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The Impact of Water Quality on Taste Profile of Made Tea in Sri Lanka

D.M.S.H. Dissanayaka*, S. Karthigayini and R.M.D.M. Lakmal

Department of Agricultural Engineering and Soil Science,
Faculty of Agriculture, Rajarata University of Sri Lanka,
Puliyankulama, Anuradhapura, Sri Lanka

*Correspondence: dissanayakashiromi@gmail.com

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පිළියෙල කිරීමට ගන්නා ජලයෙහි ලක්ෂණ අනුව තේ වල රසය, වර්ණය සහ ගන්ධය එකිනෙකට වෙනස් වන අතර මෙම අධ්‍යයනය මගින් මූලිකවම, තේ වල රසය කෙරෙහි ජලයෙහි ගුණාත්මකභාවයේ බලපෑම පිළිබඳව අධ්‍යයනය කරනු ලබයි. මෙහිදී, ශ්‍රී ලංකාවේ බහුලව භාවිතා වන පානීය ජල ප්‍රභවයන්ගෙන් ජල සාම්පල එකතු කරන ලදි. ඒවා නම්, නිකවැරටිය, මාතලේ, අනුරාධපුර, කැබිතිගොල්ලෑව යන ප්‍රදේශ වලින් තෝරා ග්නනා ලද ළිං ජල සාම්පල, ප්‍රතිආස්‍රැතිය උපයෝගී කොටගෙන පෙරන ලද සාම්පල, නල ජල සාම්පල සහ උල්පත් ජල සාම්පලයි. එමෙන්ම පාලිත පරීක්ෂණය සඳහා ආස්‍රැත ජලය යොදාගන්නා ලදි. සියලුම ජල සාම්පල වල කඨිනත්වය, ඌ අගය, ක්ෂාරීයතාව, පූර්ණ වශයෙන් ජලයේ දියවූ ඝණ ද්‍රව්‍ය ප්‍රමාණය, ජලයේ දියවූ ඔක්සිජන් මට්ටම මෙන්ම පොස්පේට් පොස්පරස්, ක්ලෝරයිඩ්, ෆ්ලුවෝරයිඩ්, නයිට්‍රේට් නයිට්‍රජන් අයන ප්‍රමාණයන්ද විද්‍යාගාර පරීක්ෂණ මගින් මැන බලන ලදි. එමෙන්ම, එක් එක් ජල සාම්පල භාවිතා කර සාදන ලද කළු තේ, හරිත තේ සහ රස එකතු කල තේ වල ආවිලයිතයන්හි රසයෙහි ඇගයීමක්, ISO 3103 – 1980 තත්ත්ව ප්‍රමිතීන්ට අනුකූලව, සම්මත රස ඇගයීම් මණ්ඩලයක් විසින් සිදුකරන ලදි. ඉහත ක්‍රමෝපායන් මගින් ලබා ගන්නා දත්තයන් SAS 9.0 මෘදුකාංගය භාවිතා කොට විශ්ලේෂණය කොට ලබාගන්නා ප්‍රතිඵල වලට අනුව, කළු තේ සඳහා සමස්ථ රස ඇගයීම් පිළිගැනීම ප්‍රතිආස්‍රැතිය උපයෝගී කොටගෙන පෙරන ලද ජල

සාම්පල වලින් සාදන ලද ආවිලයිතයන්ට ලැබුණි. එමෙන්ම මෙම ජල සාම්පල වල කඨිනත්වය, ක්ලෝරයිඩ් අයන ප්‍රමාණය සහ පූර්ණ වශයෙන් ජලයේ දියවූ ඝණ ද්‍රව්‍ය ප්‍රමාණය අනෙක් ජල සාම්පල වලට වඩා සාපේක්ෂව පහළ මට්ටමක පැවතිණි. එමෙන්ම හරිත තේ සහ රස එකතු කල තේ සඳහා ඉහළම සම්මත රස ඇගයීම් පිළිගැනීම උල්පත් ජලයෙන් වාර්ථා වූ අතර උල්පත් ජලයෙහි මනින ලද ජල තත්ව පරාමිතීන් සියල්ලම පාහේ මධ්‍යස්ථ අගයක් ගනු ලැබීය. කෙසේ වුවත් අවම සම්මත රස ඇගයීම් පිළිගැනීම අනුරාධපුර ළිං ජල සාම්පල වලින් සාදන ලද ආවිලයිතයන්ට හිමිවූ අතර එම ජල සාම්පල වල කඨිනත්වය, ක්ෂාරීයතාව, පූර්ණ වශයෙන් ජලයේ දියවූ ඝණ ද්‍රව්‍ය ප්‍රමාණය මෙන්ම ක්ලෝරයිඩ් සහ ෆ්ලුවෝරයිඩ් අයන ප්‍රමාණයද අනෙක් ජල සාම්පල හා සංසන්දනය කිරීමේදී ඉහළ අගයක් ගන්නා ලදි. එම නිසා මෙම අධ්‍යයනය මගින් ජලයෙහි ගුණාත්මකභාවය සැලකිය යුතු ලෙස තේ වල ආවිලයිතයන්හි රසයට බලපාන බවට නිගමනය කරනු ලැබීය.

