

EFFECT OF TEMPERATURE VARIATION ON QUALITY PARAMETERS OF BLACK TEA (*Camellia sinensis* L.) PRODUCED IN SRI LANKA

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ABSTRACT

Increase in temperature can alter the chemical composition of made tea, which determine the final quality and marketable price. Therefore, the influence of temperature variations based on elevation changes, and raised temperature naturally using enclosures on quality parameters of black tea was evaluated.

Tea estates of Ratnapura, Hanthana, Talawakelle and Nuwara-Eliya which belong to four different elevations of 30m, 760m, 1380m and 2040m amsl, respectively, were selected. Selection was done with the objective of acquiring wide range of temperature variations, which recorded average temperatures during the study period (March - October, 2010) of 31°C, 27°C, 24°C and 17°C, respectively for these locations. Fresh tea shoots of TRI 2025 clone grown under similar agronomic practices were collected from three replicates (60 tea bushes/plot) in each location. For the study of impact of elevated temperatures, an experiment was conducted at the Nuwara-Eliya tea estate, which is located in the highest elevation category by constructing transparent polythene enclosures (10 m length x 3 m width and 1.7 m height [above the plucking table]) on a mature field of PK-2 tea clone. One set of enclosure was fully covered (enclosure 1 - to raise the temperature naturally) and the other was kept sides open (enclosure 2 - ambient temperature). Both enclosures recorded similar shading conditions, and the recorded average temperature in the enclosure-1 was 2.4°C higher than the enclosure-2 during the experimental period. Tea leaves were plucked in regular intervals for both experiments and tea was manufactured using a miniature unit and the essential biochemical and quality parameters of tea liquor were analyzed.

A significant variation in both chlorophyll a and b was observed in fresh tea leaves in different elevation categories. Leaf chlorophyll contents of both a and b increases gradually with the increase of elevation from low-country (Ratnapura - 31°C) to up-country (Talawakelle - 24°C), however it decline when elevation increases beyond that (top elevation; Nuwara-Eliya - 17°C) indicating optimum temperature for higher chlorophyll production exists in the Talawakelle region. Accumulation of quality determining chemical compounds of total polyphenols and amino acids contents gradually decreased while liquor color determining components of Theaflavin (TF), Thearubigin (TR), total colour and brightness increased with temperature rise from 17°C to 31°C as the elevation change. Sensory evaluation revealed that strength and colour of tea liquor increased while infused leaf colour decreased with temperature increase.

The clone PK 2 grown in the same location at Nuwara Eliya estate under elevated temperature (+ 2.4°C) compared to the normal outside temperature (17°C) indicated that the polyphenols, amino acids, caffeine and total catechin contents increased, while TF %, TR %, and brightness decreased with increasing temperature. The tea liquor colour and strength were also higher in the elevated temperature condition. Results indicated that slight increase in temperature may improve the quality aspects of high grown tea where the average temperature is cooler. Results also showed varying response of different cultivars (PK2 and TRI 2025) to changing temperatures. Overall results highlight the importance of assessing cultivar responses to changing temperatures to identify better resilient cultivars capable of producing quality made tea as an adaptation measure for impending climate change.

INTRODUCTION

Ceylon tea is considered as the best tea in the world due to its inherent unique characteristics and reputation acquired for more than hundred and forty years. Sri Lanka is the fourth largest tea producer in the world and the tea industry is one of the main sources of foreign exchange earner accounting for 1.3% of the Gross Domestic Production in 2011 (Economic and Social Statistics of Sri Lanka, 2013). In 2011, the total tea production in Sri Lanka was 328.6 million kg and it was around 17 percent of the world production. The total exported amount was 98% of the total production and has 14% of share out of total exports in Sri Lanka in 2011 (Economic and Social Statistics of Sri Lanka 2013).

