Original Article

Quality and Safety of Black and Green Tea in Uganda

Michael Bamuwamye[1] , Denis Odur[2] , Patrick Ogwok[3*]

1- PhD Department of Food Science and Technology, Faculty of Science, Kyambogo University, Kyambogo, Uganda

2- Master Uganda National Bureau of Standards (UNBS), Standards House, Plot 2-12 By-pass Link, Bweyogerere Industrial and Business Park, Kampala, Uganda

3- PhD Department of Food Science and Technology, Faculty of Science, Kyambogo University, Kyambogo, Uganda

Received: April 2025 **Accepted:** February 2026

ABSTRACT

Background and Objectives: Tea quality and safety are global challenges. This study assessed the quality and safety of green and black teas locally consumed in Uganda by analyzing proximate components (moisture, fat, protein, ash, fiber, and carbohydrate), as well as vital and harmful elements, and polyphenol and flavonoid levels.

Materials and Methods: Proximate components were determined using standardized methods developed by the Association of Official Analytical Chemists. Chemical elements were analyzed using Atomic Absorption Spectrophotometry. Total polyphenol content was quantified using the standard Folin-Ciocalteu assay. The total flavonoid content was determined using the aluminum chloride colorimetric assay.

Results: The tea components ranged from 2.64 to 8.43, 0.87 to 3.74, 12.41 to 29.28, 4.34 to 9.08, 12.12 to 31.46, and 28.65 to 61.13%, for moisture, fat, protein, ash, crude fiber, and carbohydrate, respectively. Metal concentrations (mg/kg) ranged from 694.95 to 2681.83, 4.53 to 11.77, 17.51 to 32.59, 47.60 to 141.17, 39.77 to 280.94, 1.18 to 2.28, and 8.30 to 37.69 correspondingly for potassium, sodium, magnesium, manganese, calcium, copper and iron. All tea samples contained no detectable levels of lead, arsenic, cadmium and mercury. Green and black tea contained 82.17 to 159.31 mg of total polyphenols per gram of dry weight, measured in gallic acid equivalents, and 122.12 to 183.24 mg of total flavonoids per gram of dry weight, measured in rutin equivalents.

Conclusion: Tea in Uganda is of good quality and generally safe for human consumption. Green tea can be considered a nutrient-rich food due to its high content of polyphenols and minerals, which provide antioxidant, anti-inflammatory, and anticancer benefits.

Recommendations: Lead, arsenic, cadmium, and mercury levels in both green and black tea were below internationally set limits, making the teas safe to consume. Green tea can be preferred over black tea for its higher antioxidant benefits due to minimal oxidation, which preserves its polyphenols. A comprehensive evaluation of the teas' antioxidant capacity is recommended to get complete and thorough knowledge of their capacity to scavenge free radicals and reduce oxidative stress.

Keywords: *Camellia sinensis*, Black tea, Green tea, Quality, Safety

Highlights

- The moisture and ash contents were within internationally recommended limits.
- Green and black tea can supplement the diet with vital minerals such as potassium, magnesium, and manganese.

Introduction

Tea beverage is the infusion of the leaves of the shrub *Camellia sinensis* (L.) O. Kuntze of the Theaceae family. Over three billion cups of tea are consumed daily worldwide, making it the second most-consumed beverage after water (1). Tea production contributes significantly to poverty reduction and the availability of food in many low-income countries. The world tea trade is forecast to rise in

***Address for correspondence:** Patrick Ogwok, Prof, PhD Department of Food Science and Technology, Faculty of Science, Kyambogo University, Kampala, Uganda. E-mail address: ogwokp@yahoo.com

value at an average increment of 4 to 5.5% per year, from \$50 billion in 2017 to over \$73 billion by 2024 (2). Uganda ranks among the top four leading producers and exporters of tea in Africa, and approximately 95% of its tea is sold through the Mombasa auction (3). Tea is categorized into non-fermented green tea, semi-fermented oolong tea, and fully fermented black tea based on the extent of oxidation during processing. Black tea is the most commonly produced tea globally, holding a majority share of 78% of total tea production, with green tea coming in second position at 20% and oolong tea making up only about 2% (4).

Regular tea-drinking has been linked to increased immunity and to preventing blood clots, stomach and intestinal disorders, cardiovascular disease, and diabetes (5). The health benefits of tea derive from polyphenols, caffeine, and amino acids, which are the primary bioactive compounds (6). Tea is also a source of chlorophyll, volatile organic compounds, and minerals such as potassium (K), calcium (Ca), magnesium (Mg), copper (Cu), and manganese (Mn), which also play a role in its nutritional and health-promoting effects. The taste and quality of processed tea are also dependent on the composition of the processed leaves (7). Despite the health benefits, tea bioaccumulates toxic metals such as lead (Pb), cadmium (Cd), arsenic (As) and mercury (Hg), which have been proven to be harmful at very low concentrations (8). Exposure to these metals can interfere with indispensable human body processes, leading to developmental, neurological, immunological, reproductive, teratogenic, and genotoxic effects.

Therefore, the presence of As, Cd, Pb, and Hg in tea is a major quality and safety concern, as chronic exposure can pose significant health risks (9). This research is a prudent initiative aimed at improving Uganda's tea quality and safety to boost its trade in the global market.

Materials and Methods

Materials

To ensure the validity and reliability of experimental results, chemicals of high quality and purity were used. Sulphuric acid (H_2SO_4; 98%), sodium hydroxide (NaOH; > 98%) anhydrous pellets, boric acid (H_3BO_3; 99.95%), hydrochloric acid (HCl; 37%), copper(II) sulphate pentahydrate ($CuSO_4.5H_2O$; > 98%), petroleum ether (PE; boiling range 60 to 80°C) and phosphate buffer pH 4 and 7 were obtained from Sigma-Aldrich (The Federal Republic of Germany). Multi-element standard (1000 µg/l) in 2 to 5% nitric acid (HNO_3), obtained from Reagecon Diagnostics Limited (Ireland), was used to quantify metallic elements in the tea. Phosphate buffered saline (PBS; tablet) used to prepare the tea extract, methanol (CH_3OH), 10% Folin–Ciocalteu reagent, sodium hydrogen carbonate ($NaHCO_3$; 7.5%), aluminum chloride hexahydrate ($AlCl_3.6H_2O$; 99%), sodium nitrite ($NaNO_2$; 98%) and gallic acid (GA) used to determine total polyphenolic content (TPC) were similarly obtained from Sigma-Aldrich.