මුඛ්‍ය පද: ජලයෙහි ගුණාත්මකභාවය, තේ වල රසය, රස ඇගයීම්

1. Introduction

Tea is one of the most popular non-alcoholic and healthy beverages in the world. *Camellia sinensis* is the scientific name of the tea plant (Ni *et al.*, 2008) which is a sub-tropical evergreen plant native to Asia but is now grown around the world. Tea gives economic benefits to Sri Lanka as it is one of the top ten tea producer and tea exporter and also exports more than 95% of tea production to about 140 countries in the world (Karthigayini and Goonasekere, 2020). It is a very effective and important agricultural product in mountainous areas which are suitable for tea. It can be divided into unfermented green tea, partially fermented oolong tea and fully fermented black tea differing in the level of oxidation of the leaf during the processing step. It is the second most consumed beverage in the world next to the water. Nowadays, it attracts much attention as a beverage due to its potential health benefits, which arise from its main active compounds that include polyphenolics, amino acids, vitamins, caffeine and other purine alkaloids. It has been consumed for centuries due to these health benefits. Furthermore, tea is a highly efficient, key agricultural product in the tea-suitable mountainous regions. In general, tea is taken after brewing with hot water, and this infusion step is vital for extracting the active compounds (Zhang *et al.*, 2017).

The art of tea processing plays an important role in determining the final flavour of the liquor. By processing, the leaves from the Tea tree (*Camellia sinensis)* are converted into dry leaves to brew tea. Even though the quality of tea depends on the chemical composition of harvested shoots, how they are handled, processed and stored, a high-quality tea that has been gone through many labour intensive steps can be ruined by improper brewing. It can be observed that the quality of water is different from one area to another around the

island. However, the impact of the quality of water on tea infusions has not been widely explored locally as well as internationally.

Tea is 99% water, so it's going to have a dramatic effect on the flavour of the tea. The type of water used for brewing makes a difference in taste profile, colour and, the aroma of the made tea or tea infusions despite using tea with the same quality. Water quality is the condition of water including the chemical, physical and biological characteristics usually concerning its suitability for a particular purpose such as drinking (Service, 2011). It is a measure of the requirements of one or more species or the state of water for human needs and purposes. It is most frequently used by referring to a set of criteria that can generally evaluate the compliance achieved through the treatment of water. The most common criteria used to evaluate water quality are related to ecological health, the safety of human contact, and drinking water.

Water quality depends on several parameters such as pH, mineral content, oxygen concentration etc. Hence, this study aimed to investigate the impact of water quality on the taste profile and aroma of black tea, green tea and flavoured tea produced in Sri Lanka by studying the water quality parameters of selected potable water sources and evaluating sensorily all three types of tea brewed using these selected water sources.

2. Materials and Methods

2.1 Laboratory evaluation of water quality characteristics

Water samples were collected from most commonly used potable water sources in Sri Lanka. The selected water sources were 1. Well water from selected locations (from Nikaweratiya, Matale, Anuradhapura, Kebithigollewa), 2. RO filtered water, 3. Tap water /Chlorinated water, 4. Distilled water and 5. Mineral water. Physiochemical parameters such as pH, Total Dissolved Solids (TDS), Dissolved Oxygen concentration (DO), nitrate-nitrogen concentration (NO_3^-N), phosphate-phosphorous concentration (PO_4^{-3}-P), fluoride concentration (F^-), chlorine concentration (Cl^-), hardness, total alkalinity of water samples were determined. Table 01 shows the measured parameters and methods used for the analysis.

Table 01: Analytical Parameters of Water Quality

Water quality parameters	**Method of analysis**
pH	Multi parameter analyzer (HACH: Sension 156)
Electrical Conductivity (EC)	Multi parameter analyzer (HACH: Sension 156)
Total Dissolved Solids (TDS)	Multi parameter analyzer (HACH: Sension 156)
Dissolved Oxygen concentration (DO)	Multi parameter analyzer (HACH: Sension 156)
Nitrate - Nitrogen concentration (NO_3^-N)	UV visible spectrophotometer
Phosphate - Phosphorous concentration (PO_4^{-3}-P)	UV visible spectrophotometer
Total alkalinity	Acid titration method
Hardness	Ethylene-Diamine-Tetra Acetic acid (EDTA) method
Fluoride	SPADNS method- Colorimetry
Chloride	Silver nitrate method- Titrimetric

2.2 Sensory evaluation of tea infusions

Preparation of the tea infusions for the sensory evaluation was done according to the procedure given by the International Organization for Standardization (1980). Black tea, Green tea and Flavored tea (**2g**) extracted in **150** ml of freshly prepared boiling water for **3** min. Infusions were prepared in porcelain teapots covered with porcelain lids during brewing. After the completion of brewing, infusions were filtered and used for the analysis. The brewing temperature, time, vessel, the water to leaf ratio and the water composition are the factors that alter the taste of the brewed cup (Mossion *et al,* 2008). This study aimed at focusing on the water used to brew tea, specifically how water quality influences the sensory qualities of black, green and flavoured tea. The sensory evaluation was performed according to the national standards outlined in ISO 3103-1980 (International Organization for Standardization, 1980). The prepared tea infusions were tasted by two tasting panels consisted of an experienced tasting panel (five tasters) and non-experienced tasting panel (thirty individuals) using a structured sensory evaluation form that includes factors such as colour, aroma, flavour and overall acceptability at Amazon Trading (Pvt) Ltd, 257, Siri Dhamma Mawatha, Colombo 10, Sri Lanka.

