The Effect of Water Quality on Green and Black Tea

A Project Paper

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Master of Professional Studies in Agriculture and Life Sciences

Field of Food Science

by

Melanie Franks

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ABSTRACT

Tea is a processed leaf of the Camellia Sinensis plant, and a beverage derived from those leaves. *Camellia Sinensis* is a tropical and subtropical evergreen plan native to Asia and is now grown commercially in many places around the world. Tea grows at altitudes ranging from seal level to 7,000 feet and at latitudes as far north as the black sea areas of Turkey and the re Republic of Georgia to Argentina in South America. In general, *Camellia Sinensis* prefers warm humid climate, plenty of well-distributed rainfall and long sunlit days (Preedy, 2013). All types of tea start out as a green leaf on a bush. It is how the leaf is processed that determines the type of tea it becomes. The one stage of the processing that most determines the type of tea that is produced is the degree of oxidation of the leaf. The five basic types are as follows: White (Full withered-dried, essentially this tea is unprocessed and non-oxidized), Green tea non-oxidized, Oolong tea (partially oxidized, black tea (fully oxidized), and Puerh (fermented and aged). The factors that affect tea brewing is temperature, water, brewing vessel, time, and water to leaf ratio. This project focuses on the water quality aspect of tea brewing. The purpose of this project was to determine if the type of water used to brew tea matters to the everyday tea drinker. Black and green tea were brewed in bottled water, tap water, and deionized water. The samples were analyzed through instrumentation for color, turbidity, total phenolics, and EGCG content and a consumer sensory evaluation study was done to determine acceptability. The project concluded that the type of water used to brew tea affects consumer acceptability for green tea as well as the antioxidant content. For the everyday tea drinker who drinks tea for health, the type of water used to brew does matter because compared highly mineralized water a purer water extracts a higher catechin content.

BIOGRAPHICAL SKETCH

Melanie Franks is a professional Chef who holds a degree in both Culinary Arts from the Culinary Institute of America and a Bachelor of Science in Environmental Chemistry from Texas A&M at Corpus Christi. Melanie is also a Certified Tea Specialist, which she acquired from the Specialty Tea Institute. Melanie decided to combine her love of food and science by pursuing a Master of Professional Studies (MPS) at Cornell University in food science. During her time at Cornell she has been a part of the Dr. Robin Dando's Lab and Competed with the Cornell Dairy Product Sensory Evaluation Team.

In memory of Winnie Yu.

ACKNOWLEDGMENTS

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CHAPTER 1

INTRODUCTION

Tea is a beverage that is steeped in culture and history. Tea has been consumed for centuries and is valued for its taste and caffeine (Lin et al 2014). The botanical name for tea is *Camellia Sinensis*. The young tender leaves of *Camellia Sinensis* are responsible for black, green, oolong, puerh, white, and yellow tea. There are many other plants used for extraction such as rooibos and chamomile, however they are not strictly teas, and instead are classified under the category of tisanes or herbal infusions. In this report, the term tea will refer only to a caffeinated extraction derived from *Camellia Sinensis*.

The tea plant is an evergreen tree or shrub from the genus *Camellia* and from the family *Theaceae*. Of the over two hundred species of *Camellia Theaceae* only *Camellia Sinensis* is used to make tea. The main difference between various styles of tea is the level of oxidation of the leaf in processing. Green and white teas are unoxidized, oolongs vary in levels of oxidation, and black tea leaves are fully oxidized. There are different varieties of tea plants, but the most common are *Camellia Sinensis Sinensis*, *Camellia Sinensis Assamica*, and *Camellia Sinensis Cambodiensis*. *Camellia Sinensis Sinensis* is a small leaf variety from China, where tea originated and is believed to be the oldest varietal used. *Camellia Sinensis Assamica* is a large leaf varietal conducive to tropical climates, that is widely grown in India. *Camellia Sinensis Cambodiensis* is also a large leaf varietal that is often not as highly valued as others and is often hybridized to create new tea cultivars (Gascoyne et. al 2014 and Wachira et. al 2013).

1.1 Tea Processing

A cup of tea is made from processed fresh tea leaves. Biochemical changes that occur during processing help to reduce the bitter taste of fresh tea leaves. Processing the tea leaves lowers water content to aid in shelf stability, deactivates enzymes, adds sweetness, and also a myriad of colors to the cup. Each tea undergoes similar processing post-harvest with some slight modifications, or additional steps. After tea leaves are harvested they undergo withering. Withering is a process by which the tea leaves are prepared for further processing by reducing the moisture content of the fresh leaf. The leaves are laid onto factory floors, bamboo mats, or trays. Physically the leaf transforms from a sturdy crisp leaf to limp and pliable during withering. Chemically, caffeine content increases, hydrolysis of non water soluble carbohydrates begins, non-gallated catechins and aroma compounds form, levels of chlorophyll and various enzymes increase (Ahmed and Stepp 2013).

After withering, for most tea styles the leaves are heated to stop oxidation in a process called fixing. For green tea the leaves are fixed directly after withering to avoid any oxidation, and thus the catechin content remains high compared to black tea. For black teas, after withering, the leaves are purposefully crushed to speed oxidation. This step is what gives black tea its defining quality, whereby enzymatic oxidation coverts catechins into Theaflavins and Thearubigins, polyphenols that give black tea its reddish-brown coloration (Menet et al 2004). Once the tea leaves have gone through fixing, depending on the tea style they may go through a rolling and shaping process. The age of the tea leaves will determine how much pressure is used to deter leaf breakage and discoloration from oxidation and chlorophyll hydration. Tea leaves can be shaped into several configurations from wiry needles, round balls, flattened leaves, compressed bricks, and twists, to name a few (Ahmed and Stepp 2013). The last step of tea process is drying. Drying the stage increases the of the finished tea leaves as well as prevent mold growth.

1.2 Tea Flavanols

The main polyphenols found in tea come from the Flavonoid group (Figure 1). Flavonoids are a group of bioactive compounds synthesized during plant metabolism. Flavonoids are found in fruits and vegetables, prominently in spinach, apples, and blueberries, as well as in beverages like tea and wine. Previous health-related research on tea has largely focused on the flavonoid group. Flavonoids contain two six-carbon rings linked by a three-carbon unit, also known as a chalcone structure (Hodgson and Croft 2010). Flavanols are bioactive compounds that are a subclass of Flavonoids, the largest group of phenolic compounds in plants. Flavanols, also referred to as catechins, in tea are the main secondary metabolites. This means that they are not essential to the growth or reproduction of the plant, but instead play more of communication role related to the plants surrounding environment. The main flavanols in tea are: (+) catechin, (-) epicatechin, (-)epicatechin gallate, (-)epigallocatechin, (-)epigallocatechin-3-gallate, and (+) gallocatechin. The main flavanol structures in tea are shown below in Figure 1.

Flavanol content in tea differs by tea type or style. For example, flavanols in green tea are relatively stable as they do not go through oxidation during processing.. The main flavonoids in green tea are catechins. Catechins are what give green tea its characteristic bitterness and astringency. In black tea production the leaves go through oxidation which in turn reduces the tea's flavanol content. In black tea, the catechins are largely oxidized and are converted to Theaflavins and Thearubigins (Hodgson and Croft 2010). The amount of catechins in black tea is reduced by 85% compared to that of green tea due to oxidation in processing (Preedy et. al 2013).

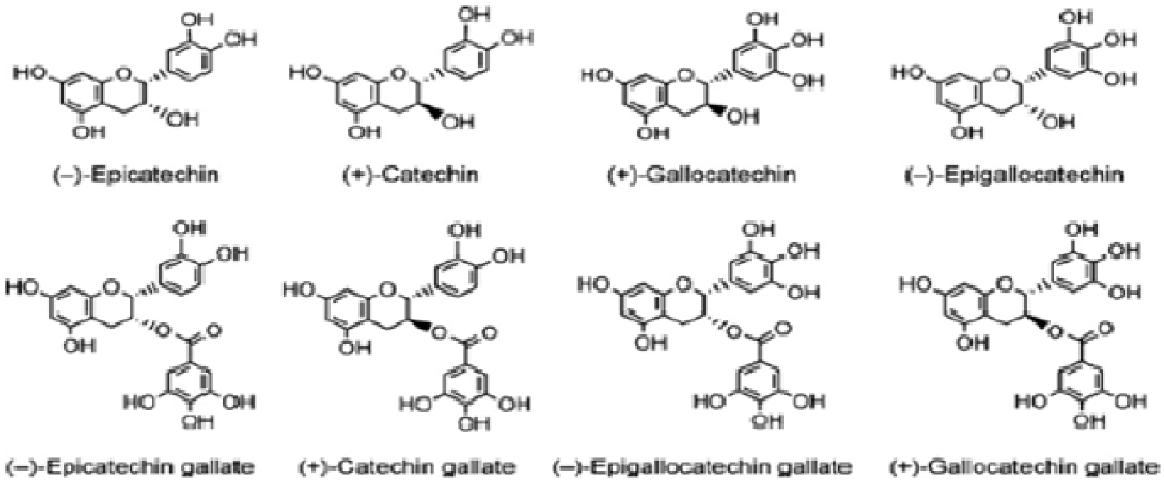


Figure 1. Chemical Structure of main flavanols in tea (Del Rio et. al 2010)

1.3 Tea and Water

After tea leaves are harvested and processed, the final product is ready to consume. However, unlike many other beverages, the final processing step is left to the consumer. A high-quality tea that has gone through many labor-intensive steps can be ruined in an instant by improper brewing. If the tea leaves have no defects the main factors that alter the taste of the brewed cup are temperature, brewing time, the brewing vessel, water composition, and the water to leaf ratio (Kokhar and Magnusdottir 2002 and Moisson et. al 2007). This study focuses on the water aspect of brewing tea. In particular, how water quality effects the sensory and chemical qualities of black and green tea.