Sri Lanka is a tropical island located in the Asiatic Monsoon Region. It receives most of its rainfall from the two monsoons of South-West and the North-East. The average rainfall varies from above 1000 mm in the dry areas of the north-west and south-east of the island to over 4000 mm at certain locations on the south-western slopes of the hills. The regional differences in temperature are due to altitude. The mean temperature in the low lands is around 26.6 - 27.7°C and it decreases up to 15.5°C at *Nuwara Eliya* (1890 m amsl) (Wijeratne *et. al.*, 2007). Tea plantations are covering all three elevation categories; low-country (<300 m amsl), mid-country (300-900 m amsl) and up-country (>900 m amsl). High grown tea is found in *Nuwara Eliya* and *Badulla* districts while *Ratnapura*, *Galle* and *Matara* are the major low-country tea growing districts. 60 percent of the total amount of made tea production comes from the tea smallholding sector and majority of them are located in the low-country. Tea grows well within a temperature range of 18 - 25°C and an air temperature below 13°C and above 30°C is found to reduce growth (Wijeratne, 2009).

Tea produced at higher elevations in Sri Lanka is known as one of the best quality tea products in the world. Sri Lanka has the ideal climatic conditions for a proper tea growth thus, a better flavor and aroma comes to Sri Lankan tea

naturally. Especially, tea from the areas such as *Nuwara Eliya*, *Passara*, *Lindula* etc. which are located in the high elevation with lower temperature, provides quality made tea.

As a result of the industrialization and other anthropological activities, the global warming is at a high phase. This will definitely make a drastic change in Sri Lankan climate. The scientists have predicted that, by year 2070 the range of temperature increase will be around, 0.4°C to 3°C in Sri Lanka (Wijeratne *et. al.*, 2007).

Since there has been a severe competition at the world market, Sri Lanka must continue to produce high quality tea for export market. If this temperature rise has a negative influence on the tea quality, it can severely affect the Sri Lankan export economy. Though researches currently concentrated more on the impact of temperature on the productivity of tea cultivation, there is a vacuity in the research on the effect of temperature on quality aspects of made tea. This research project was initiated to find the effect of environmental temperature change on quality of made tea in both sensory and chemical aspects.

Specific objectives of the study were to;

Assess, how the growth and physiological parameters of tea shoots and quality characteristics of made tea of a selected tea clone vary with the temperature changes based on elevation.

Investigate the possible impact of elevated temperature on the quality characteristics of made tea of a selected tea clone, at the highest elevation category where the temperature is the lowest.

MATERIALS AND METHODS

Two experiments were carried out to investigate the above two specific objectives;

Experiment 01

Quality variation of made tea as affected by different temperatures regime bases on elevation changes.

Four tea estates representing the four main elevation categories among which significant temperature differences exist were selected. They are namely; estate of *Ratnapura* Tea Research Institute (TRI) of low-country (60 m amsl; 30.9°C), estate of *Hantana* TRI of mid-country (760 m amsl; 27°C), St. Coombs estate of *Talawakelle* TRI of up-country (1380 m amsl; 23.7°C) and *Nuwara-Eliya* estate of Kelani Valley plantations of top-country (2040 m amsl; 16.6°C).

A popular tea clone TRI 2025, which has been grown in all four-elevation categories and at the mid pruning with similar age category where shading is not present and also grown in less steep lands was selected. Three replicates each having 8m x 9m sampling area which could produce one kilogram of green leaves (adequate for miniature manufacturing) were demarcated from all sites. Every sampling plot in each elevation category was applied with VPUM 910 fertilizer mixture (as recommended by the TRI), three weeks prior to plucking was started and fine plucking was practiced.

Experiment 02

This experiment was conducted to study the impact of elevated temperature at top elevation on quality variations of made tea. *Nuwara-Eliya* estate of Kelani valley plantation which is located in the highest elevation category was selected (16.6°C, 2040 m amsl). Tea clone PK 2, which produce high quality made tea was used.

Plot preparation

Two polythene shelters (enclosures to raised temperature naturally) with a length of 10 m, a width of 3 m and a height (above the plucking table) of 1.7 m were constructed heading the East-West direction. Transparent polythene of gauge 300 was used to cover the enclosure. One shelter was partially covered (to represent ambient temperature as the control, but top was covered to simulate similar light level as in the fully covered enclosure), while the other was completely enclosed to raise temperature several degrees above the control. Both chambers provided the same shading levels. Daily maximum and

minimum temperatures were recorded from both enclosures.

Plucking

Tea bushes in both enclosures were treated alike and left to acclimatize to the respective shelters for five weeks prior to leaf samples were taken for the analysis. Three weeks before plucking tea shoots for chemical analysis, VPUM 910 fertilizer mixture was applied. Plucking was done three times, with an interval of two weeks.