2.3 Analysis of laboratory and sensory evaluation

The data collected from laboratory and sensory evaluation were compared with the WHO drinking water standards and excel graphs were used to show the comparisons graphically. The data from questionnaires were analyzed using Statistical Package for the

Social Sciences (SPSS) version 22 and descriptive statistics and paired t-test were used as methods of statistical analysis.

3. Results and Discussion

3.1 Water Sample Analysis

3.1.1 Analysis of water quality parameters

pH

pH is an important parameter in evaluating acidic or alkaline nature of drinking water. WHO has recommended permissible limits of pH from 6.5 to 8.5 of water for drinking purpose (Meride and Ayenew, 2016). The water that does not fall within this range, if it is alkaline, is not necessarily unsafe, but, it can have an unpleasant smell or taste. And if it is acidic (pH less than 6.5), it is more likely to be contaminated with pollutants and making it unsafe for drinking purpose. According to weather patterns, human activity and natural processes, freshwater varies across the world. Water source with very low or high pH can be a sign of chemical or heavy metal pollution.

The mean pH values of purified water in all four categories varied from 6.7 to 7.2 (Table 02). Hence, most of the RO plants in all four categories were within the WHO standards. However, several community level and school level RO plants showed slightly deviated pH values from minimum WHO standards. In general pH value of purified water in all tested RO plants were well within the suitable range for drinking purpose.

Electrical Conductivity (EC) and Total Dissolved Solids (TDS)

The amount of dissolved solids in water determines the Electrical Conductivity (EC). Increase in ions concentration enhances the electrical conductivity of water. It is a measure of water capacity to convey electric current. The maximum permissible level of EC in drinking water is 1.5mS/cm according to WHO standards (Kavindra, 2020).

Water can dissolve a wide range of inorganic and organic substances. These substances produced un-wanted taste and diluted colour in the appearance of water (Dhammawardana, *et al*, 2015). The water with high Total Dissolved Solids (TDS) value indicates that water has more dissolved inorganic and organic substances. Inorganic substances include water-soluble ions and salts. Therefore, TDS represents soluble substances in water and it is one of the major factors affecting the taste and the appearance of drinking water (WHO, 2011). Mean TDS values of RO purified water were within the range of 255 to 423 ppm. According to the WHO standards maximum permissible level of TDS to be present in drinking water is 500 ppm. It exhibited that measured values of purified water in all RO plants were below the

Table 02: Mean values of measured parameters of commonly used potable water sources in Sri Lanka

Selected water samples	pH	TDS	DO	Alkalinity	Phosphate-Phosphorus	No3- N	Cl-	F-	Hardness
Nikaweratiya water	6.1±0.02	62±0.09	3.56±0.08	111±2.7	0.03±0.006	9±1.5	36	0.04	40
Matale water	5.9±0.02	79±0.08	4.08±0.19	162±1.5	0.02±0.001	18±1.3	50	0.01	90
Anuradhapura water	7.1±0.04	412±0.47	3.79±0.06	1020 ±5.5	0.02 ±0.002	8±1	230	0.4	400
Kebithigollewa water	5.8±0.03	41±0.05	5.64±0.04	76±3.2	0.01±0.001	11±1.3	28	0.07	28
Reverse osmosis	6.7±0.09	3±0.04	7.47±0.01	8±0.9	0.01 ±0.002	3±1.5	8	0.01	16
Tap water	7.9±0.05	122±0.05	7.71±0.01	297±0.9	0.01 ±0.003	6±1.0	60	0.16	110
Distilled water	7.1±0.16	0.6±0.01	7.35±0.02	8±1.8	0.01 ±0.001	3±0.4	8	0.02	12
Mineral water	7.0±0.03	72±0.14	7.39±0.02	311±4.6	0.02±0.002	3±0.6	16	0.03	40
Maximum permissible level	6.5 – 8.5	500ppm	7.5mg/l	250mg/l	0.03mg/l	10mg/l	250mg/l	1mg/l	200mg/l

maximum permissible level. However, Jayasumana *et al.,* (2016) reported much lower TDS (range 9-65 ppm) of filtered water in large and medium scale RO plants in North Central Province, Sri Lanka.

