Food Production, Processing and Nutrition

RESEARCH

Open Access

Quality analysis and antioxidant activity of different types of tea powder

Yutong Ye[1,2], Zeyi Ai[1], Ronglin Li[1], Yang Tian[2] and Yiyang Yang[1*]

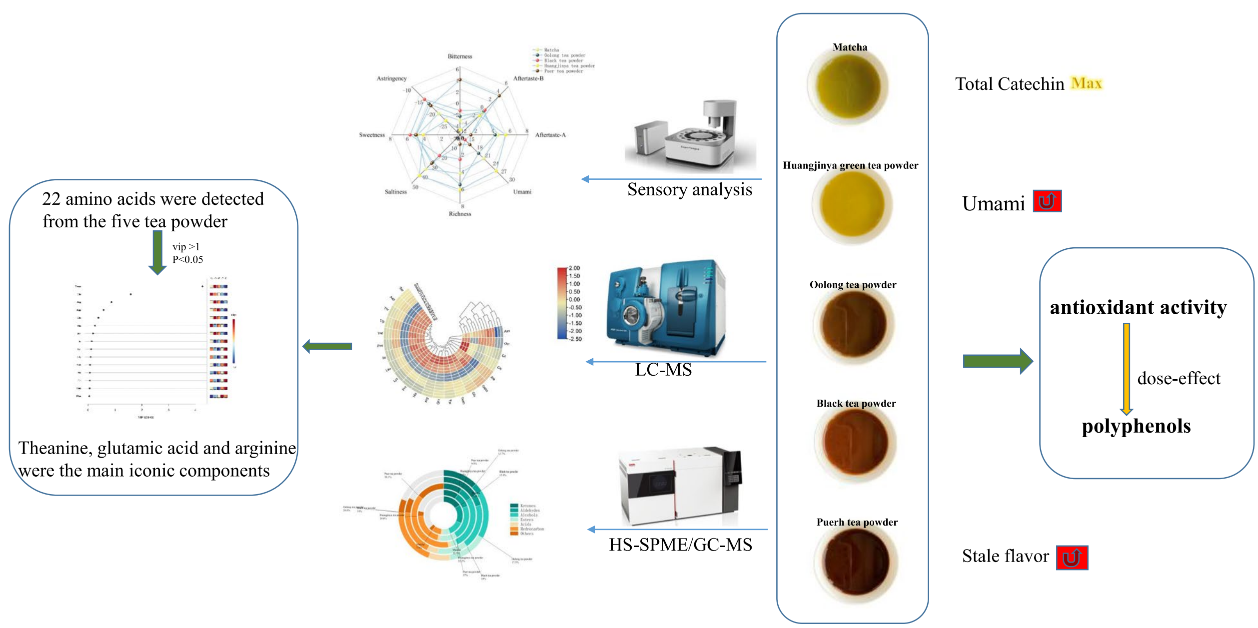
Abstract

As a natural product with health benefits, tea powder (TP) is widely used in food processing field. In order to explore sensory evaluation, quality components and antioxidant activities among different types of TP, matcha TP, Huangjinya green TP, oolong TP, black TP and Pu-erh TP were used as the research objects. Our results showed that total scores of sensory evaluation of unfermented TPs were higher than those of fermented TPs, whilst the colour of those unfermented TPs was more bright. Furthermore, taste attributes showed that sweetness was conducive to the formation of the taste of black TP, and aftertaste-bitterness was beneficial to matcha and Pu-erh TP. Umami was suggested as a vital contributing factor to the mellow taste of Huangjinya green TP, while sourness and bitterness were not propitious to form the taste quality of tea powder. The non-volatile quality components analysis revealed that tea powders with more fermentation usually contained fewer amino acids and catechins, but glutamate and gamma-aminobutyric acid were higher in black TP than in oolong TP. Theanine, glutamic acid and arginine were the main iconic components affecting the amino acid composition of different types of tea powder in our study. Meanwhile, the contents of ester catechins (ECG, EGC, EGCG) in black TP and Pu-erh TP were significantly lower than those in green TP and oolong TP. In addition, the free radical scavenging ability of unfermented TPs were stronger than that of fermented TPs. Therefore, to maximize the health benefits and sensory attributes of different types of TP, the use of unfermented tea powder is recommended. However, different manufacturing process of tea powder can enrich the taste of tea foods, thus giving people more choices.

Keywords Tea powder, Different types, Quality components, Volatile components, Antioxidant activity

*Correspondence:
Yiyang Yang
yiyangyang@jaas.ac.cn
Full list of author information is available at the end of the article

Graphical Abstract



Background

China, where the origin of tea (Camellia sinensis (L.) Kuntze), is the first country to discover and use tea in the world. With the long-term natural evolution and artificial selection, China now owns tremendous tea plant resources, including seed resources and cultivated varieties (Xu et al. 2017). The manufacturing process is among the most crucial factors affecting tea quality, and it substantially determines both the types and relevant chemical constituents of tea. According to their manufacturing process, tea is classified into six types, green tea, yellow tea, white tea, oolong tea, black tea and dark tea (Xu et al. 2017). Catechins and alkaloids are considered to be the major bioactive chemicals in all tea types. Therefore, tea exhibits numerous bioactivities, such as antioxidant, antimicrobial, anti-cancer, anti-inflammatory, and anti-hyperglycemic activity (Liu et al. 2017).

Dried tea leaves are used not only for beverages but also as an additive to various kinds of food, especially in the form of ground powder. Tea powder is a new type of tea product developed on the basis of superfine crushing technology, which can crush tea leaves into powder with particle size below 1 μm ~ 10 μm and has the characteristics of micronization (Talib Hamzah et al. 2022). It is reported that superfine grinding of green tea could markedly increase the extraction of total polysaccharides, leading to an improvement of antioxidant activity against hydroxyl radicals (•OH) (Hu et al. 2012). Adding a certain amount of matcha in cake production, the fresh tea flavour can not only reduce the sweetness of the cake but also make the cake have certain health-care functions (Wei et al. 2023). Fresh noodles with a distinct aroma of rice crust could be realised by adding large-leaf yellow tea powder (Wang et al. 2023).

Nevertheless, previous studies on tea powder have mostly focused on optimizing its process as an additive, and have mostly focused on green tea powder. The knowledge of other tea types remains unclear, therefore, our study explores the sensory quality, non-volatile and volatile quality components, and antioxidant activity of different types of TP, which could provide necessary support for the food industry and essential information for consumers when choosing tea powder.

Materials and methods

Experimental materials

Matcha TP, Huangjinya green TP, oolong TP, black TP, Pu-erh TP raw materials are from Jiangsu Xinpin Tea Industry Co., Ltd. The production date was from May 2020 to October 2020.

Analysis of taste profile of tea infusions

The taste profile of green tea infusion was measured by the Insent taste system (Sartorius BSA124S-electronic balance Technology Inc.). The tea infusion was cooled to 25° C in the water bath for taste analysis according to the previous work (Xu et al. 2017).

Sensory evaluation

The tea sensory quality was assessed by 3 professional tea tasters from the Department of Tea Science at Jiangsu Academy of Agricultural Sciences, using the 100-score tea powder quality grading system according to the China National Standard (GB/T 8313–2018), in which appearance, liquor colour, aroma and taste accounts for 10%, 20%, 35% and 35%, respectively. 0.6 g tea powder of each sample was extracted with 150 mL freshly boiled distilled water for 3 min. Tea infusions were individually presented in white porcelain bowls. Panelists were instructed to smell and drink tea infusions and pause for 30 s between samples.

Measurement of amino acid, tea polyphenols, catechins and other quality components

The multiple reaction monitoring (MRM) mode was used to analyse the amino acids. The LC–MS/MS analysis was conducted using the UPLC-TQS system (Waters Corporation, Milford, MA, USA) in combination with the 5500 Q Trap mass spectrometer (AB SCIEX, Framingham, MA, USA). Amino acids were separated by chromatography using the Acquity UPLC BEH C18 column (100 × 2.1 mm, 1.7 μm, Waters Corporation, Milford, MA, USA). Water containing 0.1% (v/v) formic acid and acetonitrile were used as mobile phases A and B, respectively. Chromatographic elution settings included 0–3 min: 1% B; 3–6 min: 1% -4% B; 6–7.5 min: 4% -90% B; 7.5–9.3 min: 90% B; 9.3–9.4 min: 90% B-1% B; 9.4–12 min: 1% B. Next, the flow rate, column temperature as well as injection volume were predetermined at 0.30 mL/min, 40 °C, and 1 μL, respectively. In addition, mass spectrometer and electrospray ionization parameters were set following the methodology described by Wang et al. (2018) MultiQuant software (SCIEX, Framingham, MA, USA) was used for chromatographic peak extraction and quantitative analysis.