Manufacture

Plucked shoots from respective locations were manufactured at the TRI, *Talawakele* and manufactured to chemical analysis. The conditions of manufacture were: 16 hrs under controlled environment to facilitate withering process, precondition rolling using a mince machine, Environmentally Controlled Manufacture (ECM) cabinet for fermentation at 24°C for 3 hrs and 21 min firing using a miniature fluidized bed dryer at 95°C. Made tea samples was packed in triple laminated, aluminum foil bags, 100 g in each bag, and stored at room temperature. The particle composition of the tea sample was determined by sieve analysis with a slanted sieve set, 850-350 µm. A 100 g tea sample was used for the sieve analysis. Tea particles retained over the 850 µm size sieve were regarded as the BOP fraction. Particle sizes between 850 µm and 350 µm were considered as the BOPF grade.

Determination of chemical parameters of made tea

Thearubigin, theaflavin, total colour and brightness

Theaflavin (TF), thearubigin (TR), total colour and percentage of brightness of the infusion of the tea samples were determined according to the method previously described by Roberts and Smith (1963). Twenty five milliliters of infusion (9.0 g tea in 375 ml boiling distilled water) were extracted with an equal volume of isobutyl methyl ketone (IBMK, 4-methyl-2-pentanone) in a separating funnel. The aqueous layer and IBMK

layers were separated, and used to determine TF, TR, Total colour and Brightness, colorimetrically using the spectrophotometer (CARY 50 Bio UV-visible, Germany) at 380 nm and 460 nm. The results were expressed as a percentage of the dry weight of the samples.

Determination of Amino-acids

The colorimetric method for the determination of amino-acids based on the reaction with ninhydrin were systematically examined according to the method described by Yemm and Cocking (1955). Mixed 0.5 ml of citric buffer with 1 ml of an amino-acid solution and added 1 ml of the potassium cyanide – methyl Cellosolve – ninhydrin solution. Heat the well mixed solution for 15 minutes at 100°C, and cool for 5 minutes in running tap water. Make up the solution to a convenient volume with 60% ethanol, shake well, and determine the optical density, using a 1 cm glass cell, on a spectrophotometer (CARY 50 Bio UV-visible, Germany) at 570 nm.

Total polyphenols

Total phenolic content of the tea extracts were determined according to colorimetric Folin-Ciocalteu method (Singleton *et al.*, 1999). One milliliter of tea extract was placed in a test tube containing 5 ml of 10% Folin-Ciocalteu reagent and allowed to react for 3 min. The reaction was neutralized with 4 ml of 7.5% sodium carbonate. Absorbance at 765 nm was read after 1 hr, using a spectrophotometer (CARY 50 Bio UV-visible, Germany). Gallic acid (GA) was used as standard and data were expressed as gram gallic acid equivalents (g GAE /100 g DW of tea). The concentration of the total polyphenols was expressed as a percentage of the dry weights of the samples.

Catechins and Caffeine

Caffeine and individual catechins were determined according to the method described by Anon (2004). Samples (10 µl) of made tea extracts were analyzed using an HPLC system (Waters, Milford, MA) equipped with a 996 Photodiode Array Detector, (Waters, Milford, MA). Separations were achieved on a Phenomenex Luna 5µm (250 x

4.6 mm) column (Waters, Milford, MA). Elution was performed at a solvent flow rate of 1 ml/min and detection at 278 nm. The mobile phases consisted of 9% acetonitrile v/v, 2% acetic acid v/v, with 20 µg ml⁻¹ EDTA (A) 80% acetonitrile v/v, 2% acetic acid v/v, with 20 µg ml⁻¹ EDTA (B), all of HPLC grade. A gradient program was performed (% B): 0-10 min (0%), 10-25 min (0-32%), 25-35 min (32%), 35-36 min (32-0%), and 36-46 min (0%) to return to finish a cycle. The individual catechin and caffeine contents of made tea extracts were calculated by comparisons of their peak area values with pure standards and expressed as percentages.

Determination of growth and physiological factors of fresh tea shoots

Dry matter content of flush leaf sample

Weigh about 50 g of the fresh leaves and oven dried at 103 ± 2°C for 6 hours. Cool in the desiccators and weigh. The dry matter content of the sample expressed as a percentage by mass.

