The effect of *Eurotium cristatum* (MF800948) fermentation on the quality of autumn green tea

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**ABSTRACT**

Autumn green tea (AT) has poor taste quality for its strong astringency. This study aims to improve the taste quality as well as the aroma of AT by *Eurotium cristatum* (MF800948) fermentation and to produce a fermented autumn green tea (FT). Results showed that the aroma quality of AT was improved, and the content of terpene alcohols that impart characteristic flowery aroma to FT significantly increased. The umami intensity of FT was comparable to that of AT while the astringency tasted much weaker mainly due to the oxidation of the catechins. The results also confirmed that theabrownins exhibited strong umami taste, not astringent taste. Finally, a metabolic map was analyzed to show the effect of *E. cristatum* (MF800948) on the quality of AT, and to visualize the changes of differential compounds in AT and FT. The work provides insights into the quality improvement of autumn green tea.

1. Introduction

Green tea is a kind of non-fermented tea, which is consumed worldwide and especially popular in China and Japan. Polyphenols (especially the catechins) and free amino acids are important quality determinants of green tea, as they mainly impart the astringent and umami taste to the green tea, respectively. The concentration of polyphenols and amino acids, as well as their ratio are crucial for the taste quality of green tea (Li et al., 2016). In China, green tea is divided into spring, summer, and autumn green tea according to different growing seasons. Summer and autumn green teas have higher content of catechins and lower content of amino acids than spring green tea, and they are accordingly bitterer and more astringent than spring green tea (Dai et al., 2015). Taste is one of the most important factors for consumers when choosing green tea. Summer and autumn green teas with inferior taste are not favored as spring green tea, which limits their markets. Therefore, methods should be developed to improve the quality, especially the taste quality, of summer and autumn green teas.

Catechins, especially for (-)-epigallocatechin gallate (EGCG) and (-)-epicatechin gallate (ECG), are recognized as the major contributors to the bitterness and astringency of green tea (Narukawa, Kimata, Noga, & Watanabe, 2010; Xu, Zhang, Chen, Wang, Du, & Yin, 2018). Moreover, the bitter and astringent intensity of green tea is positively correlated with the content of catechins (Narukawa et al., 2010). In this regard, several attempts have been made to improve the taste of autumn green tea by reducing the content of catechins. For example, Cao et al. (2019) reported that the bitterness and astringency of autumn green tea decreased with the decreased ratio of gallated catechins after tannase treatment of autumn tea leaves and tea infusion. Furthermore, Zhang et al. (2016) improved the sweet aftertaste and overall acceptability of green tea infusion by hydrolyzing EGCG and ECG with tannase. These methods reduced the bitterness and astringency of autumn green tea, and new methods should be developed to improve its overall quality, including taste and aroma quality.

*Eurotium cristatum* is the predominant fungus found in Fuzhuan brick tea, a type of post-fermented dark tea. During fermentation, *E. cristatum* secretes extracellular enzymes to promote the metabolism of chemical compounds in tea leaves, which affects the quality of Fuzhuan brick tea (Rui et al., 2019). When applied in the fermentation of green tea leaves, *E. cristatum* causes the biotransformation of phenolic compounds in tea leaves and decreases the content of catechins (Xiao, Zhong, Bai, Wu, & Gao, 2020a; Xiao, Zhong, Bai, Wu, & Gao, 2020b). It indicates the potential of *E. cristatum* in reducing bitterness and astringency of autumn green tea. Therefore, the strain *E. cristatum* (MF800948) was

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applied in the fermentation of autumn green tea to study its effect on the quality of autumn green tea, particularly the taste improvement. The results presented in this work can provide insights into the quality improvement of autumn green tea.

2. Materials and methods

2.1. Materials and chemicals

Autumn green tea (AT) was kindly provided by the Pingwu Xuebaoding Cha Industry Development Co. Ltd. (Sichuan, China). Fresh tea leaves (one bud with 3–4 leaves) were collected from local tea gardens at an altitude of about 800 m (104.59°E, 32.10°N, Sichuan, China). Samples used in the present study were processed in late August. The strain *E. cristatum* (Accession No. MF800948) was isolated from Pingwu Fuzhuan brick tea and identified by morphological characteristics and phylogenetic analysis of fungal 18S rDNA sequencing (Xiao et al., 2020a). It was activated on potato dextrose agar (PDA) plate in advance, and used for fermentation. Caffeine, theobromine, theophylline, gallic acid (GA), epicatechin gallate (ECG), epigallocatechin gallate (EGCG), catechin (C), epicatechin (EC), epigallocatechin (EGC), theanine and n-alkane mixture (C6 to C24) were purchased from Sigma-Aldrich Co. (St. Louis, MO, USA). Standard solution of amino acids was purchased from MembraPure GmbH (Hennigsdorf, Brandenburg, Germany). Methanol (HPLC grade) was purchased from Kelong Chemicals Co. Ltd. (Chengdu, Sichuan, China). Ultrapure water was prepared using a Milli-Q water purification system (Millipore, Billerica, MA, USA).