The total polyphenol content was assessed according to the China National Standard (GB/T 8313–2018). Soluble sugar content was determined by anthrone—sulfuric acid colourimetric method (Bai et al. 2023).

The concentrations of GA, caffeine (CAF) and catechins in tea infusions were determined by HPLC (Agilent-1260 High Performance Liquid Chromatography, Germany) detection (Xu et al. 2017). The samples were filtered through a 0.45 μm Millipore filter before injection and separated as follows: Agilent TC-C18 column (4.6 mm × 250 mm,5 μm; Agilent Technologies); column temperature 35 °C; post-run time 5 min; injection volume 5 μL; flow rate 0.8 mL min^{-1}; detection wavelength 278 nm. The mobile phases were A: 0.1% acetic acid; B: 100% acetonitrile. The elution solvent was initially 20% B, then ramped linearly to 25% B at 6 min, held at 30% B until 13 min, then ramped back to 20% B at 30 min.

All the standard reagents, including gallocatechin (GC), catechin (C), epigallocatechin (EGC), epigallocatechin gallate (EGCG), epicatechin (EC), gallocatechin gallate (GCG), epicatechin gallate (ECG), catechin gallate (CG) were purchased from Shanghai Yuanye Biotechnology Co., Ltd.

Measurement of volatile compounds

Based on the previously modified headspace-solid phase microextraction (HS-SPME) method (Yang et al., 2007), volatile compounds were directly extracted from each sample and identified by TRACE-DSQ-II GC–MS (Thermo Fisher Scientific, USA). Briefly, in a 10 mL headspace vial, 2 g of each sample crushed by liquid nitrogen was first brewed with 10 mL boiling water and immediately sealing the vial. After fixing the polydimethylsiloxane/divinylbenzene (PDMS/DVB) fiber on its upper end, the headspace vial was kept in a 60 °C water bath for 60 min to absorb the volatile gases, followed by taking the fiber out of the vial and instantly inserting it into the GC's entryway for aroma analysis. The fiber was desorbed for 5 min at 250 °C in between injections. The mass spectrometric identification was performed on the chromatographic detection system equipped with a TG-5MS column (30 m × 0.25 mm i.d. × 0.25 μm film thickness, Thermo Fisher) under the following conditions: GC oven temperature was programmed as follows: For 30 m column, 40 °C (hold 2 min) to 120 °C at 4 °C/min to 260 at 30 °C/min; for 60 m column, 40 °C (hold 5 min) to 200 °C at 5 °C/min then to 280 °C at 10 °C/min (hold 10 min); The mass selective detector was operated in positive EI mode with a mass scan range from m/z 45 to 500 at 70 eV. The quantitative analysis was performed by peak area normalization method using the NIST spectral library data processing system to obtain the percentage content of each compound in the volatile components of tea leaves.

Comparative analysis of Antioxidant capacity

The 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging activity was carried out following the procedure reported by Pavlović (Pavlović et al. 2020). 100 μL tea infusion or Trolox standard was added to 3.9 mL of a DPPH stock solution ($6 * 10^{-5}$ M) and the reaction was left for 2 h in the dark at room temperature. The absorbance of the reaction mixture was determined at 515 nm.

The $ABTS^{\cdot+}$ scavenging activity (ABTS) assay was conducted according to the procedure described by Łepecka (Łepecka et al. 2023). The ABTS radical cation ($ABTS^{\cdot+}$) was formed by reaction of an ABTS stock solution (7 mM) with potassium persulfate (2.45 mM) in equal volumes and leaving the mixture in the dark for 12–16 h before use. Aliquots (1 mL) of the $ABTS^{+}$ solution were diluted with 35 mL of methanol to an absorbance of 0.70 (±0.02) at 734 nm. The dilute $ABTS^{\cdot+}$ solution (2 mL) was mixed with 20 µL of the tea infusions, and the mixtures were allowed to equilibrate for 7 min before absorbance was determined at 734 nm.

The superoxide anion (O^{2-}.) assay was conducted according to the procedure described by Chih et al. (2005). 500 µL tea infusion was added to 3.5 mL of pH 7.8 tris–HCL and the reaction was left for 30 min in the dark at room temperature.

Statistical analysis

The differences among different types of TP were tested by one-way ANOVA using SPSS 22.0; Figures were made by Origin 2022; TB tools was used to plot the heatmap of the non-volatile compound content; MetaboAnalyst tool software was carried out for PLS-DA (Partial least squares discriminant analysis) analysis.

Results and discussion

Sensory quality analysis of different types of tea powder

The sensory evaluation results revealed that matcha TP > Huangjinya green TP > Pu-erh TP > Black TP > Oolong TP (Table 1). In terms of appearance, five kinds of tea powder had the characteristics of fine, uniform, pure and good tenderness (Table S1). In addition, matcha TP had the highest score of fresh colours. Liquor colour showed that oolong TP and black TP scored lower. In terms of aroma, oolong TP had a slightly floral aroma, Pu-erh TP showed a unique stale flavor, and matcha had a high score due to its fresh green appearance colour and prominent aroma with seaweed aroma. The characteristics of Huangjinya green TP were similar with green power, but its colour was more brighter.

The results of sensory attributes revealed bitterness, astringency, saltiness, umami and richness were significantly different, and the response values of the sensors for umami and saltiness were relatively large, while the response values of the sensors for sweetness and aftertaste-astringency almost overlapped (Fig. 1A&B). Which indicated that the content of compounds related to umami and saltiness was higher, and there was a certain correlation between sweetness and aftertaste-astringency.

Principal component analysis (PCA) showed that the variance contribution rate of PC1 and PC2 were 74.1% and 22.6%, respectively. Indicating that the information extraction of taste components of five tea samples by electronic tongue was relatively complete (Fig. 2). And the data points of oolong TP and Huangjinya green TP were close to those of matcha TP, indicating that the taste compounds of these three kinds of tea powder were similar. It showed that the extent of fermentation might be an important factor affecting the taste compounds of tea powder (Ye et al. 2022).

Table 1 Sensory quality of different types of tea powder

Evaluate items	Matcha	Huangjinya green TP	Oolong TP	Black TP	Pu-erh TP
					
Appearance (10%)	94.67±0.58a	91.67±0.58b	87.67±1.15c	91.33±0.58b	91.33±1.15b
Liquor colour (20%)	92.33±0.58a	90.78±0.92b	85.82±0.67d	88.83±0.76c	92.17±0.29a
Aroma (35%)	92.75±0.35a	90.63±0.76c	86.67±1.15d	86.76±0.80d	91.34±0.86b
Taste (35%)	92.37±0.85a	88.43±1.00d	87.47±1.11c	89.73±0.32b	90.77±0.67b
Total score	92.72±1.13a	91.30±0.89b	86.88±0.34e	88.67±0.43d	90.00±1.61c