The first written mention of the importance of water in brewing tea can be found in The Classic of Tea by Lu Yu in 758 (Mair and Ho 2009). Lu Yu was an orphan during the Tang Dynasty that was raised by an abbot in Dragon Cloud Monastery. He authored an efficient 7000-character book that detailed how to harvest, process, and make tea, including what types of water are suitable for tea as well as the proper tools and utensils. Lu Yu felt that tea made from mountains streams was ideal, river water was sufficient, and well water was inferior (Yu 758). Towards the end of the Tang Dynasty, there were several other works that expressed the attention to detail of tea brewing like "A Record of Water for Decocting Tea" by Ahan Youxins, which lists the twenty best water sources in China for tea. (Mair and Ho 2009).

It has been shown previously that tap water can decreases the amount of tea flavanols extracted in green tea compared to brewing green tea with purified water (Wang and Helliwell 2000). Tap water has a different mineral balance, depending where it is obtained. Hard water is high in minerals, primarily calcium and magnesium. Cations like sodium and calcium, and anions such as chlorine, and metals like magnesium can alter the taste of water (Whelton et. al 2007). Tea infusions are particularly affected by calcium. Previous studies have shown that theaflavins and caffeine extraction decrease with high levels of calcium (Spiro and Price 1987). Magnesium and calcium promote two undesirable outcomes of the tea brewing: tea cream and scum formation (Mossion et. al 2007). Tea cream is the precipitate matter that forms as tea cools and is caused reaction between caffeine and tea flavanols. Tea scum is a surface film that forms on the tea infusion surface, composed of calcium, hydrogen carbonates and other organic material. Tea scum happens particularly when tea is brewed with hard water. The film occurs due to calcium carbonate triggering oxidation of organic compounds (Mossion et. al 2007). It has also been found from previous studies that catechin extraction can be increased in white tea when brewed in a pure water (Zhang et al 2017).

1.4 Tea Flavor

The complex taste of tea arises from soluble, and non-volatile compounds. Phenolic compounds make up most of the compounds in tea, with flavanols being the biggest class represented in tea. Between 25-35% percent of the fresh tea leaf is composed of phenolic compounds, with 80% of these being flavanols (Belitz 2009). Both phenolic compounds and alkaloids like caffeine account for the bitter taste in tea (Zhang et. al 2014). Glucose, fructose, sucrose, and arabinose are some of the carbohydrates in tea that account for its sweet taste. Free amino acids make up about 1-3% of the dry leaf, with 50% of this coming from theanine. Amino acids in tea, and in green tea specifically, yield the umami characteristics of tea (Belitz 2009). Astringency, albeit not a taste, is a common oral sensation in tea, largely arising from its catechin content (Yin et. al 2014). Some common flavor descriptors for tea are described in the below.

Table 1. Common Flavor Characteristics to Describe Tea (Ahmed and Stepp 2013)

Common Flavor Descriptors for tea	
Acidic	**Metallic**
Astringent	**Earthy**
Bitter	**Smooth**
Bitter with a sweet aftertaste	**Mellow**
Floral	**Acrid**
Fruity	**Burnt**
Grassy	**Creamy**
Salty	**Vegetal**
Smoky	**Fishy**
Sour	**Full**
Sweet	**Weak**

The goal of this project was to discover if the type of water used to brew tea matters to the everyday drinker, influencing their liking of either black or green tea. In this study we used a green and a black loose-leaf tea from the same farm in Zhejiang Province, China. We brewed the teas with three different water types: Poland spring bottled water (BW), tap water (TW), and distilled water (DW). The tea samples where both analyzed instrumentally (list the analyses used), as well as with sensory evaluation.

CHAPTER 2

MATERIALS AND METHODS

Part 1: Instrumental Analysis

2.1 Analysis of Physicochemical properties of Water Samples

Ithaca city tap water, Poland spring bottled water, and Deionized water used for the study were tested by the Community Science Institute, Inc in Ithaca New York, assaying Calcium, Iron, Magnesium, Sodium, and Copper.

2.2 Preparation of Tea Infusions

The two loose leaf teas, Zhejiang green and Mao Feng black for the study were purchased from In Pursuit of Tea based in New York City. Both the green and black teas are from Zhejiang Province in China, a highly regarded tea region (Gascoyne et. al 2014), with both produced on the same farm. For the green tea samples, 2.5 grams of tea were weighed out into prewarmed Gaiwan tea brewing vessel (see Figure 2). 125 ml of water at 175 degrees Farenheit was added to the Gaiwan. The green tea infusion was brewed for three minutes and then strained 3-inch through a fine mesh strainer. This process was repeated for each water infusion: green tea brewed with Ithaca city tap water (GT), with Poland spring bottled water (GB), and with deionized water (GD). Black tea samples were also brewed in prewarmed Gaiwan, again with 2.5g of tea leaves and 125ml of water, now at 210 degrees Farenheit for 5 minutes (more typical for black tea preparation), and then strained through a mesh strainer, with black tea samples again brewed in tap water (BT), in Poland spring bottled water (BB), and in deionized water (BD), all are brewed in triplicate. Upon completion of brewing and straining, the tea samples were cooled to room temperature for instrumental analysis. Table 2 is a summary of brewing methods for the samples.

Figure 2. Illustration of Tea brewing Gaiwan

Table 2.
Brewing Methods of 6 Tea Samples

Samples	Tea Leaves (grams)	Water (ml)	Temperature of water (F)	Length of brewing time (min)
Green Tea with tap water (GT)	2.5	125	175	3
Green Tea with Poland Spring, bottled water (GB)	2.5	125	175	3
Green Tea with distilled water (GD)	2.5	125	175	3
Black tea with tap water (BT)	2.5	125	210	5
Black tea with Poland Spring, bottled water (BB)	2.5	125	210	5
Black tea with distilled water (BD)	2.5	125	210	5

2.3 Color Measurement of Tea infusions

Analysis of tea color was performed with a Hunter Lab UltraScan VIS colorimeter (Reston Virginia, USA). L, a, and b values were recorded for each sample. Each of the samples were measured in triplicate.

2.4 Analysis of Turbidity

The turbidity of each sample was measured in triplicate with use of a HACH portable Turbidity meter model 2100P (Loveland Colorado, USA), with measurements recorded in Nephelometric Turbidity Units (NTU). The samples were held at 90 degrees to the incident beam using single detection. The turbidity meter was standards: .1 NTU, 20 NTU, and 100 NTU.

2.5 Analysis of Total Phenolics

The total polyphenol content was measured using the Folin-Ciocalteau's method with a Thermo Fisher Scientific GENESYS spectrophotometer model G10s UV-Vis (Waltham Massachusetts USA) (Montreau, 1972). Analyses of tea samples were performed in triplicate. Folin-Ciocalteau reagent sodium bicarbonate, and Gallic acid was purchased from Fisher Scientific. Standard curves of gallic acid were made with 6 concentrations of gallic acid.

In a glass test tube 80µl of tea, 1.04µl of distilled water, and 200 µl of Folin-Ciocalteau reagent were added and vortexed briefly. The solution was then incubated at room temperature for six minutes. After six minutes 800 µl of 7% (w/v) sodium carbonated solution was added to end the reaction. The solutions were then vortexed and incubated for 90 minutes at room temperature. The absorbance for each tea infusion sample and standard was taken using a spectrophotometer. Analyses were performed in triplicate

2.6 Analysis of EGCG

Epigallocatechin Gallate in the tea infusions was measured using High Performance Liquid Chromatography (HPLC). Samples were run by an Aglient 1100 HPLC system with a DAD detector. Separations were carried out using a Waters Cortecs C18 (4.6mmx100mm) column using an isocratic solvent system consisting of 90% 0.01% phosphoric acid in Millipore water (v/v) and 10% methanol with a flow rate of 0.6 ml/ min. Column was held at a constant temperature of 30 °C. The DAD detector was set to 210nm. Sample injection volume was 10 µl. Total run time was 20 minutes. Quantification was performed by the use of an external standard curve using pure EGCG purchased from Sigma Alrich. The identification of EGCG the tea treatments was done by using the retention time of the pure standards (10.26 mins). All samples were filter just before being loaded onto the HPLC using a 0.22 µm filter from Celltreat®

Part 2: Sensory Evaluation

2.7 Sensory Evaluation

All study procedures were reviewed and approved by the Cornell University Institutional Review Board for Human Participants. A total of 103 panelist completed the study and were recruited from the Cornell University student body and staff. To qualify for the tea study, all panelists were pre-screened on their tea drinking behavior. All the participants in the study drank tea at least three to five times a week and were green and black tea drinkers. The panelist either habitually consumed tea with no milk or sugar added to it or stated no dislike of tea in this manner. Participants knew that the study involved tea but were unaware of the true objective to the research. The study took place at the Sensory Evaluation Center on the Cornell University campus, in one session that took approximately 45 minutes, with panelists compensated for their time. Each panelist answered questions about samples in individual booths, on a computer screen using Red Jade Sensory Evaluation Software.

Samples were delivered monadically, with order was randomized, but panelists either received the green tea samples (GT, GB, GD) or the black tea samples (BT, BB, BD) first. Each tea sample was evaluated for overall liking, appearance liking and flavor liking with 9-point scales, and then using the generalized Labeled Magnitude Scale (gLMS) to test sweetness, bitterness, sourness, astringency, vegetal quality (for green tea only), and earthiness (for black tea only), . All panelists were trained on how to use the gLMS before beginning the questionnaire. The color of the tea was also evaluated, by giving the panelists a color scale (below) from which they chose the closest match for each sample.

