SOME SELECTED PHYSIOLOGICAL AND BIOCHEMICAL RESPONSES IN ORGANICALLY AND CONVENTIONALLY GROWN TEA (*CAMELLIA SINENSIS (L.) O. KUNTZE*) TO INCREASED AMBIENT TEMPERATURE

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ABSTRACT

This study was conducted to elucidate responses on some selected physiological, soil and biochemical parameters of organically and conventionally managed, mature tea plants to variations in ambient temperature. Increased temperature (2- 4 oC increase) was simulated via structures that fully enclosed tea bushes with transparent polythene, which were compared with open (ambient temperature, average daily temperature around 19 oC) field grown tea in the 'TRI-ORCON' long-term organic and conventional comparison trial, Tea Research Institute, Talawakelle, Sri Lanka. Some selected physiological, growth, soil and biochemical parameters were monitored and data were analyzed by General Linear Model. Increasing ambient temperature under both organic and conventional systems increased photosynthesis, stomatal conductance, transpiration and specific leaf area. This could be due to the elevated temperature exposing the canopy to conducive temperature within the optimum range. However, water use efficiency, leaf total polyphenol content and yield components measured as shoot dry weight were reduced with increasing temperature. The specific leaf area increased with increased temperature, but this increase was significantly less with the organic system indicating possibility of better water use efficiency in plants. There was no significant difference between the two systems with the other measured parameters. The results depicted that with further evaluation, organic tea cultivation may be highlighted as a precautionary measure to reduce the negative impacts of increasing ambient temperature to ensure sustainability of tea.

Key words: climate change, conventional system, organic system, physiological responses

INTRODUCTION

Tea (*Camellia sinensis* (L) O. Kuntze) is an important beverage crop grown in Sri Lanka as large commercial plantations and smallholdings, in different elevation categories (Low country < 600 m, Mid country 600 - 1200 m, and Up country > 1200 m amsl) (Balasuriya, 1996) mainly as a rain-fed crop. Growth, yield and quality of tea largely depend on climatic and soil factors (Wijeratne, 2018a). Tea crop prefers warm and humid conditions, well-distributed rainfall and nutrient rich soils. Almost all climatic parameters, such as solar radiation, rainfall, temperature, vapour pressure deficit and wind influence tea (Watson, 2008).

Sri Lanka has been identified as one of the topmost climate change-affected countries, as per the Global Climate Risk Index 2020 (Eckstein *et al*., 2019). Further, tea crop has been identified as a vulnerable crop to climate change (Wijeratne, 2018b), and tea in Sri Lanka is also predicted to be negatively affected in future due to climate change (Jayasinghe and Kumar, 2019). Increase in ambient temperature coupled with decrease or shift in rainfall are known to be amongst the major effects of climate change in addition to more frequent occurrences of extreme weather events. A majority of tea plantations in Sri Lanka are predicted to be adversely affected due to climate change impacts, except which are at high elevations, i.e. above 1200 m amsl. In these studies, mid elevations have been identified to have negligible or neutral impacts, while the tea at low elevation category was identified as highly vulnerable. The main reasons for these observations were the negative impacts of increasing temperatures on growth and productivity of tea plants in the aforementioned elevations (Ratnasiri *et al.*, 2007; Wijeratne *et al.*, 2007, 2011; Wijeratne, 2016). At present, majority of tea production comes from the low elevations and thereby this would negatively affect the economy of Sri

Lanka if timely precautionary measures are not taken. Therefore, it is highly important that proper adaptation and mitigation strategies are implemented. These climate change effects will have negative impacts on plant physiological processes resulting in physiological and biochemical changes and crop losses in the future. Therefore, a fair understanding on the climate change impacts on tea crop physiology is essential for the identification of mitigating measures. Although many studies have been conducted to identify the impacts of climate change on growth and productivity of tea, in-depth physiological studies on the impact of increasing ambient temperature on tea are scarce.

