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Physicochemical properties and sensory evaluation of Green Kyllinga (*Kyllinga brevifolia*) green, oolong and black tea

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Abstract

Green Kyllinga (*Kyllinga brevifolia*), a perennial sedge, is commonly distributed in moist to wet tropical regions and flourishes in disturbed habitats like lawns, pastures, and sunlit, humid locales. Despite its prevalence, the untapped potential of Green Kyllinga as a source for herbal tea remains significant. This investigation aimed to delve into the physicochemical attributes and sensory evaluation of green, oolong, and black teas derived from Green Kyllinga, focusing on their antioxidative potential for prospective application in herbal tea manufacturing. The samples underwent analyses for total phenolic content (TPC), total flavonoid content (TFC), 2,2-diphenyl-2-picrylhydrazyl (DPPH), and ferric-reducing antioxidant potential (FRAP), revealing notable discrepancies in colour and antioxidant profiles across the three Green Kyllinga tea variants. Remarkably, black tea exhibited the lowest pH value of 5.5, contributing to its distinct bitterness in contrast to the mildly acidic green and oolong teas. Green Kyllinga green tea showcased elevated phenolic and flavonoid levels, signifying substantial antioxidant capability, with TPC and TFC values recorded at 0.94±0.02 mg GAE/g and 0.17±0.002 mg QE/g, respectively. The DPPH assay showcased an antioxidant activity of 61.11±1.40%, while the FRAP assay rendered a value of 0.71±0.007 mg/L AAE/g. Sensory assessments of the Green Kyllinga teas unveiled diverse degrees of consumer acceptance, ranging from mild aversion to neutral preference, implying that taste inclinations might not be universally appealing. This study elucidates the latent prospects of Green Kyllinga as a valuable resource for herbal tea production, shedding light on a hitherto underexplored avenue.

1. Introduction

Tea is a well-liked beverage across the world because of its alluring aroma and distinctive flavour (Zeng *et al*., 2020; Sarkar *et al*., 2022). It was manufactured from the leaves or leaf buds of *C. sinensis*, an ornamental evergreen plant in the genus Camellia of the family Theaceae (Namita *et al*., 2012). Other types of tea were produced using additional plants or herbs in addition to C. sinensis. Even though it looks like tea and is made in the same way, herbal tea was not thought of as a "real" tea (Ravikumar, 2014). Tea made from herbs was not from the *C. sinensis* beverage. Typically, it is created using various crops' blossoms, seeds, leaves, or roots (Taufik *et al*., 2016). Teas made from herbs are well-known for having therapeutic or medical benefits (Ravikumar, 2014). The existence of phytochemical substances in plant materials, such as phenolic acids and flavonoids, which support antioxidant activity, may be responsible for these health advantages (Mukherjee *et al*., 2018). This has led to a rise in interest in the research of antioxidants.

Kyllinga brevifolia, commonly referred to as Green

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Kyllinga, is a perennial grass-like plant that thrives in a range of damp to wet environments (Molin *et al*., 1997). This notable botanical specimen, categorised as a type of turf weed, features densely clustered seedheads. The true attraction of Green Kyllinga's potential is found in its captivating blossoms. It contains antioxidant phytochemicals such as flavonoids and phenolic acids, which can be used to treat a variety of diseases caused by free radicals (Aryal *et al*., 2019). This weed has a lot of potential for use in healthy foods such as herbal tea made from green, oolong, and black tea.

Antioxidants, notably flavonoids, have garnered substantial scientific attention owing to their multifaceted biological activities and their capacity to confer favourable health outcomes (Roy *et al*., 2022). These compounds, often accountable for the vibrant hues in the botanical realm, exhibit an intricate interplay of antioxidant, anti-inflammatory, and antimicrobial attributes (Pandey and Abhay, 2013). Consequently, the potential is considerable for harnessing this weed for the creation of health-promoting comestibles, such as herbal teas spanning green, oolong, and black variants. Given the scarcity of research on the antioxidant potential of Green Kyllinga, this study seeks to augment the limited knowledge by scrutinising the plant's total phenolic and flavonoid content, in conjunction with its antioxidant activity. Crafting products that optimally capitalise on Green Kyllinga's attributes is imperative to effectively introduce this underutilised herb to the market. Thus, the current study aims to evaluate the physical and chemical properties of Green Kyllinga tea in its green, oolong, and black iterations while also assessing the sensory acceptance of these teas originating from Green Kyllinga.

