*Malaysian Journal of Soil Science 2023 Vol. 27: 147-163*

# Edaphic Influences on the Nutrient Concentrations and Antioxidant Activity of Different Tea Clones (*Camellia sinensis* (O.) Kuntze) Grown at the Lowland Tea Plantation, Bukit Cheeding, Selangor, Malaysia

**Amirah, S.S.[1], Khairil, M.[1,2]*, Murdiono, W.E.[1], Halmi, M.I.E.[2,3], Amalina, N.R.[4], Yong, J.W.H.[5], and Burslem, D.F.R.P.[6]**

*[1]Department of Crop Science, Faculty of Agriculture, Universiti Putra Malaysia,*
*43400 Seri Kembangan, Selangor, Malaysia*
*[2]Biodiversity Unit, Institute of Bioscience (IBS), Universiti Putra Malaysia,*
*43400 Seri Kembangan, Selangor, Malaysia*
*[3]Department of Land Management, Faculty of Agriculture, Universiti Putra Malaysia,*
*43400 Seri Kembangan, Selangor, Malaysia*
*[4]Centre of Toxicology (CORE), Faculty of Health Science, Universiti Kebangsaan*
*Malaysia (UKM), Jalan Raja Muda Abdul Aziz, 50300 Kuala Lumpur, Malaysia*
*[5]Department of Biosystems and Technology,*
*Swedish University of Agricultural Sciences (SLU), Alnarp, Sweden*
*[6]School of Biological Sciences, Department of Plant and Soil Sciences, Cruickshank*
*Building, University of Aberdeen, AB242UU, Aberdeen, United Kingdom*

**Correspondence: khairilmahmud@upm.edu.my*

## ABSTRACT

*Tea (Camelia sinensis) is one of the most consumed beverages in the world. Research on the nutritional characteristics of tea, particularly lowland tea plantations, is limited in Malaysia. Thus, we aimed to investigate the nutritional characteristics (N, P, K, Ca, Mg, Al, Fe) and antioxidant activity of seven clonal teas (663, 2026, 2024, AT53, TV9, 1294, and 1428) planted at a tropical lowland tea plantation, Bukit Cheeding, Selangor, and their association with the soil edaphic factor. All foliar nutrient concentrations except for Ca and antioxidant activities varied significantly ($p<0.05$) among tea clones. Clone AT53 had the highest foliar K (1.84 ± 0.7 mg $g^{-1}$), Mg (0.80 ± 0.3 mg $g^{-1}$), Fe (12.97 ± 1.4 mg $g^{-1}$), and Al (16.61± 1.4 mg $g^{-1}$). Clone 663 had the highest P (13.76 ± 1.06 mg $g^{-1}$), and clone 2026 had the highest N (4.39 ± 0.2%). Clone 1248 had the highest antioxidant activity at 50.66 ± 3.2 µg $mL^{-1}$. Tea foliar N and P concentrations were significantly associated with the N and P of the soil. Besides, several soil nutrients were significantly intercorrelated with foliar nutrient concentrations. Results from this study may benefit growers in selecting better quality clones and managing lowland tea plantation at Bukit Cheeding, Selangor, Malaysia. Good farm management may improve the productivity and sustainability of tea plantations.*

**Key words**: ***Camellia sinensis*; Peninsular Malaysia; antioxidant activities; nutrient concentrations; lowland tea**

## INTRODUCTION

Tea (*Camellia sinensis*) is one of the most popular beverages in the world. Over the past decade, global tea consumption has increased by 3.5%, underlining its continued popularity (FAO, 2022). Malaysia is a prominent producer and consumer of tea, ranked as the 11th largest tea importer and the 27th largest tea exporter worldwide, with a more than 70% increase in local consumption from 2007 to 2019 (Mansur, 2019).

Tea has become incredibly popular due to its delightful flavour, alluring aroma, and myriad of health advantages, which include antioxidants (Bag *et al.*, 2022). It was also reported that an estimated 30,000 phenolic compounds may be present in tea (Bhebhe *et al.*, 2016). Due to its high levels of antioxidants, tea consumption has been linked with potentially preventing various illnesses such as cancer, diabetes, arthritis, cardiovascular disease, stroke, genital warts, and obesity (Hayat *et al.*, 2015). Tea leaves possess diverse essential minerals, including macro-elements such as K, Ca, Mg, and P, and trace elements like Fe, Zn, and Mn (Tseng and Lai, 2022). The mineral composition of tea leaves is impacted by various factors such as geographical location, cultivar type, type of soil, weather conditions, and season change, which ultimately influence the quality of tea (Zhao *et al.*, 2017).

Research focusing on the nutritional characteristics of tea, particularly those grown in the tropical lowlands of Peninsular Malaysia, remains limited. Past studies in Malaysia have concentrated primarily on the antioxidant activity (AOA) and total phenolic content (TPC) of tea leaves from lowland plantations (Chan *et al.*, 2007) and the phytochemical and antioxidant properties of highland plantations like Sabah (Izzreen and Fadzelly, 2013). Investigations into soil properties effect on nutritional characteristics of tea is limited to highland plantations such as Sabah (Chong *et al.*, 2008) and Cameron Highland (Hamzah *et al.*, 2011).

This study has two main objectives, which are (1) to study the nutritional characteristics (N, P, K, Ca, Al and Fe), TPC, and AOA of the tea leaves from different clonal teas, and (2) to investigate the association of foliar nutrient concentrations with the physicochemical of soil at the lowland tea plantations. We hypothesize that the foliar nutrient concentrations and antioxidant activities significantly vary among tea clones, and these variations are associated with soil edaphic factors. To our knowledge, this is one of the first study to compare foliar nutrient concentrations, TPC, AOA, and their association with soil physicochemical properties of tea clones grown in Malaysian lowland tea plantations. This pioneering effort will offer invaluable insights into tea cultivation and plantation management.