Total leaf chlorophyll contents

Weigh 5 g of flush and homogenize with 40 ml 80% acetone for 3 minutes, transfer into 50 ml volumetric flask and make up to volume with 80% acetone. Mix thoroughly and filter through a whatman No. 4 filter paper. Take 5 ml of the filtrate into a 25 ml volumetric flask and make up to volume with 80% acetone. Mix and read the absorbance at 645 nm and 663 nm using a spectrophotometer. Chlorophyll a and b contents were calculated using following equations.

$$Ch_a = \frac{(12.3 A_{663} - 0.86 A_{645}) \times V \text{ mg/g}}{1000 \times W}$$

$$Ch_b = \frac{(19.3 A_{645} - 3.6 A_{663}) \times V \text{ mg/g}}{1000 \times W}$$

Data analysis

Statistical comparisons of the mean values were performed using analysis of variance (ANOVA), followed by Duncan's multiple-range test

($P < 0.05$). The least significant different (LSD) were also performed (SAS 8.3 software, SAS Ins. Inc., Cary, USA). Comparisons of the rank median values of treatments were followed by Friedman Test ($P < 0.05$) by performing sensory evaluation (Minitab 11, USA).

RESULTS AND DISCUSSION

Effect of temperature on growth

Experiment 01

Leaf chlorophyll content

A significant variation in both chlorophyll a and b was observed in fresh tea leaves in different elevation categories (Table 1). Leaf chlorophyll content increased gradually with the increase of elevation from low-country to up-country. However, the lowest amounts were recorded in the *Nuwara Eliya* estate at top-elevation category where the temperature was lowest compared to other sites. Lower chlorophyll contents in lower elevation may be associated with the high light intensities, high temperature and transient moisture stress during mid-day in this region, which may reduce or sometimes even degrade chlorophyll. The highest chlorophyll content was observed in the mid-country (762 m amsl) where the temperature is favourable for tea. Several studies have reported that higher leaf chlorophyll contents were observed in regions where tea is grown under optimum temperature (Hazarika and Mahanta, 1984; Wickremasinghe *et al.*, 1966; Sud and Baru, 2000).

Internode length

Internode length between the first and second leaf and between the second and the third leaf were significantly different among all elevation categories (Table 1). Internode length significantly decreased with the elevation increases. In general, growth is promoted when temperature rises. Low-country estate where the temperature was high and the light intensity was favorable, internode length was increased by about 65-75% compared to top elevation category. It has been found that change of day length and the light intensity also directly impact on vegetative and reproductive growth of plants. Low temperature causes slower growth and low yield of tea in the hill country of Darjeeling in comparison to the plains of Dooars and Assam (<http://www.tocklai.net/activities/tea-cultivation/>).

Dry matter (%)

When dry matter content of 50 grams of fresh leaves was measured, it showed no significant difference, indicating that moisture content present in tea leaves was similar in all elevation categories (Table 1). The rate of dry matter production was affected by the prevailing weather conditions.

Experiment 02

When the variation of the selected parameters were considered in relation to the elevated and ambient temperatures, results suggested that the chlorophyll a and b contents and the dry weight of 50 grams of fresh leaves were not statistically different (Table 2). However, significant difference

Table 01. Variation of chlorophyll a and b, and dry matter percentage of tea leaves and internode length of tea shoots with the changing temperature in different elevation categories.

Location	Chlorophyll A (mg/g)	Chlorophyll B (mg/g)	Dry matter %	Internode length	
				1 st to 2 nd Leaves (cm)	2 nd to 3 rd Leaves (cm)
LC (30.90C)	1.48 ^{ab}	0.51 ^a	22.10 ^b	1.61 ^a	3.57 ^a
MC (27 OC)	1.54 ^a	0.54 ^a	22.99 ^a	1.47 ^b	3.06 ^b
UC (22.70C)	1.63 ^a	0.55 ^a	23.04 ^a	0.94 ^c	2.17 ^c
TC (16.60C)	1.34 ^b	0.45 ^b	22.92 ^a	0.91 ^d	2.15 ^d

(Means with same superscript letter are not significant different)

Table 02. Variation of chlorophyll a and b, and dry matter percentage of tea leaves and internode length of tea shoots with the changing temperature at top elevation

Location	Chlorophyll A (mg/g)	Chlorophyll B (mg/g)	Dry matter %	Internode length	
				1 st to 2 nd Leaves (cm)	2 nd to 3 rd Leaves (cm)
Elevated Tem (23.8°C)	1.49 ^a	0.51 ^a	22.92 ^a	3.20 ^a	2.69 ^a
Ambient Tem (21.4°C)	1.48 ^a	0.50 ^a	22.98 ^a	1.26 ^b	0.96 ^b

(Means with same superscript letter are not significant different)

was observed for internode lengths between the first and second leaf, and between the second and the third leaf under two temperature treatments (Table 2). Internodal lengths increase when the temperature rises due to increase crop growth under high temperature.