2. Materials and methods

2.1 Raw materials

Fresh Green Kyllinga was sourced from Pengkalan Chepa, Kelantan. The leaves were cleansed using tap water to remove soil and dust. After cleaning, the Green Kyllinga leaves were gently dried with paper towels and left to air dry at a room temperature (25±1°C) for 10 min.

2.2 Preparation of Green Kyllinga green tea

Approximately 100 g of clean fresh Green Kyllinga was steamed for 8 min, and then soaked in icy cold water for 30 sec to stop the cooking process. Then, the sample was dried at 50°C for 6 h using a drying cabinet (FSD-380, PROTECH, Malaysia). The dried sample was ground using a lightweight blender (MX-801S, Panasonic, Japan) and stored at 4°C prior to further treatments (Shin *et al*., 2019).

2.3 Preparation of Green Kyllinga oolong tea

Cleaned fresh Green Kyllinga was subjected to a withering process at 30°C for 30 min in a drying cabinet (FSD-380, PROTECH, Malaysia) until 70% moisture content was obtained. One-hundred grams of the Green Kyllinga was sprinkled with distilled water in 1:1 (w/v) ratio before undergoing the oxidation-fermentation process for 24 h at room temperature (25°C). Then, the sample was dried at 50°C for 6 h in the drying cabinet. The dried sample was then ground using a lightweight blender (MX-801S, Panasonic, Japan) and stored at 4°C prior to further treatments (Barek *et al*., 2015; Shin *et al*., 2019).

2.4 Preparation of Green Kyllinga black tea

Cleaned fresh Green Kyllinga was subjected to a withering process at 30°C for 30 min in the drying cabinet until 70% moisture content was obtained. One-hundred grams of the Green Kyllinga was sprinkled with distilled water in a 1:1 (w/v) ratio before undergoing the oxidation-fermentation process for 48 h at room temperature (25°C). Then, the sample was dried at 50°C for 6 h in the drying cabinet. The dried Green Kyllinga was ground using a lightweight blender (MX-801S, Panasonic, Japan) and stored at 4°C prior to further treatments (Barek *et al*., 2015; Shin *et al*., 2019).

2.5 Preparation of processed Green Kyllinga infusion (hot water infusion)

Dried Green Kyllinga was ground using a lightweight blender (MX-801S, Panasonic, Japan) for 1 min, to ensure that the tea leaves were not too small to maintain the quality of the tea. Ground samples were stored at 4°C. One gram of dried processed Green Kyllinga was infused with 125 mL of hot water (95°C) and continuously stirred for 2 min. The infusion was left to cool for 10 min before filtering. After cooling down at room temperature, tea infusions were stored at 0°C until further analysis (Shin *et al*., 2019).

2.6 Physicochemical analysis

2.6.1 Determination of colour

The tea infusions were placed within a beaker, and subsequently, the colour reading was acquired using a Minolta CR 300 (Japan) colourimeter. This sequence of steps was replicated for consistency across various samples. Each sample analysis was performed three times to ensure reliability (Chew *et al*., 2020).

2.6.2 Determination of pH value

The pH measurement was conducted employing a pH meter (Orion Star A121, Malaysia). Prior to its application, the pH meter underwent calibration, wherein

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the electrode was submerged in both deionised water and standard solutions with pH values of 4 and 7. Subsequently, the pH values of the samples were meticulously recorded (Hashim *et al*., 2021).

2.6.3 Determination of moisture content

Moisture content was determined using the oven-drying method (AOAC Official Method 925.45), whereby 3 g of the samples were placed in the dried crucible and dried in the hot air oven at 105°C for 16 h. The crucibles, along with samples, were cooled in the desiccator and weighed accurately (AOAC, 2019). The moisture content of the samples was calculated using the following expression:

$$\text{Moisture (\%)} = (w - d / d) \times 100$$

Where w and d stand for wet weight and dry weight, respectively.

2.6.4 Determination of ash content

Ash content was determined by incineration in a muffle furnace (AOAC Official Method 923.03). Approximately 5 g of samples were placed in the muffle furnace (Carbolite, Malaysia) and combusted at 550°C for 24 h. The samples were then cooled in the desiccator and w weighed after it reached the room temperature (AOAC, 2019). The total ash content of the samples was calculated using the following expression:

$$\text{Ash (\%)} = (\text{weight of ash (g)} / \text{weight of sample (g)}) \times 100$$

2.6.5 Mineral extraction

One gram of the ash sample was diluted in 2 mL of HCI and evaporated to dryness on a hot plate (Favorit, Malaysia). Then, 10 mL of 20% concentrated HNO_3 was added and transferred into test tubes. They were then immersed in water bath for 1 h before being made up to 100 mL with distilled water. The samples were then filtered through Whatman No.1 filter paper and kept chilled at 4°C.