## MATERIALS AND METHODS

### Study Site

Samples were collected from the BOH Tea Plantation in Bukit Cheeding, Selangor (altitude ~20 m asl), 52 km from Kuala Lumpur. According to Kuala Langat District Council (2016), the tea plantation located at Bukit Cheeding was established in 1927 with 210 acres and is operated by BOH Plantations. The temperature ranges from 27 to 31 °C and has a monthly rainfall range of 53.6 to 596.3 mm.

### Soil and Leaf Materials

Seven representatives from Bukit Cheeding clonal tea cultivars were used in this study. The seven clonal teas are 663, 2026, 2024, TV9, AT53, 1294, and 1248 (Figure 1). All the clonal teas were planted for decades and were imported from India. Nine young and fully expanded leaves were collected from three different individuals of each clonal tea. The leaves samples were kept in an envelope before analysis. The soil samples were collected at 0 – 15 cm depth using a soil auger within a 1-meter radius of each tea plant at each clone location. All the samples were labelled before being transferred to UPM for further analysis.

### Soil Analysis

Soil samples were air-dried at room temperature till the weight was constant. The dried samples were ground with mortar and pestle and sieved through a 2 mm sieve to obtain a homogenized powder sample. Another batch of soil samples was sieved with 0.25 mm for total N determination. The soil physicochemical properties that were determined included soil pH, electrical conductivity, soil organic matter, cation exchange capacity (CEC) (Sumner and Miller, 1996). The total concentrations of P, K, Ca, Mg, Fe, and Al were determined by digesting the soil sample using aqua regia, and then analyzed by microwave plasma atomic emission spectrometer (MP-AES Agilent Technologies G8003A) (Mokhtar *et al.*, 2015). While the total N was determined using the Kjeldahl method (Bremner, 1996).

### Leaf Analysis

Fresh tea leaves were rinsed with distilled water and dried in an oven at 60°C for four days. They were then grounded using a grinder until a fine powdered texture was achieved. To determine the nutritional content of foliar (P, K, Ca, Mg, Fe, and Al), dry ashing technique was utilized, as described by Musa *et al.* (2020). The digital ultrasonic bath extracted the tea sample using 80% aqueous methanol to determine TPC and antioxidant activity, as described by Bakht *et al.* (2019), with minor modifications. Total N was analyzed using Kjedahl method following Bremner (1996), while other nutrients concentration (P, K, Ca, Mg, Fe, and Al) were determined by microwave plasma atomic emission spectrometer (MP-AES Agilent Technologies G8003A), TPC was analyzed following Sánchez-Rangel *et al.* (2013) and analyzed using a spectrophotometer at the absorbance of 765nm in a microplate well. The absorbances were converted into TPC by comparing against the gallic acid calibration curve (12.5 – 400 µg $mL^{-1}$) and expressed as mg gallic acid equivalent per millilitre (mg GAE $mL^{-1}$).

We analyzed the 1,1-diphenyl-2-picrylhydrazyl (DPPH) free-radical scavenging assay of tea leaves following Bobo-García *et al.* (2015) and were analyzed using a spectrophotometer at the absorbance of 517 nm. The AOA was expressed as an $IC_{50}$ value determined by GraphPad Prism 8 program (GraphPad Software, San Diego, CA, USA). Chan *et al.* (2007) state that lower $IC_{50}$ values indicate higher antioxidant activity. Other analyses that we used to determine the antioxidant activities in tea leaves were using FRAP analysis (Pérez-Burillo *et al.*, 2018). The FRAP reagent was prepared by mixing 25 mL of acetate buffer (0.3 M, pH 3.6), 2.5 mL of a solution of 10 mM TPTZ in 40 mM HCl, and 2.5 mL of 20 mM $FeCl_3$ with a ratio of 10:1:1 (v/v/v). The extract was then analyzed using a spectrophotometer at the absorbance of 593 nm. A standard curve was prepared with 0.1-1.0 mM $L^{-1}$ concentrations of Iron (II) sulphate, and the results were expressed as mM $Fe^{2+}$ $g^{-1}$ dry weight.

### Statistical Analysis

Statistical analyses were conducted using R version 3.3.1 (R Development Core Team 2021). One-way ANOVA examined the variation of nutrient concentrations, AOA and soil physicochemical content among tea clone populations. Pearson's correlation analysis and principal component analysis (PCA) were performed to associate the soil properties and the nutritional content of the clonal tea.

## RESULTS

### Nutritional Characteristics, TPC and AOA of Tea

The mean (± SE) range of foliar N (2.97 ± 0.2 to 4.39 ± 0.2 mg $g^{-1}$), P (9.19 ± 1.2 to 13.76 ± 1.06 mg $g^{-1}$), K (0.15 ± 0.1 to 1.84 ± 0.7 mg $g^{-1}$), Mg (0.11 ± 0.0 to 0.80 ± 0.3 mg $g^{-1}$), Fe (2.67 ± 0.4 to 12.97 ± 1.4 mg $g^{-1}$) and Al (3.66 ± 0.7 to 16.61 ± 1.4 mg $g^{-1}$) concentrations in tea vary significantly at $p \leq 0.001$ between the seven clones (Table 1). However, there were no significant variations in foliar Ca concentrations among the clonal teas ($p > 0.05$). Clone AT53 contained the highest amount of nutrients, namely K (1.84 ± 0.7 mg $g^{-1}$), Mg (0.80 ± 0.3 mg $g^{-1}$), Fe (12.97 ± 1.4 mg $g^{-1}$) and Al (16.61 ± 1.4 mg $g^{-1}$). In terms of TPC, we found insignificant variations among the seven clonal teas ($p > 0.05$), indicating all these tea clones have similar TPC (Table 1).

PCA of foliar element concentrations of tea leaves displayed a first axis explaining 36.77% of the variance, and the first four PC axes cumulatively explained 89.44% of the variance (Figure 2). It was determined that total P and FRAP (AOA) variation had a significant positive association with the first PC axis ($p < 0.05$). Variations in foliar N, Ca, Fe, Al, and TPC were all positively correlated with the second PC axis (Table 2).