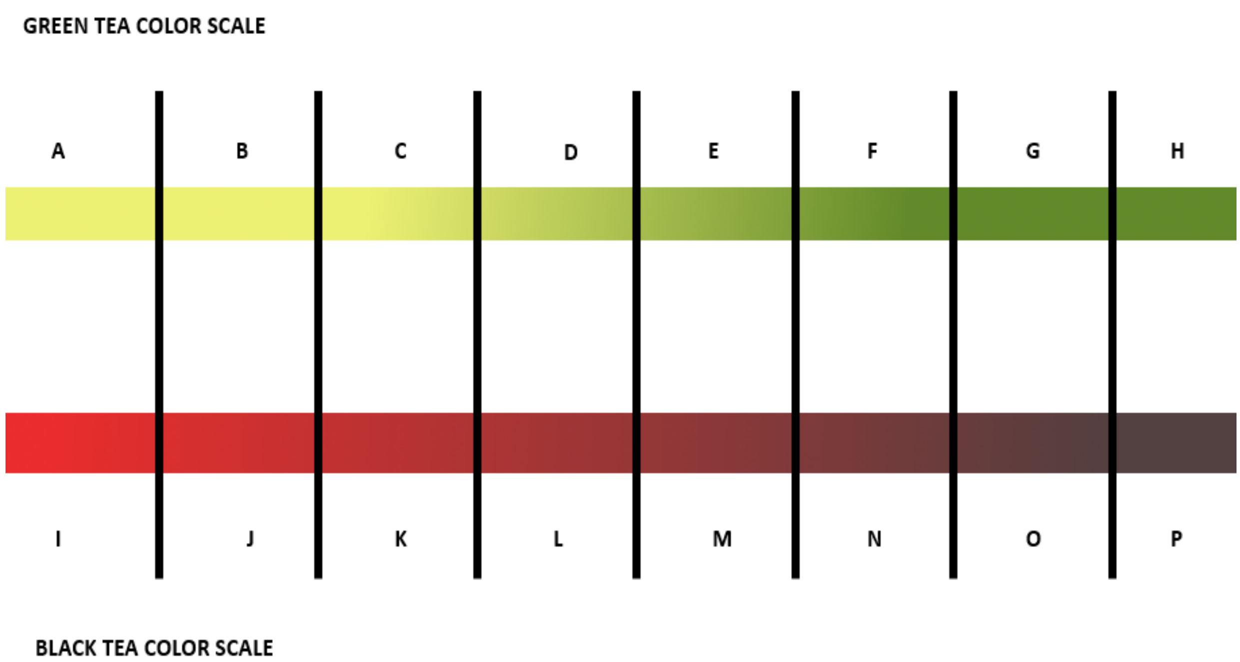


Figure 3. Color Scale Chart

The teas were freshly brewed every 30 minutes. For the green tea, 10 grams of tea was brewed with 500ml of water at 175 degrees Farenheit for 3 minutes and strained. For black tea, 10 grams of tea was brewed with 500 ml of water at 210 degrees Fahrenheit for three minutes and then strained.   All six tea infusions were kept warm in a pre-heated, insulated carafe until the panelist was ready for the sample. Each tea sample was labeled with a random 3-digit code. The samples were served in white ceramic Gung Fu cha tea cups. Tea cups were pre heated to 170 degrees Fahrenheit and freshly brewed tea was served to panelists at 170-175 degrees Fahrenheit for green tea and between 200-205 degrees Fahrenheit for black tea. After each sample panelists were instructed to cleanse their palette with water and non-salted crackers to avoid fatigue as well as deter any lingering bitterness or astringency. At the end of the questionnaire panelist were asked a series of demographic questions. 88 of the participants were female, 23 male, with 1 non-conforming individual. The data were analyzed with repeated measures analyses of variance (ANOVA) and post-hoc Tukey's tests using Graphpad Prism 5.0 (Graphpad Software, La Jolla CA).

CHAPTER 3

RESULTS AND DISCUSSION

3.1 Water Analysis

Deionized, tap, and bottled water samples were tested for calcium, magnesium, copper, iron, residual chlorine, and sodium (Table 3, Figure 4). The amount of calcium, magnesium, and sodium in Ithaca tap water was significantly higher than that found in bottled water or deionized water. High concentrations of calcium or magnesium in water is known to cause cloudiness and tea scum in tea infusion as well as have some effects on tea's sensory properties (Feng Yin et. al 2014, Mossion et. al 2007)

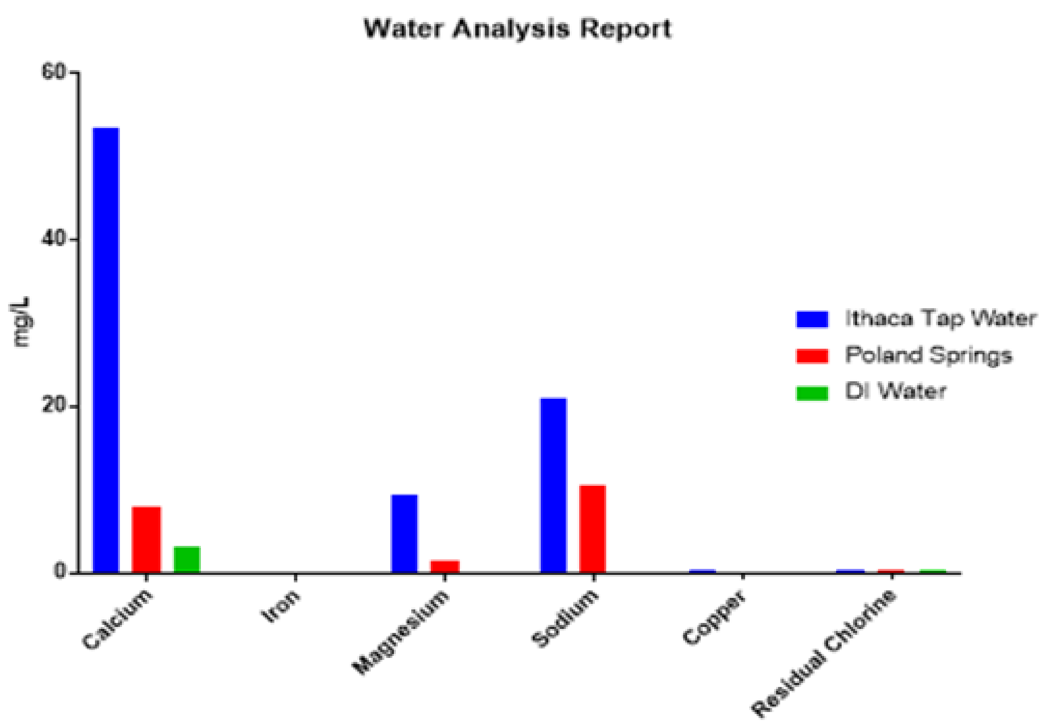


Figure 4. Chemical content (mg/L) of tap, bottled, and deionized water

Table 3. Physiochemical properties of the different water types in mg/L

	Ithaca City Tap Water	Bottled Water	Deionized Water
Calcium	53.600	8.000	3.000
Iron	0.050	0.050	0.050
Magnesium	9.460	1.370	0.100
Sodium	20.900	10.600	0.100
Copper	0.176	0.002	0.002
Residual Chlorine	0.200	0.200	0.200

3.2 Turbidity

Figure 5 is a photograph that illustrates the appearance of tea samples when brewed with 3 water types. The tea brewed in tap water appears more cloudy and darker in color than teas brewed in tap water or DI water for both green and black teas. Figure 6 shows turbidity measurements of each tea sample in Nephelometric turbidity units (NTU). There is a significant difference between green tea brewed in tap water versus green tea brewed in DI or bottled water ($p < 0.001$). Similary, there is also a significant difference between black tea brewed in tap water compared to black tea brewed in DI and bottled water ($p = <.0001$).

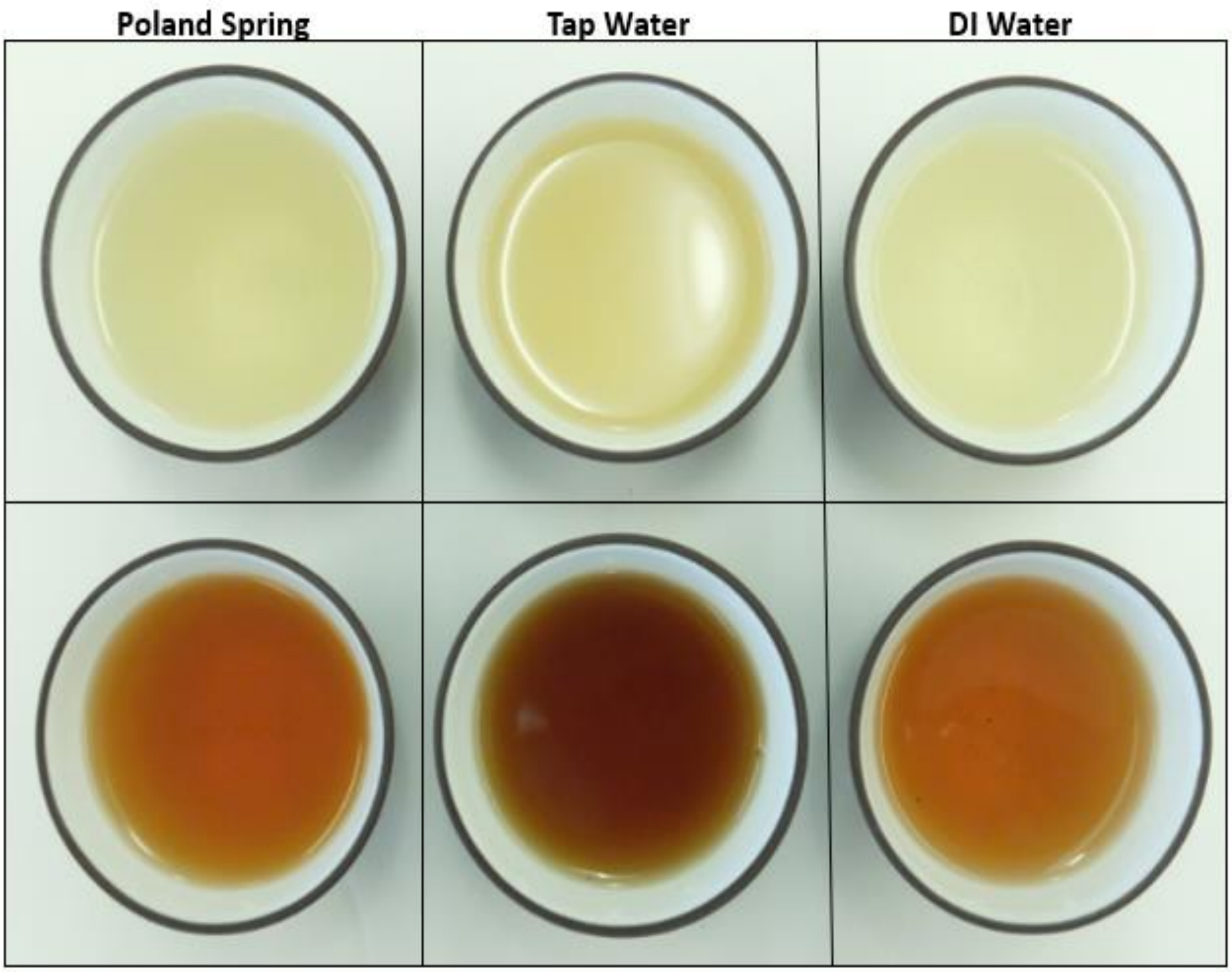


Figure 5. Image of black and green tea samples brewed in tap, bottled or deionized water. For both green and black tea, the tea infusions were darker and cloudier compared to the teas brewed in DI and bottled water.

