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Research Paper

An exploratory analysis on pH levels and water hardness that affect the rate of brewing as well as the colour on different types of 'tea' (Green, Black tea and Oolong tea.)

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Abstract: *Different types of tea like Green, Black and Oolong are manufactured from different tea shrubs. These are grown under different climatic conditions in different countries. Though the basic chemical composition may be the same, the end result depends on various other factors. These could range from the pH content, hardness of water as well as the brewing of the tea leaves. The health benefits attributed to this plant is tremendous, and is being continuously discovered.*

Research question*: How does the PH level impact the brewing of various types of tea? Does it also impact the colour of the brew? Hardness of the quality of water also impacts both the above factors 'brew' and 'colour'. How does this impact the taste and fragrance of the 'Tea' consumed?*

Key words: *Camellia sinensis, Dicotyledonous shrub, non-alcoholic, morphological, biochemical, natural hybridisation, Polyphenols, Alkaloids, Polysaccharides*

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I. Introduction

Tea has been consumed in many countries. They are classified according to the region of origin e.g. China, Ceylon, Japanese, Indonesian and African tea, or by smaller districts like Darjeeling, Assam and Niligiri from India, Uva and Dimbula from Sri lanka ,Keemun from Chi-men in China's Anhwei Province, and Enshu from Japan. Tea products are made from leaves of the tea plant (Camellia sinensis). This is a dicotyledonous shrub that was initially found 3000 years ago in China as a beverage and medicine. It is likely that it originated in the borderlands of south-western China and northern Myanmar. Green tea is made from this plant.

Figure 1; Visual representation of *Camellia sinensis*

Source; herbalogymanchester.wordpress.com

Tea is one of the major non-alcoholic beverages in the world. It has gained popularity due to its palatability and comparatively low cost. Tea, *camellia sinensis* is indigenous to Asia. It is a heterogeneous plant with many morphological, biochemical and physiological attributes due to its free natural hybridisation (Banerjee, 1988).

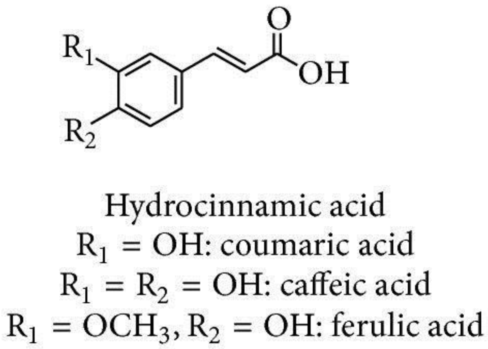
Tea plants are grown in latitudes that range from 45ºN to 27ºS.It grows on acidic soils with a pH of 4.5 to 5.0. It requires a minimum rainfall of 1,150 mm and a maximum of 8000 mm per annum, and a temperature ranging between 8ºC and 35ºC, with a photoperiod from 9.4 to 15h
The beverage contains vitamins A, B, C, E and K, and minerals like iron, copper, fluoride, manganese and zinc. It also has a large amount of antioxidants.

II. Active Ingredients in Tea

The main active ingredients of tea include;