### Physicochemical Properties of Soil

The soils of the seven tea populations are categorized as acidic soil with pH values between 3.83 ± 0.2 to 4.80 ± 0.4 (Table 3). The EC, CEC, and soil nutrient concentrations, particularly total N and Ca, varied significantly among the samples ($p < 0.05$). Based on the PCA, the first axis of a PCA of the soil data described 38.14% of the variation, and the first four axes explained 91.06% variation collectively (Figure 3). The first PC axis was shown to have a significant positive association ($p < 0.05$) with variation in total N, total P, total K, total Ca, Total Mg, total Fe, total Al, pH, CEC and organic matter (OM). The second PC axis was positively associated with variation in total P, total K, total Ca, total Mg, and EC concentrations (Table 4).

### The Association of Foliar Nutrient Concentrations with the Soil Edaphic

We found that some foliar concentrations had a significant intercorrelation with soil physicochemical. Mean foliar N concentration has a significant correlation with total N ($r=0.443$, $p < 0.05$) but was negatively correlated with the total Ca ($r= -0.626$, $p < 0.01$) in soil (Table 5). Mean foliar P concentration was positively correlated with the total P ($r=0.590$, $p < 0.01$), total K ($r=0.666$, $p < 0.001$), total Ca ($r=0.444$, $p < 0.05$), total Mg ($r=0.717$, $p<0.001$), and pH ($r=0.446$, $p < 0.05$). Foliar Mg concentration also had a positive correlation with soil EC ($r=0.658$, $p < 0.01$).

## DISCUSSIONS

### Nutritional Characteristics and Antioxidant Activity of Tea

Among the major nutrients, N played the most crucial role in improving the yield and quality of tea (Oh *et al*., 2006). In our study, the range of foliar N concentration (2.97 to 4.39%, $p < 0.01$) was consistent with the findings of Tseng and Lai (2022), at 2.75 to 4.33%. Nitrogen is deficient in the tea plant when the N content of the leaf is less than 3.5% (Owuor and Wanyoka, 1983). As a result, the N levels in the four tea clones (AT53, 1248, 2024, and 2026) are within the desirable range for optimal growth and productivity. A sufficient supply of nitrogen ensures vigorous plant growth and contributes to the production of high-quality tea leaves (Xie *et al*., 2023). Compared to many other crop species, tea only requires a small amount of P and is highly tolerant of P deficiency (Salehi and Hajiboland, 2008). The P concentration in our tea samples (ranging from 9.19 ± 1.2 to 13.76 ± 1.06 mg $g^{-1}$, $p < 0.001$) was higher than in the teas planted in China at 1.94 to 2.49 mg $g^{-1}$ (Sun *et al*., 2019). The elevated P concentrations observed in our results indicated that tea plants have an ample supply of phosphorus, which is important for energy transfer, root development, photosynthetic respiration, and overall plant growth (Xia *et al*., 2021).

**Figure 1.** The seven clonal tea samples: a)663, b)2026, c)2024, d) AT53, e)TV9, f)1294, g)1248.

Table 1. The mean (±SE) foliar nutrient concentrations, TPC and AOA of seven lowland tea clones, Banting, Selangor

| **Foliar** | **663** | **2026** | **2024** | **AT53** | **TV9** | **1294** | **1248** | **p value** |
|---|---|---|---|---|---|---|---|---|
| N (%) | 2.97 ± 0.1 | 4.39 ± 0.1 | 3.79 ± 0.1 | 3.55 ± 0.2 | 3.10 ± 0.3 | 3.24 ± 0.4 | 4.21 ± 0.4 | 0.018** |
| P (mg g$^{-1}$) | 13.76 ± 0.6 | 9.19 ± 0.7 | 9.45 ± 0.3 | 10.22 ± 0.6 | 11.85 ± 0.5 | 11.06 ± 0.3 | 11.11 ± 0.2 | 0.000*** |
| K (mg g$^{-1}$) | 0.55 ± 0.1 | 0.47 ± 0.1 | 0.31 ± 0.1 | 1.84 ± 0.4 | 0.15 ± 0.0 | 0.24 ± 0.0 | 0.26 ± 0.1 | 0.000*** |
| Ca (mg g$^{-1}$) | 0.58 ± 0.1 | 0.64 ± 0.1 | 0.38 ± 0.0 | 0.70 ± 0.1 | 0.68 ± 0.1 | 0.38 ± 0.0 | 0.61 ± 0.1 | 0.116 |
| Mg (mg g$^{-1}$) | 0.27 ± 0.1 | 0.22 ± 0.0 | 0.14 ± 0.1 | 0.80 ± 0.2 | 0.11 ± 0.0 | 0.23 ± 0.0 | 0.22 ± 0. | 0.000*** |
| Fe (mg g$^{-1}$) | 3.32 ± 0.5 | 3.43 ± 0.7 | 6.01 ± 0.7 | 12.97 ± 0.8 | 10.26 ± 0.4 | 2.67 ± 0.2 | 12.77 ± 0.5 | 0.000*** |
| Al (mg g$^{-1}$) | 4.43 ± 0.5 | 3.72 ± 0.4 | 16.19 ± 0.1 | 16.61 ± 0.8 | 3.66 ± 0.4 | 3.91 ± 1.0 | 4.53 ± 0.7 | 0.000*** |
| TPC (mg GAE g$^{-1}$) | 19.03 ± 0.2 | 19.23 ± 0.2 | 19.29 ± 0.3 | 19.29 ± 0.3 | 19.30 ± 0.0 | 19.04± 0.1 | 19.64 ± 0.2 | 0.428 |
| IC$_{50}$ (µg mL$^{-1}$) | 62.90 ± 4.9 | 72.49 ± 2.0 | 74.25 ± 2.8 | 74.36 ± 5.0 | 73.89 ± 4.3 | 54.61 ± 3.6 | 50.66 ± 1.9 | 0.000*** |
| FRAP (mM Fe$^{2+}$ g$^{-1}$) | 1.90 ± 0.3 | 1.65 ± 0.2 | 1.99 ± 0.1 | 1.55 ± 0.2 | 1.86 ± 0.2 | 1.76 ± 0.3 | 2.10 ± 0.1 | 0.551 |

Notes: '* $p \leq 0.05$, '**' $p \leq 0.01$, '***' $p \leq 0.001$.