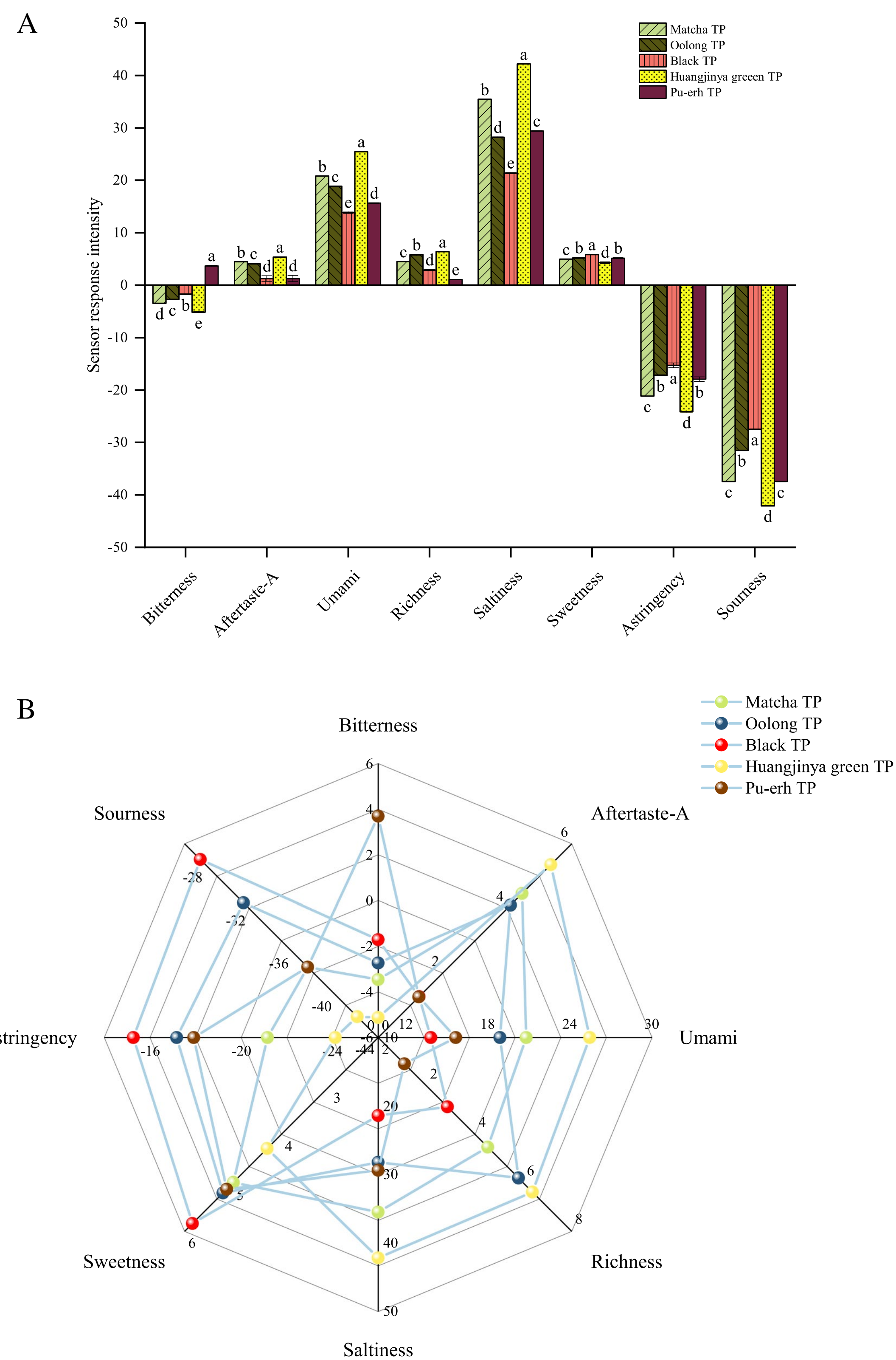


Fig. 1 Analysis of response intensity of electronic tongue of different tea powder. Note: Different lowercase letters indicate significant differences in similar substances ($P < 0.05$). **A** radar of electronic tongue analysis. **B** Response value of electronic tongue sensor for different types of TP

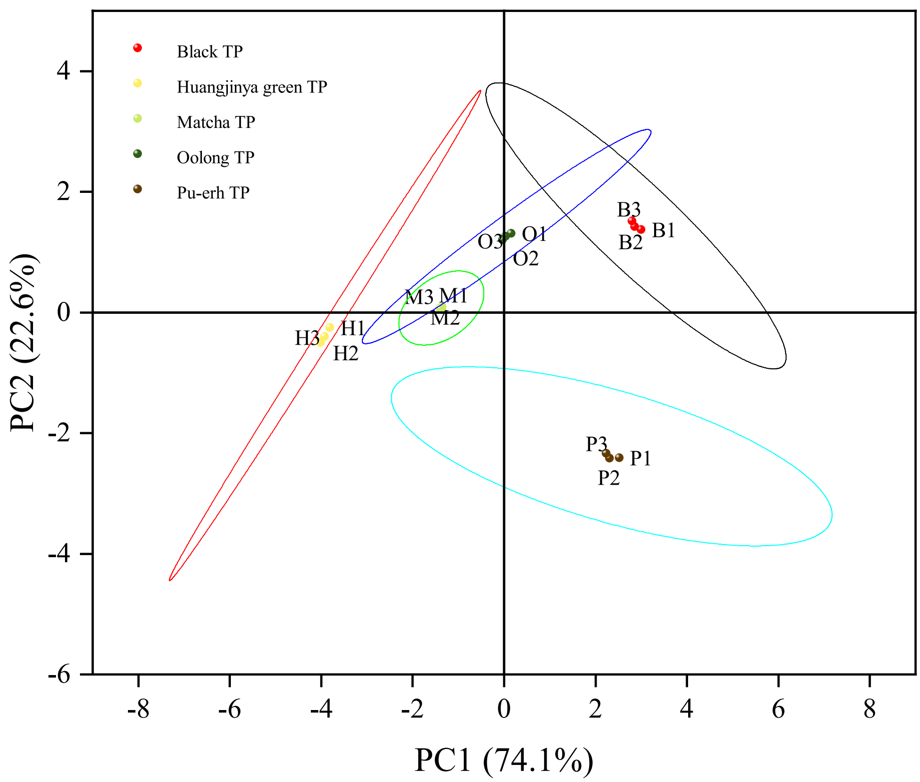


Fig. 2 Analysis of electronic tongue response value of different types of tea powder by PCA diagram

In order to explore the taste characteristics of different tea powders, the correlation between the response value of the electronic tongue sensor and the taste sensory evaluation score was analyzed (significant R ≥ 0.8, Table 2). The results showed that the umami had a significant positive correlation with Huangjinya green TP (R = 0.993). The taste score of black TP was significantly correlated with sweetness (R = 0.986). For oolong TP, aftertaste-bitterness (R = -0.991) was negatively correlated with the taste score. Bitterness (R = -0.988) and sourness (R = -0.997) were negatively correlated with the taste score of Pu-erh TP, while aftertaste-bitterness (R = 0.959) was positive with the taste score. The results of correlation analysis suggest that sweetness was conducive to the formation of taste in black TP, aftertaste-bitterness was conducive to the taste of matcha and Pu-erh TP, and umami might be an important contribution factor to the mellow taste of Huangjinya green TP. A recent study reported that taste was an important factor affecting the quality of tea and was influenced by various components cooperate and coordinate with each other (Sun et al. 2023). In addition, studies have shown that compounds such as tannins and tea polyphenols can stimulate saliva secretion, leading to oral astringency in humans (Rossetti et al. 2008); And the complex of caffeine with amino acids and tea polyphenols is beneficial for the formation of tea infusion flavor (Liang et al. 2021).

Table 2 Analysis of correlation between sensory score of taste

Taste	Matcha	Huangjinya green TP	Oolong TP	Black TP	Pu-erh TP
Sweetness	-0.782	-0.580	-0.743	0.986*	-0.782
Umami	0.583	0.993*	0.791	-0.500	-0.583
Richness	-0.647	-0.809	0.971	-0.637	-0.647
Bitterness	-0.988*	0.305	0.586	-0.721	-0.988*
Astringency	-0.779	-0.105	0.570	-.656	-0.779
Aftertaste-A	-0779	0.591	0.566	0.045	-0779
Aftertaste-B	0.959*	0.297	-0.991	0.629	0.959*
Saltiness	0.755	0.906	0.948	-0.817	0.755
Sourness	-0.997*	-0.914	0.507	0.610	-0.997*

*Indicates significant differences at $p<0.05$

Analysis of non-volatile quality components of different types of tea powder

The total polyphenol content was higher in matcha and oolong TP compared to Huangjinya green TP, black TP and Pu-erh TP. The soluble sugar content showed that black TP had the highest value whilst Pu-erh TP had the lowest value, which was consistent with the response value of the electronic tongue sweetness.

Catechins were polyphenols with flavanol skeleton, which was an important flavour substance in tea and an important contributor to the bitterness and astringency of tea (Ye et al. 2022). During tea processing, catechin monomers could continuously convert into catechin derivatives under the influence of heat (Fan et al. 2016). Our results showed that eight catechin monomers were detected in Huangjinya green TP, and the total amount of catechins displayed the highest value. However, Pu-erh TP only detected three catechin monomers, including GC, EC, GCG, and the total amount of catechins displayed the lowest value (Table 3, Fig. 3B). The hierarchical clustering heatmap revealed that black and Pu-erh TP were clustered into one category, while oolong, matcha and Huangjinya green TP were clustered into another category, indicating that the contents of catechins in black and Pu-erh TP were close, while Huangjinya green TP was close to matcha and oolong TP.