2.2. Preparation of *E. cristatum* (MF800948) fermented autumn green tea

Preparation of *E. cristatum* (MF800948) fermented autumn green tea (FT) was conducted according to a previous report (Xiao et al., 2020b). Briefly, 200 g of autumn green tea (AT) was sterilized at 121°C for 20 min. After cooling down to room temperature, tea leaves were inoculated with *E. cristatum* (MF800948) fungal suspension at 6 × 10^7 CFU/ml. Fermentation was conducted at 28°C for 21 days at following humidity conditions: days 1–4 at 80% humidity; days 5–14 at 70% humidity; days 15–18 at 65% humidity; and days 19–21 at 45% humidity. After fermentation, the FT samples were dried at 50°C for 48 h and stored at −20°C for further analysis. Five fermentation repetitions were conducted.

2.3. Aroma composition analysis

The aroma was analyzed using headspace solid-phase micro-extraction (HS-SPME) coupled to GCMS-QP2010 SE (Shimadzu, Japan) for 5 min desorption at 240°C. The oven temperature was programmed as follows: the initial temperature of 40°C was held for 3 min, increased by 3°C/min to 85°C and held for 3 min, then increased by 3°C/min to 160°C, and finally increased by 10°C/min to 240°C and maintained for 5 min. Purified helium (>99.999%) was used as the mobile phase flowed at 1.0 mL/min. The EI mass spectra were generated at 70 eV in a full scan mode from 35 to 240 amu. The temperature of ion source was 230°C. Identification of volatiles was performed by comparing their retention indices (RI) to n-alkanes (C6–C24), and mass matching to NIST14s MS data library with similarity degree exceeding 90%. Quantification of volatiles was performed by peak area normalization and calculated as a percentage of the total peak area. Data were then subjected to the supervised orthogonal partial least square-discriminate analysis (OPLS-DA) using SIMCA-P version 14.1 software (Umetrics AB, Umeå, Sweden).

2.4. Profile of amino acids

The extraction of amino acids was performed according to the previously reported method (Xu, Song, Li, & Wan, 2012). One gram of ground sample was extracted with 20 mL of boiling water for 30 min in a boiling water bath. Tea infusions were filtered and cooled to room temperature. When diluted to 20 mL with ultrapure water, tea infusions were analyzed by an A300 automatic amino analyzer (MembraPure GmbH, Brandenburg, Germany). Data were recorded and analyzed by the Chromatography Data Handing System software.

2.5. Quantification of gallic acid, catechins and purine alkaloids

Gallic acid, catechins, and purine alkaloids were extracted by sonication 1.0 g of ground sample in 20 mL of 70% v/v methanol solution for 15 min (Xin et al., 2018). The HPLC analysis was performed using a Thermo Ultimate 3000 HPLC system equipped with an Ultimate 3000 diode array detector (Thermo Fisher Scientific, Waltham, MA, USA). Chromatographic separation was achieved on an Inertsil ODS-4 column (4.6 mm × 250 mm × 5 μm; GL-science Inc., Tokyo, Japan). Ultrapure water-0.1% formic acid solution (eluents A) and methanol (eluents B) were used as the mobile phases flowed at a rate of 0.8 mL/min. The gradient elution was programmed as follows: 5–22% B at 0–5 min; 22–24% B at 5–20 min; 22–24% B at 20–35 min; 24–25% B at 35–45 min; 25–40% B at 45–50 min; and 40–45% B at 50–60 min. The column temperature was kept constant at 30°C, and the injection volume was 10 μL. The instrument control, data acquisition and data analysis were conducted using Chromeleon Chromatography Data System software.