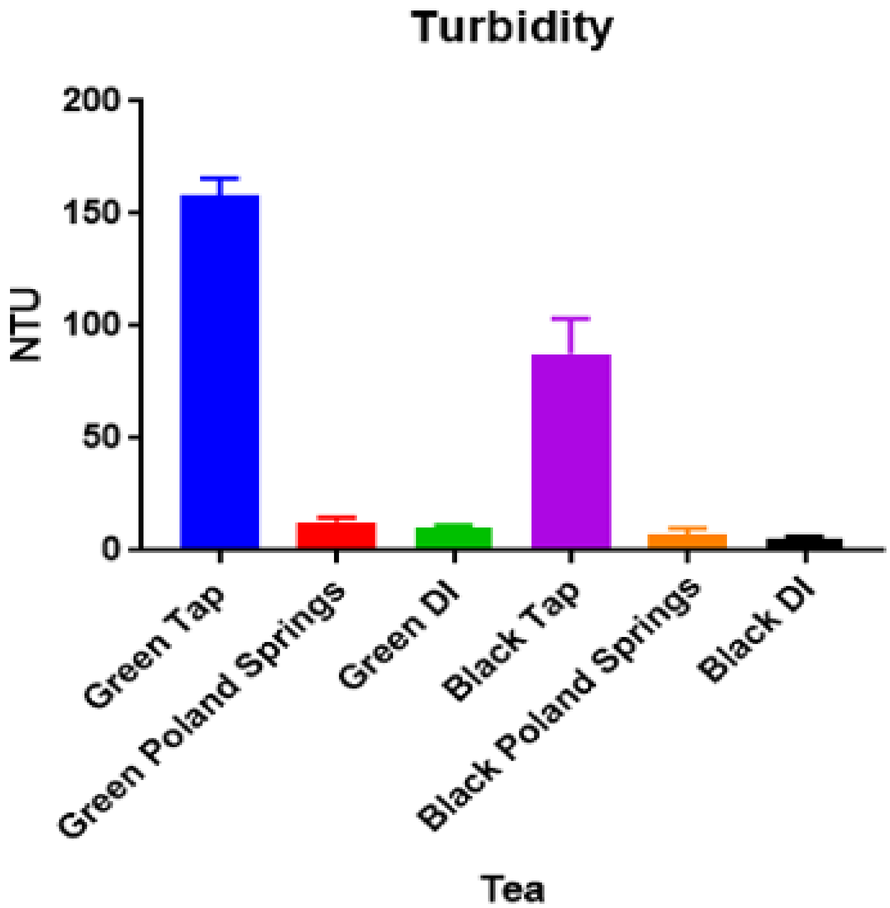


Figure 6. Turbidity measurements (NTU) for each tea infusion. Both green ($p < 0.001$) and black ($p < 0.001$) teas were more turbid when brewed in tap water. Error bars represent SEM.

3.3 Colorimetry

Figure 7 shows colorimeter results for green tea brewed in tap, bottled and deionized water. Green tea brewed in tap water had a lower L value compared to the same tea brewed in bottled water and DI water. There was significant difference in L value between GT and GB as well as between GT and GD (p= 0.0158) The a value for GT was also higher than for GB and GD. There was a significant difference between GT and GB, between GT and GD, between GB and DI (p<0.0001). The b value for GT was higher compared to GB and GD. Significant difference was found in the b value between GT and GB as well as between GT and GD (p= 0.0001). Figure 8 shows colorimeter results for the black tea infusions. BT had a lower L value compared to BD and BB infusion, with a higher a and lower b value. There is a significant difference in L value between BT and BB as well as between BT and BD ($p = 0.0230$). Although BT has a higher a there was no significant difference ($p = 0.425$). There was a significant difference in b between BT and BB as well as between BT and BD ($p = 0.0014$).

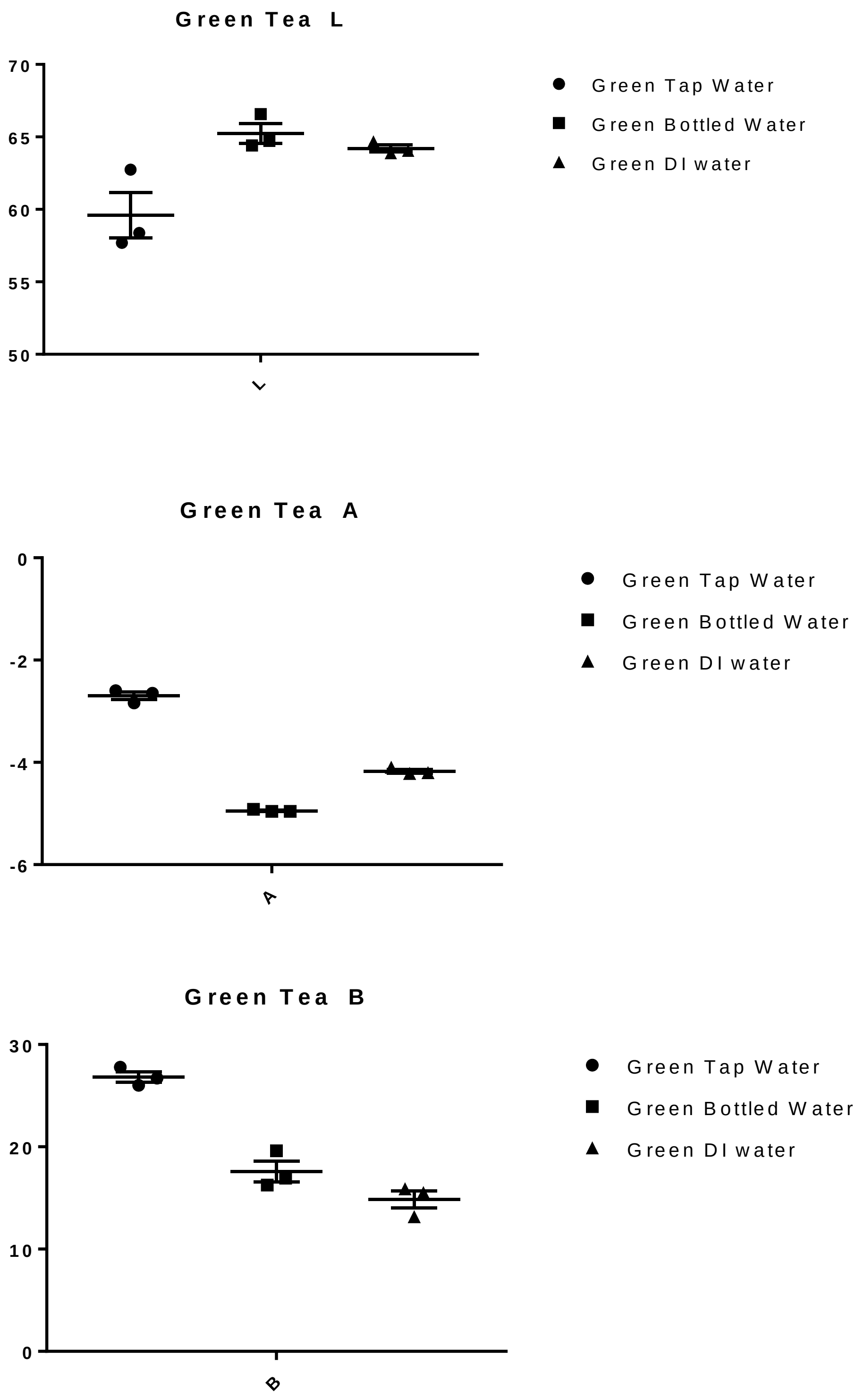
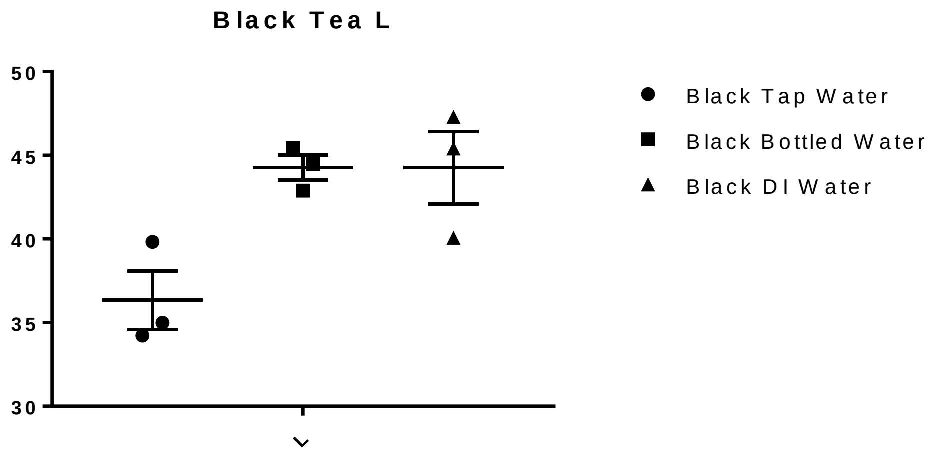
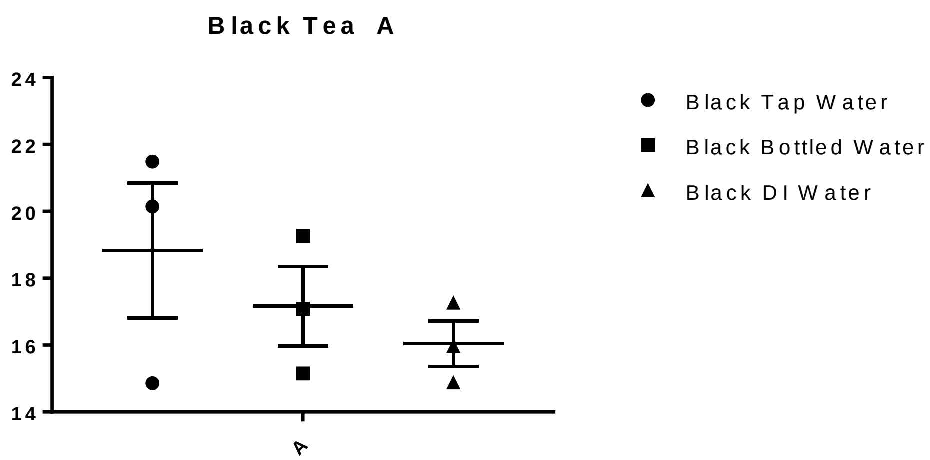


Figure 7. Colorimeter results for green tea infusion in tap water, bottled water, and deionized water.