After high temperature fixation, various enzymes in the green tea were rapidly passivated and deactivated to effectively inhibit the oxidation of polyphenols, thus maximizing the retention of catechin components (Yin et al. 2022). Oolong tea was a light fermented tea, and the main enzymatic reaction occurs in the green-making process (Zhuochen et al. 2023). The catechin components concentrated in the vacuole were in contact with enzymes such as polyphenol oxidase in the cytoplasmic matrix, and the content of tea polyphenols and catechins decreases (Gonçalves Bortolini et al. 2021). However, compared with the completely fermented black TP and the pile fermented Pu-erh TP, the oxidation degree of polyphenols in oolong TP was relatively low. This indicated that the degree of fermentation might be an important factor in distinguishing the catechin components of different types of tea powder (Chen et al. 2022).

Among the five kinds of tea powder, ECG, EGC, EGCG and CAF were clustered into one group, whereas CG, C, EC, GCG, GA and GC were clustered into another group. Our results showed that except for the GC content, the contents of ester catechins (ECG, EGC, EGCG) in black and Pu-erh TP were significantly lower than that in matcha, oolong and Huangjinya green TP. Previous research suggested that during the fermentation process, ester catechins were degraded to form simple catechins, which could further oxidize to tea pigments, resulting in the formation of unique Liquor colours (Jiang et al., 2020).

Amino acid was an important flavoring substance, which made significant contribution to the umami and sweetness of tea infusion, it was also a key precursor of tea aroma (Qiao et al. 2021). The taste of tea infusion was determined by the quality and quantity (type and proportion) of various amino acids (Zhou et al. 2022a, 2022b). Our results showed that total amino acid content of green tea powder was significantly higher than that of other tea powder (Table 4, Fig. 3A). Moreover, a total of 22 amino acids were detected from the five tea powder samples, theanine and glutamic acid were dominated. The hierarchical clustering heatmap analysis of different types of TP could be divided into two categories according to the content. The first category was matcha TP and Huangjinya green TP. As a yellow albino tea variety, Huangjinya had a particularly high amino acid content, and could be as high as 7% -10% (dry matter weight), which is 2–3 times that of normal tea leaves (Zhou et al. 2022a, 2022b). Therefore, the amino acid content of

Table 3 Contents of the main biochemical component of different types of tea powder

Component	Matcha	Huangjinya green TP	Oolong TP	Black TP	Pu-erh TP
Soluble Sugar(mg/g)	27.84±0.05^{b}	19.80±0.11^{c}	19.32±0.01^{c}	42.96±0.10^{a}	8.09±0.03^{d}
GC(mg/g)	1.09±0.02^{d}	0.35±0.02^{e}	9.18±0.04a	8.09±0.04^{b}	7.84±0.02^{c}
EGC(mg/g)	9.45±0.09^{a}	7.39±0.05^{c}	8.75±0.09^{b}	0.54±0.^{01d}	/
C(mg/g)	0.53±0.01^{a}	0.35±0.03^{b}	0.53±0.01^{a}	/	/
EGCG(mg/g)	32.86±0.07^{a}	22.57±0.17^{b}	20.78±0.07^{c}	1.53±0.01^{d}	/
EC(mg/g)	0.57±0.01^{c}	6.09±0.01^{a}	1.00±0.02^{b}	/	0.26±0.02^{d}
GCG(mg/g)	2.59±0.01^{a}	0.64±0.02^{c}	2.55±0.10^{a}	/	1.26±0.05^{b}
ECG(mg/g)	9.29±0.09^{c}	16.24±0.13^{a}	10.38±0.03^{b}	0.65±0.02^{d}	/
CG(mg/g)	/	1.12±0.09^{a}	/	/	/
Total Catechin(mg/g)	56.49±0.16^{a}	53.63±0.08^{b}	53.17±1.05^{c}	10.81±0.02^{d}	9.36±0.08^{e}
Polyphenols(%)	13.34±0.14^{a}	11.14±0.09^{b}	13.03±0.28^{a}	6.07±0.19^{c}	5.09±0.19^{d}
GA(mg/g)	0.65±0.01^{d}	0.20±0.01^{e}	1.04±0.01^{a}	0.86±0.01^{c}	0.92±0.01^{b}
Caffeine(%)	2.48±0.04^{a}	2.68±0.02^{a}	2.06±0.04^{b}	1.22±0.01^{c}	2.68±0.02^{a}
Flavone(%)	1.01±0.01^{c}	1.16±0.02^{b}	1.19±0.05^{b}	1.00±0.03^{c}	1.81±0.01^{a}

^{a,b,c,d,e} Different letters in the same row indicate significant differences between mean values (p<0.05)

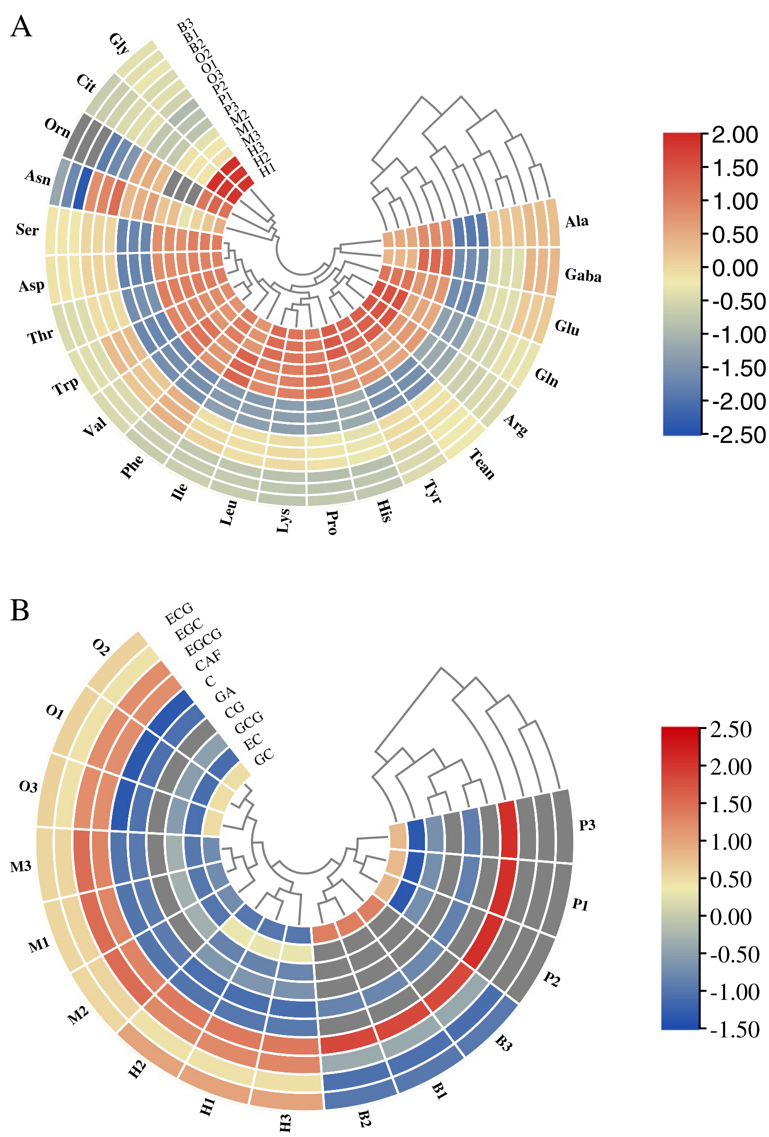


Fig. 3 HCA analysis of the main quality components of the samples in different types of tea powder. Note **A** Cluster analysis of amino acid components **B** Cluster analysis of catechin components and caffeine

Huangjinya green TP was significantly higher than that of other TPs. Matcha TP was clustered with Huangjinya green TP because of its high content of umami amino acids (glutamic acid, aspartic acid, proline) and sweet amino acids (serine, glycine, alanine) (Poojary et al. 2017). In addition, the content of citrulline and glycine was particularly prominent in Huangjinya green TP. The second category included black, oolong and Pu-erh TP. The significant correlation between oolong tea powder and black tea powder might be due to the same fermentation process, amino acids were degraded into a large number of aroma components, and combined with phenols or sugars to form quinones, aldehydes, acids, alcohols and pigment compounds (Chen et al. 2022). The content of sweet amino acids such as alanine, aspartic acid and serine in black TP and oolong TP were significantly higher than that of Pu-erh TP, while the content of citrulline (bitter amino acid) is significantly lower than that. In addition, the total amount of amino acid components in Pu-erh TP was only one percent of that in Huangjinya green TP, and the content of each amino acid component was the lowest except asparagine and ornithine, which may be related to the pile fermentation process. During the pile fermentation process, amino acids are continuously consumed by microorganisms, On the other hand, the pile fermentation process is under high temperature