Sampling and sample treatment

Ten green and 20 black tea brands (Table 1) were purchased as granular powder from supermarkets in Kampala city. For each tea type and brand, 3 samples were obtained from each of the supermarkets. Black tea production and consumption (*ca.* 90%) is far above that of green tea in Uganda. The tea leaves were packaged in well-labeled bags and transferred to the Uganda National Bureau of Standards chemistry laboratory for analysis. At the laboratory, the samples were combined to create 30 laboratory samples, which were then dried in a hot-air oven (Memmert UFE-600; Germany) at 105 °C for 6 hours, to remove all moisture before further analysis. The dry samples were stored under cool, dry conditions till analysis.

Proximate analysis

Method No. 930.15 from the Association of Official Analytical Chemists (AOAC), which involves drying a known weight of sample to a constant weight in an oven at 105 °C was used to analyze for moisture. Total nitrogen was determined using Kjeldahl's method (AOAC Method No. 920.103), and the nitrogen was converted to protein content using a Jones factor of 6.25. Total fat was determined in a Soxhlet apparatus (AOAC Official Method No. 930.09) using petroleum ether as an extraction solvent. Total ash was determined using the dry ashing technique (AOAC Official Method No. 920.100). Crude fiber content was determined as per the procedure described in AOAC Official Method No. 985.29. The carbohydrate content was determined by difference.

Metal analysis

The Na, K, Ca, Mg, Cu, Fe, Mn, Pb, Cd, As and Hg content in the tea leaves was determined on a Shimadzu AA6800 (Japan) Atomic Absorption Spectrophotometer (AAS) in conjunction with an ASC-6100 Auto Sampler. The equipment was calibrated using standards prepared from multi-element standard stock solutions (1000 ppm) supplied by Spex®. Calibration curves (Table 2) were generated by plotting the absorbance (A) of the respective elements against the concentrations of the standard. From the absorbance, the metal concentrations (mg/kg) in the different tea samples were obtained.

Table 1. Specification and origin of tea samples analyzed in the study

Tea type	Batch No.	Origin	Sampling date	Manufacture date	Expiry date
G1	10/2021	Uganda	14/9/2021	10/2021	10/2024
G2	3217	Uganda	14/9/2021	5/2021	5/2023
G3	APA	Uganda	15/9/2021	7/2021	12/2022
G4	24/7/ 2021	Rwanda	15/9/2021	7/2021	7/2023
G5	12/6/2020	Rwanda	15/9/2021	6/2020	6/2023
G6	A1055	Kenya	28/11/2021	8/2021	8/2024
G7	10/11/2020	China	28/10/2021	11/2020	11/2022
G8	L0049	U.K	14/9/2021	2/2021	2/2023
G9	52	Kenya	14/9/2021	5/2021	5/2023
G10	RCL0721	Uganda	14/9/2021	7/2021	7/2023
B1	C21	Uganda	15/9/2021	9/2021	9/2023
B2	RCL 0221	Uganda	15/9/2021	2/2021	2/2023
B3	3/2021	Uganda	15/9/2021	3/2021	3/2024
B4	30/3/2021	Uganda	21/9/2021	3/2021	3/2023
B5	2021204	Uganda	21/9/2021	9/2021	9/2023
B6	02/11/21	Uganda	14/9/2021	11/2021	10/2023
B7	23	Kenya	14/9/2021	2/2021	2/2024
B8	EUCHU	Uganda	15/9/2021	11/2020	11/2022
B9	16/9/2021	Uganda	15/9/2021	9/2021	9/2022
B10	RCL052021	Uganda	15/9/2021	4/2021	4/2023
B11	02/1/2020	Uganda	15/9/2021	1/2020	11/2022
B12	03. 2021	Uganda	15/9/2021	3/2021	4/2023
B13	8/2021	Uganda	28/10/2021	8/2021	8/2023
B14	1/2021	Uganda	28/10/2021	1/2021	1/2023
B15	04:13:52	Kenya	28/10/2021	5/2021	5/2024
B16	1/2021	Uganda	28/10/2021	1/2021	12/2022
B17	9/2021	Uganda	28/10/2021	9/2021	9/2023
B18	5/5/2021	Uganda	15/9/2021	5/2021	5/2023
B19	7/2021	Uganda	15/9/2021	7/2021	7/2024
B20	2/2020	Uganda	15/9/2021	2/2020	2/2022

B: black tea; G: green tea.

Table 2. Calibration data used in the quantification of metals by Atomic Absorption Spectrophotometry

Element	λ (nm)	Concentration range (mg/L)	Equation of the line	R^2
K	766.5	0.0035-0.0698	y = 0.0074x - 0.0023	0.9939
Na	589.0	0.2332-1.990	y = 0.1918x - 0.0059	0.9879
Mg	285.2	0.1620-9.9840	y = 0.9821x + 0.1804	0.9997
Ca	422.7	0.1729-0.8910	y = 0.0363x - 0.0087	0.9992
Cu	324.8	0.0011-0.3810	y = 0.0956x - 0.0068	0.9991
Fe	248.3	0.0103-0.3893	y = 0.0971x + 0.0021	0.9999
Mn	279.5	0.0221-0.8001	y = 0.1989x + 0.0023	0.9998
Pb	283.3	0.00176-0.0678	y = 0.017x + 0.0003	0.9994
Cd	228.8	0.0035-0.1559	y = 0.1544x + 0.0017	0.9999
As	193.7	0.055-0.30	y = 0.0709x + 0.0131	0.9970
Hg	253.7	0.003-0.210	y = 0.0266x - 0.0008	0.9981

Quantification of polyphenols and flavonoids

Tea extract was prepared by boiling tea powder (50 g) in 300 mL of distilled water for 45 minutes, and filtering the mixture on a Whatman No.1 filter paper (10). The product of filtration was lyophilized, and the dried powder was stored at 4°C. A solution of concentration 400 mg/mL of the powder in phosphate-buffered saline was prepared. The total amounts of polyphenols and flavonoids were determined in the solution on a Shimadzu UV-1800 UV-Vis Spectrophotometer. The Folin-Ciocalteu (F-C) reagent, which reacts with phenolic compounds to form a blue complex, was used to quantify total polyphenols (11). Measurements were made against gallic acid as the reference and expressed as milligrams of gallic acid equivalents (GAE) per gram of tea extract. The aluminum chloride colorimetric method was used to selectively measure flavonoid polyphenols. Aluminium chloride combines with flavonoids to form yellow complexes whose color intensity is used to calculate the total flavonoid concentration as milligrams of rutin (quercetin-3-*O*-rutinoside)/g of tea extract.