Dissolved Oxygen (DO)

Dissolved oxygen analysis measures the amount of gaseous oxygen dissolved in an aqueous solution. It is an important measure of water quality as it indicates a water body's ability to support aquatic life. Because it indirectly indicates whether there is some kind of pollution. Adequate dissolved oxygen is needed and necessary for good water quality. It can affect the solubility and availability of nutrients, which can be released from sediments under conditions of low dissolved oxygen. According to WHO standards, the minimum level of permissible level of DO in drinking water is 7.5mg/L (Ugwu *et al*, 2016). However, the amount of oxygen which water can hold depends upon the temperature, pressure and salinity. Colder water, greater pressure and lower salinity are the conditions for the ability of oxygen to dissolve in water. The concentration deviates from this range is harmful and not suitable for drinking water. It can be concluded that the measured DO values of purified water in all Ro plants were within the range of permissible level.

Phosphate – Phosphorus (PO_4^{3-} - P)

Biological productivity is mostly limited by the amount of phosphorus in the water. The total phosphorus is differentiated into phosphate phosphorus with ratio usually of soluble phosphate phosphorus to total phosphorus of 1:10. The total phosphorus can be much high (30mg/m^3) while the WHO standard for the phosphate phosphorus level of the drinking water should be less than 0.03mg/L. Eutrophication, a water quality problem mainly caused by phosphorus. Some aquatic resources such as wetlands, naturally serve as sinks for phosphorus dissolved in water. Even though there are various impacts in the water quality, here it is predicted that phosphate phosphorus level is acceptable in all the selected purified water samples. Hence, when compared to other water sources, well water shows non-significant higher value, maybe due to seepage of water mixed with agricultural fertilizers, manure and organic wastes to the well.

Chloride (Cl^-)

The measured chloride ions can be used to know salinity of different water sources. Some common chlorides like sodium chloride, calcium chloride and magnesium chloride which are the inorganic compounds resulting from the combination of chlorine gas with metal. Chlorine alone as Cl_2 is toxic but, the small amount of chloride combination with metal such as sodium, magnesium, calcium required for normal cell functions and becomes

essential for life. The WHO standards require chloride level not to exceed 250mg/L due to the sodium chloride may impact a salty taste at 250mg/L while the taste impact by calcium and magnesium chloride can be detected when chloride level reaches 1000mg/L. Therefore, the water that is used for drinking purpose has recommended maximum chloride level of 250mg/L and all the water samples mentioned in Table 2 shows an acceptable level of chloride. And also it can be proved that the very low level of chloride in the RO water sample and a distilled water sample is due to the salt rejection capability of RO plant and distillation process.

Fluoride (F^-)

Fluoride may be found as a natural contaminant or as an additive in drinking water to provide health protection from dental caries through artificial water fluoridation. Traces of it can be found highly in underground sources. The presence of this element in drinking water plays its role according to the level it appears in the water. According to WHO standard fluoride should be less than 1 mg/L in safe drinking water. Even though all the measured values of water samples were recorded within the permissible range, the fluoride content is very low in RO water sample as the RO is an effective defluoridation method.

Hardness

Hardness can be defined as the sum of calcium and magnesium concentrations and is a measure of the capacity of water to precipitate soap. The best quality water for brewing is soft water as it is not containing minerals which are reducing the natural taste of tea. In the hard water, it contains minerals such as calcium and magnesium which can impart a strong bitter flavour to the tea infusion. WHO standard maximum permissible value for hardness in drinking water is 250mg/L. Hence, all the selected water samples except Anuradhapura well water were recorded within the maximum level. There were the lowest values recorded for distilled water and RO water. In the distilled water, during distillation, all the impurities are removed and make water pure and safe to drink. However, it may lead to lacking healthy minerals by drinking only distilled water. but, in RO water, it is also very close to the same quality as distilled water in removing impurities while remaining the oxygen in the water. So that when RO water used at tea making, it gives better taste and allows more flavour due to lack of minerals in it.

Alkalinity

Alkalinity is a measure of the capacity of water to neutralize acids. It is primarily due to bicarbonates, carbonates, and hydroxides which remove H+ ions and lower the acidity of the water. They usually do this by combining with the H+ ions to make new

compounds. Without this acid-neutralizing capacity, any acid added to a stream would cause an immediate change in the pH. Measuring alkalinity is important in determining a stream's ability to neutralize acidic pollution from rainfall or wastewater. It's one of the best measures of the sensitivity of the stream to acid inputs.

The maximum level of alkalinity prescribed by WHO for drinking water is 200mg/L. Very high level of alkalinity compared to permissible level was recorded for Anuradhapura well water (1019.7 mg/L) as a result of rocky areas with a lot of limestones. The more pure the source of water is, the more CO_2 it can absorb and the more acidic it will get. This is the reason for the alkalinity values of RO and distilled water were very low compared to other samples.

Nitrate – Nitrogen (NO^{3-} - N)

According to the WHO guidelines, NO_3^--N level of drinking water should be less than 10 mg/L. However, according to the results of this study, the highest NO_3^--N level was recorded as 18 mg/L for Matale well water. While the lowest level was recorded as 3.4 mg/L for Bottled drinking water and RO. High levels of nitrate in well water often result from improper good construction, location, overuse of chemical fertilizers or improper disposal of human and animal waste.