Table 4 Contents of amino acid component of different types of tea powder

Amino Acid(ug/g)	Matcha TP	Huangjinya green TP	Oolong TP	Black TP	Pu-erh TP
Tean	4702.400 ± 8.65[b]	25,440.000 ± 4.15[a]	1218.400 ± 5.34[c]	944.000 ± 5.63[d]	62.200 ± 2.19[e]
Glu	2240.000 ± 9.87[b]	4272.000 ± 9.45[a]	363.360 ± 0.97[d]	430.240 ± 5.12[c]	43.904 ± 1.31[e]
Asp	2180.800 ± 8.39[b]	2561.600 ± 8.19[a]	538.880 ± 0.67[c]	390.240 ± 9.54[d]	27.216 ± 1.05[e]
Gln	339.840 ± 3.44[b]	2331.200 ± 16.79[a]	46.960 ± 0.31[d]	67.616 ± 1.08c	9.805 ± 0.12[e]
Ser	606.720 ± 3.11[b]	840.800 ± 9.60[a]	149.264 ± 0.56[c]	112.704 ± 1.23[d]	7.837 ± 0.14[e]
Thr	393.280 ± 4.42[b]	398.880 ± 1.02[a]	127.280 ± 0.63[c]	86.480 ± 0.75[d]	26.608 ± 1.13[e]
Pro	179.520 ± 2.41[a]	161.120 ± 2.05[b]	58.064 ± 0.65[c]	33.456 ± 1.03[d]	21.200 ± 0.23[e]
Ala	575.680 ± 1.65a	286.400 ± 1.10[b]	143.968 ± 0.87[d]	180.160 ± 0.88[c]	1.017 ± 0.05[e]
Arg	1193.920 ± 2.70[b]	5932.800 ± 7.21[a]	103.616 ± 1.12c	108.912 ± 0.87[c]	26.752 ± 0.81[d]
Lys	255.200 ± 1.47[b]	308.000 ± 3.15[a]	55.360 ± 0.66[c]	18.896 ± 0.61[d]	7.797 ± 0.09[e]
Val	228.320 ± 9.32[a]	160.480 ± 1.48[b]	93.760 ± 1.06[c]	50.864 ± 0.78[d]	16.896 ± 0.65[e]
GABA	253.440 ± 0.91[a]	135.408 ± 1.16[b]	76.288 ± 1.03[c]	134.400 ± 0.47[b]	32.912 ± 0.23[d]
Ile	203.360 ± 1.98[a]	145.856 ± 2.41[b]	90.768 ± 0.49[c]	62.224 ± 0.91[d]	40.160 ± 1.22e
Asn	16.512 ± 0.64[b]	16.896 ± 0.45[b]	17.968 ± 0.48[a]	12.848 ± 0.98[c]	16.896 ± 0.34[b]
Cit	23.312 ± 0.32[b]	60.688 ± 1.10[a]	20.832 ± 0.50[c]	18.448 ± 0.41[d]	17.712 ± 0.[23e]
Tyr	204.800 ± 2.04[b]	287.200 ± 4.32[a]	120.464 ± 1.16[c]	90.944 ± 0.87[d]	46.064 ± 0.55[e]
Orn	/	5.894 ± 0.68[a]	4.514 ± 0.21[b]	/	5.538 ± 0.24
Phe	162.560 ± 1.34[b]	217.920 ± 0.91[a]	116.496 ± 0.47[c]	37.504 ± 1.21[d]	13.637 ± 0.59[e]
His	125.488 ± 0.15[b]	244.000 ± 1.35[a]	38.800 ± 0.65[c]	22.864 ± 0.21[d]	14.368 ± 0.52[e]
Leu	172.800 ± 1.12[b]	235.200 ± 0.80[a]	71.312 ± 0.69[c]	41.696 ± 1.10[d]	23.280 ± 1.36[e]
Trp	238.560 ± 1.66[a]	223.680 ± 1.62[a]	129.648 ± 0.74[b]	62.272 ± 0.80[c]	16.912 ± 0.33[d]
Gly	34.208 ± 1.52[b]	68.016 ± 0.87[a]	32.112 ± 0.95[c]	32.096 ± 0.59[c]	27.856 ± 0.78[d]
Total Amino Acid (mg/g)	14.331 ± 4.32[b]	44.334 ± 6.35[a]	3.618 ± 6.32[c]	2.939 ± 1.53[d]	0.507 ± 1.32[e]

[a,b,c,d,e] Different letters in the same row indicate significant differences between mean values (*p*<0.05)

and high humidity conditions, which is conducive to the production of nitrite. Nitrite can react with amino acids to form corresponding hydroxyl acids, resulting in a decrease in amino acid content(Li et al. 2022).

PLS-DA analysis was performed on the amino acid components of different types of TP, and a PLS-DA model with supervised mode was established. The classification Y matrix variables were randomly arranged for 100 times for permutation test (Fig. 4A), where R2 = 0.83358, Q2 = 0.75316, P1 < 0.01, indicating that there was no overfitting phenomenon in the built model. It could discriminate the amino acid components of different types of TP. With variable VIP > 1 in the PLS-DA model, the corresponding variables could be defined as the key variables of the discriminant model, and the influence on the sample classification was statistically significant, which could be used as a differential marker. The VIP value showed that theanine, glutamic acid and arginine were the main iconic components affecting the amino acid components of different types of TP. The difference of theanine in different types of TP was the most significant, and the VIP value reached 4 (Fig. 4B).

Analysis of volatile quality components of different types of tea powder

Aroma was an important attribute affecting the quality of tea, which was mainly determined by the volatile substances in tea (Bai et al. 2023). Totally 153 volatile compounds were identified in the tea powders (Fig. 5). 40 volatile compounds were identified in matcha, 50 in Huangjinya green TP, 65 in Pu-erh TP, 52 in black TP and 54 in oolong TP. The total volatile concentration varies widely among the TP samples from the different types of processing. Pu-erh TP had the highest total volatile concentration, followed by oolong TP, black TP, Huangjinya green TP, and matcha powder. 79 compounds (≥ 1.0%) with high relative content in different samples, including 37 common components and 42 specific components (Table S2). The common components included aldehydes, alcohols, ketones, esters, acids and hydrocarbons, among which alcohols and terpenes accounted for the largest proportion. In particular, the content of terpenes in Pu-erh TP was the highest, reaching 46%. The content of alcohols in black TP and matcha powder was high, up to 16%.

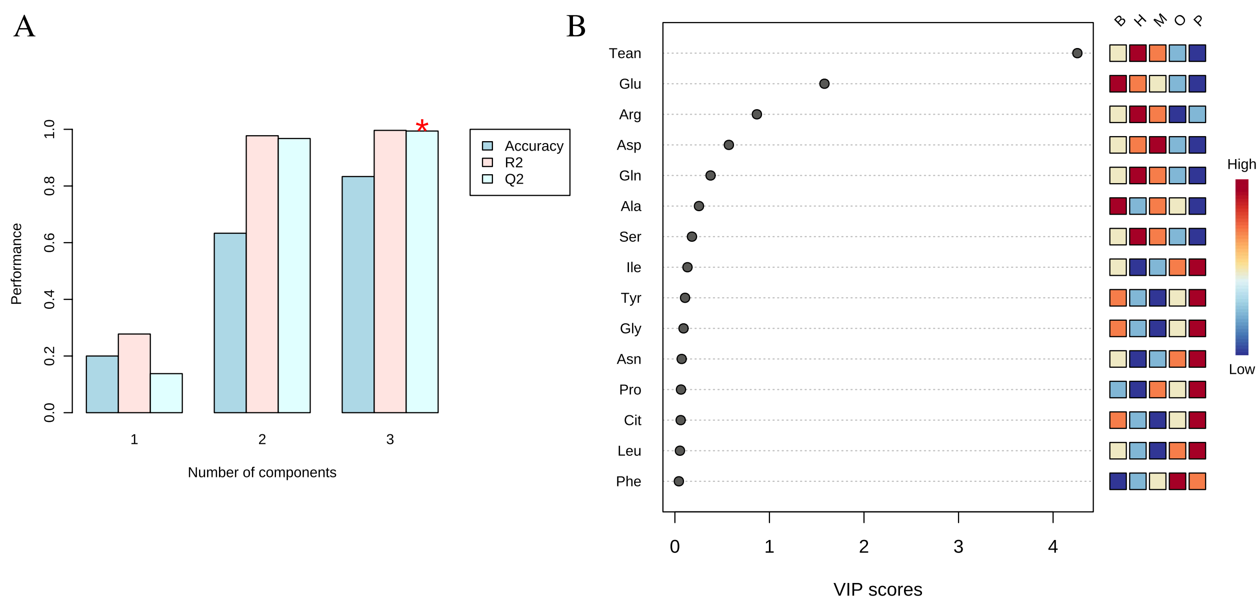


Fig. 4 PLS-DA analysis of amino acid components of the samples in different types of tea powder. Note **A** PLS-DA cross validation variance test **B** VIP plot of PLS-DA