● Polyphenols

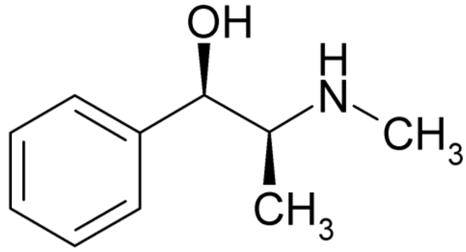
Figure 2; Image of Polyphenols



Source; Research gate

● Alkaloids-

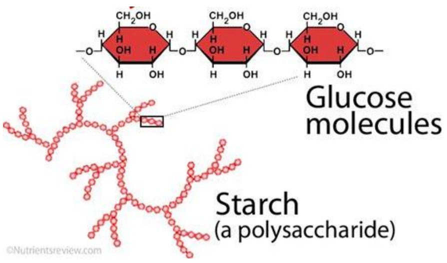
Figure 2: representation of Alkaloids



Source: wikidoc.org

● Polysaccharides

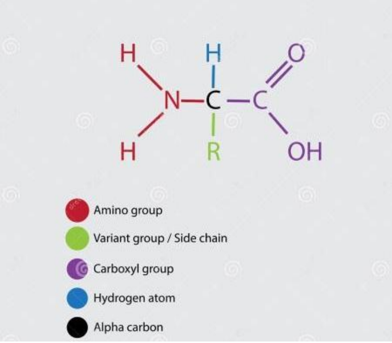
Figure 3: Image of Polysaccharides



Source: nutrientsreview.com

- Amino acids

Figure 4: Image of Amino acids



Source: dreamstime.com

- Aroma
- Volatile constituents.

These are categorised into four categories:

- Unoxidised tea (oolong tea)
- Oxidised tea (Black Tea)
- Post–fermented tea

Green tea in recent years has shown its potential health benefits by having a high content of catechins(these are natural polyphenolic phytochemicals that exist in food and medicinal plants, such as tea, legumes and rubiaceae) and polyphenols which are important components in tea leaves. Along with the tea leaves, there are health benefits that are obtained from the water in which the leaves are brewed that are equally important. These are;

- Water Hardness,
- ion content
- pH determinant

It is thus the interaction between catechins and water components that affect the flavour profile of infusions (in the form of different types of tea leaves).
Tea is broadly classified by oxidation (green, yellow, white, oolong, black/red, fermented), and specifically by production methods within oxidation categories.

III. Definition

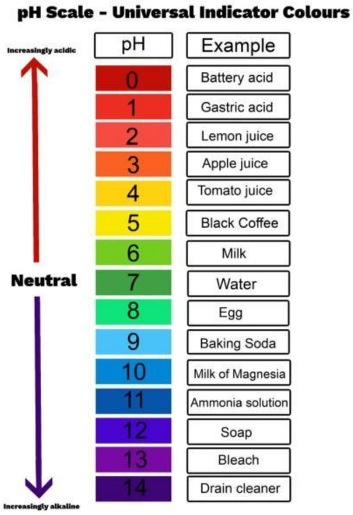
Tea brewing depends on a number of factors like pH levels, hardness of water, oxidation and where the tea plant is grown.

3.1 pH levels

The pH levels of a solution are a measure of its acidity and are equal to the negative logarithm of the hydrogen ion concentration. The full form of pH is the "Potential of Hydrogen." It is inversely related to hydrogen ion concentration, $[H^+\}$.Themeaning of pH is defined as the strength or power of hydrogen. In an aqueous solution the product of $[H^+]$ and hydroxyl ion concentration, $[OH^-]$, is constant: $1*10^{-14}$Eq/litre.

It is a measure of how acidic or basic a substance or solution is, pH stands for the power of hydrogen, and is calculated on the number of hydrogen ions in a liquid. It is measured on a scale of 0-14. On this scale, a pH level of 7 is neutral, meaning that it is neither acidic nor basic. A pH level of less than 7 means it is more acidic, and a pH value of more than 7 means it is more basic. The pH level indicates the potential of hydrogen, as pH is effectively a measure of the concentration of hydrogen ions (ie protons) in a substance. The pH scale was devised in 1923 by a Danish Biochemist Soren Peter Lauritz Sorensen (1868-1969).Due to the uncertainty about the physical significance of the hydrogen ion concentration; the definition of the pH is an operational one, based on a method of measurement. The U.S. National Institute of Standards and Technology has defined pH values in terms of the electromotive force that exists between standard electrodes in specified solutions.