Effect of temperature on chemical characters of made tea

Experiment 01

Thearubigin and theaflavin contents in the BOPF grade of made tea

Percentages of thearubigin and theaflavin in BOPF were shown in Figs. 1 and 2. With the increasing elevation and decreasing temperature, theaflavin percentage of made tea is significantly ($P < 0.05$) reduced. The average temperature difference between low-country and top-country was 14°C. Between these two temperature extremes, the theaflavin content of made tea is reduced by 8% in top-country from the mean value of low-country as temperature decreases with elevation increases. There was no significant difference of theaflavin contents of made tea ($P < 0.05$) between low-country and mid-country and between up-country and top-country. The thearubigin percentage was also highest in the low-country and lowest in top-country (Fig. 2). Thearubigin contents of made tea in mid and up country conditions were similar. Between two temperature extremes similar to theaflavin contents, the thearubigin content of made tea in low-country condition reduced by 19% when temperature decreases to up-country condition with elevation increases.

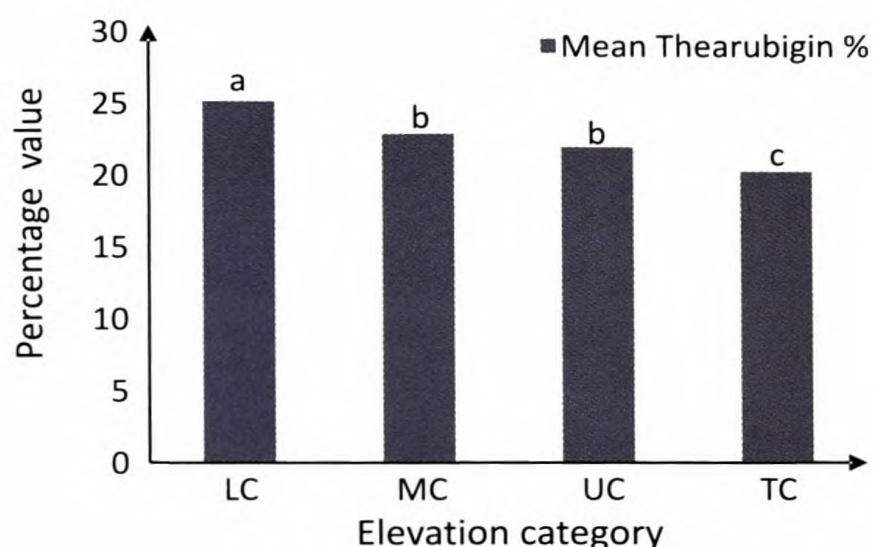


Fig. 1. Effect of temperature variation based on elevation change on Theaflavins (%) of made tea of TRI 2025

[Treatment means with same letter/s are not significantly different; LC (low-country; 30.9°C), MC (mid-country; 27°C), UC (up-country; 23.7°C) and TC (top-country; 16.6°C)]