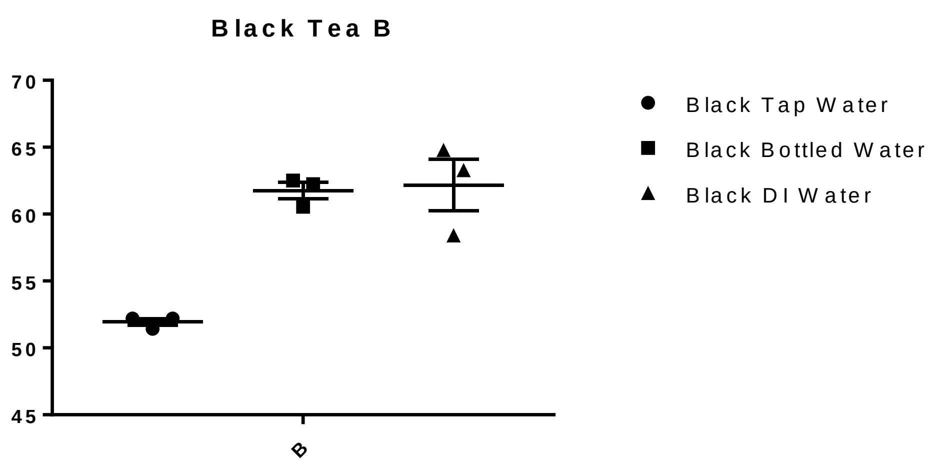


Figure 8. Colorimeter results for green tea infusion in tap water, bottled water, and deionized water.

3.4 Total Phenolics

The results for total phenolics using the Folin-ciocalteu method showed that black tea brewed in tap water had lower total phenolics than black tea brewed in bottled water or deionized water. Green tea brewed in tap water extracted less total phenolics than green tea brewed in bottled water and deionized water. Although, there was less extraction for tap water infusions, we found no statistically significant difference for both green and black tea. There was no significance for GT and GB ($p = .6288$), between GT and GD ($p= .7063$), and for GB and GD ($p > 0.9999$) There was no significance for black tea between BT and BB ($p= 0.8734$), between BT and BD ($p= 0.8226$), and between BB and BD ($p > 0.9999$) The results of the total phenolics are shown in Figure 9 and 10.

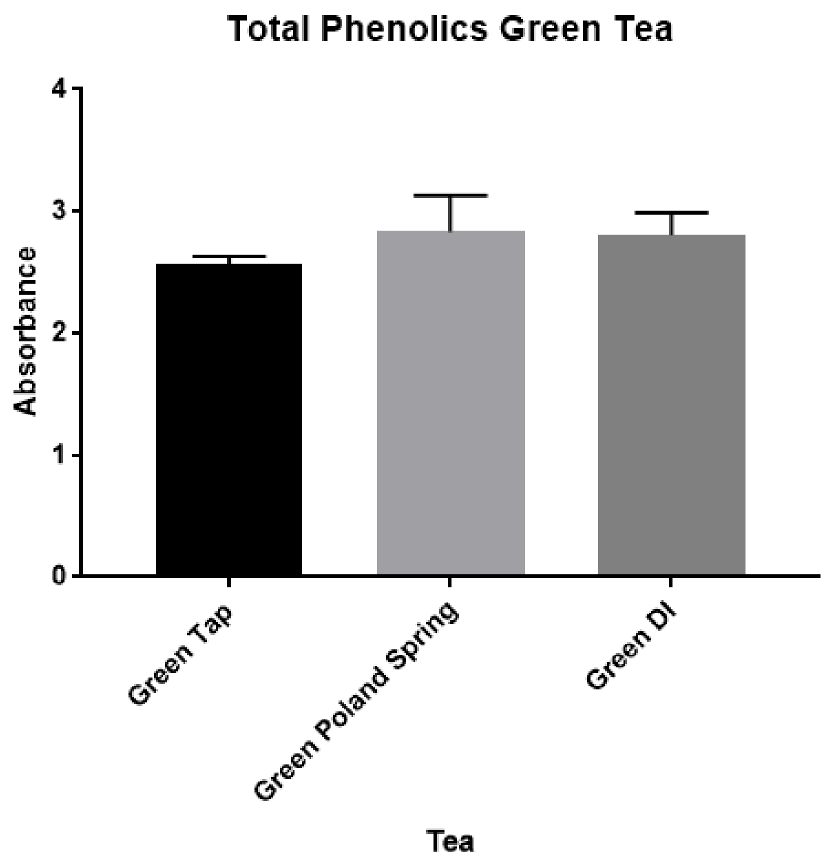


Figure 9. Total phenolics of green tea brewed in tap water, bottled water, and deionized water. Error bars represent SEM.

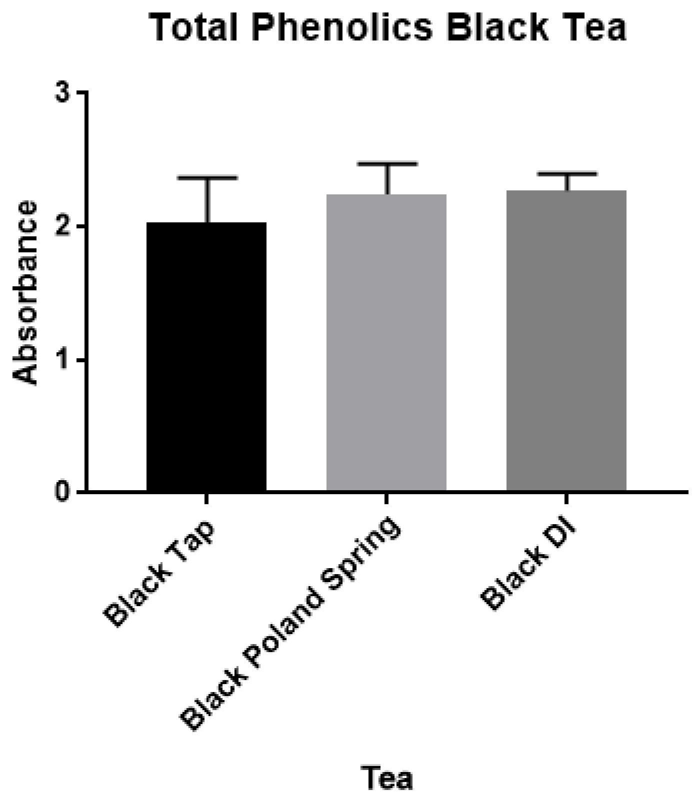


Figure 10. Total phenolics of black tea brewed in tap water, bottled water, and deionized water. Error bars represent SEM.

3.5 EGCG Content

The amount of epigallocatechin gallate in black tea is less than that found in green tea as the majority of the catechins in black tea are converted to theaflavins and thearubigins (Tea and health 2010). The small amount of EGCG in the black tea infusions showed no change with water type (Figure 8). Conversely, with green tea (natively higher in EGCG), there was a significant difference between green tea infusions. Green tea brewed in bottled water and

Deionized water had around double the amount of EGCG compared to green tea brewed in tap water ($p < 0.0001$, Figure 11).

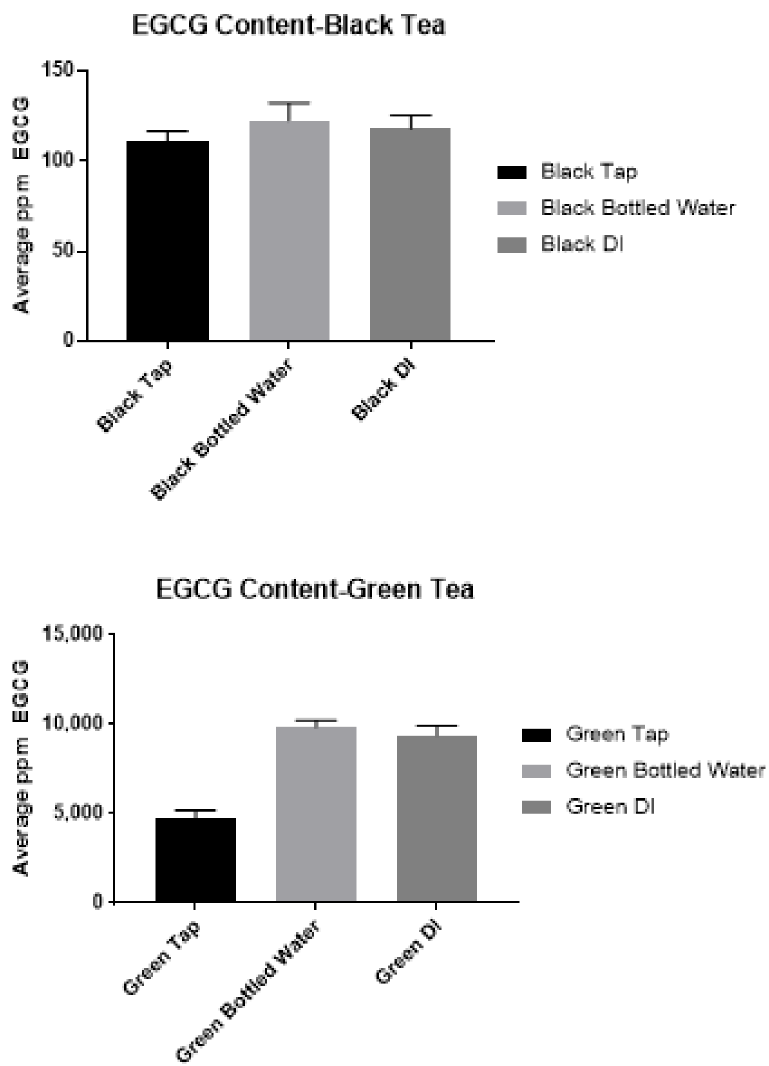


Figure 11. Total EGCG content for green and black tea brewed in tap, bottled and deionized water. Error bars represent SEM.