Statistical analysis

Data were processed using Minitab Statistical Software (v21.0, Minitab Inc., USA). A one-way analysis of variance (one-way ANOVA) was used to test if there were any significant differences among group means. Means were regarded as significantly different at a significance level of p=0.05.

Results

Proximate composition

The moisture content of the teas varied between 2.64 and 8.43%. Green tea had a significantly ($p < 0.05$) higher moisture content than black tea (Table 3). The majority (86.7%) of the samples had moisture content greater than 4%. Few (13.3%) samples, which were black teas, had moisture content falling between 2.64 and 3.98%. The lipid content in green tea ranged from 1.31 to 2.82%, while that of black tea ranged from 0.87 to 3.74%.

Table 3. Proximate composition (%) of green and black tea consumed in Kampala

Sample	Moisture	Total fat	Crude protein	Ash	Crude fibre	Carbohydrate
G1	6.97 ± 0.11^{efg}	1.39 ± 0.05^{jkl}	17.99 ± 0.33^{jkl}	5.76 ± 0.29^{b}	12.12 ± 0.03^{m}	55.77 ± 0.71^{c}
G2	5.16 ± 0.06^{kl}	1.31 ± 0.00^{kl}	13.23 ± 0.01^{j}	5.82 ± 0.20^{b}	13.36 ± 0.14^{kl}	61.13 ± 0.17^{a}
G3	8.23 ± 0.10^{ab}	2.82 ± 0.11^{b}	19.77 ± 0.07^{b}	9.08 ± 2.74^{a}	31.46 ± 0.34^{a}	28.65 ± 2.23^{m}
G4	4.31 ± 0.04^{mn}	1.56 ± 0.00^{ijk}	17.80 ± 0.75^{ijk}	6.45 ± 3.64^{ab}	15.34 ± 0.13^{ghijk}	54.54 ± 4.03^{de}
G5	7.05 ± 0.09^{defg}	1.42 ± 0.13^{jkl}	20.07 ± 0.11^{fe}	4.34 ± 0.19^{b}	14.55 ± 0.09^{jkl}	52.58 ± 0.19^{efg}
G6	5.18 ± 0.01^{jkl}	1.38 ± 0.09^{jkl}	15.25 ± 0.06^{ghi}	5.41 ± 0.80^{b}	13.80 ± 0.20^{jkl}	58.98 ± 0.63^{b}
G7	8.26 ± 0.07^{ab}	2.21 ± 0.04^{cd}	16.72 ± 0.14^{ghi}	5.39 ± 0.40^{b}	22.50 ± 0.35^{b}	44.92 ± 0.80^{jkl}
G8	7.22 ± 0.05^{cdef}	1.63 ± 0.05^{ghij}	17.39 ± 0.05^{ghi}	5.01 ± 0.07^{b}	23.54 ± 0.03^{b}	45.23 ± 0.06^{ijkl}
G9	5.73 ± 0.11^{hij}	1.49 ± 0.03^{ijk}	18.14 ± 0.36^{ghi}	5.64 ± 0.59^{b}	15.32 ± 0.21^{ghijk}	53.69 ± 0.95^{def}
G10	6.50 ± 0.07^{gh}	1.58 ± 0.01^{ghijk}	17.23 ± 0.22^{ghi}	5.32 ± 0.02^{b}	14.76 ± 0.14^{jkl}	54.32 ± 0.72^{def}
B1	7.69 ± 0.04^{bc}	1.57 ± 0.07^{ghijk}	26.49 ± 1.32^{b}	5.66 ± 0.03^{b}	15.57 ± 0.14^{ghij}	43.03 ± 1.23^{jkl}
B2	5.94 ± 0.04^{hi}	1.42 ± 0.04^{jkl}	27.96 ± 1.13^{b}	5.91 ± 0.03^{b}	16.51 ± 0.58^{ghij}	42.26 ± 0.80^{kl}
B3	6.12 ± 0.08^{ab}	1.18 ± 0.07^{l}	12.41 ± 0.70^{k}	5.31 ± 0.02^{b}	15.22 ± 0.56^{ijk}	59.76 ± 0.91^{b}
B4	2.64 ± 0.08^{o}	2.41 ± 0.07^{c}	25.71 ± 0.87^{c}	5.36 ± 0.00^{b}	17.55 ± 0.19^{def}	46.33 ± 1.08^{ijk}
B5	7.52 ± 0.11^{cde}	1.46 ± 0.11^{ijkl}	29.28 ± 0.45^{a}	5.32 ± 0.02^{b}	14.67 ± 0.15^{jkl}	41.75 ± 0.32^{l}
B6	5.14 ± 0.12^{kl}	1.97 ± 0.01^{def}	22.16 ± 0.45^{de}	6.47 ± 0.00^{ab}	18.92 ± 0.15^{de}	45.35 ± 0.43^{ijk}
B7	7.16 ± 0.05^{cdef}	1.61 ± 0.03^{ghij}	17.83 ± 0.35^{ghi}	5.19 ± 0.05^{b}	17.88 ± 0.07^{def}	50.34 ± 0.25^{ghij}
B8	2.87 ± 0.06^{o}	0.87 ± 0.04^{m}	17.88 ± 0.07^{ghi}	5.68 ± 0.12^{b}	12.87 ± 0.32^{l}	59.85 ± 0.34^{b}
B9	4.89 ± 0.11^{lm}	1.58 ± 0.08^{ghijk}	19.91 ± 0.06^{g}	5.14 ± 0.07^{b}	17.12 ± 0.34^{efgh}	51.36 ± 0.35^{fghi}
B10	7.00 ± 0.03^{efg}	1.96 ± 0.03^{def}	20.23 ± 0.50^{fe}	5.35 ± 0.06^{b}	20.24 ± 0.11^{cd}	45.23 ± 0.46^{jkl}
B11	8.36 ± 0.09^{a}	2.03 ± 0.00^{de}	21.18 ± 0.81^{ed}	6.37 ± 0.03^{ab}	16.44 ± 0.12^{ghij}	45.61 ± 0.89^{ijk}
B12	6.80 ± 0.11^{fg}	1.84 ± 0.00^{efg}	19.14 ± 0.07^{ghi}	6.05 ± 0.02^{b}	17.67 ± 1.48^{def}	48.50 ± 1.58^{ghij}
B13	8.43 ± 0.05^{a}	1.66 ± 0.16^{ghij}	21.57 ± 0.16^{def}	5.80 ± 0.35^{b}	15.30 ± 0.54^{ghijk}	47.24 ± 0.86^{ghijk}
B14	5.18 ± 0.03^{kl}	2.73 ± 0.00^{b}	19.68 ± 0.26^{g}	5.56 ± 0.00^{b}	17.53 ± 0.29^{efg}	49.31 ± 0.55^{ghij}
B15	3.97 ± 0.09^{n}	1.50 ± 0.33^{ijk}	21.36 ± 0.14^{ed}	6.49 ± 0.01^{ab}	14.94 ± 0.33^{ijkl}	51.75 ± 0.66^{efgh}
B16	7.38 ± 0.18^{cdef}	1.81 ± 0.04^{efgh}	17.23 ± 0.80^{ghi}	5.64 ± 0.05^{b}	21.59 ± 0.08^{c}	46.34 ± 0.91^{ghijk}
B17	5.39 ± 0.90^{jkl}	3.74 ± 0.02^{a}	19.67 ± 0.35^{g}	6.03 ± 0.36^{b}	17.12 ± 0.15^{fghi}	48.06 ± 1.25^{ghijk}
B18	7.62 ± 0.16^{cd}	1.71 ± 0.14^{fghi}	20.26 ± 0.05^{ed}	6.49 ± 0.19^{ab}	21.64 ± 0.16^{b}	42.28 ± 0.29^{jkl}
B19	2.72 ± 0.09^{o}	1.97 ± 0.02^{def}	19.02 ± 0.35^{ghi}	5.85 ± 0.76^{b}	14.98 ± 0.23^{ijk}	55.46 ± 0.63^{cd}
B20	6.06 ± 0.11^{hi}	1.46 ± 0.02^{ijkl}	17.48 ± 0.36^{ghi}	5.84 ± 0.39^{b}	15.12 ± 0.54^{ijk}	54.04 ± 0.70^{def}