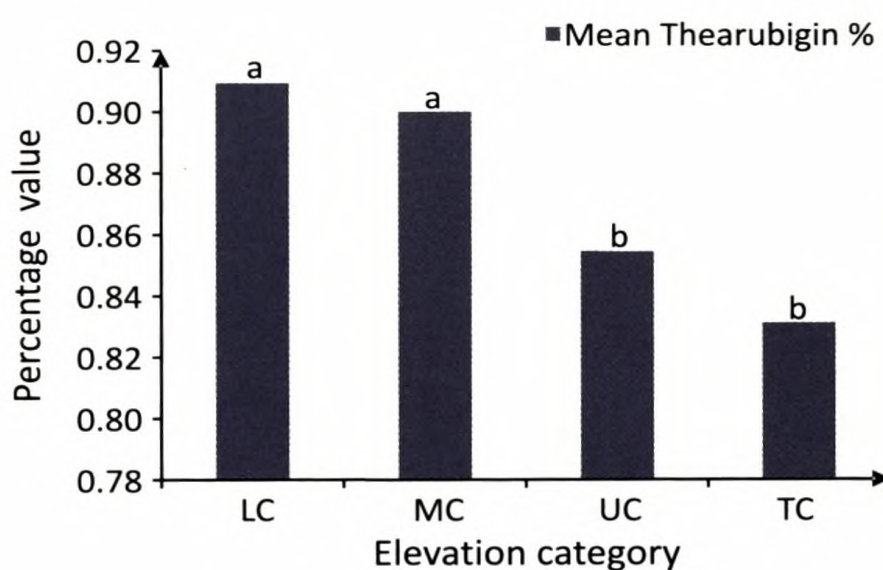


Fig. 2. Effect of temperature variation based on elevation change on Thearubigin (%) of made tea of TRI 2025

(For legend, see Fig. 1)

Total colour and brightness

When atmospheric temperature decline as the elevation increases, total colour and brightness of the tea liquor (Roberts and Smith, 1963)

decreased by 15% and 24% in top-country condition compared to the respective means of low-country condition (Table 3). According to Robert and Smith, (1963), total tea liquor colour was mainly dependent on theaflavins, while brightness is decided by the thearubigin contents. Therefore, the colour and the brightness were reduced due to reduce amount of theaflavins and thearubigins.

The Thearubigins and theaflavins ratio in good quality tea manufactured following standard procedure to be at the ratio of 1/ (12-15). However, in this study the obtained ratio exceeded this value. This may be due to the different manufacturing process used in this study (orthodox mincing method) due to the limited sample available, deviating from the standard practice of orthodox rotovane. Though the absolute values may depend on specific manufacturing process, what is important to know how the relative chemical composition and quality parameters change for a given clone with temperature change.

Total polyphenols and amino acids

Total polyphenol and amino acids contents of made tea is usually expressed in dry basis (g/kg) or in percentages. When the made tea of different elevation categories for the same clone is considered, percentage changes of the above

chemical compounds with elevation increase are presented compared to the mean values of respective compounds reference to the low-country condition. Results showed that total Polyphenols contents increased by 14%, 22%, 27%, and amino acid contents also increased by 25%, 50%, and 75% respectively in elevation categories of mid-country [MC (27°C), up-country [UC (22.7°C)] and top country [TC (16.6°C)] compared to the respective compounds of low-country condition [LC (30.9°C)] ($P < 0.05$). It is clearly shown that as the elevation increases (temperature decreases), the content of these two compounds increases significantly. Since increase temperature and the content of quality determining these compounds have a negative relationship, global warming will lead to decrease the quality of tea in the future.

Experiment 02

Thearubigin and theaflavin (%)

When the temperature was raised by 2.4°C inside the fully covered enclosure than the ambient temperature, theaflavin and thearubigin contents of PK2 clone were significantly ($P < 0.05$) decreased. As observed in the experiment 1, the brightness of made tea significantly decreased due to reduced theaflavin and thearubigin contents (Table 4). Slight increase of total colour was observed when temperature was increased.

Table 3. Effect of temperature variation based on elevation change on total colour % and brightness (%) of tea liquor of TRI 2025 clone

Location	Brightness %	Total colour %
LC (30.9 OC)	14.7 ^a	6.9 ^a
MC (27 OC)	13.5 ^b	6.6 ^b
UC (22.7 OC)	12.3 ^c	6.2 ^c
TC (16.6 OC)	11.3 ^c	5.9 ^d

(Treatment means with same letter are not significantly different)

Table 4. Effect of temperature variation on brightness, total colour, theaflavin, and thearubigin, (%) of made tea for PK-2 clone.

Location	Brightness %	Total colour %	Theaflavins %	Thearubigins %
Elevated T (23.8°C)	23.5 ^b	6.1 ^b	1.2 ^b	14.8 ^b
Ambient T (21.4°C)	26.3 ^a	5.5 ^a	1.6 ^a	16.8 ^a

(Treatment means with same letter are not significantly different)

PK 2 clone grown under elevated temperature (+2.4°C) indicated that total polyphenols and amino acid contents increased by about 50% for both compounds compared to the contents present in the ambient temperature condition.