2.6.6 Mineral composition determination using Inductively coupled plasma-optical emission spectrometry

The mineral composition (Ca, Mg, Fe, and Cu) within the Green Kyllinga samples was determined using Inductively Coupled Plasma – Optical Emission Spectrometry (ICP-OES) with the utilisation of an Optima 8300 instrument (PerkinElmer, USA). The identification of mineral elements was achieved through measurement of their emission lines, specifically: Ca (Radial 1), Mg (285.213 nm), Fe (238.204 nm), and Cu (327.393 nm). Subsequent to data acquisition, comprehensive analysis was performed employing dedicated computer software (Akpinar-Bayizit *et al*., 2010).

2.7 Antioxidant properties assays

2.7.1 Total phenolic content

The determination of total phenolic content (TPC) was executed employing the Folin-Ciocalteu method. An aliquot of 0.5 mL was combined with varying concentrations of gallic acid: 300, 250, 200, 150, 100, 50, and 0 mg/L. Subsequently, 2.5 mL of a 10% (w/v) Folin-Ciocalteu reagent was introduced into each respective test tube and agitated. Following this, 2 mL of a 7.5% (w/v) sodium carbonate solution was added and made up to 10 mL using distilled water. The samples were then incubated at room temperature (25°C) for a duration of 30 min. The absorbance was measured at 760 nm using a UV-visible spectrophotometer (SHIMADZU, Kyoto, Japan). The resulting TPC data for the tea infusion were expressed in mg of gallic acid equivalent per gram of the extract (mg GAE/g) (Appendix A, $y = 0.0078x – 0.0596$, $R^2 = 0.9868$) (Tuan Putra *et al*., 2021).

2.7.2 Total flavonoid content

The quantification of total flavonoid content (TFC) was conducted using the aluminium chloride colourimetric assay (Azuan *et al*., 2020). In this procedure, 100 µL of test samples and quercetin standards at various concentrations (5.0, 2.5, 1.0, 0.5, and 0.1 mg/mL) were placed in separate test tubes. Subsequently, a mixture of 500 µL distilled water and 100 µL 5% sodium nitrate solution was added and allowed to incubate for 6 min. Following this, 150 µL of a 10% solution of aluminium chloride was introduced and allowed to react for 5 min, followed by the sequential addition of 200 µL of a 1M sodium hydroxide solution. The absorbance was measured at 510 nm using a UV-visible spectrophotometer (Shimadzu, Kyoto, Japan). The resulting TFC data for the tea infusion were presented as mg of quercetin per gram of the extract (mg GE/g).

2.7.3 2,2-diphenyl-2-picryhydrazyl free radical scavenging ability of radical

Concisely, a freshly prepared solution of 100 µM 2,2 -diphenyl-2-picryhydrazyl Free radical scavenging ability of radical (DPPH) in methanol was utilised for the analysis. Subsequently, 2 mL of the DPPH radical solution (100 µM) was introduced to a test tube containing 1 mL aliquots of the sample, along with ascorbic acid and butylated hydroxytoluene (BHT). The resulting mixture underwent a reaction period of 1 h in darkness at room temperature (25°C). The absorbance

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was measured at 517 nm using a UV-visible spectrophotometer (SHIMADZU, Kyoto, Japan) (Tuan Putra *et al*., 2021). The percentage of inhibition was determined employing the following formula:

$$\% \text{ Inhibition} = (A_0 - A_t / A_0) \times 100$$

Where A_0 represents the absorbance of the blank sample, and A_t corresponds to the absorbance of the tested extract solution.

2.7.4 Ferric reducing antioxidant potential assay

The Ferric reducing antioxidant potential (FRAP) reagent was prepared by 300 mM sodium acetate buffer (pH 3.6), 20 mM iron chloride and 10 mM 2,4,6-tripyridyl-s-triazine dissolved in 40 mM hydrochloric acid at a ratio of 10:1:1 (w: v: v). After mixing, the reagent was warmed to 37°C in a water bath for 30 min before use. The initial reading of the reagent was measured at 593 nm using a UV-visible spectrophotometer (SHIMADZU, Kyoto, Japan). An aliquot of 0.1 mL of tea infusion was then added to 2.9 mL of FRAP reagent and kept in the dark for 30 min. Ascorbic acid was used to create the calibration curves. Results were expressed as mg/L AAE/ (Khairil Anuar *et al*., 2020).