All types of tea powders have high content of cis-linalool oxide (furan type), especially in matcha (8.78%), which was 1.03, 3.03, 5.49 and 1.19 times that of oolong TP, black TP, Pu-erh TP and Huangjinya green TP, respectively. The main aroma components of matcha powder and Huangjinya green TP with green tea as raw material include linalool, α-ionone, β-ionone, (E, E) -2,4-heptadienal, 6-methyl-5-hepten-2-one and nonanal. These compounds were mainly alcohols and ketones, and most of them showed floral, fruity or fresh, which was consistent with the results of sensory evaluation. Previous studies believed that C6 and C9 alcohols and aldehydes were the main sources of tea fresh aroma (Yin et al. 2022). These compounds such as hexanal, trans-2-octenal, 2-butyloctanol, 2,4-dimethylcyclohexanol were only detected in green TP, especially 1-penten-3-ol, which gives matcha TP a unique seaweed aroma (Huang et al. 2022). The highest content of hydrocarbon compounds was 2,2,4,6,6,6-pentamethylheptane, which was only found in oolong TP (16.47%), black TP (6.02%) and Pu-erh TP (9.68%). Trans-2-hexen-1-ol, β-cyclocitral, linalool oxide, α-farnesene, dihydroactinidiolide, and other floral-type compounds were abundance in oolong TP, which played important role in key aroma components (Qi et al. 2021). Previous studies showed the aroma substances of oolong tea were mainly formed in the process of green-making, shaking and standing (or drying) (Feng et al. 2019). Under the action of mechanical damage and water stress, the synthesis and decomposition of secondary metabolites occur, which made the content and composition of volatile substances change continuously, thus promoting the formation of floral and fruity of oolong tea (Guo et al. 2022). The aroma of black tea mainly came from the enzymatic oxidant coupling reaction of polyphenols during fermentation, the linalool and its oxides, benzaldehyde and methyl salicylate with typical floral and sweet aroma in black TP had a high level, which was consistent with the Meng's research on the formation of black tea aroma during fermentation (Meng et al. 2021). The content of 1,2, 3-trimethoxybenzene, 3,4, 5-trimethoxybenzene,3, 4-dimethoxybenzene and other aromatic compounds in Pu-erh TP were relatively high, these compounds were unique among the volatile components of Pu-erh tea and could be used to distinguish them from other teas. The aroma of Pu-erh tea is mainly formed during the fermentation and drying process. Research suggested that during the post fermentation process, the damp heat effect and microbial biotransformation lead to the hydrolysis of a large number of compounds with a fresh aroma, resulting in the complete disappearance of the coarse astringency and sun exposure, and the appearance of the delicate fragrance of stale and camphor wood (Wang et al. 2022).

Comparison of antioxidant activity of different types of tea powder

Tea contains a variety of natural bioactive components, such as tea polyphenols, tea polysaccharides, caffeine, amino acids, flavonoids, lipids and minerals (Shao et al. 2022). Therefore, tea has shown various health functions such as anti-inflammatory, anti-allergic, antioxidant,

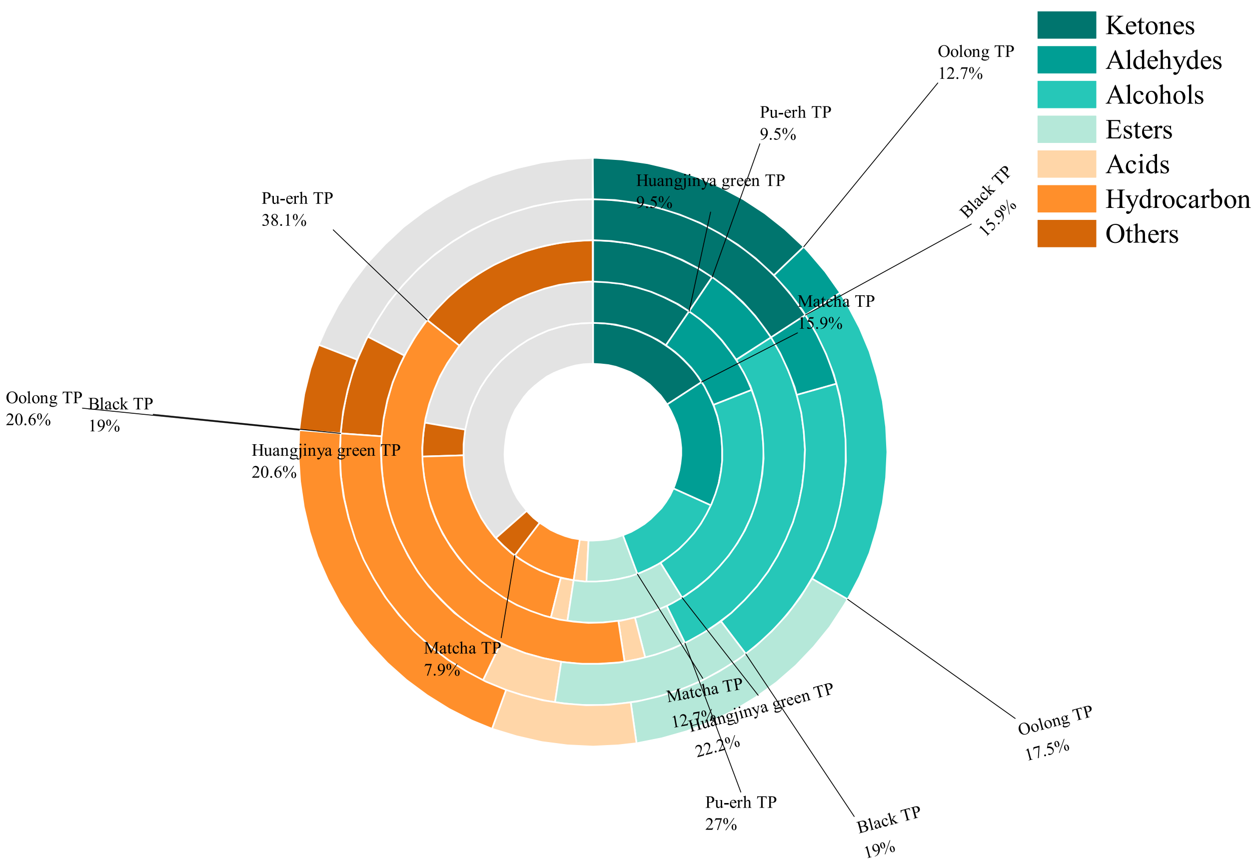


Fig. 5 The contents of different chemical classes of volatile compounds in the different types of tea powder. Note: Matcha TP, Huangjinya green TP, Pu-erh TP, black TP, Oolong TP from inside to outside

anti-cancer, antibacterial, metabolism-promoting, hypoglycemic and hypolipidemic, as well as refreshing and anti-fatigue effects (Kumar et al. 2022; Lin et al. 2021). Especially catechins, accounting for about 80% of the total tea polyphenols, can effectively scavenge oxygen free radicals and lipid free radicals, and is an ideal natural antioxidant.

DPPH, ABTS and superoxide anion radical scavenging ability were selected to measure the antioxidant activity of different types of TPs. The antioxidant capacity of different types of TPs was compared by IC50 value, the smaller the IC50 value, the greater the antioxidant capacity. In our study DPPH free radical scavenging ability of different types of TP was matcha TP > oolong TP > Huangjinya green TP > black TP > Pu-erh TP, and the scavenging ability of superoxide anion and ABTS free radical was matcha powder > oolong TP > Huangjinya green TP > Pu-erh TP > black TP (Table 5). Combined with the main chemical composition of tea powder extract, phenols in tea powder might be the main antioxidant active substances, the free radical scavenging ability is generally consistent with the order of the content of tea polyphenols and catechins.

