concentration of undissolved particles in water, by sending a light beam through the liquid, and measuring the amount of light scattered and reflected onto the sensor, in units of Nephelometric Turbidity Unit (NTU). The sensor is at a 90º angle to the light source; thus the more the reflected light the sensor receives, the higher the concentration of particles in the liquid.

II. Electrical Conductivity

The final property measured was the electrical conductivity of brewed tea, or the ability of a liquid to conduct electricity. Tea is formed of mostly organic compounds which breakdown when exposed to water. However, since the organic composition of tea was not expected to have changed due to casings or storage temperatures of the tea leaves, the ionic concentration should not vary between tea brewed from the same tea leaves. Figure 3 below describes how an electrical conductivity sensor measures the conductivity of a liquid.

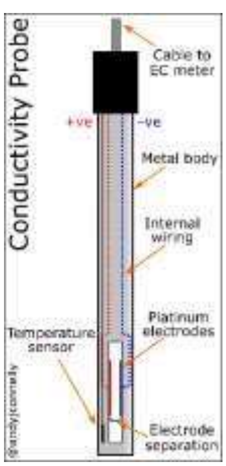

Figure 3 [7]: An electrical conductivity sensor measures the ability of a solution to conduct electricity, a property directly related to ion concentration, which the sensor measures in units of millisiemens / meter (mS). Most commonly, the sensor is used to measure concentrations of calcium, sodium, chloride, and carbonate ions, which are very relevant to water quality. The conductivity probe measures conductance, the reciprocal or resistance, measured in microsiemens. This is then divided by a constant: the distance between the electrodes divided by the area of the electrodes, which gives a value of conductivity. The Vernier Probe used is also temperature compensated, meaning that changes in temperature will not affect the calibration of the sensor [8].

3. EXPERIMENTAL DESIGN

To begin the incubation process, 2 grams Vadham Darjeeling and Assam Black Tea Leaves were placed into 30 tea filter bags. Each of these filter bags was then placed in either a #10 paper envelope or a Ziploc Snack bag, with 3 filter bags per casing material. Figure 4 displays the tea bags in their different casing materials. A paper envelope and a Ziploc bag, each with three tea bags each, were then placed in (a) freezer at -17.8 ºC, (b) in the refrigerator at 2.8 ºC, (c) at room temperature at 23.3 ºC, (d) in a toaster oven, at a constant set temperature of 32.2 ºC, and (e) in a toaster oven, at a constant set temperature of 43.3 ºC.

Figure 4: The tea leaves in their casing material, divided by storage temperature. Each bag contains 3 filter bags, each with 2 grams of Vadham tea leaves. The duplicates of bags were for multiple trials.

After a week-long period of incubation, to ensure a sufficient duration over which the casing materials and storage temperatures could affect the tea leaves, the filter bags were removed from their casings, and brewed in 100 mL of boiling distilled water in a standard glass beaker. Then, after steeping for 3 minutes, the filter bags were removed from the tea. A Vernier pH sensor and a Vernier turbidity sensor, connected using the Logger Pro software, were used to measure the pH and turbidity of the brewed tea, collecting 60 samples over the duration of a minute. For the turbidity sensor, a sample of tea was poured into the specified vial and placed inside the sensor. Both sensors were re-calibrated when either the casing material or the storage temperature of the tea leaves in filter bags changed. The electrical conductivity sensor was dipped into each beaker of brewed tea 5 times. The experimental set-up is shown below, in Figure 5.

Figure 5: The experimental setup of the tea, with 100 mL of liquid in 2 standard beakers. The Vernier pH sensor and the Vernier turbidity sensor were both connected to the Logger Pro software on a laptop, and continuously measured data over a duration of 1 min, with a sampling frequency of 1 sample/second. The HM Digital COM-100 electrical conductivity sensor was manually inserted into the tea, and the reading, in millisiemens per meter, was recorded.