2.6. Determination of total polyphenols, flavonoids, water-soluble carbohydrates and tea pigments

The Folin-Ciocalteau method was used to determine the polyphenols (Velioglu, Mazza, Gao, & Oomah, 1998), and the content was presented as GA equivalent (mg GA/g tea). The aluminum trichloride colorimetric method was used to determine the content of flavonoids, which was presented as rutin equivalent (mg rutin/g tea) (Ordoñez, Gomez, Vattuone, & Isla, 2006). The phenol–sulfuric acid method was used in the determination of carbohydrates, and the result was presented as glucose equivalent (mg glucose/g tea) (Albalasmez, Berhe, & Ghezzehei, 2013). Tea pigments, including theaflavins, thearubigins and theabrownins, were analyzed with the system analysis method as described previously (Huang, Xiao, Cong, Wu, Huang, & Yao, 2016).

2.7. Taste characteristics of tea infusion and theabrownins

Taste evaluation was performed with an E-tongue sensor system TS-5000Z (Insert Inc., Fukuoka, Japan). The TS-5000Z comprises six lipid membrane sensors for detection of bitterness (SB2C00), astringency (SB2A2E1), sourness (SB2CAO), sweetness (SB2GL1), saltiness (SB2CTO), and gustatory stimuli umami (SB2AAE). For taste evaluation of tea infusion, sample was prepared according to the national standard GB/T 23776–2009 (Xu, Wang, & Zhu, 2019). The theabrownins were prepared at concentrations of 0.6, 1.8, 3.6, and 7.2 mg/mL based on its content in FT infusion (0.6 mg/mL). In each measurement, 80 mL of tea infusion or theabrownins solution was poured into a 120-mL beaker, in which the sample was continuously detected for 120 s at 25°C, followed the detection of the sample aftertaste for another 30 s. Each sample solution was measured 4 times, and the most stable 3 data points were selected for further analysis.
2.8. Data analysis and statistics

Data were expressed as means ± standard deviations (n = 3 for AT, and n = 5 for FT). Significant differences were analyzed by student’s t-test using SPSS version 22.0 software (SPSS Inc., Chicago, IL, USA). Data were pretreated with the Z-score method when submitted to the OPLS-DA and hierarchical cluster analysis (HCA). The OPLS-DA was performed with the SIMCA-P version 14.1 software (Umetrics AB, Umea, Sweden). The HCA was achieved by the R (version 4.0.2). The variable importance projection (VIP) values of metabolites were calculated, and the metabolites with VIP exceeding 1.0 and p-values below 0.05 were selected as biomarkers in the pathway analysis. The pathway analysis was carried out on the MetaboAnalyst website following a previous report (Chong, Wishart, & Xia, 2019). A visualized integration metabolic map of the main metabolic pathways and related metabolites was presented based on the Kyoto Encyclopedia of Genes and Genomes (KEGG).

Fig. 1. Analysis of volatile compounds. (A) Total ion chromatogram; (B) Relative abundance of different types of volatiles; (C-D) Results of OPLS-DA analysis, $R^2X = 0.953$, $R^2Y = 0.999$, $Q^2 = 0.993$. AT, autumn green tea; FT, *E. cristatum* (MF800948) fermented autumn green tea.

Fig. 2. Analysis of non-volatile compounds. (A-C) Free amino acids; (D) Gallic acid and catechins; (E) Polyphenols, flavonoids and water-soluble carbohydrates; (F) Tea pigments; (G) Purine alkaloids. Thea, l-theanine; GABA, γ-aminobutyric acid. # and * represented significant difference at $p < 0.05$ and $p < 0.01$ level, respectively. AT, autumn green tea; FT, *E. cristatum* (MF800948) fermented autumn green tea.
3. Results and discussion

3.1. Aroma characteristics of E. cristatum (MF800948) fermented autumn green tea

As shown in Fig. 1, volatiles changed significantly after E. cristatum (MF800948) fermentation. The levels of 87 identified volatiles were presented in Supplementary Table S1 in detail. Alcohols were the most abundant in both AT and FT, accounted for 40.11% and 76.17%, respectively (Fig. 1B). Linalool (8.67%), (Z)-geraniol (5.84%), 1-octen-3-ol (3.53%) and hotrienol (3.35%) were the main alcohols in AT, while (Z)-linalool oxide (32.82%), linalool (17.32%), (E)-linalool oxide (furanoid) (9.87%) and 1-octen-3-ol (3.06%) were the main alcohols in FT. Aldehydes in AT accounted for 24.96%, mainly consisted of hexanal (furanoid) (9.87%) and 1-octen-3-ol (3.06%) were the main alcohols in FT. esters, (Z)-linalool oxide (furanoid), linalool, (Z)-geraniol, hexanal and nonanal. High content of (Z)-linalool oxide, linalool, and (E)-linalool oxide (furanoid) in FT endowed FT with characteristic flower aroma. Alcohols, especially for linalool oxides, have also been found to be abundant in other post-fermented dark teas, such as Pu-erh teas and Fuzhuan brick teas (Cao et al., 2018; Ly, Wu, Li, Xu, Liu, & Meng, 2014); however, their contents were less than those observed in FT. It indicates that E. cristatum (MF800948) could promote the metabolism of terpene alcohols (flower aroma) in autumn green tea fermentation. The fungal/flower aroma is the unique aroma of high-quality post-fermented dark tea (Xu, Mo, Yan, & Zhu, 2007). In this regard, the aroma quality of autumn green tea was improved after E. cristatum (MF800948) fermentation.