This study showed that there were significant differences in the antioxidant strength of different types of TP. The tea polyphenols react with free radicals to generate more stable phenolic oxygen free radicals, which can inactivate free radicals. With the process of fermentation, polyphenols undergo strong oxidation and coupling, the number of phenolic hydroxyl groups decreases more (Han et al. 2022),

Table 5 Free radical scavenging ability of different types of tea powder

50% inhibiting concentration	Matcha TP	Oolong TP	Black TP	Huangjinya green TP	Pu-erh TP
DPPH•(μg/ml)	11.71 ± 0.14[e]	45.78 ± 4.41[d]	454.53 ± 1.40[b]	49.11 ± 0.55[c]	539.81 ± 1.76[a]
O_2^{-}•(μg/ml)	1.24 ± 0.34[e]	2.172 ± 0.24[d]	7.75 ± 0.46[a]	2.34 ± 0.54[c]	5.98 ± 0.23[b]
ABTS•(μg/ml)	7.11 ± 0.06[e]	26.02 ± 0.47[d]	167.13 ± 0.61[a]	50.58 ± 1.72[c]	86.09 ± 1.63[b]

[a,b,c,d,e] Different letters in the same row indicate significant differences between mean values ($p < 0.05$)

and the antioxidant capacity decreases accordingly. Therefore, the overall performance of free radical scavenging ability is unfermented > light fermentation > full fermentation, indicating a good dose–effect relationship between polyphenol content and antioxidant activity. However, due to the variety characteristics of high ammonia and low phenol, the content of tea polyphenols and catechins in Huangjinya green TP was lower than that of oolong TP, so the free radical scavenging ability was weake.

Conclusion

In summary, from the perspective of sensory quality, the overall score of unfermented TP is higher than that of fermented TP, and the colour is also brighter. And from the aspect of quality components, the non-volatile quality components and volatile components of different types of TP had accumulated and transformed to varying degrees. As unfermented TP, green TP had the highest content of catechins and amino acids, and its volatile components had a certain fresh properties. Due to its variety characteristics, the amino acid content of Huangjinya green TP was the highest, especially theanine content was 5.41 times of matcha powder. The contents of catechins, caffeine and amino acids in semi-fermented oolong TP decreased significantly compared with green TP, but a large number of compounds with floral characteristics were accumulated. The content of catechin in black TP was significantly lower than that in oolong TP, but the content of glutamic acid and γ-aminobutyric acid were increased compared with that in oolong TP, and the floral and fruity compounds were largely accumulated. Due to the stacking fermentation process, quality components of Pu-erh TP decreased significantly compared to other TPs, and its unique aroma of stale and camphor wood began to appear. And the contents of ester catechins (ECG, EGC, EGCG) in black and Pu-erh TP were significantly lower than that in light fermented TP. The analysis of amino acid components of different types of TPs showed that theanine, glutamic acid and arginine were the main signature components affecting the amino acid components of different types of TP. In addition, the determination of antioxidant activity showed that unfermented TPs were stronger than that of fermented TPs. Therefore, to maximize the health benefits and sensory attributes of different types of TP, the use of unfermented TP is recommended. However, different manufacturing process of tea powder can enrich the taste of tea foods, thus giving people more choices.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s43014-023-00198-1.

Additional file 1: Table S1. Sensory Evaluation of different types of tea powder. **Table S2.** Contents of aroma components in different types of tea powder.

Acknowledgements
Not applicable.

Authors' contributions
Yutong Ye conceived the research, wrote and edited the manuscript. Zeyi Ai,Ronglin Li and Yang Tian assisted in analytical work and compilation of data. The overall supervision was done by Yiyang Yi. All authors read and approved the final manuscript.

Authors' information
Ye Yutong is a probationer at the Jiangsu Academy of Agricultural Sciences, China. Zeyi Ai, Yiyang Yang and Ronglin Li are assistant researchers, associate researchers and fellows in the same unit. Yang Tian is a professor at Yunnan Agricultural University, China.

Funding
Supported by the Jiangsu Agricultural Science and Technology Independent Innovation Fund (CX(22)2008) and Jiangsu Province modern agricultural industrial technology system (JATS[2022]275).

Availability of data and materials
The datasets used and/ or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

Author details
[1]Institute of Leisure Agriculture, Jiangsu Key Laboratory for Horticultural Crop Genetic Improvement, Jiangsu Academy of Agricultural Sciences, Nanjing 210014, China. [2]College of Food Science and Technology, Yunnan Agricultural University, Kunming 650201, China.

Received: 9 May 2023 Accepted: 5 November 2023
Published online: 07 March 2024

References

Bai, F., Chen, G., Niu, H., Zhu, H., Huang, Y., Zhao, M., Hou, R., Peng, C., Li, H., Wan, X., & Cai, H. (2023). The types of brewing water affect tea infusion flavor by changing the tea mineral dissolution. *Food Chemistry: X, 18*, 100681. https://doi.org/10.1016/j.fochx.2023.100681

Chen, Q., Zhu, Y., Liu, Y., Liu, Y., Dong, C., Lin, Z., & Teng, J. (2022). Black tea aroma formation during the fermentation period. *Food Chemistry, 374*, 131640. https://doi.org/10.1016/j.foodchem.2021.131640

Chih, T., Jao, H.-J., & Wang, C. M. (2005). Glucose sensing based on an effective conversion of O2 and H2O2 into superoxide anion radical with clay minerals. *Journal of Electroanalytical Chemistry, 581*(2), 159–166. https://doi.org/10.1016/j.jelechem.2004.12.018

Fan, F.-Y., Shi, M., Nie, Y., Zhao, Y., Ye, J.-H., & Liang, Y.-R. (2016). Differential behaviors of tea catechins under thermal processing: Formation of non-enzymatic oligomers. *Food Chemistry, 196*, 347–354. https://doi.org/10.1016/j.foodchem.2015.09.056

Feng, Z., Li, Y., Li, M., Wang, Y., Zhang, L., Wan, X., & Yang, X. (2019). Tea aroma formation from six model manufacturing processes. *Food Chemistry, 285*, 347–354. https://doi.org/10.1016/j.foodchem.2019.01.174

Gonçalves Bortolini, D., Windson Isidoro Haminiuk, C., Cristina Pedro, A., de Andrade Arruda Fernandes, I., & Maria Maciel, G. (2021). Processing, chemical signature and food industry applications of Camellia sinensis teas: An overview. *Food Chemistry, 12*, 100160.