4. Results and Discussion

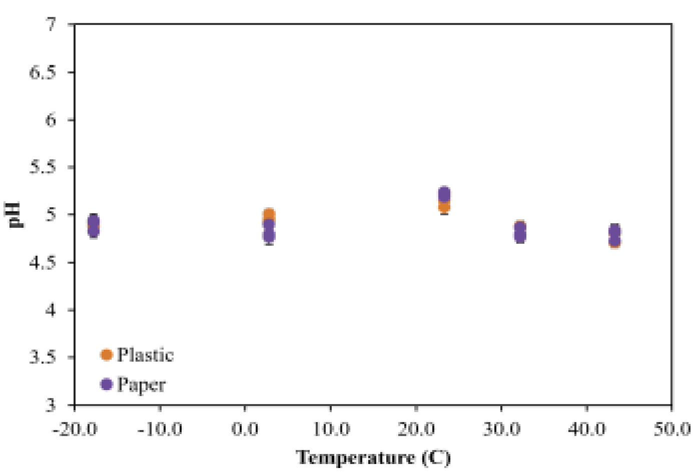

Figure 6: Plot of pH averages of trials of tea leaves stored in paper and plastic casings at 5 different temperatures. The three averages of each run, as well as the error bars are shown. There is no significant difference between the pH of tea leaves stored in paper or plastic casings, however, the pH of tea brewed from tea leaves stored at room temperature is significantly greater than the pH of tea brewed from leaves at any other temperature

As shown in Figure 6, the pH of tea brewed from tea leaves stored at room temperature is significantly higher than that of leaves stored at any other temperature. This means that brewed tea is less acidic when the tea leaves are stored at room temperature. These results do not agree with previous studies, which claim that higher storage temperatures of tea leaves lead to more acidic brewed tea. The discrepancy may be due to sources of error. The most pertinent source of error is the small sample size, as compared to the study. More trials would need to be conducted to either confirm or reject these conclusions.
The uncertainty involved with each trial was very low, with the highest uncertainty at $\pm$1.41%. This is because the pH sensor was very consistent in its readings. There is no significant difference between the pH of tea leaves stored in paper of plastic casings, as confirmed by p-tests, with values below 0.05, as well as overlapping uncertainty bounds.

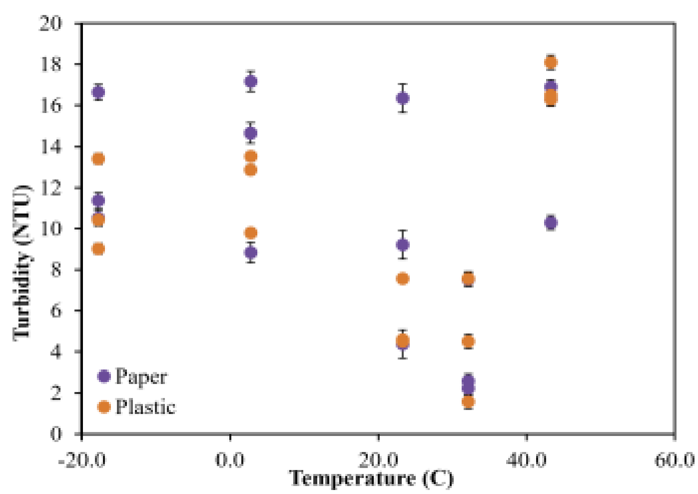

Figure 7: Plot of averages of trials of turbidity brewed from tea leaves stored in paper and plastic casings at various temperatures. There is no significant difference between the turbidity of tea brewed from leaves stored in paper and in plastic, nor

is there a significant correlation between storage temperature and turbidity.

Figure 7 indicates that there is no correlation between the turbidity of brewed tea and the storage methods of tea leaves. The turbidity of brewed tea is more reliant on factors, such as the temperature of the water when the tea is steeped, or the amount of agitation the tea experienced over the steeping period, which allow particles to dissolve faster. These factors varied independent of the trial, and thus, there is no correlation shown in Figure 7. Since there was no previous research claiming a correlation between storage temperature and turbidity, the results appear to be valid. The storage methods of tea leaves do not have an impact on the smoothness, or turbidity, of brewed tea.