Results are presented as mean ± standard deviation of 3 analyses. G: Green tea; B: Black tea. Values with different superscript letters in a column are significantly different ($p<0.05$).

Table 4. Concentration (mg/kg) of vital and harmful elements in tea samples purchased from supermarkets in Kampala city

Sample	K	Na	Mg	Ca	Cu	Fe	Mn	Harmful elements*
G1	2207.83 ± 2.97^{b}	11.47 ± 0.15^{c}	18.24 ± 0.14^{l}	46.19 ± 0.22^{l}	1.34 ± 0.01^{kl}	8.46 ± 0.31^{l}	141.17± 1.01^{a}	ND
G2	1502.71 ± 0.54^{cd}	10.73 ± 0.12^{cd}	29.20 ± 0.2^{ghij}	67.84 ± 0.14^{kl}	2.28 ± 0.02^{a}	11.22 ± 0.18^{jkl}	92.13 ± 0.31^{def}	ND
G3	758.36 ± 2.90^{kl}	6.40 ± 0.10^{jkl}	17.51 ± 0.40^{m}	39.77 ± 0.25^{m}	1.61 ± 0.02^{ghijk}	33.72 ± 0.17^{c}	62.57 ± 0.25^{jkl}	ND
G4	847.33 ± 2.75^{jkl}	6.60 ± 0.20^{jkl}	22.26 ± 0.22^{jkl}	82.75 ± 0.23^{jkl}	1.58 ± 0.03^{ijk}	10.62 ± 0.20^{kl}	67.67 ± 0.51^{ijkl}	ND
G5	694.95 ± 2.85^{m}	6.20 ± 0.10^{jkl}	25.40 ± 0.36i^{jkl}	191.75 ± 0.25^{cd}	1.26 ± 0.03^{l}	8.30 ± 0.20^{m}	47.60 ± 0.36^{m}	ND
G6	1432.63 ± 0.48^{de}	8.80 ± 0.10^{ghij}	26.33 ± 0.32^{ijk}	113.84 ± 0.15^{ijkl}	1.51 ± 0.02^{jkl}	23.76 ± 0.21^{ghijk}	78.47 ± 0.35^{ghijk}	ND
G7	935.49 ± 0.29^{ijkl}	7.13 ± 0.15^{ijkl}	24.62 ± 0.20^{jkl}	104.38 ± 0.22^{jkl}	1.60 ± 0.02^{hijk}	11.61 ± 0.22^{jkl}	61.80 ± 0.40^{jkl}	ND
G8	821.69 ± 1.42^{jkl}	7.43 ± 0.15^{ijk}	19.32 ± 0.25^{jkl}	118.65 ± 0.63^{ijk}	1.48 ± 0.03^{jkl}	13.64 ± 0.16^{jkl}	58.43 ± 0.35^{jkl}	ND
G9	711.64 ± 0.55 ^{l}	6.70 ± 0.10^{jkl}	18.56 ± 0.19^{kl}	127.82 ± 0.50^{k}	1.18 ± 0.02^{m}	29.35 ± 0.22^{i}	55.40 ± 0.36^{kl}	ND
G10	856.69 ± 1.47^{jkl}	6.87 ± 0.06^{jkl}	23.41 ± 0.36^{jkl}	165.42 ± 0.47^{def}	1.56 ± 0.04^{ghijk}	15.42 ± 0.16^{ijkl}	60.47 ± 0.31^{jkl}	ND
B1	1114.70 ± 0.36^{ghijk}	10.40 ± 0.20^{def}	30.51 ± 0.30^{de}	158.52 ± 0.30 ^{ghij}	1.86 ± 0.02^{ghijk}	23.71 ± 0.10^{ghijk}	97.70 ± 0.46^{de}	ND
B2	911.91 ± 0.30^{jkl}	4.53 ± 0.21^{m}	30.39 ± 0.22^{def}	204.47 ± 0.32^{c}	1.84 ± 0.02^{jkl}	29.61 ± 0.22^{de}	68.70 ± 0.20^{ijkl}	ND
B3	966.70 ± 0.85^{ijk}	8.71 ± 0.22^{ghijk}	27.40 ± 0.20^{hijk}	107.53 ± 0.55^{jkl}	1.87 ± 0.20^{l}	19.67 ± 0.15^{ijk}	70.53 ± 0.25^{hijk}	ND
B4	1362.73 ± 0.41^{def}	11.71 ± 0.2^{b}	27.87 ± 0.14^{ghijk}	140.71 ± 0.20^{hijk}	1.64 ± 0.02^{c}	21.69 ± 0.20^{hijk}	101.67 ± 0.35^{cd}	ND
B5	1033.87 ± 0.35^{hijk}	8.58 ± 0.24^{ghijk}	28.55 ± 0.15^{ghijk}	142.54 ± 0.39^{ghijk}	1.56 ± 0.03^{ijk}	11.42 ± 0.18^{jkl}	88.43 ± 0.35^{def}	ND
B6	1622.07 ± 2.00^{c}	9.60 ± 0.20^{def}	30.39 ± 0.21^{efg}	157.24 ± 0.39^{ghij}	1.75 ± 0.02^{efgh}	43.92 ±0.25^{a}	105.80 ± 0.40^{c}	ND
B7	1245.97 ± 0.21^{efg}	11.62 ± 0.16^{b}	25.62 ± 0.16^{hijkl}	74.48 ± 0.34^{jkl}	1.66 ± 0.02^{ghij}	25.43 ± 0.36^{ghfghi}	79.43 ± 0.35^{ghij}	ND