2.8 Sensory evaluation

An acceptance test was carried out to assess the teas' sensory qualities. The evaluation used a hedonic scale that offered ratings from 1 (extreme dislike) to 7 (extreme like), enabling the evaluation of the tea samples' odour, colour, taste, bitterness, and overall acceptance. A panel comprising thirty untrained individuals was chosen from the student body of Universiti Malaysia Terengganu. Clear instructions detailing the sensory evaluation procedures were provided to the panellists prior to the commencement of the assessment (Shin *et al*., 2019).

2.9 Statistical analysis

Statistical analysis was performed through one-way analysis of variance (ANOVA) utilising Minitab 21 statistical software. Statistical significance was established at a threshold of $p < 0.05$. The acquired data underwent analysis using one-way ANOVA to facilitate a comparison among the various tea samples. After the ANOVA, mean comparisons were executed using Fisher's least significant difference (LSD) method, with results presented in the format of mean±standard deviation (SD).

3. Results and discussion

3.1 Physicochemical analysis

3.1.1 Colour profile analysis

Table 1 shows that the a* value of Green Kyllinga teas decreased gradually as fermentation time increased. The control had the greatest a* value of 0.26±0.09, while the lowest a* value was -5.15±0.14 for Green Kyllinga black tea. The a* value represents the redness to greenness colour, with a positive number representing red and a negative number representing green (Luana *et al*., 2014). In green, oolong, and black tea samples of Green Kyllinga, a lower a* value implies a higher intensity of greenness. Prasanth *et al*. (2019) reported that the presence of chlorophyll, a green pigment found in plants, causes the greenness in tea leaves. The processing method used to create tea can alter the degree of greenness in tea leaves. Green tea leaves, for example, are less processed and retain greater chlorophyll content, but oolong and black tea leaves are fermented. When the fermentation period was increased, the L* value gradually increased. The L* value of the Green Kyllinga teas differed significantly ($p < 0.05$) between green tea and black tea but not between control and oolong tea ($p > 0.05$). Black tea had the greatest L* value among the samples, while oolong tea and the control had similar L* values.

Mohd Zin *et al*. (2023) reported that a lower L* value resulted in a darker colour, whereas a higher L* value resulted in a lighter colour. In contrast to this study, improper storage of Green Kyllinga tea leaves, such as exposure to light, heat, or moisture, may have caused the Green Kyllinga black tea to lose colour and become lighter. Aside from that, over-brewing time might cause the colour to lighten as some of the pigments are extracted into the liquid (Abou Elmaaty *et*

Table 1. The L* value, a* value and b* value in Green Kyllinga teas.

Attributes	Acceptance score			
	Control	Green tea (GT)	Oolong tea (OT)	Black tea (BT)
L* value	52.07±2.66^{ab}	51.03±0.45^{b}	53.58±2.58^{ab}	55.41±1.08^{a}
a* value	0.26±0.09^{a}	-3.41±0.08^{b}	-4.09±0.25^{c}	-5.15±0.14^{d}
b* value	8.92±0.17^{c}	13.49±0.17^{b}	14.06±0.85^{b}	15.02±0.07^{a}
Colour	Yellowish red	Light greenish	Yellowish green	Darker green

Values are presented as mean±SD (n = 4). Values with different superscripts within the same row are statistically significantly different (p<0.05). L* value (degree of lightness to darkness), a* value (degree of redness to greenness), and b* value (degree of yellowness to blueness).

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al., 2022).

The b* value in different types of Green Kyllinga teas showed a significant difference ($p < 0.05$) between the control and Green Kyllinga teas. Green Kyllinga black tea had the highest b* value of 15.02±0.07, while the control had the lowest b* value of 8.92±0.17. The b* value represents the degree of yellowness to blueness, with a positive number representing yellow and a negative number representing blue (Luana *et al*., 2014). In Green Kyllinga black tea, a greater b* value may suggest a more yellowish colour than a lower value. The yellowing of black tea leaves was caused by the oxidation process, which occurred after the tea leaves were crushed and exposed to air. This process causes the chlorophyll in the leaves to degrade and turn yellow, resulting in the distinctive dark colour and powerful flavour associated with black tea. Black tea has more oxidation than green and oolong tea, which are less processed and have less oxidation.