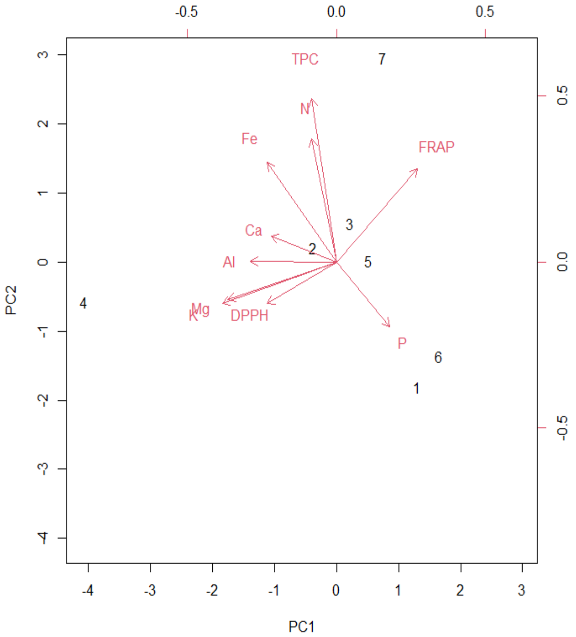

Figure 2. Biplot of scores for principal component axes (PC) 1 and 2 from principal component analysis of tea leaves from 7 clones. PC1 and PC2 accounted for 36.77% and 24.27% of the total variation, respectively. The arrows show the loadings of each element on the first two PC axes.

**Table 2.** Summary statistics of PCA axis related to foliar variables

| Importance of components | PC1 | PC2 | PC3 | PC4 |
|---|---|---|---|---|
| Eigenvalue | 3.676 | 2.427 | 1.770 | 1.070 |
| Percent of Variance (%) | 36.76 | 24.27 | 17.70 | 10.70 |
| Cumulative Proportion (%) | 36.76 | 61.04 | 78.74 | 89.44 |
| Loadings of foliar properties | | | | |
| Total N | -0.105 | 0.465 | -0.342 | 0.331 |
| Total P | 0.224 | -0.242 | 0.589 | -0.133 |
| Total K | -0.480 | -0.156 | 0.114 | -0.108 |
| Total Ca | -0.275 | 0.100 | 0.450 | 0.516 |
| Total Mg | -0.456 | -0.142 | 0.164 | -0.129 |
| Total Fe | -0.290 | 0.376 | 0.367 | -0.195 |
| Total Al | -0.361 | 0.004 | -0.259 | -0.591 |
| TPC | -0.103 | 0.617 | 0.132 | -0.050 |
| DPPH | -0.291 | -0.157 | -0.247 | 0.138 |
| FRAP | 0.339 | 0.352 | 0.116 | -0.411 |

Table 3. Soil properties among seven lowland tea clones, Banting, Selangor

| **Foliar** | **663** | **2026** | **2024** | **AT53** | **TV9** | **1294** | **1248** | **P value** |
|---|---|---|---|---|---|---|---|---|
| N (%) | 0.11± 0.0 | 0.16 ± 0.0 | 0.12 ± 0.0 | 0.08 ± 0.0 | 0.10 ± 0.0 | 0.11 ± 0.0 | 0.11 ± 0.0 | 0.166 |
| P (mg $g^{-1}$) | 0.37 ± 0.0 | 0.09 ± 0.0 | 0.12 ± 0.0 | 0.19 ± 0.0 | 0.31 ± 0.0 | 0.37 ± 0.1 | 0.20 ± 0.0 | 0.003** |
| K (mg $g^{-1}$) | 1.08 ± 0.1 | 0.39 ± 0.0 | 0.83 ± 0.1 | 0.51 ± 0.0 | 1.16 ± 0.0 | 0.77 ± 0.0 | 1.04 ± 0.1 | 0.000*** |
| Ca (mg $g^{-1}$) | 1.04 ± 0.4 | 0.29 ± 0.0 | 0.24 ± 0.0 | 0.33 ± 0.0 | 0.28 ± 0.2 | 0.53 ± 0.1 | 0.37 ± 0.0 | 0.059 |
| Mg (mg $g^{-1}$) | 0.39 ± 0.0 | 0.18 ± 0.0 | 0.20 ± 0.0 | 0.18 ± 0.0 | 0.22 ± 0.0 | 0.19 ± 0.0 | 0.35 ± 0.0 | 0.000*** |
| Fe (mg $g^{-1}$) | 10.22 ± 0.8 | 9.78 ± 0.9 | 6.12 ± 0.6 | 6.51 ± 0.8 | 8.69 ± 1.0 | 7.27 ± 0.5 | 9.45 ± 0.3 | 0.007** |
| Al (mg $g^{-1}$) | 22.15 ± 1.6 | 23.75 ± 1.4 | 20.18 ± 1.7 | 16.17 ± 1.7 | 20.79 ± 2.0 | 18.09 ± 1.2 | 14.16 ± 1.8 | 0.012* |
| pH | 4.80 ± 0.2 | 4.18 ± 0.1 | 4.27 ± 0.0 | 3.83 ± 0.1 | 3.86 ± 0.1 | 4.35 ± 0.2 | 4.35 ± 0.2 | 0.022* |
| EC (mS $cm^{-1}$) | 35.40 ± 2.0 | 59.63 ± 3.9 | 34.70 ± 1.7 | 80.67 ± 1.9 | 55.90 ± 0.5 | 51.47 ± 4.0 | 37.60 ± 3.0 | 0.000*** |
| CEC ($cmol_c$ $kg^{-1}$) | 8.33 ± 0.3 | 11.83 ± 1.2 | 9.00 ± 0.6 | 6.07 ± 0.5 | 5.47 ± 0.3 | 6.77 ± 0.2 | 8.17 ± 0.5 | 0.000*** |
| OM (%) | 8.64 ± 0.5 | 8.58 ± 0.3 | 8.26 ± 1.2 | 8.18 ± 0.7 | 6.44 ± 1.0 | 7.42 ± 0.7 | 8.45 ± 0.7 | 0.443 |

Notes: '*' $p \leq 0.05$ , '**' $p \leq 0.01$, '***' $p \leq 0.001$.