3.2 Sensory analysis

3.2.1 Sensory evaluation by a trained panel

Black Tea

Acceptability (%) of colour, aroma, flavour and overall acceptability of black tea made from different water samples were evaluated by trained sensory evaluation panel is shown in figure 01. According to that, panellists did find significant differences ($p<0.05$) between tea infusion brewed by using Anuradhapura well water and all the other water samples for all sensory parameters. But, there were no significant differences between the tea infusions brewed by using other water samples (RO, TW, DW and BDW) for any quality attributes (colour, flavour, aroma and overall acceptability).

According to figure 1, the colour and overall acceptability attribute in black tea were highly preferable in tea infusion by using bottled drinking water while the flavour and aroma quality attribute was preferred in black tea infusion using RO water sample. As it has fewer minerals in it, the flavour and aroma may be enhanced and preferred for the tasters.

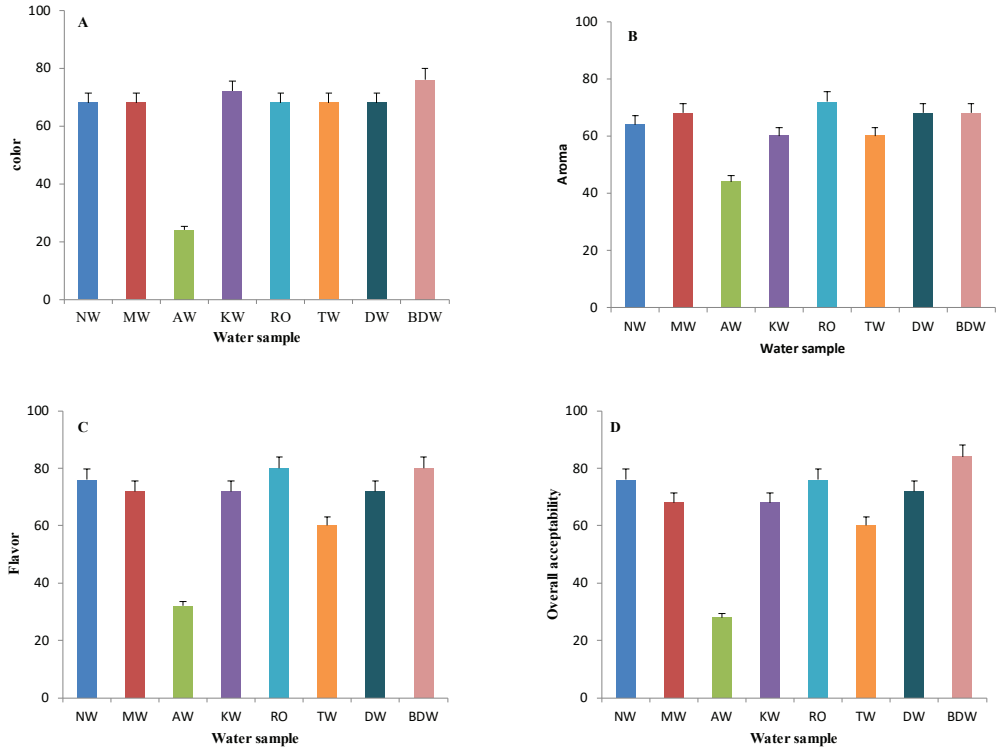

Figure 01: Acceptability (%) of colour (A), aroma (B), flavour (C) and overall acceptability (D) of black tea made from different water samples

Green Tea

Figure 02 shows acceptability (%) of colour, aroma, flavour and overall acceptability of green tea made from different water samples evaluated by the trained sensory evaluation panel. As per the figure, there was a significant difference ($p<0.05$) between the tea infusion brewed by using Anuradhapura well water and all other water samples for all quality parameters. But, there were no significant differences between the tea infusions brewed by using other water samples (RO, TW, DW and BDW) for any quality attributes (colour, flavour, aroma and overall acceptability).

Similar to black tea, the colour and overall acceptability attribute were highly preferred in tea infusion by using bottled drinking water (figure 2A and 2D) while the flavour and aroma quality attribute was preferred in black tea infusion using RO water sample (figure 2B and 2C).