Results of the experiment 1 showed the opposite results of experiment 2 for total polyphenols and amino acids. This may be due to other factors such as clonal difference, varying response of PK 2 to temperature than TRI 2025, which has impacted differently on the quality of tea. Results would indicate that the higher elevation beyond *Talawakele* may not provide the optimum condition for quality tea production due to lower temperature than the minimum level. Therefore, slight increase in temperature may have improved the quality of high grown tea in top-country conditions.

Caffeine and total catechines

The most important phenolic compounds found in tea are flavonols. Out of these flavonols, total catechins are considered to be more important. Presence of five different catechin types namely; catechin (+C), epicatechin (EC), epigallocatechin (EGC), epigallocatechin gallate (EGCG) and epicatechin gallate (ECG), is presented in the table 7. These are concentrated more in the terminal

bud of the tea leaves (Roberts and Smith, 1963).

Results of the experiment 2 indicated that flavonol compounds have been increased when the temperature was elevated by 2.4°C than the ambient temperature (Table 5). Out of the five types of catechins, ECG should be found with the highest amount. But, according to the results in this study, the highest amount found was the EGC. Partially oxidized polyphenolic compounds may be the reason for this. Within these compounds, caffeine content is the most abundant non-phenolic compound (Wickremasinghe *et al.*, 1966). Results indicated that the caffeine content was 13% ($P < 0.05$) higher in elevated temperature condition compared to the ambient temperature.

Effect of temperature on sensory quality

The sensory evaluations were carried by a well experienced group of tea tasters (Table 6). Rank 1 (the lowest) was assigned for the superior level and the highest rank of 7 for infused leaf, color, strength and the rank of 10 for quality were assigned for the poorest level. The results showed that the infused leaf and quality was the highest when the temperature was the lowest. Colour and strength are the highest when the temperature is the highest.

Table 5. Effect of temperature variation on gallic acids and total catechines (%) of made tea of PK-2 clone grown under different temperature regimes.

Enclosure Temperature	GA	+C	EC	EGC	EGCG	ECG
Elevated Tem (23.8 °C)	0.34 ^a	0.09 ^a	1.34 ^a	9.18 ^a	1.74 ^a	4.03 ^a
Ambient Tem (21.4 °C)	0.13 ^b	0.01 ^b	1.05 ^b	6.09 ^b	0.81 ^b	1.30 ^b

Table 6. Sensory characteristics of made tea to varying temperature of experiment 1 (based on elevation change) and experiment 2 (raised temperature using enclosure)

	For TRI 2025 Exp-1				For PK-2 Exp-2	
	LC 30.9°C	MC 27°C	UC 22.7°C	TC 16.6°C	Elevated T (23.8°C)	Ambient T (21.4°C)
Infused Leaf (rank 1-7)	3.8	4.1	4.1	3.3	4.0	5.0
Colour (rank 1-7)	2.2	2.7	3.0	3.0	5.5	3.5
Strength (rank 1-7)	3.5	4.2	4.5	4.7	5.0	4.0
Quality (rank 1-10)	8.8	8.3	8.1	7.1	5.5	7.5

The quality change at the same location when the temperature was increased in the experiment 2 was presented in the table 6. According to the results, infused leaf and the quality shows the highest level when the temperature is elevated by 2.4°C. Colour and strength is the highest at the ambient temperature. These results showed the opposite response compared to that observed in experiment 1. The temperature of *Nuwara-Eliya* at top-country may be slightly lower than the optimum temperature required for the best quality Ceylon tea.

CONCLUSIONS

Quality of made tea of clone TRI 2025 exposed to varying temperature as elevation changes exhibit significant quality variations. When temperature increases, quality of made tea was negatively influenced while the color and brightness was positively influenced. Therefore, increases temperature may impact on the image of quality Ceylon Black Tea in the world market if the global warming becoming a reality.

Quality of made tea of PK 2 clone exposed to 2.4°C elevated temperature than the ambient temperature at the highest elevation category at *Nuwara Eliya*, where the average daily temperature was 16.6°C, also indicate significant quality variations. When atmospheric temperature increased, quality of made tea increases while the color and brightness decreased. Results indicate that tea clones respond differently to temperature variations, which need further investigations using more tea clones especially at higher elevation category.

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