3.2 Determination of moisture, ash content and pH value

As fermentation time increased, the moisture content of Green Kyllinga teas gradually decreased. Table 2 highlights a significant difference ($p < 0.05$) among all Green Kyllinga tea samples. The highest moisture content was observed in green tea (11.06%) with no fermentation time, followed by Oolong Tea (9.58%) and Black Tea (8.10%). This reduction in moisture could result from continuous water loss during the fermentation process, leading to the wilting of leaves (Jabeen *et al*., 2019). Adnan *et al*. (2013) proposed that the elevated moisture content in green tea might be attributed to the absence of the fermentation process during green tea production, unlike black tea. This omission of fermentation helps preserve moisture-retaining polyphenols that would otherwise be compromised during the fermentation procedure. The ash content was higher in black tea (8.04%) than in green tea (5.21%). Black tea leaves exhibited a greater mineral concentration compared to their green tea counterparts. The ash content primarily consists of minerals and inorganic constituents present in the tea leaves, including calcium, magnesium, potassium, and phosphorus. These minerals contribute to the tea's ash content, which serves as a vital indicator of quality. The elevated ash concentration in tea could be attributed to its lower moisture level (Jayawardhane *et al*., 2016).

Table 2 also shows the pH value for different Green Kyllinga teas and a commercial tea. The pH variations among the control tea, green tea, oolong tea, and black tea gradually decreased with increasing fermentation time, ranging from 7.82±0.06 to 5.54±0.01. Notably, the pH value of black tea was substantially higher (5.54±0.01) compared to the control tea's pH of (7.82±0.06), indicating that fermentation time has the potential to influence the pH of the tea. During fermentation, yeast and bacteria play a role in breaking down tea leaves, leading to the production of organic acids and carbon dioxide. Organic acids such as acetic acid and lactic acid can contribute to a decrease in tea pH, while carbon dioxide generated during the process can elevate the pH. Consequently, the specific pH of fermented tea can be influenced by the types and quantities of yeast and bacteria present. It's noteworthy that the pH of traditional black tea was discovered to be below the critical pH threshold of 5.5 as determined by Akyuz *et al*. (2010). These findings align with our results, implying that the Green Kyllinga teas achieved a comparable high quality to commercially available teas.

Table 2. Moisture and ash content of Green Kyllinga teas.

Sample	Moisture Content (%)	Ash Content (%)	pH
Control	18.06±0.16^a	12.06±0.067^a	7.36±0.16^a
Green Tea	11.06±0.18^b	5.21±0.05^d	5.96±0.18^b
Oolong Tea	9.58±0.09^c	7.16±0.03^c	5.28±0.09^c
Black Tea	8.10±0.18^d	8.04±0.04^b	5.10±0.18^d

Values are presented as mean±SD (n = 4). Values with different superscripts within the same column are statistically significantly different ($p<0.05$).

3.3 Mineral analysis

Calcium is a fundamental mineral essential for bone health, nerve transmission, and muscle contraction. In this study, the calcium content was found to be highest in Green Tea (648.09 mg/kg), followed by Oolong Tea (435.46 mg/kg), and Black Tea (361.28 mg/kg), with Control tea falling in between. This variation in calcium content might be attributed to the different processing methods employed for each type of tea, impacting the mineral retention. Research has demonstrated that calcium is an integral component of tea leaves, and its content can vary based on tea processing methods (Chen *et al*., 2018). Furthermore, Green Tea (300.41 mg/kg) exhibited a slightly lower magnesium content compared to Control (314.91 mg/kg), while Oolong Tea (143.08 mg/kg) and Black Tea (143.45 mg/kg) displayed the lowest magnesium levels. The variation in magnesium content could be influenced by the degree of oxidation and fermentation during tea processing. Magnesium content in tea leaves has been shown to be influenced by environmental factors and processing conditions (Larsson *et al*., 2011). Moreover, Green Tea exhibited a lower iron content (28.43 mg/kg) compared to Control (39.63 mg/kg), with Oolong Tea (18.91 mg/kg) and Black Tea (20.63 mg/kg) having even lower iron levels. The variations in iron content could be attributed to

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processing methods and the presence of iron-chelating compounds in tea leaves. Iron availability from tea is influenced by its chemical form and interactions with other components (Wang *et al*., 2020). On the other hand, green tea showed a higher copper content (2.64 mg/kg) compared to control (0.56 mg/kg), while oolong tea (0.41 mg/kg) and black tea (0.11 mg/kg) exhibited lower copper levels. The variations in copper content may be linked to factors such as soil composition and tea plant genetics. In this investigation, Green Kyllinga teas were found to contain vital trace elements that are beneficial to human health (Table 3). Ca, Mg, Fe, and Cu are essential for bodily function (Dawudu *et al*., 2013; Shin *et al*., 2020).