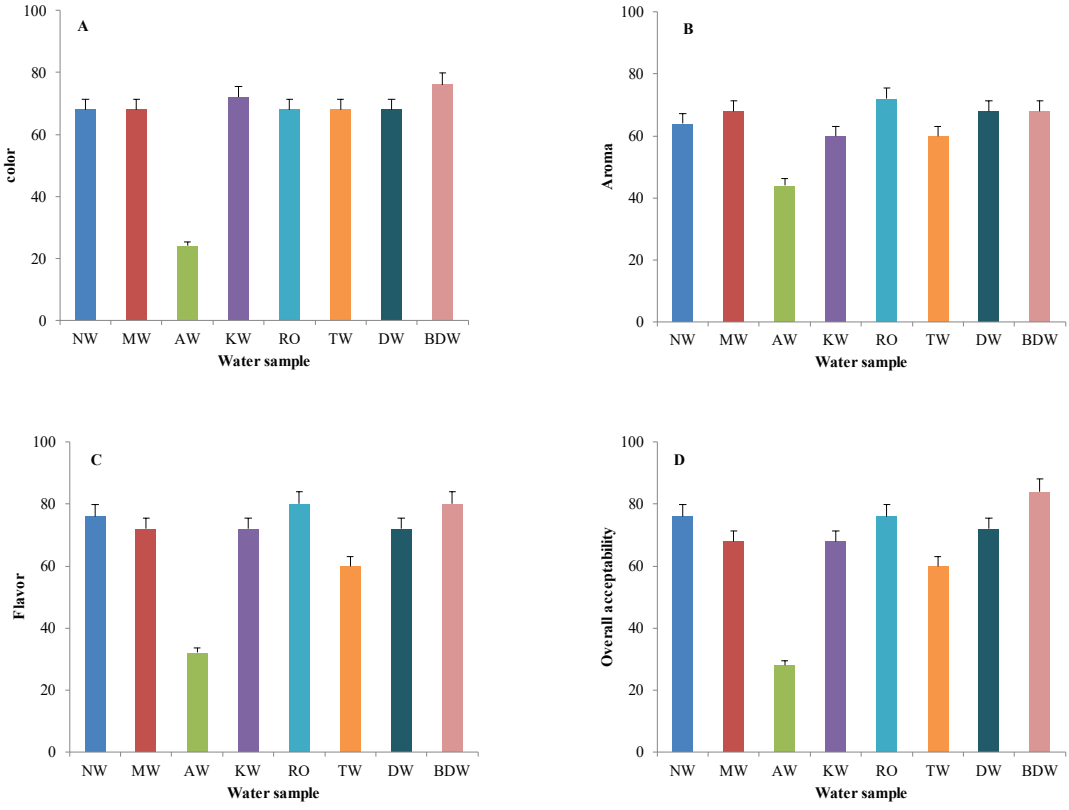

Figure 02: Acceptability (%) in terms of colour (A), aroma (B), flavour (C) and overall acceptability (D) of green tea made from different water samples

Flavoured Tea

Figure 03 below shows acceptability (%) of colour, aroma, flavour and overall acceptability of flavoured tea made from different water samples were evaluated by the trained sensory evaluation panel. To that, panellists did find a significant difference ($p<0.05$) between tea infusion brewed using Anuradhapura well water and all other water samples with the quality parameters such as colour, flavour and overall acceptability.

Similar to black tea and green tea, the colour and overall acceptability attribute were highly preferred in tea infusion by using bottled drinking water (figure 3A and 3D) while the flavour and aroma quality attribute was preferred in black tea infusion using RO water sample (figure 3B and 3C).