3.6 Sensory Results - Black Tea

There was no significant difference between samples of black tea for overall liking or flavor liking. Panelists did find significant differences in appearance liking between the samples (P= 0.0345), which was likely due to color differences between the black tea infusions (Figure 12).

Panelists evaluated various flavor attributes of the black tea infusions after a period of training on using the gLMS. There were no significant differences between the black tea infusion for astringency, bitterness, sourness, or sweetness, however panelists did find a significant difference in earthy flavor between black tea brewed in bottled water compared to black tea brewed in tap water (Figure 13).

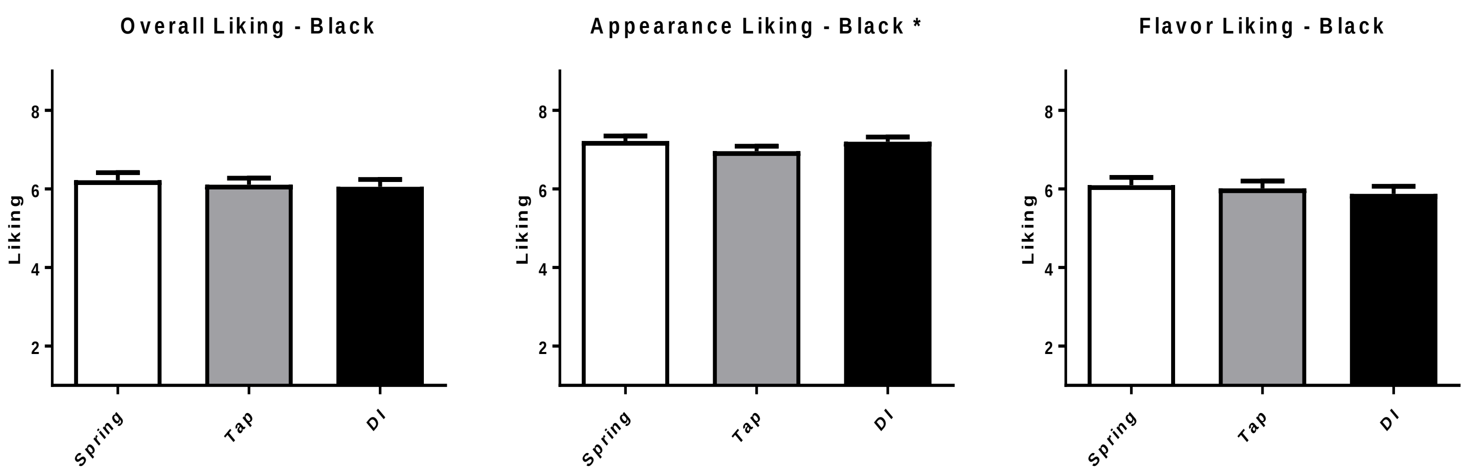


Figure 12. Sensory perceptions of black tea brewed in tap water, bottled water, and deionized water. Error bars represent SEM.

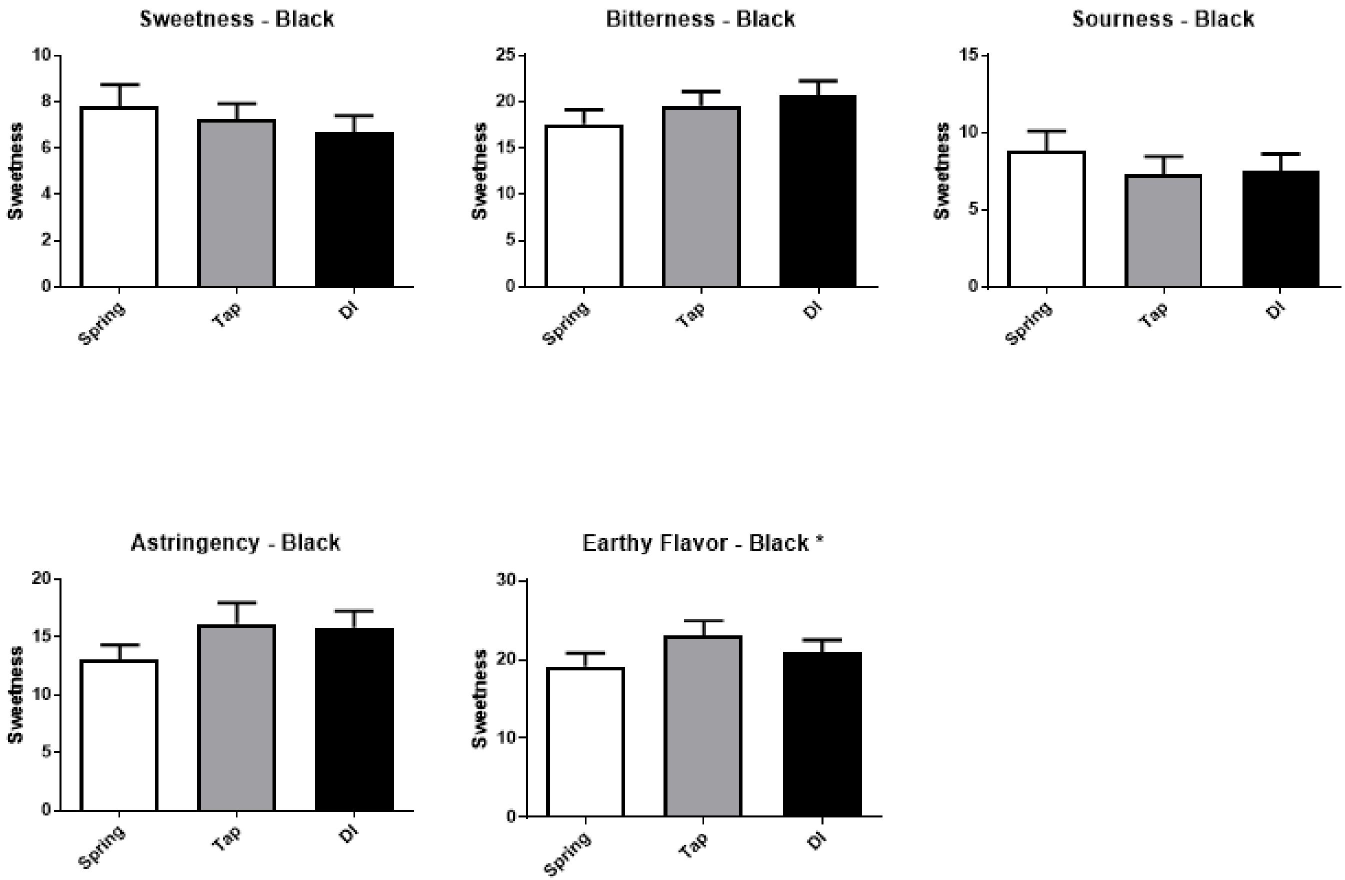


Figure 13. Panel's perception of black tea brewed in tap water, bottled water, and deionized water. Error bars represent SEM.

3.7 Sensory Results - Green Tea

The panelist scored overall liking, appearance liking, and flavor liking of the green tea brewed with different water types on a 9-point hedonic scale. The panelists liked the green tea sample brewed with tap water significantly more than the other samples ($p < 0.001$). When examining why, no difference in appearance liking was reported ($p = 0.099$) , however the panel's liking of the flavor of green tea brewed in tap water was significantly higher than that brewed in bottled water or deionized water ($p = 0.001$, Figure 14).

Between green tea infusions, the panelist found no significant difference in astringency, sourness, or vegetal flavor (p = 0.851, p = 0.081, p = 0.7363), however the panel perceived the green tea with tap water to be the sweetest (p = 0.012) of the tea infusions and as well as the least bitter (p = 0.0001) of all green tea infusions (Figure 14), likely due to the presence of less bitter catechins in the sample.

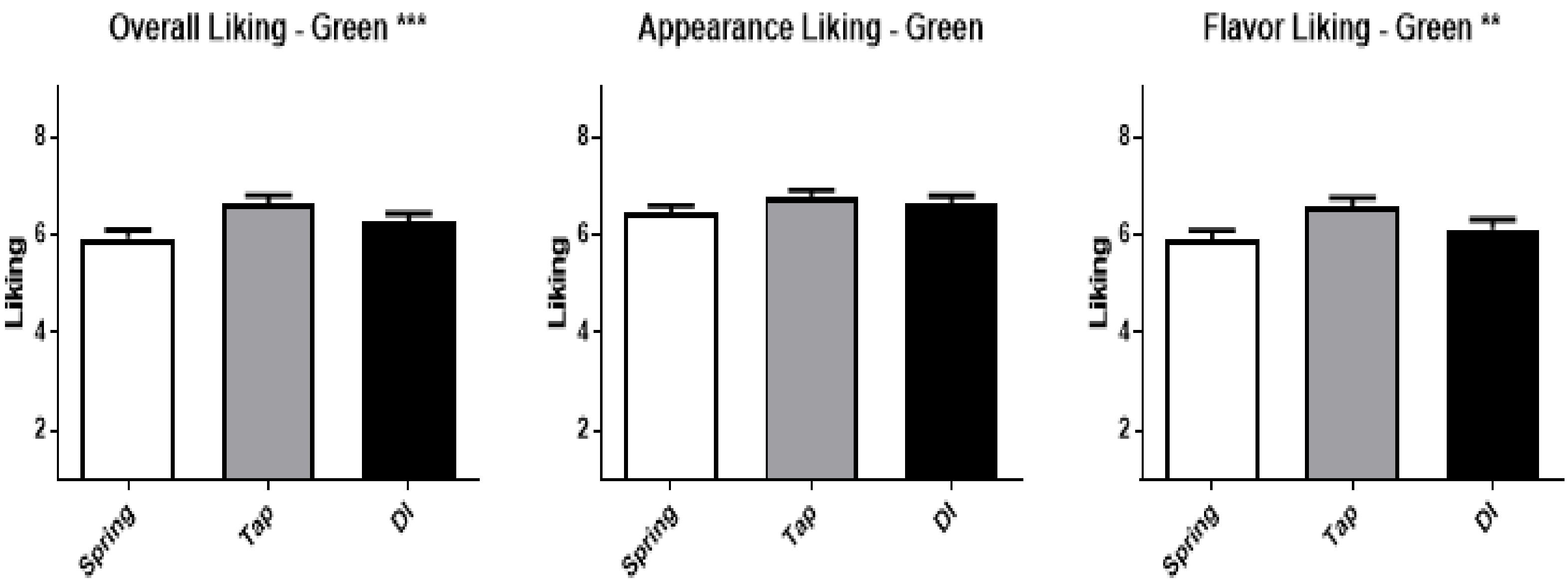


Figure 14. Sensory perceptions of green tea brewed in tap water, bottled water, and deionized water. Error bars represent SEM.