3.4 Antioxidative properties

3.4.1 Total phenolic content

Total phenolic contents (TPC) were represented as mg gallic acid equivalent per gram of tea infusion and ranged from 0.18±0.01 mg GAE/g to 0.94±0.02 mg GAE/g, as illustrated in Table 4. TPC of Green Kyllinga teas was significantly different ($p < 0.05$) between all the samples. The structural modification of the phenolic components resulted in the highest TPC in Green Kyllinga green tea. Several mechanisms can affect the molecular structure of phenolic substances, influencing the antioxidant effectiveness. In the instance of Green Kyllinga green tea, structural modification of the phenolic components appears to have resulted in a higher TPC. Galloyl groups of EGCG and ECG were cleaved during tea fermentation, resulting in an increase in free gallic acid (Tan *et al*., 2023).

TPC levels in plant samples increased during various stages of fermentation, according to Lee *et al*. (2016). They discovered that the duration of tea fermentation can influence the TPC of *Clicanthus nutans*. In contrast, the TPC of Green Kyllinga teas, on the other hand, was considerably ($p < 0.05$) lower in oolong and black tea, which were 0.47±0.003 mg of GAE/g and 0.3±0.003 mg of GAE/g, respectively. Low TPC in fermented samples could be due to the synthesis of colour and flavour molecules during the fermentation process, which reduced polyphenol content (Rabeta *et al*., 2015). Fermentation reduces the TPC content of plant samples, according to research. TPC of *Centella asiatica* herbal tea fermented for 24 h was found to be lower than that of non-fermented tea (Ariffin *et al*., 2011).

3.4.2 Total flavonoid content

Table 4 also shows the total flavonoid content TFC of Green Kyllinga teas ranging from 0.09±0.003 mg of QE/g to 0.17±0.002 mg of QE/g. The result shows that TFC was a significant difference ($p< 0.05$) between control and Green Kyllinga teas. The TFC for Green Kyllinga black tea differs slightly from the TFC for the control. Shin *et al*. (2019) have observed that the TFC for fermented Napier grass was not substantially different from the TFC for fresh Napier grass. This observation was corroborated by the fact that, while the TPC of *C. asiatica* herbal teas was massively reduced after fermentation, the TFC of *C. asiatica* was unaffected by fermentation duration (Ariffin *et al*., 2011).

TFC of Napier grass was significantly ($p < 0.05$) reduced at 12 h and 24 h of fermentation period in the previous study (Shin *et al*., 2019). Similarly, the TFC for Green Kyllinga oolong tea differed considerably ($p < 0.05$) from that of Green Kyllinga black tea, which was 0.11±0.004 mg of GE/g and 0.09±0.005 mg of GE/g, respectively. TFC may be reduced due to the conversion of catechins into theaflavins and thearubigins (Yuniartini *et al*., 2015). Chen *et al*. (2023) previously reported that TFC decreased as fermentation time increased.

3.4.3 2,2-diphenyl-2-picrylhydrazyl radical

Table 4 also highlights a significant difference ($p < 0.05$) in the scavenging activity of the 2,2-diphenyl-2-picrylhydrazyl radical (DPPH) among the Green Kyllinga teas, particularly when comparing Green Kyllinga green tea to both oolong and black teas. The maximum DPPH scavenging activity was found in green tea (61.11±1.40%), followed by oolong tea (43.55±2.97%) and black tea (47.88±1.59%). Oolong and black tea are produced from fully fermented tea, whereas green tea is made from unfermented or partially fermented tea. Oxidation took place in oolong and black tea, resulting in a decrease in the antioxidant qualities of the tea. The decrease in antioxidant activity may be due to flavonoid breakdown caused by long fermentation

Table 3. Mineral content of Green Kyllinga teas.

Elements	Control (mg/kg)	Green Tea (mg/kg)	Oolong Tea (mg/kg)	Black Tea (mg/kg)
Ca	636.52±14.9^{a}	648.09±9.11^{a}	435.46±6.38^{b}	361.28±3.52^{c}
Mg	314.91±4.01^{a}	300.41±3.06^{b}	143.08±1.19^{c}	143.45±1.99^{c}
Fe	39.63±0.58^{a}	28.43±0.48^{b}	18.91±0.42^{c}	20.63±2.67^{c}
Cu	0.56±0.19^{b}	2.64±0.10^{a}	0.41±0.08^{b}	0.11±0.03^{c}

Values are presented as mean±SD. Values with different superscripts within the same row are statistically significantly different ($p<0.05$).