B8	1047.63 ± 0.71^{ghijk}	5.61 ± 0.22^{l}	32.42 ± 0.42^{b}	280.94 ± 0.44^{a}	1.64 ± 0.02^{ghijk}	24.76 ± 0.14^{ghijk}	69.37 ± 0.21^{ijk}	ND
B9	2681.83 ± 0.42^{a}	11.77 ± 0.16^{a}	29.61 ± 0.21^{ghij}	174.55 ± 0.27^{de}	1.27 ± 0.05^{kl}	29.45 ± 0.15^{def}	114.53 ± 0.31^{b}	ND
B10	1002.37 ± 0.74^{ijk}	8.87 ± 0.15^{ghij}	30.28 ± 0.11^{fghi}	206.76 ± 0.37^{b}	1.74 ± 0.02^{fghi}	35.52 ± 0.29^{def}	79.83 ± 0.21^{ghij}	ND
B11	1062.94 ± 1.27^{ghijk}	9.23 ± 0.15^{fgh}	30.31 ± 0.30^{efgh}	169.44 ± 0.19^{def}	1.93 ± 0.02^{b}	24.20 ± 0.19^{ghij}	82.37 ± 0.31^{efgh}	ND
B12	1137.57 ± 0.50^{ghij}	9.60 ± 0.20^{def}	32.20 ± 0.21^{b}	159.29 ± 0.92^{fghi}	1.79 ± 0.03^{def}	19.49 ± 0.30^{ijkl}	84.57 ± 0.25^{efg}	ND
B13	1166.32 ± 0.50^{ghij}	8.30 ± 0.20^{ijk}	29.19 ± 0.30^{ghijk}	159.55 ± 0.74^{efgh}	1.86 ± 0.02^{cd}	28.47 ± 0.33^{efg}	80.47 ± 0.35^{fghi}	ND
B14	1167.65 ± 0.45^{fghi}	9.53 ± 0.25^{efg}	30.59 ± 0.32^{cd}	148. 83 ± 0.31^{ghijk}	1.67 ± 0.03^{ghij}	21.34 ± 0.29^{ijk}	78.83 ± 0.45^{ghij}	ND
B15	1847.01 ± 1.57^{b}	10.50 ± 0.36^{de}	27.38 ± 0.44^{ijk}	113.51 ± 0.34^{ijkl}	1.49 ± 0.02^{jkl}	26. 37 ± 0.40^{efgh}	121.63 ± 0.35^{b}	ND
B16	948.87 ± 0.76^{ijkl}	7.43 ± 0.35^{ijk}	30.43 ± 0.25^{def}	224.78 ± 0.33^{b}	1.84 ± 0.04^{def}	28.67 ± 0.32^{def}	48.57 ± 0.31^{kl}	ND
B17	1151.64 ± 0.56^{ghij}	8.47 ± 0.31^{hijk}	30.40 ± 0.20^{def}	165.81 ± 0.27^{def}	1.55 ± 0.04^{ijkl}	37.69 ± 0.27^{b}	76.87 ± 0.15^{ghijk}	ND
B18	1323. 84 ± 0.29^{def}	9.53 ± 0.15^{efgh}	32.59 ± 0.22^{a}	152.60 ± 0.49^{ghij}	1.77 ± 0.02^{efg}	24.39 ± 0.37^{ghij}	69.47 ± 0.49^{ijk}	ND
B19	1173.73 ± 1.19^{def}	8.73 ± 0.21^{ghij}	29.43 ± 0.16^{ghij}	146.20 ± 0.34^{ghijk}	1.86 ± 0.02^{de}	22.84 ± 0.21^{ghijk}	77.80 ± 0.36^{ghijk}	ND
B20	1397.77 ± 0.34^{def}	9.23 ± 0.15^{ghij}	31.22 ± 0.18^{c}	163.19 ± 0.38^{efg}	1.68 ± 0.03^{ghij}	31.79 ± 0.16^{cd}	86.47 ± 0.35^{def}	ND

Results are presented as mean ± standard deviation of 3 analyses. ND = Not detected. G: Green tea; B: Black tea; K: potassium; Na: sodium; Mg: magnesium; Ca: calcium; Cu: copper; Fe: iron; Mn: manganese; * lead; cadmium; arsenic; mercury. Values with different superscript letters in a column are significantly different ($p<0.05$).

Green tea had protein content varying from 13.23 to 20.07% while that of black tea was between 12.41 and 29.28%. No significant ($p > 0.05$) difference in protein content was found among the tested tea brands. Green tea had ash content ranging from 4.34 to 9.08% while black tea was between 5.14 and 6.49%. Crude fiber content ranged from 12.12 to 31.46% for green and 12.87 to 21.64% for black tea. Carbohydrate ranged from 28.65 to 61.13% in green tea and 41.75 to 59.85% in black tea.