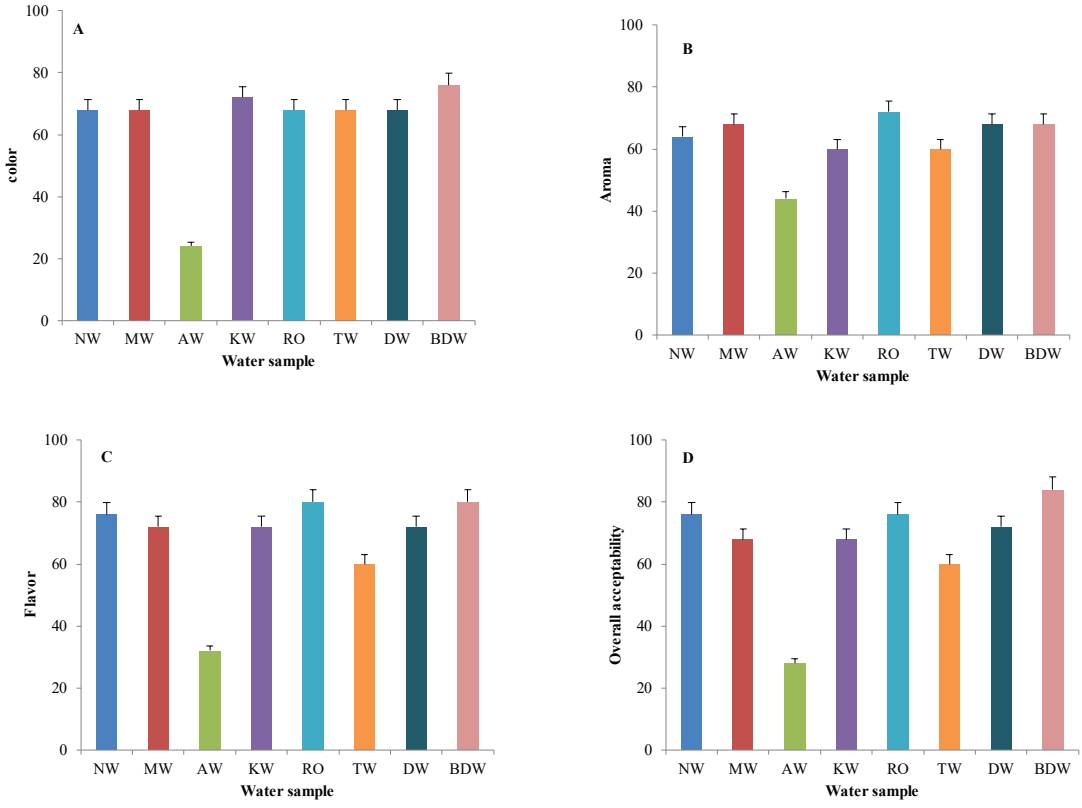

Figure 03: Acceptability (%) of colour (A), aroma (B), flavour (C) and overall acceptability (D) of flavoured tea made from different water samples

3.2.2 Sensory Evaluation Analysis by Untrained Panel

Acceptability (%) of colour, aroma, flavour and overall acceptability of black tea made from different water samples were evaluated by the untrained sensory evaluation panel. As like trained panel, panellists did find a significant difference ($p<0.05$) between black tea, green tea and flavoured tea infusions made by Anuradhapura well water and all other water samples for all the quality parameters.

3.3 Statistical analysis

Overall Acceptance vs Water Quality

The relationship among water quality parameters such as [alkalinity], TDS, [Cl^-], [F^-], [hardness] vs overall acceptance was evaluated for black tea, green tea and flavored tea. According to the figures 04, 05 and 06, it can be concluded that there was very strong

relationship between overall acceptance with TDS, alkalinity, [Cl^-], [F^-] and [hardness] for all three types of tea.

According to the figure 04, the percentage of TDS (83%) plays a major role in overall acceptance of black tea among the panelists while 86% of Fluoride in green tea (figure 05) and 96% of chloride in flavored tea (figure 06).

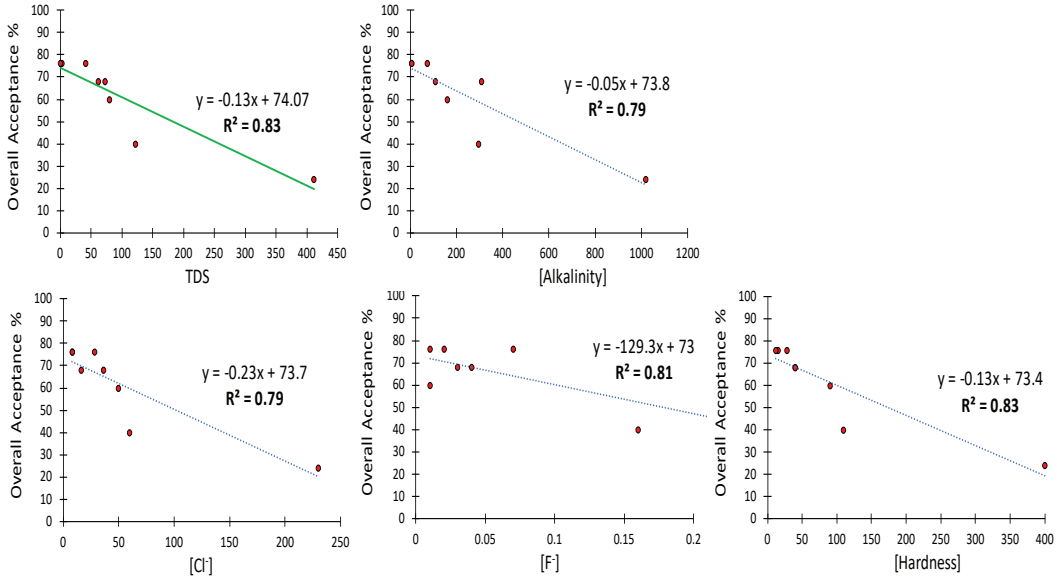

Figure 04: Relationship of overall acceptance (%) and water quality parameters; TDS, Alkalinity, [Cl-], [F-], [Hardness] for Black Tea