Figure 5; pH scale

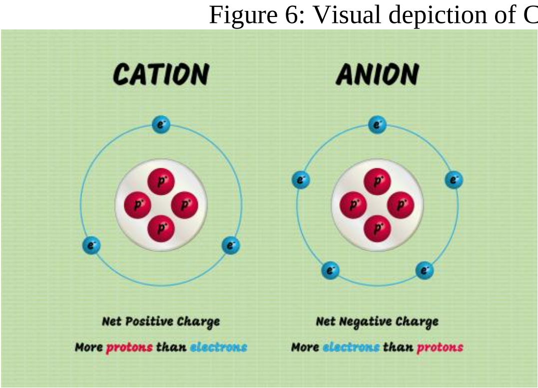


Source: science-sparks.com

3.2Hardness of Water

The hardness of water is mainly contributed by calcium and magnesium ions.It is defined as total parts per million (ppm) of $CaCO^3$ by weight (eg. the hardness of water 10 ppm effectively means 10g of $CaCO^3$ in one million grams of water. Hardness could also be caused by several other types of dissolved metals that form divalent or multivalent cations,(cations have a positive charge, i.e. they have lost one or more of their electrons, leaving more positively charged protons without an electron counter balance).

Figure 6: Visual depiction of Cation



Source: sciencenotes.org

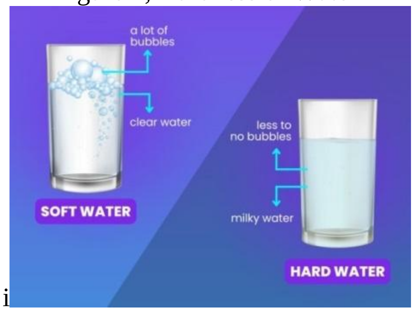
That includes aluminium, barium, strontium, iron, zinc, and manganese. These cations have a propensity to come together with anions in the water to form stable salts; there is a distinction between two types of hardnesscarbonate and non-carbonate hardness. Water hardness is the measurement of the sum of molar concentrations of dissolved cations in the water. The more divalent cations dissolved in the water the "harder" the water. These divalent ions impact the taste of water.

Carbonate hardness is caused by metals combined with a form of alkalinity (alkalinity is the capacity of water to neutralise acids and is normally attributed to compounds such as carbonate, bicarbonate, hydroxide and occasionally borate, silicate, and phosphate. Carbonate hardness is sometimes called temporary hardness because it can be removed by boiling water.

Non-carbonate hardness on the other hand cannot be broken down by boiling water and is thus called permanent hardness. The ratio of calcium and magnesium in water is a crucial factor indicating the hardness of water.

Water hardness is not usually expressed as a molar concentration but rather in the form of units such as English degrees. In tea, the precipitated calcium carbonate and phenolic aggregates form a surface scum which is undesirable for the consumer (McGee, 2004). Tea scum is defined as "surface film composed of calcium, hydrogen carbonates and organic matter" and occurs only in the infusions prepared with hard water. Tea scum is formed by the oxidation of organic compounds which is induced in the presence of calcium carbonate (Spiro &Jaganyi, 1994). The divalent calcium in hard water slows the extraction of bitter compounds like caffeine, catechins (natural polyphenolic phytochemicals that exist in food and medicinal plants, such as tea, legume and rubiaceae) (Sheibani et al., 2014). A catechins is a type of antioxidant.

Figure 7; Hardness of Water



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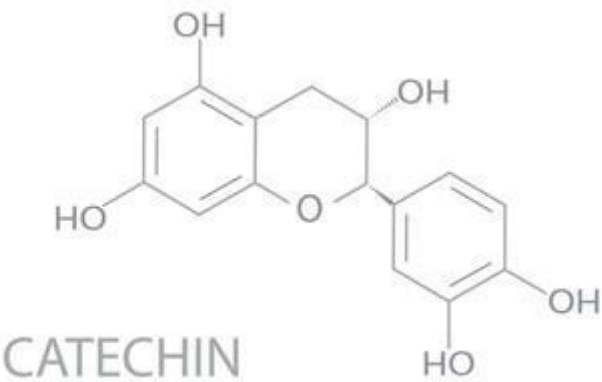
Source; waterscience.in