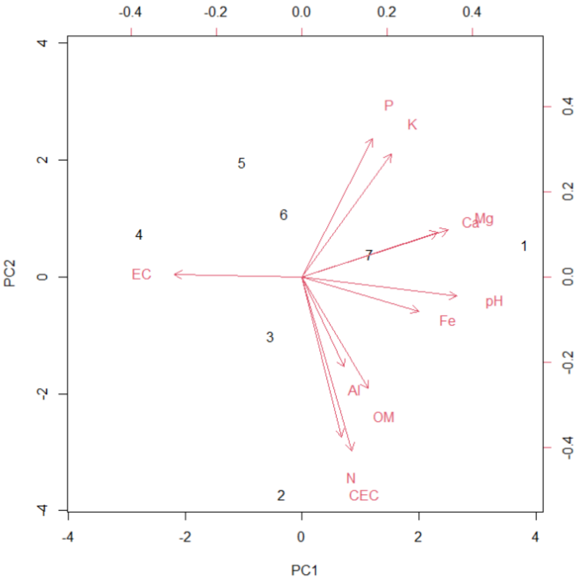

Figure 3. Biplot of scores for principal component axes (PC) 1 and 2 from the principal component analysis showing variation in soil N, P, K, Ca, Mg, Fe, Al, pH, EC, CEC, and OM from seven tea clone populations. PC1 and PC2 accounted for 38.14% and 31.60% of the total variation, respectively. The arrows show the loadings of each variable on the first two PC axes

Table 4. Summary statistics of PVA axis related to soil physicochemical properties

| Importance of components | PC1 | PC2 | PC3 | PC4 |
|---|---|---|---|---|
| Eigenvalue | 4.195 | 3.477 | 1.336 | 1.009 |
| Percent of Variance (%) | 38.14 | 31.60 | 12.15 | 9.18 |
| Cumulative Proportion (%) | 38.14 | 69.74 | 81.89 | 91.06 |
| Loadings of soil properties | | | | |
| Total N | 0.116 | -0.469 | -0.272 | -0.175 |
| Total P | 0.206 | 0.405 | -0.271 | 0.290 |
| Total K | 0.261 | 0.360 | -0.120 | -0.467 |
| Total Ca | 0.398 | 0.130 | -0.020 | 0.503 |
| Total Mg | 0.428 | 0.137 | 0.231 | -0.058 |
| Total Fe | 0.342 | -0.101 | -0.245 | 0.070 |
| Total Al | 0.123 | -0.263 | -0.639 | 0.138 |
| pH | 0.453 | -0.057 | 0.123 | 0.086 |
| EC | -0.374 | 0.008 | -0.068 | 0.562 |
| CEC | 0.146 | -0.510 | 0.021 | -0.067 |
| OM | 0.193 | -0.327 | 0.544 | 0.243 |

Note: EC, electrical conductivity; CEC, cation exchange capacity; OM, organic matter

Table 5. Pearson correlation coefficients comparing mean foliar N, P, K, Ca, Mg and Al with soil chemical properties for seven lowland tea clones, Banting, Selangor

| | **Pearson correlation** | | | | | |
|---|---|---|---|---|---|---|
| **Soil variable** | Foliar N | Foliar P | Foliar K | Foliar Ca | Foliar Mg | Foliar Al |
| Total N | 0.443* | -0.173 | -0.184 | -0.202 | -0.226 | -0.159 |
| Total P | -0.378 | 0.590** | -0.175 | 0.051 | -0.099 | -0.349 |
| Total K | -0.090 | 0.666*** | -0.425* | -0.031 | -0.392 | -0.317 |
| Total Ca | -0.626** | 0.444* | 0.026 | 0.260 | 0.062 | -0.236 |
| Total Mg | -0.129 | 0.717*** | -0.202 | 0.118 | -0.174 | -0.369 |
| Total Al | -0.200 | 0.061 | 0.078 | 0.067 | -0.136 | -0.065 |
| pH | -0.424 | 0.446* | -0.277 | -0.327 | -0.310 | -0.302 |
| EC | 0.096 | -0.296 | 0.658*** | 0.272 | 0.639** | 0.259 |
| CEC | 0.349 | -0.332 | -0.108 | -0.130 | -0.192 | -0.106 |
| OM | -0.193 | 0.107 | 0.148 | -0.083 | 0.086 | 0.170 |
| Soil PC Axes | | | | | | |
| PC1 | 0.262 | -0.721*** | 0.410 | 0.031 | 0.395 | 0.474* |
| PC2 | 0.409 | -0.349 | -0.033 | -0.122 | -0.122 | -0.056 |

Notes: '*' $p \leq 0.05$ , '**' $p \leq 0.01$, '***' $p \leq 0.001$.

We observed significantly higher K concentrations (ranging from 0.15 ± 0.0 to 1.84 ± 0.4 mg $g^{-1}$) in tea leaves across the seven clones compared to the 0.11 mg $g^{-1}$ reported in previous Bangladeshi studies (Rashid *et al*., 2016). The higher K concentrations observed in our results suggest that the tea plants have an abundant supply of K, essential for regulating water uptake, improving drought tolerance, and enhancing tea plant health and productivity (Teotia *et al*., 2016).

Although some research suggests that tea is a calcifuge and acidophilic plant, Ca is also a necessary nutrient for tea plants and can increase tea growth after application (Fung and Wong, 2004). In our study, the range of Ca concentrations (0.38 ± 0.0 to 0.70 ± 0.1 mg $g^{-1}$) was slightly lower than other studies reported in Thailand, with 5.88 mg $g^{-1}$ (Chupeerach *et al*., 2021). Inadequate Ca levels can lead to various physiological disorders in tea, such as leaf tip burn and poor root development. Ca deficiency can also reduce plant tolerance to environmental stresses, including drought (Benton, 2018).