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Table 4. Antioxidative properties of Green Kyllinga teas.

Sample	TPC (mg GAE/g)	TFC	DPPH (%)	FRAP
Control	0.18±0.01^{d}	0.08±0.01^{d}	39.70±5.47^{c}	0.45±0.01^{c}
Green Tea	0.94±0.06^{a}	0.17±0.01^{a}	61.11±4.61^{a}	0.71±0.03^{a}
Oolong Tea	0.30±0.01^{c}	0.09±0.01^{c}	43.55±3.94^{bc}	0.55±0.02^{b}
Black Tea	0.47±0.01^{d}	0.12±0.01^{d}	47.88±3.72^{b}	0.45±0.02^{c}

Values are presented as mean±SD (n = 4). Values with different superscripts within the same column are statistically significantly different ($p<0.05$).

hours (Shin *et al*., 2019).

The finding that the TFC and DPPH assay results are equivalent shows that flavonoids function as free radical scavengers. In redox processes, plant phenolic compounds act as reducing agents, hydrogen donors, and singlet oxygen scavengers (Lee *et al*., 2016). Since the hydroxyl groups are linked to the aromatic ring, the flavonoids can contribute to a redox reaction and scavenge free radicals (Lee *et al*., 2016). Mohd Zin *et al*. (2016) discovered that fermentation affects the antioxidant activity of various plant samples, as the longer *C. nutans* tea ferments, the less antioxidant activity it has.

3.4.4 Ferric reducing antioxidant power assay

The results (Table 4) also demonstrate a significant difference ($p < 0.05$) in the ferric reduction potential of Green Kyllinga teas. Green Kyllinga green tea (0.71±0.01 mg/L AAE/g) had considerably higher antioxidant activity ($p < 0.05$) than oolong tea (0.55±0.01 mg/L AAE/g), control, and black tea (0.45±0.003 mg/L AAE/g), showing that the antioxidant activity of Green Kyllinga teas was reduced during fermentation. Green Kyllinga green tea has higher antioxidant activity than oolong tea, control, and black tea, which is likely due to differences in processing methods. Salman *et al*. (2022) postulated that the tea leaves were oxidised during the manufacturing of oolong and black tea, which caused a reduction in the antioxidant capabilities of the tea.

The high TPC content of the sample may have contributed to the considerable increase in antioxidant activity of Green Kyllinga green tea. This is due to the FRAP assay results, which could be correlated to phenolic and flavonoid compounds like thiols and proteins, which function by quenching radicals (Rabeta *et al*., 2015). Furthermore, while phenolic chemicals contribute to plant antioxidant activity, the total antioxidant capacity of the plant is also affected by probable strong interaction between plant elements (Kasote *et al*., 2015). The decrease in antioxidant activity of oolong and black tea suggested that long fermentation times have a negative effect on antioxidants in Green Kyllinga teas.

3.5 Sensory evaluation

3.5.1 Odour

Table 5 shows the findings of the odour scores of tea samples, revealing a significant difference ($p < 0.05$) between Green Kyllinga green tea and the other samples. The control had the greatest odour liking score of 4.70±1.49, whereas Green Kyllinga green tea had the lowest score of 3.33±1.88. There was no significant difference between the Green Kyllinga oolong tea (4.63±1.54), Green Kyllinga black tea (4.57±1.36) and control (4.70±1.49). The greatest liking score for odours in control, oolong, and black tea, showing that the fermenting method could increase tea aroma. Aroma is an important feature of tea quality since it influences tea acceptance prior to consumption (Hu *et al*., 2022).

3.5.2 Colour

Table 5 also shows that the liking scores for Green Kyllinga oolong tea (4.97±1.43) were significantly ($p<0.05$) higher than those for the control (4.57 1.59), Green Kyllinga black tea (4.77±1.76), and Green Kyllinga green tea (3.97±1.97) teas. Compared to the green tea sample, Green Kyllinga oolong tea scored better for colour. Given that both the oolong and black teas were darker than the Green Kyllinga green teas, this might be because consumers favour teas with deeper hues. Adnan *et al*. (2013) assert that during fermentation, catechins caused the amino acids in tea to oxidise, which resulted in a change in the beverage's colour. The brightness of tea's colour was also influenced by the concentration of thearubigins and theaflavins (Adnan *et al*., 2013). The tea infusion will be more vibrant the more theaflavin it contains (Duan *et al*., 2018).