Figure 8: Chemical Formula of Catechin



Source: shutterstock.com

3.3Concept of Brewing in Tea

Brewing is an essential process to release flavour compounds from tea leaves. Its main factors include the selection of brewing water, water/tea ratio, brewing temperature and time. The tea infusions brewed in water with higher pH and total dissolved solids (TDS) had a darker colour. These infusions had less catechins, particularly galloylated- catechins and had higher antioxidant capacity, but were much more susceptible to high mineral brewing water. Green tea was the most susceptible one to the type of water used while dark tea was the most stable one.

Tea brewing is normally the first step in tea consumption. It involves putting tea leaves into a cup, adding hot drinking water, brewing for some time, after which the tea infusion can be strained and drunk. The water that is normally used is drinking water that contains natural mineral water, natural spring water, purified water, mineral water and other drinking water.

The brewing process is a crucial step affecting the formation and release of aromatic compounds (Kang et al., 2019)

Figure 9; Brewing Of Different Types of Tea

TEA STEEPING CHART

TEA TYPE	WATER	6-8 OZ	TIME
White	175°-185°	1 tbsp	1-3 min
Green	180°-185°	1 tsp	3 min
Black	206°	1 tsp	3-5 min
Darjeeling	185°	1 tsp	3 min
Oolong Rolled	185°-206°	1 tsp	3-5 min
Oolong Long Leaf	185°-206°	1 tbsp	3-5 min
Tisane	206°	1 tbsp	5-7 min
*Raw Pu-erh	195°	1 tbsp	3-5 min
*Half & Full Baked Pu-erh	206°	1 tbsp	3-5 min

*First soak for 30 seconds, flush, then re-steep.
Most teas may be steeped multiple times.

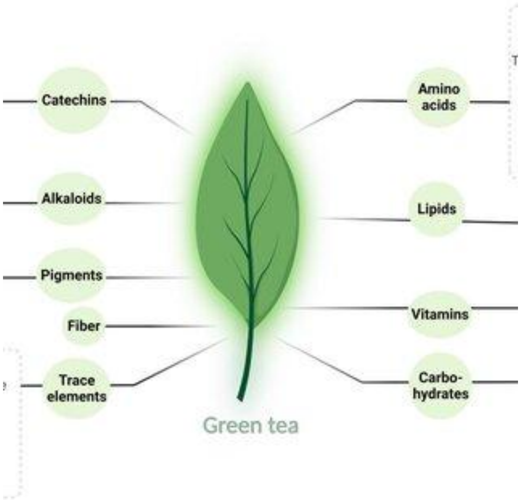
Source: eliosewilkinson.z21.web.core.windows.net

IV. Green Tea and its chemical composition

Green- Green tea mainly consists of catechins, much more than chocolate, red grapes, wine and apples. The main chemical constituents of green tea are phenols, alkaloids, flavonoids, tannins and steroids. One-third part of green tea is made up of polyphenols which include catechins like epigallocatechin gallate(EGCG), epigallocatechin(ECG), epicatechin-3-gallate and epicatechin(EC).Green tea is prepared by pan frying or steaming fresh tea leaves at elevated temperature to inhibit polyphenol-oxidase mediated processes.

Green tea is less processed, which is why it has the maximum antioxidant property than any other form of tea. They have the ability to neutralise free radicals and boost the detoxification activity of enzymes, including glutathione peroxidase, catalase and glutathione reductase. It also contains flavonoids and glycosides (Kurshid et al., 2016). Green tea plants are mostly grown in warm climates and at high altitudes. The green tea plant takes 3-5 years to grow before commercial picking occurs.