We found that the lowland tea in our study had slightly lower Mg concentrations with a range of 0.14 ± 0.1 to 0.80 ± 0.2 mg $g^{-1}$ than other research, such as in Bangladesh with 0.52 mg $g^{-1}$ (Rashid *et al*., 2016) and China with 1.66 mg $g^{-1}$ (Li *et al*., 2018). Mg deficiency reduces chlorophyll production, phloem loading, and photoassimilates partitioning between roots and shoots (Uzilday *et al*., 2017). The range of foliar Fe concentrations (3.32 ± 0.5 to 12.97 ± 0.8 mg $g^{-1}$, $p < 0.001$) in our study was higher than a study by Zhang *et al*. (2018) with the range of Fe concentrations from 0.57 to 0.28 mg $g^{-1}$. The tropical soil's acidity increased Fe and Al concentrations, which may affect tea's Fe uptake. Therefore, adequate iron levels are essential for plant chlorophyll synthesis and enzyme activities (Kumar *et al*., 2022).

Tea is an Al hyperaccumulator as it accumulates high concentrations of Al (>1 mg $g^{-1}$). Tea has the ability to tolerate high concentrations of Al. This tolerance mechanism involves the release of organic acid from the root to prevent direct contact with Al and alkalinization of the rhizosphere by reducing the uptake of cations over anions, modified cell wall, redistribution of Al, and internalization of Al (Riaz *et al*., 2018). By generating Al complexes with organic acids or other chelators and securing these complexes in the vacuoles to maintain a low level of free Al in the plant cytoplasm, Al-accumulating plants can internally detoxify Al (Singh *et al*., 2017). The differences in nutrition concentration between this study's clonal teas and those of other researchers, as we discussed above, could be influenced by differences in soil properties, nutrient status, and fertilizer application in the fields (Rashid *et al*., 2016; Sun *et al*., 2019).

TPC plays a vital role in determining the antioxidant potential of plant-based foods, including tea leaves (Yang and Liu, 2013). Phenolic compounds are known for their potent antioxidant properties, which can scavenge free radicals and protect against oxidative stress-related diseases (Oluwole *et al*., 2022). The TPC of lowland tea leaves (19.03 ± 0.2 to19.64 ± 0.2 mg GAE $g^{-1}$) in our study was slightly lower compared to Chan *et al.* (2007) with the value of 76.7 mg GAE $g^{-1}$. Izzreen and Fadzelly (2013) also reported higher TPC values of 80.27 mg GAE $g^{-1}$ (green tea) and 76.93 mg GAE $g^{-1}$ (black tea) at Sabah Tea Plantation, Malaysia. These findings imply that optimizing environmental conditions may help enhance the phenolic content of tea leaves, potentially leading to increased AOA and associated health benefits. The AOA content of the tea leaves in this study (FRAP range between 1.55 to 2.1 mM $Fe^{2+}$ $g^{-1}$) was at a medium level when compared to tea plantations in China, where the FRAP value ranged from 0.61 to 5.38 mM $Fe^{2+}$ $g^{-1}$ (Tang *et al*., 2019). The variation in the FRAP and DPPH values among the tea clones further emphasizes the differences in AOA and suggests the presence of genetic variations that influence the phenolic compounds responsible for antioxidant properties (Gonbad *et al*., 2015; Li *et al*., 2023).

## Foliar nutrient and soil physicochemical association

Foliar N and P were significantly associated with the soil N and P concentrations. There were also some inter-correlations between soil nutrients and tea's foliar nutrient concentrations. However, no direct significant association was found between foliar Ca, Mg, K, Fe and Al concentrations of clonal tea with soil chemistry. As an Al hyperaccumulator, we also found that the differential expression of Al accumulation in tea populations is uncoupled to local variation in soil Al concentrations. The insignificant association between most foliar nutrient concentrations with soil chemistry is similar to the finding by Tseng and Lai (2022). The concentration of the nutrient assimilated by plants, particularly metal hyperaccumulators, may be due to their phylogenetic influence, by which the plant can absorb the metal nutrient regardless of the nutrient level in the soil (Khairil and Burslem, 2018).

The nutrient variation in tea leaves could be associated with the biochemical activities associated soil microbes. Soil microbes can mineralize insoluble mineral and organic P compounds, making them available for plants (Bergkemper *et al*., 2016). Yang *et al*. (2022) reported that rhizosphere microbial had a direct positive effect on several nutrients, including the N and P content of the tea plants. Besides, the changes in soil pH also influence the availability of essential plant nutrients, which differ among nutrients, crops, and soil types (Holland *et al*., 2018). At low pH, P is easily fixed by Fe and Al, resulting in the lack of available P for plants (Redel *et al*., 2016). Therefore, a higher pH would increase the soluble P and make the P available for plant uptake, especially in acid soils (Johan *et al*., 2021).

## CONCLUSION

The variation in the mean foliar nutrients showed that different clones had varying abilities to accumulate nutrients. This variation is, however, not directly reflected by all nutrients in the soil except for macronutrients such as N and P. Since N and P are the major nutrients for tea, supplying the optimum fertilizer is essential for tea growth and productivity. Clones AT53 and 1248 are considered better clones in accumulating minerals and have a higher AOA. These clones can be strategic choices for growers to produce the best quality of tea with added nutritional value and market appeal. Analyzing the effect of nutrient applications on the growth and physiology of tea clones is required for future research.

## ACKNOWLEDGEMENTS

The authors are grateful to BOH Plantation Sdn. Bhd. for their invaluable cooperation and support in providing the sample subjects for the research study. This study was funded by Geran Putra Universiti Putra Malaysia (grant number GP-IPM/2020/9690400).

## REFERENCES

Bag, S., Mondal, A., Majumder, A., and Banik, A. 2022. Tea and its phytochemicals: Hidden health benefits & modulation of signalling cascade by phytochemicals. *Food Chemistry* 371: 131098.