It has been reported that when the other environmental factors are not limiting, the ambient temperature becomes the most prominent factor which influences the rate of plant development, expansion of leaves, shoots and roots (Carr and Stephens, 1992). Urban *et al*. (2017) also reported that the changing temperature affects most of the plant physiological processes, including photosynthesis and transpiration which are regulated by stomatal conductance. Climate change affects the polyphenols and amino acids in tea shoots significantly as they are mainly the results of nitrogen and carbon metabolism (Han *et al*., 2018a). Increasing temperature, together with moisture stress results in heat stress which restricts the growth and development of the tea plant and thereby complex biochemical and physiological adaptations occur within diverse environments (Wang *et al*., 2018).

Sri Lanka is the pioneering organic tea producer and exporter in the world. A considerable demand exists in the world for organic tea (Hajra, 2018). Organic cultivation, which exposes the crop to a holistic approach integrating many facets as per International Federation for Organic Agricultural Movement (IFOAM) guidelines, is believed to impart tolerance to adverse climatic conditions in crops (Han *et al*., 2018b), improve the soil quality (Han *et al*., 2013; Mohotti *et al*., 2008) and ultimately improve the crop performance (Han *et al*., 2013; Hennayake *et al*., 2007; Mann, *et al*., 2009). Therefore, we hypothesised that organic tea performs better under adverse conditions, especially under high temperature, which could be reflected in its physiology. Therefore, the main objective of this study was to evaluate some selected physiological and biochemical responses of organically grown tea to the increased ambient temperature as experienced with climate change, compared to conventionally managed tea.

MATERIALS AND METHODS

LOCATION

This study was carried out at St. Coombs Estate, of the Tea Research Institute, Talawakelle, Sri Lanka, situated at an altitude 1382 m amsl (6°56′00″N 80°39′00″E). The long-term average daily temperature and annual rainfall in the area are 19.2 °C and 2275 mm respectively. The study was carried out during 2019 to 2020.

EXPERIMENTAL DESIGN

Data were collected in the ongoing organic and conventional comparison trial (TRI ORCON trial) established in 1996. The experiment consisted of mature tea of DT1 cultivar.

The treatments were the two-cultivation system (namely; organic and conventional tea) and two temperature levels (ambient and raised temperature). The organic plots were supplied with compost at the rate of 2 kg per plant per year in 2 splits, and managed according to the IFOAM sustainable crop, soil and pest management guidelines using non-chemical methods and practices. The conventional treatment plots received the inorganic fertilizer and other agrochemicals at recommended rates by the Tea Research Institute of Sri Lanka.

The different temperatures were simulated by enclosing or not enclosing the tea bushes with a metal structure covered with transparent polythene (height of the structure was about 1.5 m above the tea canopy). Hence, two temperature treatments imposed were, tea plots that were fully enclosed by the polythene (which increased the temperature by 2 - 4 ^{o}C above ambient) and open plots (ambient temperature). In the fully enclosed structures, openings were made on the sides for air circulation with outside. Each plot comprised of 20 tea bushes. The temperature treatments were imposed in the plots that were either organically or conventionally managed. The treatments were arranged in Complete Randomized Design (CRD).

DATA COLLECTION

ENVIRONMENTAL PARAMETERS

Ambient (air) temperature and soil temperature (at a depth of 20 cm) were measured three times a day. The air temperature was measured at 3 levels: about 1 m above canopy (T1), at the canopy level (T2) and just below the canopy level (T3). The air temperature was measured using a mercury thermometer, and soil temperature (Ts) was measured using a soil thermometer.

PHYSIOLOGICAL AND GROWTH PARAMETERS

Leaf gas exchange parameters, yield components and specific leaf area were made as physiological and growth measurements.

Gas exchange parameters, i.e. rate of photosynthesis, stomatal conductance, rate of transpiration and water use efficiency were measured using an infra-red gas analyser (model: CIRAS3, PP Systems, USA). Bright, clear days with no clouds were used for the measurements. The gas exchange parameters were measured in fully expanded mature leaves on the plucking table, which consisted of an active axillary bud/ shoot. The measurements were made from around 9 am to 1.30 pm.