Metal content

A higher content of vital elements occurred in black teas than in green teas (Table 4). Among the macro-elements, K was present at the highest concentration and ranged from 694.95 to 2,207.83 mg/kg in green tea and 911.91 to 2,681.83 mg/kg in black tea. Sodium concentration ranged from 6.20 to 11.47 in green and 4.53 to 11.77 mg/kg in black tea. Magnesium was present at concentrations ranging from 17.51 to 29.20 mg/kg in green tea and 25.62 to 32.59 mg/kg in black tea. Calcium concentration correspondingly ranged from 39.77 to 191.75 mg/kg and 74.48 to 280.94 mg/kg for green and black tea. The findings of this study show comparable concentrations of Cu in green (1.18 to 2.28 mg/kg) and black (1.27 to 1.93 mg/kg) tea. The concentration of Fe ranged from 8.30 to 33.72 mg/kg for green tea and 11.42 to 37.69 mg/kg for black tea. Manganese concentration ranged from 47.60 to 141.17 mg/kg in green and black tea. The amounts of As, Cd, Pb, and Hg in the tea were too low to be accurately measured by AAS.

Total polyphenol and total flavonoid

Levels of total polyphenols ranged from 82.17 to 133.10 mg GAE/g DW in black tea and 88.93 to 159.31 mg GAE/g DW in green tea (Table 5). The total flavonoid concentration ranged from 122.12 to 177.10 mg RE/g DW in black tea and 43.36 to 183.24 mg RE/g DW in green tea. In general, black tea had a lower total polyphenol content than green tea. The total flavonoid content followed the same pattern as that of the total polyphenol content.

Table 5. Total polyphenol and total flavonoid content of tea samples purchased from supermarkets in Kampala city

Sample	Total polyphenol content (mg GAE/g)	Total flavonoid content (mg RE/g)
B1	103.43 ± 2.81^{fg}	143.08 ± 1.01^{gh}
B2	112.7 ± 0.51^{de}	167.73 ± 8.58^{cd}
B3	98.71 ± 1.63^{fg}	153.10 ± 0.50^{fg}
B4	84.76 ± 1.52^{jk}	177.10 ± 1.84^{ab}
B5	94.87 ± 0.53^{ghi}	122.12 ± 0.70^{i}
B6	95.69 ± 0.40^{gh}	153.89 ± 1.88^{ef}
B7	133.10 ± 1.15^{b}	160.26 ± 1.37^{de}
B8	121.15 ± 8.66^{c}	171.81 ± 2.85^{bc}
B9	82.17 ± 0.16^{k}	161.63 ± 1.73^{de}
B10	90.27 ± 0.91^{hij}	176.99 ± 0.24^{ab}
G1	159.31 ± 2.89^{a}	43.36 ± 0.47^{l}
G2	153.35 ± 0.47^{ab}	47.05 ± 0.99^{l}
G3	88.93 ± 4.16^{ij}	183.24 ± 0.36^{a}
G4	152.05 ± 3.13^{ab}	102.62 ± 0.58^{j}
G5	133.10 ± 1.15^{b}	160.26 ± 1.37^{ef}
G6	153.89 ± 0.49^{ab}	148.28 ± 6.25^{fg}
G7	116.99 ± 0.53^{d}	50.11 ± 1.71^{l}
G8	106.50 ± 0.77^{ef}	75.59 ± 1.49^{k}
G9	148.07 ± 0.98^{ab}	154.74 ± 2.91^{ef}
G10	151.22 ± 1.02^{ab}	136.35 ± 0.49^{h}

G: Green tea; B: Black tea; Results are presented as mean ± standard deviation of triplicate analyses; mg GAE/g = milligram Gallic Acid Equivalent per gram, mg RE/g = milligram Rutin Equivalent per gram. Values with different superscript letters in a column are significantly different ($p<0.05$).

Discussion

Proximate components

According to Dmowski and Ruszkowska (2018) (12), the moisture content in black tea should be maintained within a range of 2 to 9%. Below 2%, the product becomes hay-like, and essential oils volatilize, while above 9%, there is mold growth and the tea becomes musty. Both types of tea analyzed contained lipids, but the range for black tea was broader compared to green tea. Studies on tea reported lipid contents between 1.3 and 16.2% (13). Tea lipids are complex mixtures of phospholipids, glycolipids, and neutral lipids that are important for tea's flavor and quality (14). The lipid fatty acids, particularly linoleic acid (18:2ω6) and alpha linolenic acid (18:3ω3), are precursors for black tea flavor. Ramdani *et al.* (2013) (15) reported the protein content of tea to be 24.2% while Pradhan and Dubey (16) reported a value of 22.86%. The protein content of tea includes enzymes and amino acids. Enzymes are required for catechin oxidation during black tea processing, while alpha amino acids are converted via Strecker degradation into aromatic aldehydes (17).

The ISO recommends an ash content of 4 to 8% in tea to maintain a good quality product during storage (ISO 3720:2011). However, the ash content of black teas has been reported to range from 5 to 6% while that of green tea may be higher (14). Ash content is an indicator of a tea's richness in minerals that are vital for human health (18). Adnan et al. (2013) (19) reported crude fiber content between 12.75 and 17.21% for green tea and 11.23 and 16.33% for black tea. According to ISO 3720:2011, the crude fiber in black teas should not be more than 16.5% (20). Ten out of 20 of the black tea samples had crude fiber contents above the ISO recommendation. Crude fiber content in tea varies by type, processing, and quality, with products derived from young leaves having less fiber than those from old leaves and stems. The amount of carbohydrates observed is in line with that reported in black teas from Kenya (21). Green tea leaves contain carbohydrates made up of structural polysaccharides like cellulose and pectins, and small amounts of free sugars such as glucose, fructose, and raffinose (17). Free sugars are the parent compounds from which catechins are synthesized in the tea shoot, contribute towards the formation of aroma compounds in processed tea, and also contribute towards water-soluble solids in the tea liquor (22). Differences in the composition of tea are attributable to differences in leaf age, plant genetics, growing conditions, plucking season, and processing and storage conditions (23).

Metal elements

Bamuwamye *et al.* (2017) (24) reported mean concentrations of K of 14,740.41, 10,003.69 and 9,969.74 mg/kg in locally branded, unbranded, and imported teas in Kampala City. Fernández-Cáceres *et al.* (2001) (25) observed that K was the metal with the major content in all forms of *C.sinensis*. The Na concentration is lower than that reported by Bamuwamye *et al.* (2017) (24). According to Islam and Ebihara (2017) (26), Na, Fe and Zn occur in tea leaves in the range of 3 to 58 mg/kg. Plants generally contain low amounts of sodium since it is not considered essential for most plants, and high concentrations can even be toxic. A lower Mg concentration was observed in the teas of this study than previously reported in black tea in Kenya and some Asian countries (25). Calcium is essential for building strong bones, hence an integral component of the skeleton (27). Magnesium is a cofactor in enzymes that regulate protein synthesis, neuromuscular conduction, glycemic control, and blood pressure (28).