Bakht, M.A., Geesi, M.H., Riadi, Y., Imran, M., Ali, M.I., Ahsan, M.J., and Ajmal, N. 2019. Ultrasound-assisted extraction of some branded tea: Optimization based on polyphenol content, antioxidant potential and thermodynamic study. *Saudi Journal of Biological Sciences* 26(5): 1043-1052.

Benton, M. J. 2018. Hyperthermal-driven mass extinctions: Killing models during the Permian-Triassic mass extinction. In *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 376(2130).

Bergkemper, F., Schöler, A., Engel, M., Lang, F., Krüger, J., Schloter, M., and Schulz, S. 2016. Phosphorus depletion in forest soils shapes bacterial communities towards phosphorus recycling systems. *Environmental Microbiology* 18(6): 1988-2000.

Bhebhe, M., Füller, T.N., Chipurura, B., and Muchuweti, M. 2016. Effect of solvent type on total phenolic content and free radical scavenging activity of black tea and herbal infusions. *Food Analytical Methods* 9: 1060-1067.

Bobo-García, G., Davidov-Pardo, G., Arroqui, C., Vírseda, P., Marín-Arroyo, M.R., and Navarro, M. 2015. Intra-laboratory validation of microplate methods for total phenolic content and antioxidant activity on polyphenolic extracts, and comparison with conventional spectrophotometric methods. *Journal of the*

*Science of Food and Agriculture* 95(1): 204-209.

Bremner, J.M. 1996. Nitrogen-total. *Methods of soil analysis: Part 3 Chemical methods* 5: 1085-1121.

Chan, E.W.C., Lim, Y.Y., and Chew, Y.L. 2007. Antioxidant activity of *Camellia sinensis* leaves and tea from a lowland plantation in Malaysia. *Food Chemistry* 102(4): 1214-1222.

Chong, K. P., Ho, T. Y., and Jalloh, M. B. 2008. Soil nitrogen phosphorus and tea leaf growth in organic and conventional farming of selected fields at Sabah Tea plantation slope. *Journal of Sustainable Development* 1 (3):117-122.

Chupeerach, C., Aursalung, A., Watcharachaisoponsiri, T., Whanmek, K., Thiyajai, P., Yosphan, K., Sritalahareuthai, V., Sahasakul, Y., Santivarangkna, C., and Suttisansanee, U. 2021. The effect of steaming and fermentation on nutritive values, antioxidant activities, and inhibitory properties of tea leaves. *Foods* 10(1): 117.

FAO (Food and Agriculture Organization of The United Nations). 2022. World tea production and trade. *International tea market: market situation, prospects and emerging issues*, Available online form: https://www.fao.org/3/cc0238en/cc0238en.pdf (Accessed 1 January 2023).

Fung, K.F., and Wong, M.H. 2004. Application of different forms of calcium to tea soil to prevent aluminium and fluorine accumulation. *Journal of the Science of Food and Agriculture* 84(12): 1469-1477.

Gonbad, R.A, Afzan, A., Karimi, E., Sinniah, U. R., and Kumara, M.K. 2015. Phytoconstituents and antioxidant properties among commercial tea (*Camellia sinensis* L.) clones of Iran. *Electronic Journal of Biotechnology* 18 (6):433-438.

Hamzah, Z., S. D. Riduan, and A. Saat. 2011. Vertical profile of C, N, P, K and radionuclides in soil collected from highland tea plantation areas. *American Journal of Applied Sciences* 8(12).

Hayat, K., Iqbal, H., Malik, U., Bilal, U., and Mushtaq, S. 2015. Tea and its consumption: benefits and risks. *Critical Reviews in Food Science and Nutrition 55*(7): 939-954.

Holland, J.E., Bennett, A.E., Newton, A.C., White, P.J., McKenzie, B.M., George, T.S., Pakeman, R.J., Bailey, J.S., Fornara, D.A., and Hayes, R.C. 2018. Liming impacts on soils, crops and biodiversity in the UK: A review. *Science of the Total Environment* 610: 316-332.

Izzreen, N.M.Q., and Fadzelly, M.A. 2013. Phytochemicals and antioxidant properties of different parts of *Camellia sinensis* leaves from Sabah Tea Plantation in Sabah, Malaysia. *International Food Research Journal* 20(1): 307.

Johan, P.D., Ahmed, O.H., Omar, L., and Hasbullah, N.A. 2021. Phosphorus transformation in soils following co-application of charcoal and wood ash. *Agronomy* 11(10): 2010.

Khairil, M., and Burslem, D.F. 2018. Controls on foliar aluminium accumulation among populations of the tropical shrub *Melastoma malabathricum* L. (Melastomataceae). *Tree Physiology 38*(11) :1752-1760.

Kuala Langat District Council. 2016. *Popular attraction Kuala Langat District Council.* Available online from: https://mpkl.gov.my/destinasi-menarik/

(Accessed 18 February 2023).

Kumar, D.K., Dawson, J., Ramesh, C., Sreekanth, D., Reddy, R.R. and Dudekula, G. 2022. Effect of Nitrogen, Zinc and Iron on Growth and Yield of Baby-corn (*Zea mays* L.) under Prayagraj Condition. *International Journal of Plant & Soil Science* 13(6): 285-291.

Li, L., Wen, B., Zhang, X., Zhao, Y., Duan, Y., Song, X., Ren, S., Wang, Y., Fang, W. and Zhu, X. 2018. Geographical origin traceability of tea based on multi-element spatial distribution and the relationship with soil in district scale. *Food Control* 90:18-28.

Li, Z., Wu, Y., Zhang, L., Hasan, M. K., Zhang, L., Yan, P., Fu, J., Han, W., and Li, X. 2023. A Chemical Explanation for Variations in Antioxidant Capacity across *Camellia sinensis* L. Cultivars. *Forests 14*(2).

Liew, C.K. 2017. *Tea in Malaysia Overview and Outlook*. o-cha.net. Available at https://www.ocha.net/english/association/information/documents/CKLiewArticle.pdf (Accessed 31 January 2023).