Guo, X., Schwab, W., Ho, C.-T., Song, C., & Wan, X. (2022). Characterization of the aroma profiles of oolong tea made from three tea cultivars by both GC–MS and GC-IMS. *Food Chemistry, 376*, 131933. https://doi.org/10.1016/j.foodchem.2021.131933
Han, S., Wang, Y., Fang, Z., Zhang, Y., Zeng, W., Karrar, E., Zhang, H., Jin, Q., Wu, G., & Wang, X. (2022). Effect of olive polyphenols on lipid oxidation of high-fat beef during digestion. *Food Research International, 161*, 111843. https://doi.org/10.1016/j.foodres.2022.111843
Hu, J., Chen, Y., & Ni, D. (2012). Effect of superfine grinding on quality and antioxidant property of fine green tea powders. *LWT - Food Science and Technology, 45*(1), 8–12. https://doi.org/10.1016/j.lwt.2011.08.002
Huang, Y., Goh, R. M. V., Pua, A., Liu, S. Q., Sakumoto, S., Oh, H. Y., Ee, K. H., Sun, J., Lassabliere, B., & Yu, B. (2022). Effect of three milling processes (cyclone-, bead- and stone-millings) on the quality of matcha: physical properties, taste and aroma. *Food Chemistry, 372*, 131202. https://doi.org/10.1016/j.foodchem.2021.131202
Jiang, C.-L., Dai, J.-X., Han, H.-L.,Wang, C., Zhu, L., Lu, C.-Y., & Chen, H.-P. (2020). Determination of thirteen acidic phytohormones and their analogues in tea (Camellia sinensis) leaves using ultra high performance liquid chromatography tandem mass spectrometry. *Journal of Chromatography B, 1149*, 122144. https://doi.org/10.1016/j.jchromb.2020.122144
Kumar, V., Kaur, R., Aggarwal, P., & Singh, G. (2022). Underutilized citrus species: An insight of their nutraceutical potential and importance for the development of functional food. *Scientia Horticulturae, 296*, 110909. https://doi.org/10.1016/j.scienta.2022.110909
Łepecka, A., Szymański, P., Okoń, A., & Zielińska, D. (2023). Antioxidant activity of environmental lactic acid bacteria strains isolated from organic raw fermented meat products. *LWT, 174*, 114440. https://doi.org/10.1016/j.lwt.2023.114440
Li, Y., Hao, J., Zhou, J., He, C., Yu, Z., Chen, S., Chen, Y., & Ni, D. (2022). Pile-fermentation of dark tea: conditions optimization and quality formation mechanism. *LWT, 166*, 113753. https://doi.org/10.1016/j.lwt.2022.113753
Liang, S., Granato, D., Zou, C., Gao, Y., Zhu, Y., Zhang, L., Yin, J.-F., Zhou, W., & Xu, Y.-Q. (2021). Processing technologies for manufacturing tea beverages: From traditional to advanced hybrid processes. *Trends in Food Science & Technology, 118*, 431–446. https://doi.org/10.1016/j.tifs.2021.10.016
Lin, J.-F., Wei, X.-L., Liu, H.-Y., Li, H., Xia, Y., Wu, D.-T., Zhang, P.-Z., Gopalsamy R.-G., Li, H.-B., & Gan, R.-Y. (2021). State-of-the-art review of dark tea: From chemistry to health benefits. *Trends in Food Science & Technology, 109*, 126–138. https://doi.org/10.1016/j.tifs.2021.01.030
Liu, S., Ai, Z., Qu, F., Chen, Y., & Ni, D. (2017). Effect of steeping temperature on antioxidant and inhibitory activities of green tea extracts against α-amylase, α-glucosidase and intestinal glucose uptake. *Food Chemistry, 234*, 168–173. https://doi.org/10.1016/j.foodchem.2017.04.151
Meng, T., Zhipeng, X., Ai, H., Jiayu, C., Tianji, Y., & Zhengquan, L. (2021). Effect of 1–20 years storage on volatiles and aroma of Keemun congou black tea by solvent extraction-solid phase extraction-gas chromatography-mass spectrometry. *LWT, 136*, 110278. https://doi.org/10.1016/j.lwt.2020.110278
Pavlović, T., Dimkić, I., Andrić, S., Milojković-Opsenica, D., Stanković, S., Janaćković, P., Gavrilović, M., & Ristivojević, P. (2020). Linden tea from Serbia – an insight into the phenolic profile, radical scavenging and antimicrobial activities. *Industrial Crops and Products, 154*, 112639. https://doi.org/10.1016/j.indcrop.2020.112639
Poojary, M. M., Orlien, V., Passamonti, P., & Olsen, K. (2017). Enzyme-assisted extraction enhancing the umami taste amino acids recovery from several cultivated mushrooms. *Food Chemistry, 234*, 236–244. https://doi.org/10.1016/j.foodchem.2017.04.157
Qi, D., Miao, A., Chen, W., Wang, W., He, X., & Ma, C. (2021). Characterization of the volatile compounds profile of the innovative broken oolong-black tea in comparison with broken oolong and broken black tea. *Food Control, 129*, 108197. https://doi.org/10.1016/j.foodcont.2021.108197
Qiao, D., Mi, X., An, Y., Xie, H., Cao, K., Chen, H., Chen, M., Liu, S., Chen, J., & Wei, C. (2021). Integrated metabolic phenotypes and gene expression profiles revealed the effect of spreading on aroma volatiles formation in postharvest leaves of green tea. *Food Research International, 149*, 110680. https://doi.org/10.1016/j.foodres.2021.110680
Rossetti, D., Yakubov, G. E., Stokes, J. R., Williamson, A.-M., & Fuller, G. G. (2008). Interaction of human whole saliva and astringent dietary compounds investigated by interfacial shear rheology. *Food Hydrocolloids, 22*(6), 1068–1078. https://doi.org/10.1016/j.foodhyd.2007.05.014
Shao, J., Wei, Y., & Wei, X. (2022). A comprehensive review on bioavailability, safety and antidepressant potential of natural bioactive components from tea. *Food Research International, 158*, 111540. https://doi.org/10.1016/j.foodres.2022.111540
Sun, L., Zhang, S., Li, Q., Yuan, E., Chen, R., Yan, F., Lai, X., Zhang, Z., Chen, Z., Li, Q., & Sun, S. (2023). Metabolomics and electronic tongue reveal the effects of different storage years on metabolites and taste quality of Oolong Tea. *Food Control, 152*, 109847. https://doi.org/10.1016/j.foodcont.2023.109847
Talib Hamzah, H., Sridevi, V., Seereddi, M., Suriapparao, D. V., Ramesh, P., Sankar Rao, C., Gautam, R., Kaka, F., & Pritam, K. (2022). The role of solvent soaking and pretreatment temperature in microwave-assisted pyrolysis of waste tea powder: Analysis of products, synergy, pyrolysis index, and reaction mechanism. *Bioresource Technology, 363*, 127913. https://doi.org/10.1016/j.biortech.2022.127913
Wang, J., Wang, Y., Cheng, J., Wang, J., Sun, X., Sun, S., & Zhang, Z. (2018). Enhanced cross-category models for predicting the total polyphenols, caffeine and free amino acids contents in Chinese tea using NIR spectroscopy. *LWT, 96*, 90–97. https://doi.org/10.1016/j.lwt.2018.05.012
Wang, Z.-C., Li, Y.-H., Qian, C., Feng, B., Xiong, G.-Y., Jiang, J., & Chen, Q. (2023). Processing quality and aroma characteristics of fresh noodles intermingled with large leaf yellow tea powder. *LWT, 174*, 114391. https://doi.org/10.1016/j.lwt.2022.114391
Wang, Z., Su, D., Ren, H., Lv, Q., Ren, L., Li, Y., & Zhou, H. (2022). Effect of different drying methods after fermentation on the aroma of Pu-erh tea (ripe tea). *LWT, 171*, 114129. https://doi.org/10.1016/j.lwt.2022.114129
Wei, R., Qian, L., Kayama, K., Wu, F., Su, Z., & Liu, X. (2023). Cake of Japonica, Indica and glutinous rice: Effect of matcha powder on the volatile profiles, nutritional properties and optimal production parameters. *Food Chemistry: X, 18*, 100657. https://doi.org/10.1016/j.fochx.2023.100657
Xu, Y.-Q., Zou, C., Gao, Y., Chen, J.-X., Wang, F., Chen, G.-S., & Yin, J.-F. (2017). Effect of the type of brewing water on the chemical composition, sensory quality and antioxidant capacity of Chinese teas. *Food Chemistry, 236*, 142–151. https://doi.org/10.1016/j.foodchem.2016.11.110
Ye, J.-H., Ye, Y., Yin, J.-F., Jin, J., Liang, Y.-R., Liu, R.-Y., Tang, P., & Xu, Y.-Q. (2022). Bitterness and astringency of tea leaves and products: Formation mechanism and reducing strategies. *Trends in Food Science & Technology, 123*, 130–143. https://doi.org/10.1016/j.tifs.2022.02.031
Yin, P., Kong, Y.-S., Liu, P.-P., Wang, J.-J., Zhu, Y., Wang, G.-M., Sun, M.-F., Chen, Y., Guo, G.-Y., & Liu, Z.-H. (2022). A critical review of key odorants in green tea: Identification and biochemical formation pathway. *Trends in Food Science & Technology, 129*, 221–232. https://doi.org/10.1016/j.tifs.2022.09.013
Zhou, B., Bingsong, M., Xu, C., Wang, J., Wang, Z., Huang, Y., & Ma, C. (2022a). Impact of enzymatic fermentation on taste, chemical compositions and in vitro antioxidant activities in Chinese teas using E-tongue. *HPLC and Amino Acid Analyzer. LWT, 163*, 113549. https://doi.org/10.1016/j.lwt.2022.113549
Zhou, J., Fang, T., Li, W., Jiang, Z., Zhou, T., Zhang, L., & Yu, Y. (2022). Widely targeted metabolomics using UPLC-QTRAP-MS/MS reveals chemical changes during the processing of black tea from the cultivar Camellia sinensis (L.) O. Kuntze cv. Huangjinya. *Food Research International, 162*, 112169.
Zhuochen, W., Yuhuan, L., Qian, C., Bin, F., Guoyuan, X., Jian, J., & Qi, C. (2023). Processing quality and aroma characteristics of fresh noodles intermingled with large-leaf yellow tea powder. *LWT-Food Science and Technology, 174*, 114391. https://doi.org/10.1016/j.lwt.2022.114391

Publisher's Note