3.5.3 Taste

The Green Kyllinga oolong tea scored best in terms of flavour (3.97±1.73). The Green Kyllinga tea and the control tea had no discernible differences. As shown in Table 5, however, Green Kyllinga green tea had the lowest taste rating (3.27±1.68). This result was consistent with the earlier study by Shin *et al*. (2019), which showed that black tea and green tea from Napier grass had similar taste ratings. This might be explained by consumer preference for green tea, which is frequently thought to have a more delicate, lighter

Table 5. Sensory evaluation of different Green Kyllinga teas.

Attributes	Control	Green Tea	Oolong Tea	Black Tea
Odour	4.70±1.49[a]	3.33±1.88[b]	4.63±1.54[a]	4.57±1.36[a]
Colour	4.57±1.59[ab]	3.97±1.97[b]	4.97±1.43[a]	4.78±1.76[ab]
Taste	3.93±1.55[a]	3.27±1.68[a]	3.97±1.73[a]	3.60±1.48[a]
Bitterness	4.57±1.46[a]	3.67±1.63[b]	3.93±1.57[ab]	3.70±1.29[b]
Overall Acceptability	4.33±1.40a	3.53±1.50[b]	4.33±1.65[a]	4.03±1.47[ab]

Values are presented as mean±SD. Values with different superscripts within the same row are statistically significantly different ($p<0.05$).

flavour than black tea. In addition, some consumers might think that green tea tastes overly grassy or weak, giving it a lower taste rating than black tea. In contrast to Adnan *et al*. (2013) findings, which showed that green tea scores better on the taste scale than black tea.

3.5.4 Bitterness

The scores for the bitterness of the Green Kyllinga tea samples are also shown in Table 5, which showed a significant difference ($p < 0.05$) between the control and the other samples. The Green Kyllinga green tea scored lowest (3.67±1.63), and the control had the highest maximum bitterness liking scores (4.57±1.46). Green Kyllinga black tea (3.70±1.47) and Green Kyllinga green tea (3.67±1.63) did not have statistically different liking scores. Green Kyllinga black tea had a higher liking score for bitterness than Green Kyllinga green tea, which had the lowest. This might be connected to the distinct bitterness of green and black tea. The flavour was greatly influenced by a variety of chemical substances. The flavour of the tea was significantly influenced by a variety of chemical substances. Enhancing the flavour of *C. sinensis* tea requires caffeine. On the other hand, herbal teas and green teas typically contain very little or no caffeine. Due to its role in the synthesis of flavouring compounds during infusion, caffeine has a significant impact on the quality of tea (Adnan *et al*., 2013; Duan *et al*., 2018).

3.5.5 Overall acceptability

The findings for the overall acceptability of Green Kyllinga teas are also shown in Table 5, and they reveal a significant difference ($p < 0.05$) between Green Kyllinga oolong tea (4.33±1.64) and Green Kyllinga green tea (3.53±1.50). The panel members approved Green Kyllinga oolong tea, which scored similarly to the control. The Green Kyllinga green tea's poor overall acceptability may be attributed to its low ratings in terms of aroma, colour, taste, and bitterness. The quantity of chemical and volatile components present may also have an impact on general acceptance (Zhao *et al*., 2022).

4. Conclusion

Green Kyllinga green tea stood out as the most palatable among all the samples analysed, boasting a pH of 6.02 that facilitated consumer enjoyment by avoiding excessive bitterness or acidity. Notably, moisture and ash content exhibited significant variations among the Green Kyllinga teas. The control exhibited the highest moisture content (18.06±0.16%), while Green Kyllinga black tea recorded the lowest (8.10±0.18%). The full oxidation-fermentation process in Green Kyllinga black tea led to reduced moisture content compared to unoxidized green tea. Similarly, the control displayed the highest ash concentration (12.06±0.06%), while green tea displayed the lowest (5.21±0.05%). This was attributed to the fermentation process impacting chemical changes, resulting in reduced ash formation during combustion. Unlike fully fermented black tea, the Green Kyllinga teas exhibited a yellowish-green colour profile. Remarkably, Green Kyllinga green tea exhibited the highest phenolic and flavonoid content, along with potent antioxidant activity in TPC, TFC, DPPH, and FRAP assays. Additionally, mineral analysis confirmed the presence of trace elements such as Ca, Mg, Fe, and Cu in Green Kyllinga teas. The fermentation procedure significantly influenced sensory aspects and overall acceptability of Green Kyllinga teas, impacting odour, colour, taste, bitterness, and customer preference.

Conflict of interest

The authors declare that no conflict of interest.

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