Mokhtar, N.F., Aris, A.Z., and Praveena, S.M. 2015. Preliminary study of heavy metal (Zn, Pb, Cr, Ni) contaminations in Langat river estuary, Selangor. *Procedia Environmental Sciences* 30: 285-290.

Musa, A.M., Ishak, C.F., Karam, D.S., and Md Jaafar, N. 2020. Effects of fruit and vegetable wastes and biodegradable municipal wastes co-mixed composts on nitrogen dynamics in an Oxisol. *Agronomy* 10(10): 1609.

Oh, K., Kato, T., Zhong-Pei, L., and Fa-Yun, L. 2006. Environmental problems from tea cultivation in Japan and a control measure using calcium cyanamide. *Pedosphere* 16(6): 770-777.

Oluwole, O., Fernando, W. B., Lumanlan, J., Ademuyiwa, O., and Jayasena, V. 2022. Role of phenolic acid, tannins, stilbenes, lignans and flavonoids in human health – a review. In *International Journal of Food Science and Technology* 57(10).

Owuor, P.O., and Wanyoka, J.K. 1983. Fertiliser use advisory service a reminder to farmers. *Tea 4*(1): 3-7.

Pérez-Burillo, S., Giménez, R., Rufián-Henares, J.A., and Pastoriza, S. 2018. Effect of brewing time and temperature on antioxidant capacity and phenols of white tea: Relationship with sensory properties. *Food Chemistry* 248: 111-118.

Rashid, M.H., Chowdhury, M.A., Fardous, Z., Tanvir, E.M., Pramanik, M.K., Jahan, I., Alam, M.K., Moniruzzaman, M., and Gan, SH. 2016. Microbial decontamination of gamma irradiated black tea and determination of major minerals in black tea, fresh tea leaves and tea garden soil. *LWT* 73: 185-190.

Redel, Y., Cartes, P., Demanet, R., Velásquez, G., Poblete-Grant, P., Bol, R., and Mora, M.L. 2016. Assessment of phosphorus status influenced by Al and Fe compounds in volcanic grassland soils. *Journal of Soil Science and Plant Nutrition* 16(2): 490-506.

Riaz, M., Yan, L., Wu, X., Hussain, S., Aziz, O., and Jiang, C. 2018. Mechanisms of organic acids and boron induced tolerance of aluminum toxicity: a review. *Ecotoxicology and Environmental Safety* 165: 25-35.

Salehi, S.Y., and Hajiboland, R. 2008. A high internal phosphorus use efficiency in tea (*Camellia sinensis L.*) plants. *Asian J. Plant Sci.* 7(1): 30-36.

Sánchez-Rangel, J.C., Benavides, J., Heredia, J.B., Cisneros-Zevallos, L., and Jacobo-Velázquez, D.A. 2013. The Folin–Ciocalteu assay revisited: improvement of its specificity for total phenolic content determination. *Analytical Methods* 5(21): 5990-5999.

Singh, S., Tripathi, D.K., Singh, S., Sharma, S., Dubey, N.K., Chauhan, D.K., and Vaculík, M. 2017. Toxicity of aluminium on various levels of plant cells and organism: a review. *Environmental and Experimental Botany* 137: 177-193.

Sumner, M.E., and Miller, W.P. 1996. Cation exchange capacity and exchange coefficients. *Methods of soil analysis: Part 3 Chemical methods* 5: 1201-1229.

Sun, L., Liu, Y., Wu, L., and Liao, H. 2019. Comprehensive Analysis revealed a close relationship between N/P/K status and secondary metabolites in tea leaves. *ACS Omega* 4(1): 176-184.

Tang, G.Y., Zhao, C.N., Xu, X.Y., Gan, R.Y., Cao, S.Y., Liu, Q., Shang, A.O., Mao, Q.Q., and Li, H.B. 2019. Phytochemical composition and antioxidant capacity of 30 Chinese teas. *Antioxidants* 8(6): 180.

Tseng, W.Y., and Lai, H.Y. 2022. Comprehensive Analysis Revealed the Specific Soil Properties and Foliar Elements Respond to the Quality Composition Levels of Tea (*Camellia sinensis L.*). *Agronomy* 12(3): 670.

Uzilday, R. Ö., uzilday, B., Yalcinkaya, T., and Türkan, İ. 2017. Mg deficiency changes the isoenzyme pattern of reactive oxygen species-relatedenzymes and regulates NADPH-oxidase-mediated ROS signaling in cotton. *Turkish Journal of Biology* 41(6): 868-880.

Xia, Z., Zhang, S., Wang, Q., Zhang, G., Fu, Y., and Lu, H. 2021. Effects of Root Zone Warming on Maize Seedling Growth and Photosynthetic Characteristics Under Different Phosphorus Levels. *Frontiers in Plant Science* 12: 2903.

Xie, W., Chen, W., Tang, D., Tan, X., Yang, Y., Tan, L., and Tang, Q. 2023. Revealing the Inhibition of Tea Cultivar' Ziyan' Root Growth Caused by High Nitrogen Based on Physiological, Metabolite, and Transcriptome Analyses. *Agronomy* 13(4): 968.

Yang, J., and Liu, R. H. 2013. The phenolic profiles and antioxidant activity in different types of tea. *International Journal of Food Science and Technology*, *48*(1).

Yang, H., Ji, L., Long, L., Ni, K., Yang, X., Ma, L., Guo, S., and Ruan, J. 2022. Effect of Short-Term Phosphorus Supply on Rhizosphere Microbial Community of Tea Plants. *Agronomy 12*(10): 2405.

Zhang, J. 2018. Research on the soil nutrient characteristics of tea plantation. IOP Publishing. In *IOP Conference Series: Earth and Environmental Science* 208(1): 012079.

Zhao, H., C. Yu, and Li, M. 2017. Effects of geographical origin, variety, season and their interactions on minerals in tea for traceability. *Journal of Food Composition and Analysis* 63: 15-20.