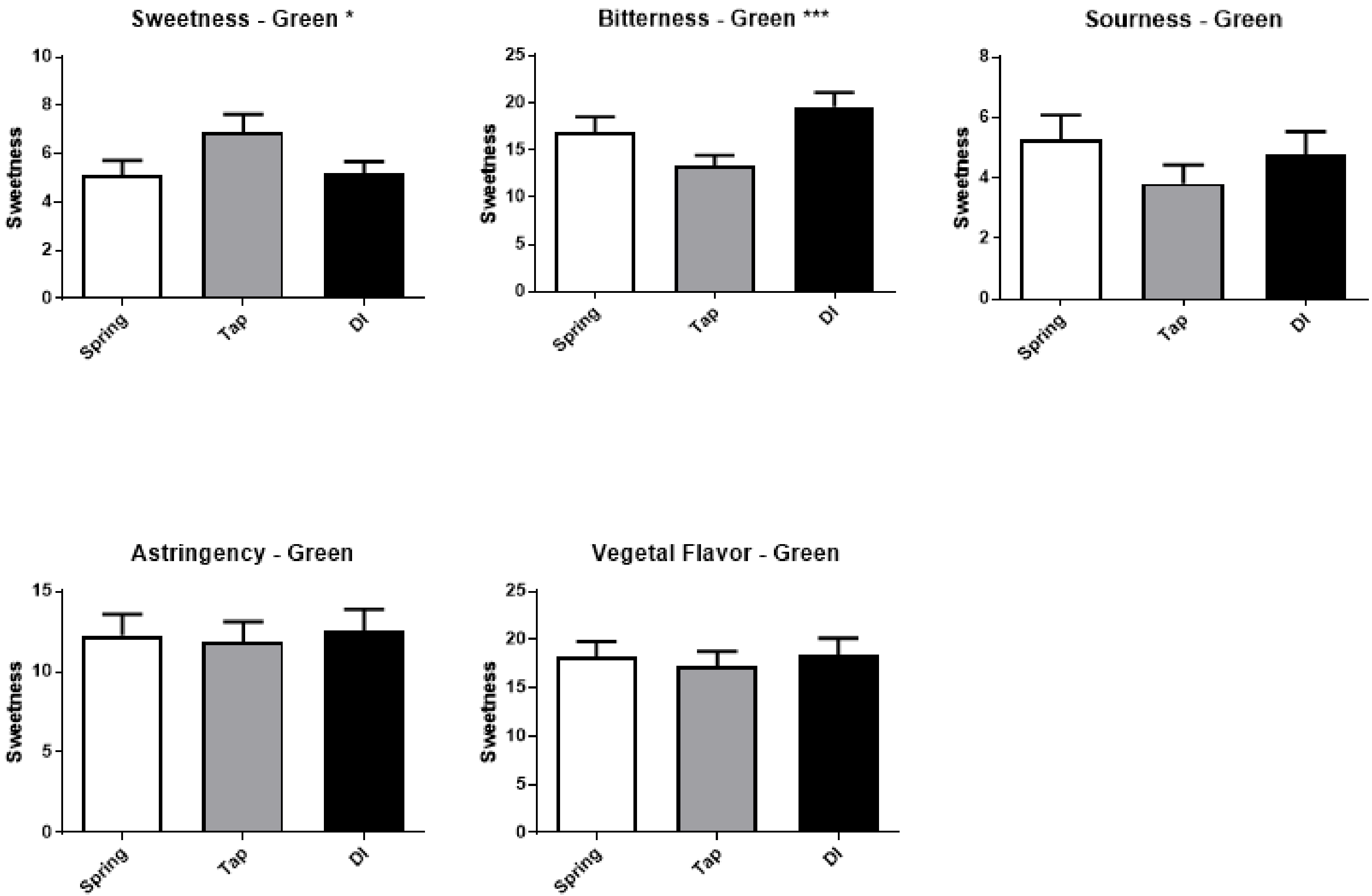


Figure 15. The chemosensory perception of green tea brewed in tap water, bottled water, and deionized water. Error bars represent SEM.

3.8 Color Judgements

Panelists analyzed their perception of the color of the tea samples using a color scale chart for both the black and green tea samples. For green tea the color scale was divided into eight color spectrums ranging alphabetically from A to H (Figure 2). A being the lightest green and H being the darkest green. There was significant difference in color between the green tea samples (chi-square 43.87, df = 6). For black tea samples the color scales were also divided in eight color spectrums ranging alphabetically from I to P. I being the lightest color and P being the darkest (Figure 2). There was significance between the colors of the black tea samples (chi-square 39.91, df = 10).

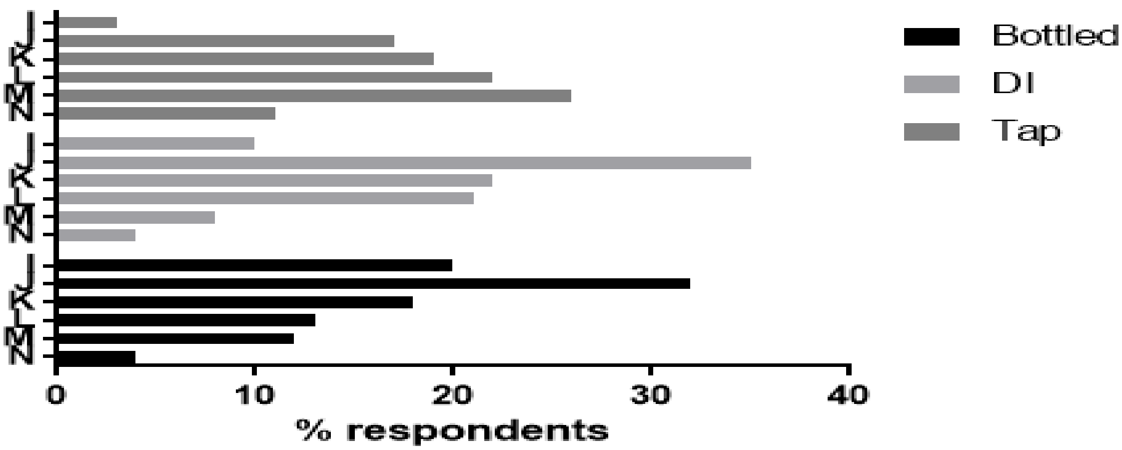


Figure 16. Black tea color judgement results

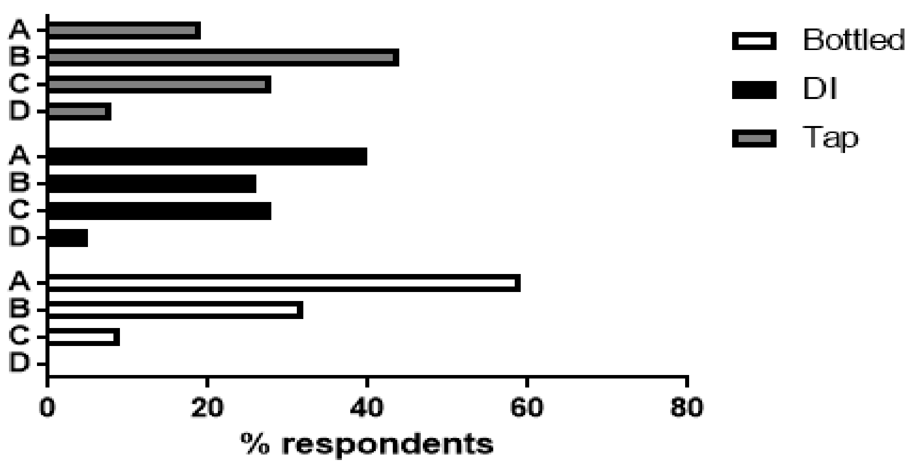


Figure 17. Green Tea color judgement results

3.9 Tea attitudes

Of the 103 panelist who took the study, 88 panelists participated in a follow-up survey. Here, panelists were asked what their primary reason was for drinking tea was, with 67% responding that taste or flavor drove their consumption. 16% of the panel said the primary reason they consume tea was due to cultural background or routine, 10% health benefits, and 7% said other. When panelists were asked the primary reason, they drink black tea 84% said it was due to taste or flavor, with only 7% due to health benefits. When panelists were asked what the primary reason they drink green tea 67% reported it was for taste or flavor, but now 26% reported drinking green tea due to health benefits, suggesting the ability to almost double the EGCG content of green tea would be of much interest to green tea consumers. The results of the survey are summarized in Figure 18-20.