Copper, Fe, and Mn are trace elements that are indispensable for many biological processes in the human body. The Cu content was lower than the levels previously reported for black tea in Uganda (24). Differences in the Cu content of teas are attributable to variations in cultivars and geographical source. Copper is essential in the functioning of the polyphenol oxidase (PPO) enzyme (29). Polyphenol oxidase is a key enzyme in black and oolong tea processing that converts catechins into theaflavins and thearubigins through oxidation (29). This transformation imparts characteristic color, flavor, and astringency to these teas. In humans, Cu plays an important role in Fe metabolism, although excessive Cu intake may lead to kidney damage and hemolytic anemia (30). The maximum daily intake for Cu from all sources that is unlikely to cause adverse health effects in most healthy adults is 10 mg/day (30). The Fe content of black tea in Uganda has been reported to range from 1.1 to 39.89 mg/kg (24), implying that the findings of this study are within range. However, Egyptian black tea has been reported to contain as much as 193.82 mg/kg Fe, black teas from China, Nepal, Japan, and Korea average 115.6 mg/kg, and green tea generally contains 56.7 mg/kg (23). The findings indicate that the type of tea and its geographical origin can significantly affect the Fe content in the tea leaves. Iron is essential for numerous bodily functions, including being a critical cofactor for enzymes in energy production and DNA synthesis, and is indispensable for cellular respiration. Compared to most studies, the levels of Mn observed in this study are generally low. According to Karak and Bhagat (2010) (31), tea leaves accumulate Mn to levels ranging between 300 and 900 mg/kg. Excessive exposure to Mn leads to a permanent neurodegenerative condition known as manganism (32).

Arsenic, Cd, Hg, and Pb are highly toxic heavy metals with no known beneficial biological functions in the human body. Bamuwamye *et al.* (2017) (24) reported Hg concentration in the range below the limit of detection (LOD) to 0.35 mg/kg, and Pb and Cd from <LOD to 8.39

mg/kg. Low levels of toxic elements are detected in green tea (31). While tea offers health benefits to regular consumers, the presence of excessive As, Cd, Pb, and Hg can cause adverse neurological, immunological, teratogenic, and genotoxic effects (8). Because of this, the four metals have been prioritized for monitoring and reduction in the food chain by many governments. Nonetheless, Jurowski *et al.* (2024) (33) reported that because As, Cd and Pb are poorly extracted into the tea beverage during the brewing of tea, exposure to those metals due to the intake of tea is generally very low (*ca.* 1%). The findings of this study imply that exposure to As, Cd, Pb, and Hg should be very low and may not deter consumers from tea consumption.

Total polyphenol and total flavonoid

The ISO has proposed minimum concentrations of total polyphenols of 9 and 11 GAE g/100 g DW for black and green tea, respectively (20, 34). The oxidation process that black tea undergoes during manufacturing reduces the levels of certain polyphenols such as catechins (23). Polyphenols are bioactive components that form the core source of dietary antioxidants in tea, and constitute up to 35% of the tea by dry weight (35). Dietary polyphenols are cardioprotective due to their potential to regulate lipid metabolism and have anti-inflammatory and anticancer properties (36). Tea polyphenols scavenge free radicals and regulate many oxidase enzymes, thus reducing the extent of cellular and DNA damage (21). The polyphenols inhibit oxidation by chelating transition metal ions, particularly Fe^{2+} and Cu^{2+}, thereby reducing their ability to catalyze the formation of radicals in the body. These mechanisms enable polyphenols to protect human beings against cardiovascular diseases (CVD), cancer, and diabetes (22). Black tea has lower levels of total flavonoids than green tea because its production involves a full oxidation process (37). Green tea, which is not oxidized, retains its original levels of those compounds.

CONCLUSION

Moisture and ash contents were within internationally recommended limits. Green and black teas are generally safe for human consumption as the levels of potentially toxic elements are below international regulatory limits. The teas are also a source of vital minerals. Green tea may provide a significant dietary source of polyphenols and can be used as a nutrient-rich food with antioxidant, anti-inflammatory, anticancer, and cardioprotective benefits for regular consumers. However, more research needs to be done to fully understand how tea benefits manifest in humans.

Financial disclosure

The authors declared no financial interest.

References

1. Phong NH, Pongnak W, Soytong K, Poeaim S, Poeaim A. Diversity of tea (Camellia sinensis) grown in Vietnam based on morphological characteristics and inter-primer binding sites (iPBS) marker. International Journal of Agriculture and Biology. 2016; 18(2): 385-392.
2. Jayasinghe SL, Kumar L. Potential impact of the current and future climate on the yield, quality, and climate suitability for tea (Camellia sinensis (L.) O. Kuntze): A systematic review. Agronomy. 2021; 11: 619.
3. Kawooya R. Accomplishments of Tea Research in Uganda in the Year 2019. European Journal of Agriculture and Food Sciences. 2021; 3(1): 75-78.
4. Kosińska A, Andlauer W. Antioxidant capacity of tea: Effect of processing and storage. Dan's processing and impact on antioxidants in beverages. 2014; 109-120.
5. Zhang L, Ho CT, Zhou J, Santos JS, Armstrong L, Granato D. Chemistry and biological activities of processed camellia sinensis teas: A comprehensive review. Comprehensive Reviews in Food Science and Food Safety. 2019; 18: 1474-1495.
6. Yadav KC, Parajuli A, Khatri BB, Shiwakoti LD. Phytochemicals and quality of green and black teas from different clones of tea plant. Journal of Food Quality. 2018.
7. Pongrac P, Tolrà R, Hajiboland R, Vogel-Mikuš K, Kelemen M, Vavpetič P, Poschenrieder C. Contrasting allocation of magnesium, calcium and manganese in leaves of tea (Camellia sinensis (L.) Kuntze) plants may explain their different extraction efficiency into tea. Food and Chemical Toxicology. 2020; 135.
8. Zhang J, Yang R, Chen R, Li YC, Peng Y, Liu C. Multielemental analysis associated with chemometric techniques for geographical origin discrimination of tea leaves (Camelia sinensis) in Guizhou Province, SW China. Molecules. 2018; 23.
9. Xu C, Liang L, Li Y, Yang T, Fan Y, Mao X et al. Studies of quality development and major chemical composition of green tea processed from tea with different shoot maturity. LWT - Food Science and Technolog. 2021; 142: 111055.
10. Nibir YM, Sumit AF, Akhand AA, Ahsan N, Hossain MS. Comparative assessment of total polyphenols, antioxidant and antimicrobial activity of different tea varieties of Bangladesh. Asian Pacific Journal of Tropical Biomedicine. 2017; 7(4): 352-357.
11. Sik B, Székelyhidi R, Lakatos E, Kapcsándi V, Ajtony Z. Analytical procedures for determination of phenolic active herbal ingredients in fortified functional foods: an overview. European Food Research and Technology. 2022; 248: 329–344.
12. Dmowski P, Ruszkowska M. Equilibrium moisture content importance in safe maritime transport of black tea. International Journal on Marine Navigation and Safety of Sea Transportation. 2018; 12(2): 399-404.
13. Abbasi E, Yousefi MH, Hashemi S, Hosseinzadeh S, Ghadimi AH, Safapour M et al. Aflatoxin B1 and heavy metals in imported black tea to Bushehr, southern Iran; Contamination rate and risk assessment. Journal of Food Composition and Analysis. 2022; 106.