Yield components (i.e. shoot density and shoot weight) were measured using a quadrat of 0.30 m x 0.30 m which was randomly placed on the plucking table. The number of shoots within the quadrat were counted and the shoot density was taken as the ratio between the number of shoots over area. Further, the shoots were grouped as ‘active’ and ‘banji’ shoots, based on the nature of the apical (terminal) bud of the shoot: The shoots containing an active terminal bud were termed as 'active shoots', while the shoots containing a terminal dormant bud were termed as 'banji' shoots. The shoots within the grid were plucked, dried to a constant weight at 85 °C in a hot air oven (JSOF 250, Korea) and weighed thereafter using a four-decimal balance (RADWAG, Poland) and the mean value was taken.

The youngest of the mature, fully opened leaves were harvested and their leaf area were measured using a leaf area meter (CD-6708, Delta T Devices Ltd., United Kingdom). They were dried to a constant weight at 85 °C in a hot air oven (JSOF 250, Korea) and the dry weights were taken using a four-decimal balance (RADWAG, Poland). The specific leaf area (SLA) was calculated as the ratio between the leaf area and leaf dry weight.

SOIL PARAMETERS

Soil moisture content was measured using a digital soil moisture meter (Field scout TDR 150, USA). Soil temperature was measured using a soil thermometer (model 89027, Forestry Suppliers Inc., USA) at a depth of 7.5 cm in the active root zone.

BIOCHEMICAL PARAMETERS

Total polyphenol content of the fresh shoots was determined by the ISO 14502-1:2005(E) method.

DATA ANALYSIS

Data were analyzed using General Linear Model (GLM) procedure in SAS statistical computer package version 9.1 and mean separation was done by using Duncan's New Multiple Range Test (DNMRT).

RESULTS AND DISCUSSION

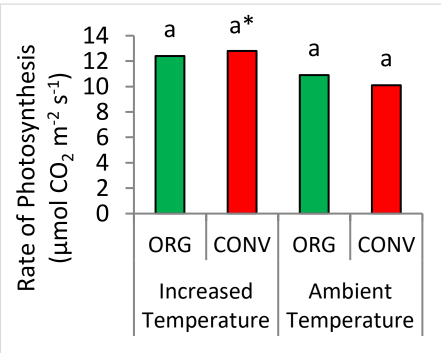
The air temperature at different levels and soil temperature of respective treatments are given in Table 1. It could be clearly seen that the fully covered structure had 2 - 4 °C higher temperature compared to the open field condition. This increase in temperature was evident above the canopy level, in the canopy level, below the canopy as well as in the soil, in plots of both management systems (Table 1). However, all the temperature values were within the optimum range of tea cultivation i.e. 18 - 30 °C (Watson, 2008) in both fully covered structure and the open field condition

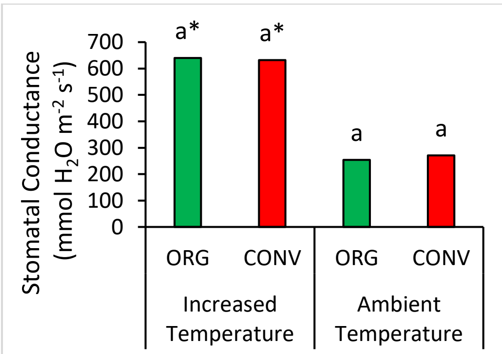
Table 1: Variation of air temperatures measured at the four different height levels.
(T1: temperature at 1 m above canopy level, T2: temperature at canopy level, T3: temperature below canopy level and Ts: soil temperature).