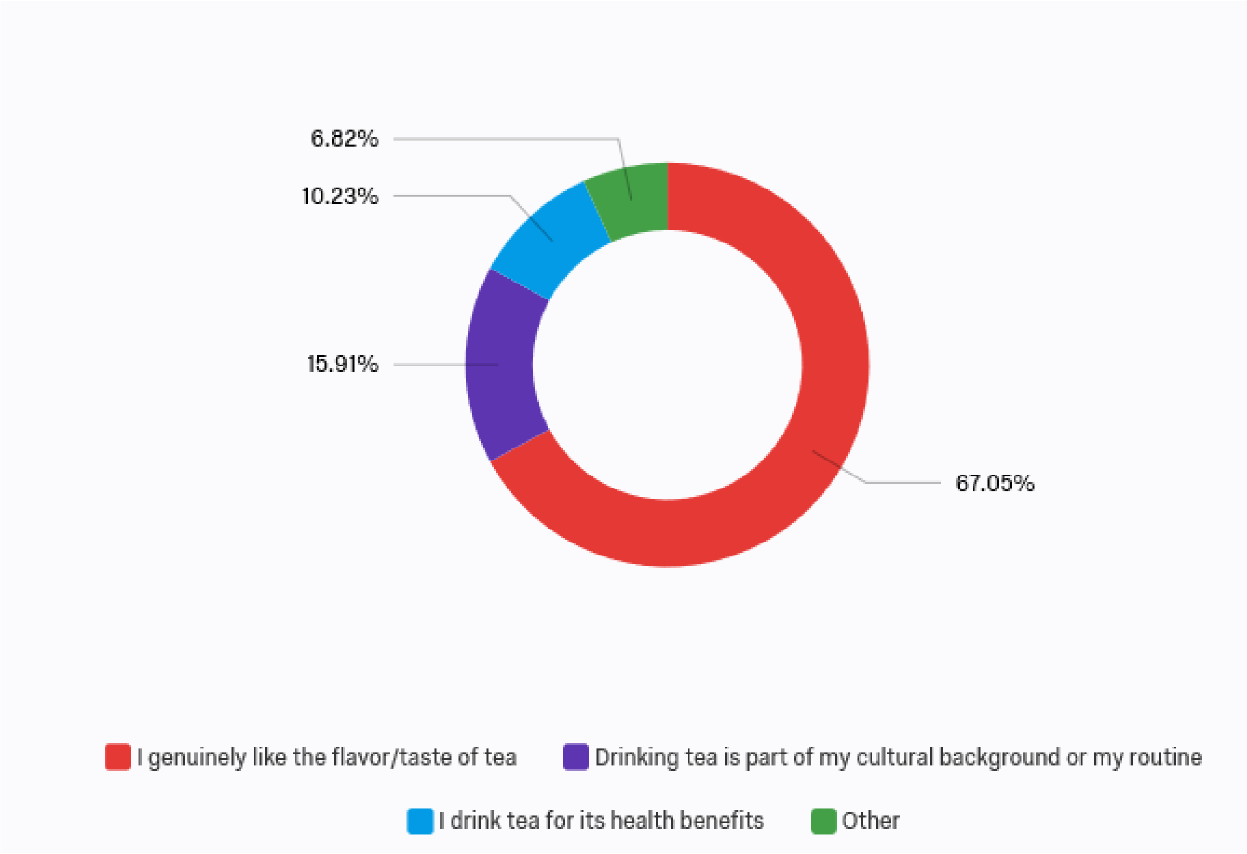


Figure 18. The post sensory survey for the primary reason the panelists drink tea.

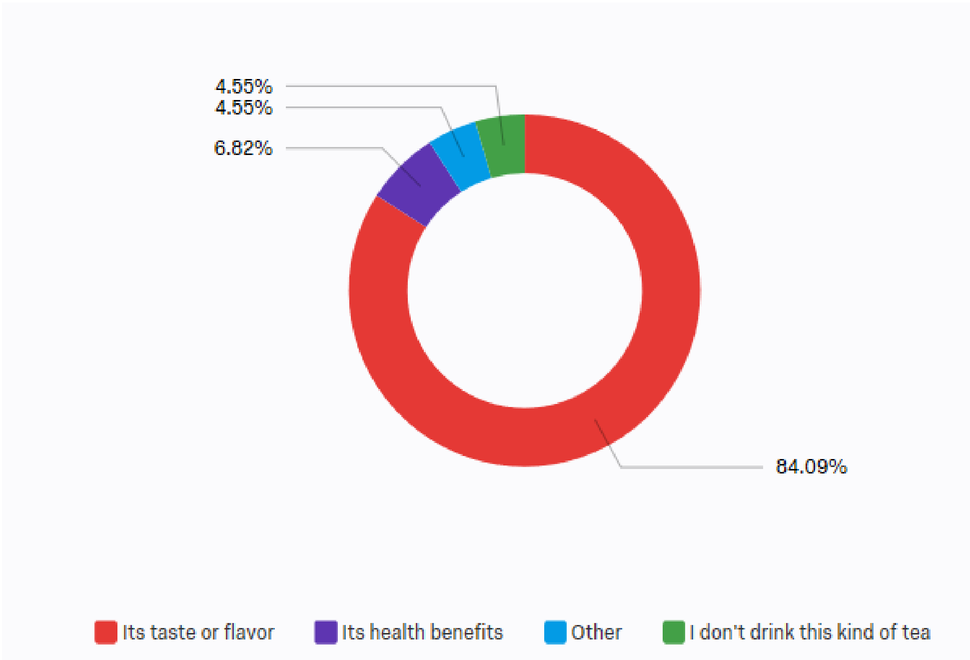


Figure 19. The post sensory survey results to the primary reason the panelist drink black tea.

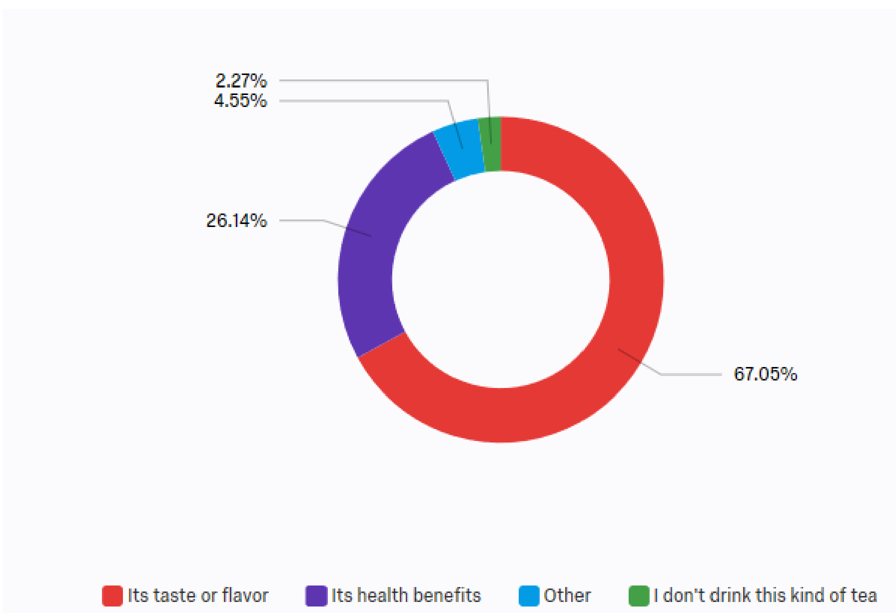


Figure 20. The post sensory survey results to the primary reason the panelists drink green tea.

3.10 Discussion

Tea is the most consumed beverage besides water in the world (Hoh and Mair 2009). Despite tea being consumed for nearly 3000 years (Hoh and Mair 2009), there are few consumer sensory studies into tea consumption (J. Lee et. al 2010), with more studies concerning evaluation by expert trained panels. This project sought to get a better understanding of whether the type of water used to brew tea matters to the everyday tea drinker, and if it ultimately influences their liking of green or black tea. Taste is a key factor in consumer acceptability of water (Whelton et. al 2007), however water is often not a top priory when making tea, despite its role as the vehicle for the infusion. Through the instrumental analysis of green and black tea brewed in tap, bottled and deionized water we demonstrate a difference in color, turbidity, and the amount of EGCG extracted. High concentration of calcium and magnesium can affect taste, color, and catechin content of tea (Zhang 2017, Jinghlei Li 2015, Yin 2014, Mossion 2007). The concentration of EGCG extracted from green tea made with tap water was half that of green tea brewed with bottled water or deionized water. Flavanols such as EGCG and alkaloids including caffeine are the major contributors to bitter taste in tea. Panelists were able to taste clear differences between the tea infusions, particularly in bitterness and sweetness (likely due to mixture suppression from less bitterness). The high mineral content of Ithaca tap water extracted less catechins and thus produced a tea that was less bitter and sweeter than the green tea brewed in bottled or deionized water. The overall liking and flavor liking of green tea brewed in tap water was higher, presumably due to this fact. Although panelists could tell there was a difference in color between black tea samples, this did not affect overall liking of the samples. The earthy flavor of black tea is generally thought of as a positive characteristic. The panel perceived the black tea brewed in tap water to be earthier, however it seemed that this was not a critical factor in determining overall liking or flavor of the tea infusions. Since black tea has fewer catechins than green tea due to the oxidation process in manufacturing, the type of water used had less of an effect on black tea for the everyday tea drinker. Survey results concluded that the primary reason consumers drink tea is for the flavor. However, when panelists were pressed to delineate between green and black tea, more people were drinking green tea for health reasons than black tea. For tea drinkers who are drinking tea mainly for health benefits, our results demonstrate that the type of water used to brew tea does clearly matter, with the mineral content of the water determining extraction of antioxidants, and thus contributing to the health benefits of the ultimate sample.

CHAPTER 4

CONCLUSIONS AND FUTURE DIRECTIONS

The type of water used to brew tea can alter the taste and hedonic properties of tea. EGCG is not the only compound in tea that causes bitter taste, and thus more research is needed on extraction parameters in tea. The more bitter a tea infusion is, the more it is likely to be disliked, while the sweeter a tea infusion is the higher the probability it will be liked. This project only covers black and green tea. Further study is needed to see how water type affects other tea styles such as oolong and white tea. White tea is not oxidized like green tea, while oolong tea is only partially oxidized. Considering the catechin content in this tea styles it would be interesting to see if teas brewed in a highly mineralized water versus a purer water would also have an influence on tea's sensory and chemical properties.

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