14. Chen P, Bornhorst J, Aschne M. Manganese metabolism in humans. Frontiers in Bioscience.2018; 23(9): 655-679.

15. Ramdani D, Chaudhry AS, Seal CJ. Chemical composition, plant secondary metabolites, and minerals of green and black teas and the effect of different tea-to-water ratios during their extraction on the composition of their spent leaves as potential additives for ruminants. Journal of Agricultural and Food Chemistry. 2013; 61(20): 4961-4967.

16. Pradhan S, Dubey RC. Proximate analysis, total phenolic content, antioxidant activity and anti-diabetic properties of Camellia sinensis and Camellia assamica. Biochemical and Cellular Archives.2020; 20(1): 15-23.

17. Wong M, Sirisena S, Ng K. Phytochemical profile of differently processed tea: A review. Journal Food Science. 2022; 87: 1925-1942.

18. Malongane F, McGaw LJ, Mudau FN. Chemical compositions and mineral content of four selected South African herbal teas and the synergistic response of combined teas. British Food Journal. 2020; 122(9): 2769-2785.

19. Adnan M, Ahmad A, Ahmed A. Chemical composition and sensory evaluation of tea (Camellia sinensis) commercialized in Pakistan. Pakistani Journal of Botany.2013; 45(3): 901-907.

20. ISO 2011a, ISO 3720: 2011. Black tea - Definition and basic requirements. International Organization for Standardization, Geneva, Switzerland.

21. Shevchuk A, Megías-Pérez R, Zemedieand Y, Kuhnert N. Evaluation of carbohydrates and quality parameters in six types of commercial teas by targeted statistical analysis. Food Research International. 2020; 133: 109122.

22. Lv Q, Long J, Gong Z, Nong K, Liang X, Qin T, et al. Current state of knowledge on the antioxidant effects and mechanisms of action of polyphenolic compounds. Natural Product Communications. 2021; 16(7): 1-13.

23. Bobková A, Demianová A, Belej L, Harangozo L, Bobko M, Jurˇcaga L. et al. Detection of changes in total antioxidant capacity, the content of polyphenols, caffeine, and heavy metals of teas in relation to their origin and fermentation. Foods. 2021; 10: 1821.

24. Bamuwamye M, Ogwok P, Tumuhairwe V, Eragu R, Nakisozi H, Ogwang PE. Dietary content and potential health risks of metals in commercial black tea in Kampala (Uganda). Journal of Food Research. 2017; 6(6): 1-12.

25. Fernández-Cáceres PL, Martín MJ, Pablos F, González AG. Differentiation of tea (*Camellia sinensis*) varieties and their geographical origin according to their metal content. Journal of Agricultural and Food Chemistry. 2001; 49(10): 4775-4779.

26. Islam MA, Ebihara M. Elemental characterization of Japanese green tea leaves and tea infusion residue by neutron-induced prompt and delayed gamma-ray analysis. Arabian Journal of Chemistry. 2017; 10(1): 677–682.

27. Pravina P, Sayaji D, Avinash M. Calcium and its role in the human body. International Journal of Research in Pharmaceutical and Biomedical Sciences. 2013;4(2): 659-668.

28. Al-Alawi AM, Majoniand SW, Falhammar H. Magnesium and human health: Perspectives and research directions. International Journal of Endocrinology. 2018; 9041694.

29. Taranto F, Pasqualone A, Mangini G, Tripodi P, Miazzi MM, Pavan S. et al. Polyphenol oxidases in crops: Biochemical, physiological and genetic aspects. International Journal of Molecular Sciences. 2017; 18(2): 377.

30. Bost M, Houdart S, Oberli M, Kalonji E, Huneau JF, Margaritis I. Dietary copper and human health: Current evidence and unresolved issues. Journal of Trace Elements in Medicine and Biology. 2016; 35: 107–115.

31. Karakand T, Bhagat M. Trace elements in tea leaves, made tea and tea infusion: A review. Food Research International. 2010;43(9):2234-2252.

32. Nyarko-Danquah I, Pajarillo E, Digman A, Soliman KF, Aschner M, Lee E. Manganese accumulation in the brain via various transporters and its neurotoxicity mechanisms. Molecules. 2020; 25(24): 5880.

33. Jurowski K, Kondratowicz-Pietruszka E, Krośniak M. The control and comprehensive safety assessment of heavy metal impurities (As, Pb, and Cd) in green Tea Camellia sinensis (L.) samples (infusions) available in Poland. Biological Trace Element Research. 2024; 20(2): 387-396.

34. ISO 11287: 2011 Green tea - Definition and basic requirements. International Organization for Standardization, Geneva, Switzerland. 2011b.

35. Tong T, Liu YJ, Kang J, Zhangand CM, Kang SG. Antioxidant activity and main chemical components of a novel fermented tea. Molecules. 2019; 24: 2917.

36. Kiyimba T, Yiga P, Bamuwamye M, Ogwok P, Schueren BV, Matthys C. Efficacy of dietary polyphenols from whole foods and purified food polyphenol extracts in optimizing cardiometabolic health: A Meta-Analysis of randomized controlled trials. Advances in Nutrition. 2023; 14(11).

37. Tanaka T, Matsuo Y. Production mechanisms of black tea polyphenols. Chemical and Pharmaceutical Bulletin. 2020;l(12): 1131-1142.