Temperature Treatment	Management Practice	Temperature (°C)			
		T1	T2	T3	Ts
FULLY COVERED (INCREASED TEMPERATURE)	Organic	26.2	25.9	24.9	22.4
	Conventional	26.6	26.3	24.8	22.3
OPEN (AMBIENT TEMPERATURE)	Organic	23.6	23.5	22.4	20.5
	Conventional	23.1	23	21.8	20.2

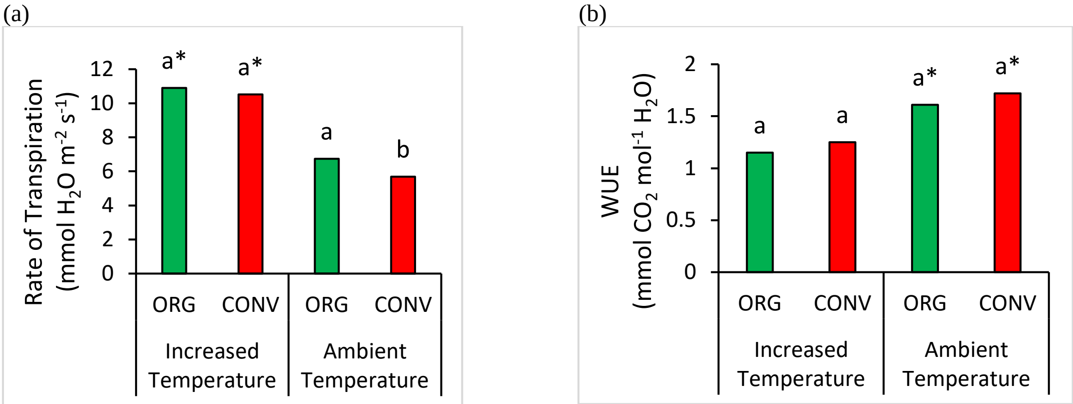
The results of the responses of gas exchange parameters showed that there were no significant differences between the organically and conventionally grown tea. However, there was a tendency to have slightly higher rate of photosynthesis, stomatal conductance and rate of transpiration but lower water use efficiency in the fully covered structures (increased temperature) compared to the open field conditions (ambient temperature) (Figure 1 a-d).

Figure 1: The responses of gas exchange parameters namely, the (a) rate of photosynthesis, (b) stomatal conductance, (c) rate of transpiration and (d) the water use efficiency (WUE) in fully covered (increased temperature) and open field condition (ambient temperature) in organically (ORG) and conventionally grown (CONV) tea.
Note: The bars with the same letters are not significantly different between the organically (ORG) and conventionally (CONV) grown tea, and * indicates the significant difference between fully covered (increased temperature) and the open (ambient temperature) systems at alpha= 0.05.





(a) (b)

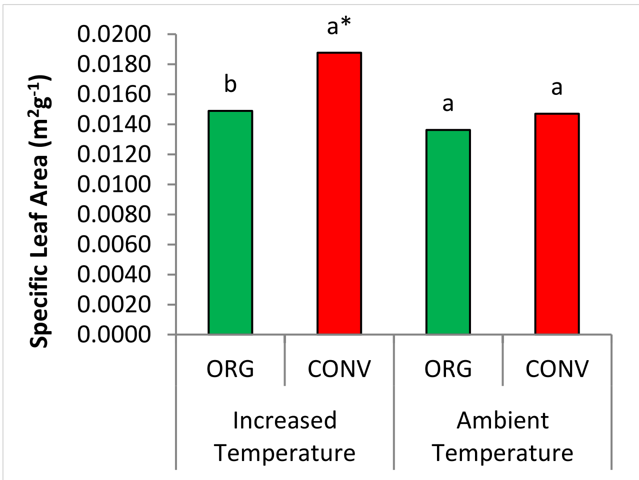


(c) (d)

In an earlier study which compared the two management systems, namely the organic and conventional, it was also found that the rate of photosynthesis was not significantly different between the tea plants grown under the organic and conventional management systems (Mohotti *et al*., 2003). The results of this study also supported their findings (Figure 1).