Figure 10: Chemical Composition of Green Tea



Source: researchgate.net

It has both antibacterial and antiviral properties. Green tea extract has shown antibacterial activity by inhibiting bacterial strains Streptococcus mutans and Lactobacillus acidophilus as well as other bacteria like Escherichia coli, Salmonella typhi, Staphylococcus,aureus, and Enterococcus faecalis (Africa et al.,2011)

4.1 Impact of Hardness of Water, pH levels, and Brewing on Green tea

It has been demonstrated that infusions made by steeping tea leaves have a lower polyphenol content than those made from the powdered form. It is the grinding process that in fact accelerates the extraction of polyphenolic compounds. Researchers like Shishikura and Khokhar have observed that given the average time that it takes to prepare tea, the powdered version is more effective and active in terms of the extraction in a relatively short time(one minute), and thus seems a better choice. It has also been concluded that the powdered form had the highest parameters of all the green teas, and the required extraction time was the shortest. Extending the brewing time of powdered 'matcha', did not increase its antioxidant capacity.

The high mineral content of hard water led to inferior extraction of catechins in green tea, producing an infusion that was less bitter in taste and perceived as sweeter than the same tea brewed in soft water.

Given the fact that the health benefits of green tea are associated with the catechin content (the higher the better), it is important to analyse the type of water that is used to brew the tea. When experiments are conducted in the laboratory, Green tea is prepared with deionised water, but casual consumers use local tap water which differs in alkalinity and mineral content depending on the region. Experiments indicated that as the hardness of the water increased, total catechin yield decreased. This was due to the autoxidation of EGC and EGCG. Autoxidation was enhanced by alkaline conditions that resulted in the browning of green tea infusions. High levels of alkaline sodium bicarbonate found in hard water can in fact result in some tap waters unsuitable for green tea preparation.

Water hardness, ion content, and pH determine the quality of brewing water. It is the interaction between catechins and water components that affected the infusions due to the water composition. As the most common method is the use of tap water for tea preparation, the result would differ depending on the water composition of the tap water, in different regions.

Results have indicated that alkaline water and alkaline electrolysed water has greater health benefits. Use of mineral water to brew tea infusion could significantly influence the quality attributes of the brew. Mineral salts exert a variety of effects on the extraction mechanism of green tea infusion.

V. Black tea; its chemical properties

During the manufacturing of black tea, leaves are crushed and subjected to enzymatic oxidation process called fermentation (Hsu et al.,) Subsequent oxidative condensation of the catechins during the fermentation leads to the production of theaflavins(TFs) (benzotropolone dimers of catechins), as well as higher molecular weight polymers, iethearubigins (TRs). Both constituents are responsible for the specific taste and colour of black tea.

Polyphenolic compounds include a substantial amount of flavonoids. These dominate the typical composition of Black Tea.(Bursill et al.,2007)

Flavonoids are classified into six groups that are based on the structure and position of the heterocyclic oxygen carbon oxygen ring.

Besides the ones above, tea also consists of amino acids, and theanine. Tea composition is associated with its;

- Origin
- Fermentation conditions
- Processing

During the production of black tea, several intricate biological and chemical processes contribute to the aroma's development. Different volatile chemicals are generated during the processing of black tea, which includes withering, rolling, fermentation (enzymatic oxidation), and drying.

Black tea is mostly made from Camellia sinensis and Camellia assamica tea varieties. These two varieties differ in their development patterns, leaf sizes, and chemical makeup, impacting how black tea's scent is formed.

The chemical composition of black tea remains dynamic during tea processing. Its volatile compounds primarily stem from the oxidation, degradation and hydrolysis of aroma precursors, such as carotenoids, unsaturated fatty acids and glycosidic aroma compounds. It is the polyphenol oxidation process during black tea fermentation that is critical in producing black tea pigments.