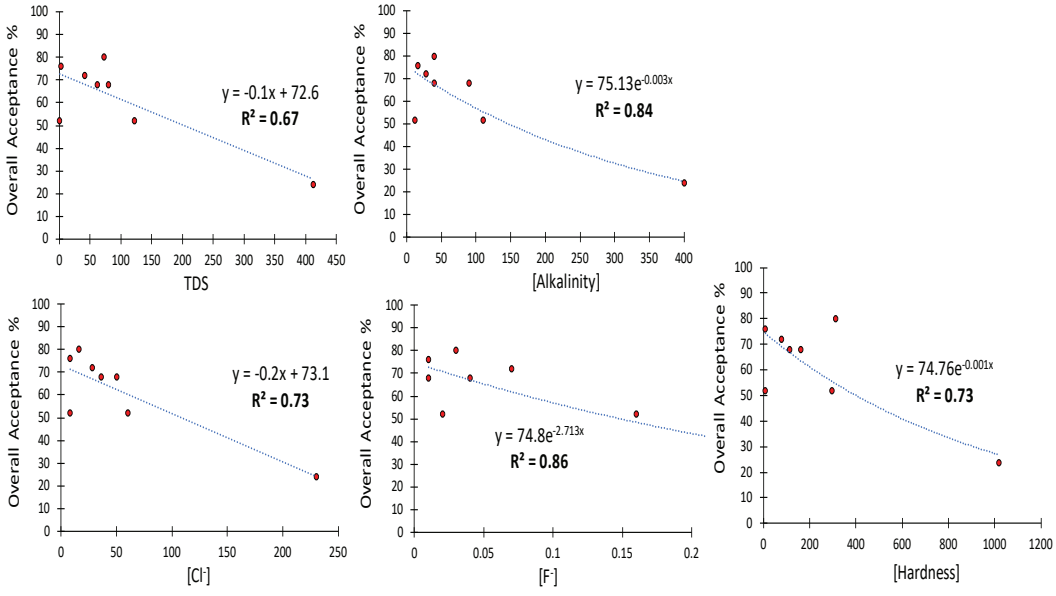

Figure 05: Relationship of overall acceptance (%) and water quality parameters; TDS, Alkalinity, [Cl^-], [F^-], [Hardness] for Green Tea

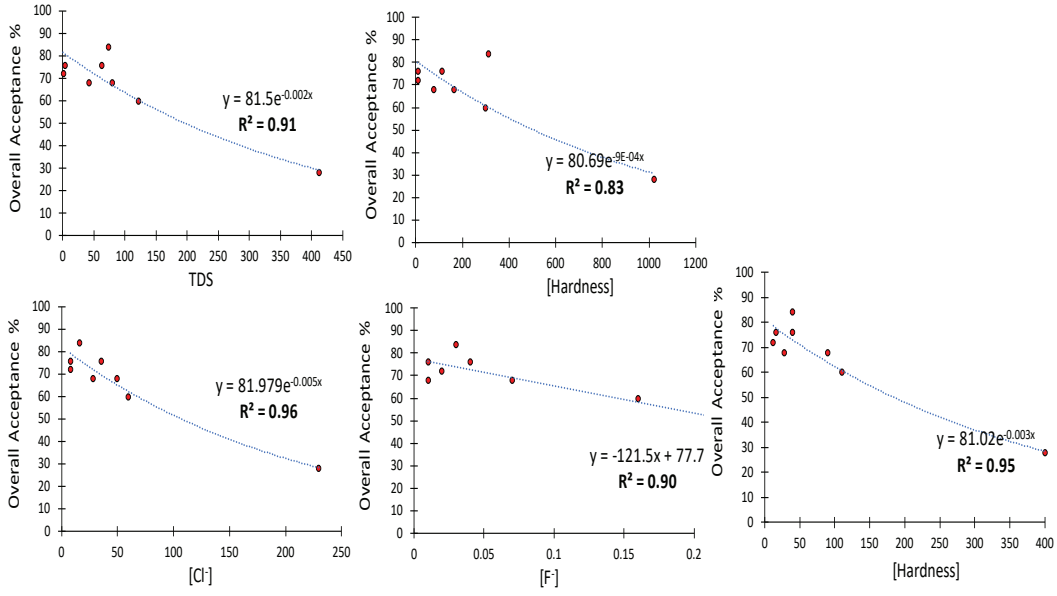

Figure 06: Relationship of overall acceptance (%) and water quality parameters; TDS, Alkalinity, [Cl^-], [F^-], [Hardness] for Flavored Tea

4. CONCLUSION AND RECOMMENDATION

Water is the main determinant of tea quality. This research was conducted to get a better understanding of the effect of water quality on the taste profile of the made tea in Sri Lanka. Through the instrumental analysis of different water samples, it was demonstrated a difference in water quality parameters (pH, TDS, alkalinity, DO, chloride, fluoride, Phosphate-phosphorus and nitrate-nitrogen). And also, through sensory analysis of tea infusions (black, green and flavoured) by the trained as well as untrained panellists, it was shown a difference in sensory attributes (colour, aroma, flavour and overall acceptability). According to the results of this study, the highest overall acceptability for black tea was recorded for the infusions made from distilled water and RO filtered water. These water samples reported lower values of TDS, Cl^- and hardness among the other water sources. Highest overall acceptance for flavoured tea and green tea was recorded from bottled drinking water attributed to moderate values for almost all the measured water quality parameters. However, the worst taste profile was reported for all three types of tea infusions made by using well water from Anuradhapura. This water sample reported above permissible value for hardness, alkalinity, TDS, Cl^- and F^- contents compared to others. According to the statistical analysis, there was a significant relationship between TDS, Alkalinity, Hardness, Cl^- and F^- with the overall acceptance of colour, aroma and the taste of black tea, green tea and flavoured tea. Therefore, this study concludes that the quality of water is significantly affecting on the taste profile of tea infusions. And also, it is recommended for further

studies with water samples from all over the island in order to test its impact on the taste profile of tea.

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