The specific leaf area (SLA) of tea under fully covered structures in conventionally managed tea was significantly higher compared to that of the open field conditions as well as in organically grown tea as shown in Figure 2. The results indicated that growing tea in higher temperatures increased the SLA in general, i.e. decreased the thickness of the leaves. The increase of SLA with increased temperature was larger in the conventional treatment, but the organic treatment did not significantly increase the SLA. High temperature is known to decrease leaf thickness, but also associated with increased cell damage and changes in metabolic pathways (Chabot and Chabot, 1977). SLA has also been proposed as a parameter that reflects plant responses to climate change (Rosbakh *et al*., 2015), which are specifically correlated at community level. According to Wright *et al*. (1994), SLA is inversely related to WUE of a crop. This was observed in this study as well where, thicker leaves or leaves with lower SLA in open ambient conditions had higher WUE. In the present study, the SLA significantly increased with the increased temperature in the conventionally grown tea, but in organic treatment SLA did not significantly vary with the increased temperature. Therefore, organic treatment may be possessing a better ability to withstand the increased temperature and have a higher WUE, which warrants further study. In an early study conducted on sap flow measurements using heat pulse technique, organically grown tea plants indicated to have a better WUE compared to conventionally grown tea (Mohotti *et al*., 2008). Since possessing of better WUE in plants is essential in future climate scenarios, and there is a growing global interest on organic cultivation, this aspect needs to be studied with more physiological measurements.

Figure 2: The response of specific leaf area measured in tea leaves under different temperatures simulated **by polythene covered structures in organically and conventionally grown tea.**
Note: The bars with the same letters are not significantly different between the organically (ORG) and conventionally (CONV) grown tea, and * indicates the significant difference between increased temperature (fully covered) and the ambient temperature (open) at alpha= 0.05.



The results of yield components of different treatments are presented in Table 2. The percentage of active shoots (P= 0.0053) per unit area were increased with increasing temperature in conventionally grown tea. However, no significant differences were observed for dry weights of active shoots (P= 0.0602) and total shoots (P = 0.2771) per unit area with the increased temperature in conventionally grown tea. Banji shoot dry weight per unit area was significantly decreased (P = 0.0378) with increasing temperature in conventionally grown tea. Active shoot (P = 0.0010), banji shoot (P = 0.0065) and total shoot (P < 0.0001) dry weights per unit area were decreased in organically grown tea with the increase of temperature. Further, no significant differences were observed between organic and conventional treatments for percentage active (P = 0.83) and banji (P = 0.83) shoots per unit area, active (P = 0.33), banji (P = 0.16) and total shoot (P = 0.0564) dry weights per unit area under fully covered structures (increased temperature).

Table 2. The comparison of yield components (percentage of active shoots, percentage of banji shoots, total shoot dry weight, dry weights of active and banji shoots) under different temperatures simulated by polythene covered structures of organically and conventionally grown tea.

Note: The values with the same letters in each row under increased temperature or ambient temperature column are not significantly different between the organically (ORG) and conventionally (CONV) grown tea, and ***** indicates the significant difference between increased temperature (fully covered) and the ambient temperature (open) at alpha= 0.05 for organically (ORG) or conventionally (CONV) grown tea.

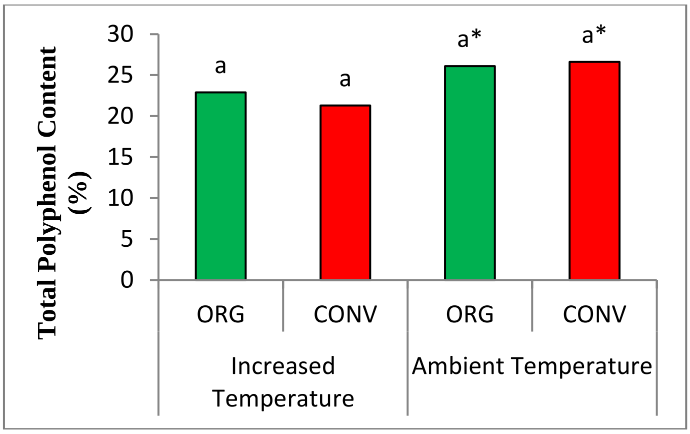
	Increased temperature		Ambient Temperature	
	Organic	Conventional	Organic	Conventional
ACTIVE SHOOTS (%)	38.09 ±3.72 a	39.09 ±4.33 a*	41.79 ±3.26 a	26.41 ±2.82 b
BANJI SHOOTS (%)	61.91 ±3.72 a	60.91 ±4.33 a	58.21 ±3.26 b	73.58 ±2.82 a*
TOTAL SHOOT DRY WEIGHT (gm^{-2})	12.02 ±0.94 a	14.36 ±1.40 a	17.24 ±1.18 a*	15.82 ±0.68 a
ACTIVE SHOOT DRY WEIGHT ($g\ m^{-2}$)	4.60 ±0.56 a	5.25 ±0.75 a	7.34 ±0.90 a*	3.91 ± 0.47 b
BANJI SHOOT DRY WEIGHT ($g\ m^{-2}$)	7.42 ±0.67 a	9.11 ±1.24 a	9.94 ±0.68 b*	11.91 ±0.71 a*