Figure 11; Camellia sinensis and Camellia assamica

Source; teapro.co.uk

5.1 The influence of pH, Hardness of water and Brewing on Black Tea.

Black tea is less acidic than coffee. Black tea was found to have a pH of 6.37. This level is important as it impacts the taste. Tea that is more acidic has a tangier and bitter taste, which is not that desirable. A pH that is higher than the ideal level of 7 will result in a darker tea infusion, while a pH that is lower than the ideal level causes lighter tea infusion. The acidic nature of tea starts from the soil in which tea is grown. The mineral composition of the soil influences the acidity. During the processing of black tea fermentation(Tanaka & Matsuo, 2020), tea leaves are crushed and rolled first and at the same time, catechins are enzymatically oxidised to quinones under the action of endogenous polyphenol oxidase (PPO) and peroxidase (POD) in the fresh tea leaves. Theaflavins(TFs) and Theasinensins(TSs) are the key components that are formed from the enzymatic oxidation of tea catechins that contribute to the biological activities and the taste of Black tea. Research has indicated that Reaction temperature, pHvalue, and duration showed significant effects on the conversion of catechin and the formation of TSs and TFs.

Brewing a tea hot or cold as well as the time also influences the pH level. Hotter water leads to a greater extraction of tannins, which impacts the pH level. Longer brewing time tends to extract more, contributing to a potentially lower pH and a "brisk" taste in tea. The bold, earthy flavours of black tea promote alertness and heart health, due to compounds like theaflavins that develop during oxidation.

Hard water results in a very dark coloured brew, compared to soft water. This tea tends to have a stronger, at times harsher taste that can overpower the tea's natural flavours and aromas.(Murugesan, Venkateswaran, &Shanmuga Selvan, 2016).

Hard water can impact the aroma by influencing the release of these compounds during brewing. The quality of water can result in cloudy or hazy tea (Murugesan et al, 2016), due to the minerals in hard water reacting with the compounds in tea, forming insoluble precipitates that cloud the liquid.

VI. Oolong Tea

This tea is of Chinese origin, made from partially oxidised tea leaves. It lies between Black tea (which is fully oxidised) and green tea (which is barely oxidised). The word 'oolong', in Chinese means "black dragon". It is a semi-fermented tea, with its own unique aroma and taste. It is made by wilting fresh leaves by the sun and then slightly bruising them. Tea polyphenols, catechins, caffeine, thealavine, gallic acid, chlorogenic acid, ellagic acid, kaempferol-3-G and free amino acids are the chemical ingredients that are prevalent in Oolong tea. It also contains small amounts of calcium, magnesium, and potassium, along with several vitamins. It has various pharmacological activities such as antioxidant activity by reducing oxidative stress, anti- cancer, anti- obesity, anti-diabetes, anti-allergy, and antiseptic, as well as prevention of atherosclerosis and hypertension.

6.1Impact of pH, hard water and brewing on Oolong tea

Oolongs are in the range of 6-7.5 pH. This creates a medium oxidation with nuanced floral and fruity flavours. Oolong tea has the unique property of not being easily affected by the type of water that is used for brewing. Hard water that contains magnesium and calcium has a bitter taste and reduces the true taste of tea; it also reduces the nutritional value of the tea. Brewing of this tea vary widely. For a single infusion,1-5minute steeping is recommended. The water temperature ranges from 80°-95°C.

VII. Conclusion

The chemical composition as well as external factors like the pH, hardness of water and the manner in which tea is brewed impacts the taste and the beneficial properties of the type of tea leaves that are used. The type of tea leaves that are used for different types of tea depends upon the climatic conditions under which they have grown, the soil content as well as the type of water used. Teas have an interesting chemical equation which enables them to have a large number of antioxidant properties that are beneficial for tea drinkers. Depending on the type of tea leaves the properties differ. The most beneficial are the ones that are attributed to Green Tea. Labelling them as Green and/or Black tea tends to bracket them into one group, but in fact there are various varieties within each group that are widely available.

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