The uncertainty of each trial the turbidity data points was low, with the greatest uncertainty at ± 6.6%. This is due to the precision of the sensor while collecting data. However, the turbidity values differed greatly across each beaker of tea brewed. There appears to be no correlation between neither the casing material and the turbidity of the brewed tea, nor the storage temperature and the turbidity of the brewed tea, as confirmed by uncertainty analysis.

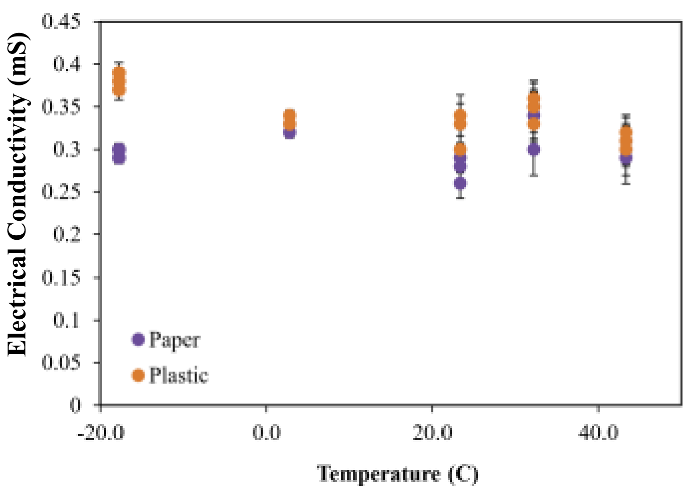

Figure 8: Plot of averaged data from electrical conductivity measurements of tea brewed from leaves stored in paper or plastic casings at various temperatures. There is no significant difference between the electrical conductivity of tea brewed from leaves stored in paper or plastic casings, nor is there a significant correlation between temperature and the ionic concentration.

The lack of dependency of ionic concentration on storage method, as shown in Figure 8, is consistent with previous research. Although tea leaves introduce ions into the distilled water when steeped, the ionic concentration should not differ across trials, since the organic composition of the leaves is not changing. The variances in electrical conductivity readings can be attributed to sources of error, including not cleaning the beakers between each run, thereby possibly biasing the data, or boiling the water in a communal water boiler, which could introduce an unknown concentration of ions with each boil.
The uncertainty of each trial is larger those seen in the pH and turbidity trials because the measurements were manual, and less samples were taken in each trial. However, the greatest uncertainty is still relatively small, at 12%. There is a significant difference between the electrical conductivity of tea brewed from tea leaves stored in paper and plastic casings in the freezer. However, this significant result was disregarded; it did not agree with previous research, and was likely due to an insufficient amount of trials. There are no other apparent correlations; all other differences in casing material are statistically insignificant, and statistical analysis shows no clear trend between electrical conductivity of brewed tea and the storage temperature of the tea leaves.

5. CONCLUSIONS

From the data, it can be concluded that there is no significant difference between paper and plastic casing of tea leaves on the acidity, smoothness, or ionic concentration of brewed tea. Thus, tea companies should look into paper casings for their tea leaves, as there seem to be no clear detriments, while the environmental impact would be positive. Additionally, it can be concluded that storage temperature of tea leaves does have an effect on the acidity of tea. It was found that with tea leaves stored at room temperature, the brewed tea was more basic. However, no correlation was seen between the smoothness or electrical conductivity of the brewed tea and the storage temperature. Therefore, when shipping teas across the world, tea companies should be careful to keep the tea leaves around room temperature, to preserve the low acidity of tea, once brewed.

These results are not all-encompassing. Other important factors on the quality of tea leaves, such as humidity and light exposure, were not measured. Plastic casings may protect tea leaves from humidity better than paper casings. Additionally, the shelf life of tea can be many years; the weeklong incubation period may be insufficient to track all of the effects. Also, teas more sensitive to temperature changes, such as herbal and green teas, may yield different results. However, given these extra factors, the difference between plastic and paper casings will likely be minimal. Given the push to reduce single use plastics, paper casing for tea leaves is an ideal solution.

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