Significantly higher percentage of active shoots (P = 0.0001) and active shoot dry weight (P < 0.0001) per unit area were observed in organically grown tea whereas significantly higher percentage banji shoots (P = 0.0001) and banji shoot dry weight (P = 0.0323) per unit area were observed in conventionally grown tea under open ambient temperature conditions. However, no significant difference (P = 0.2155) was observed in the total shoot dry weight per unit area between the organic and conventional treatments under ambient temperature conditions.

One of the major yield determining parameters is the shoot density, i.e. the number of shoots per unit area. There was a higher number of actively growing shoots in plants grown in the organic system than in the conventional system under ambient temperature (Table 2). These results also support the findings of an earlier study conducted in this field, which showed a higher yield in compost treated and organically managed tea plants which was attributed to the higher number of actively growing shoots (Premaratne, 2000). Organic manures are known to slowly release nutrients over a longer duration in contrast to inorganic fertilizers, which release nutrients quickly in a relatively higher concentration (Shaji *et al*., 2021) making them more prone to greater losses. Therefore, organically managed tea plants showed a greater number of actively growing shoots at ambient temperature. However, as shown in Table 2, these beneficial effects seemed to decrease with increasing temperature, probably due to higher organic matter decomposition under higher temperature, making them to release and lose the nutrients quicker.

The total polyphenol content in the tea leaves with different treatments is shown in Figure 3.

Figure 3: Variation of total polyphenol content measured in tea leaves under different temperatures simulated by polythene covered structures of organically and conventionally grown tea.
Note: The bars with the same letters are not significantly different between the organically (ORG) and conventionally (CONV) grown tea and * indicates the significant difference between increased temperature (fully covered) and the ambient temperature (open) at alpha= 0.05.



As shown in the Figure 3, the total polyphenol content was significantly decreased with increased temperature in both organic (P = 0.0108) and conventional (P = 0021) systems compared to the ambient temperature condition. Also, the soil moisture contents with increased temperature in the both management systems were lower compared to the ambient temperature condition (data not shown). These results are in agreement with the findings of Cheruiyot *et al*. (2007) who indicated that the declining of soil moisture content reduced the polyphenols in tea flush. Han *et al*. (2018b) mentioned that the organic tea had significantly higher concentrations of polyphenols compared to the conventional tea. This was due to the accumulation of defence compounds in plant metabolism to overcome the higher environmental stresses for plants under organic production. Further, Chin *et al*. (2010) reported a similar trend of higher polyphenol contents where tea was grown organically compared to conventionally. Although an increase in polyphenols in organic tea was not observed, it is recommended to continue the study for a longer period covering different seasons for a better understanding on the responses.

CONCLUSION

Increasing ambient temperature under both organic and conventional systems increased photosynthesis, stomatal conductance, transpiration and specific leaf area. However, water use efficiency, leaf total polyphenol content, and yield components measured as shoot dry weight decreased with the increasing temperature, indicating decreasing yield and quality with increasing temperature. The results of two management systems showed that the specific leaf area increased with the increased temperature, but this increase was significantly lower in the organic system compared to the conventional system, which may indicate a better tolerance to the increased temperature in the organic system as hypothesized. This warrants further study. However, there were no significant differences in the responses of most of the other tested parameters between the two systems. As climate change is inevitable, precautionary and mitigation measures are equally required in both systems to prevent the negative impacts of increasing ambient temperature to ensure sustainability of tea.

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