3.2. Effect of E. cristatum (MF800948) on the chemical compositions of autumn green tea

As shown in Fig. 2, contents of amino acids, catechines, alkaloids, polyphenols, flavonoids, carbohydrates, and tea pigments in AT were significantly changed after fermentation. A total of 21 amino acids, including 8 essential amino acids, 11 non-essential amino acids and 2 non-protein amino acids, were detected in the tea samples (Fig. 2A); and their contents were shown in Supplementary Table S2. Total content of amino acids dramatically dropped from 118.35 mg/g in AT to 10.58 mg/g in FT (Fig. 2D). The contents of ECGG, EGC, ECG and EC in AT, which were 47.48, 36.01, 21.49 and 11.21 mg/g, respectively, decreased to 0.37, 4.99, 0.40, and 1.14 mg/g, respectively, in FT. However, the content of C in AT, which was 2.16 mg/g, increased to 3.68 mg/g in FT. In general, hydrolysis of gallated catechines can produce non-gallated catechines and gallic acid (GA). A significant decrease in GA, EC, and EGC showed their further metabolism during fermentation. Content of catechines and GA in tea leaves has also been reported to significantly decrease after fermentation with Aspergillus niger (Accession No. EU314996) and A. fumigatus (Accession No. FJ844610) (Qin, Li, Tu, Ma, & Zhang, 2012). The reduction of catechines in AT might reduce the bitterness and astringency of AT. As shown in Fig. 2E, polyphenols and flavonoids in FT also decreased after fermentation. Moreover, the content of water-soluble carbohydrates was changed from 70.14 mg/g in AT to 42.63 mg/g in FT.

The contents of theaflavins, thearubigins, and theabrownins were shown in Fig. 2F. Theaflavins and thearubigins in AT significantly dropped, whereas the content of theabrownins greatly increased, from 15.52 mg/g in AT to 30.49 mg/g in FT. Theabrownins are polymeric compounds, and are reported to be generated from polymerization, condensation, coupling and oxidation of catechines, theaflavins, and thearubigins with other compounds (Wang, Gong, Chisti, & Sirisananeyakul, 2015). The reduction of catechines, theaflavins, and thearubigins in AT is probably related to the increase of theabrownins in FT. The peroxidase and laccases produced by microbes are closely related to the biortransformation of theabrownins, as they could continuously transform tea polyphenols to theaflavins, thearubigins, and further to theabrownins (Li, Feng, Luo, Yao, Zhang, & Zhang, 2018). The Aspergillus, Rasamsonia, Lithoeitima, and Debaryomyces can produce peroxidase and laccases during the fermentation of Pu-erh tea, and contribute to the production of theabrownins (Li et al., 2018).

Fig. 3. E-tongue analysis of taste characteristics. (A) Tea samples; (B) Theabrownins at 0.6 mg/mL, 1.8 mg/mL, 3.6 mg/mL, and 7.2 mg/mL. AT, autumn green tea; FT, E. cristatum (MF800948) fermented autumn green tea (FT).
Furthermore, Aspergillus spp. (e.g. *A. niger*, *A. tamarii* and *A. fumigatus*) are reported to produce glycoside hydrolases, glycosyltransferases, tannase, laccase, vanillyl-alcohol oxidases and benzoquinone reductase during dark tea fermentation. These enzymes catalyze the hydrolysis, oxidation, conversion, and biodegradation of phenolic compounds, causing the increased theabrownins level (Ma et al., 2020). Additionally, increased content of theabrownins also caused the tea infusion to possess more brownish-red color. Similarly, tea infusion of AT was yellowish green, while tea infusion of FT became brownish-red color after fermentation (Supplementary Fig. S1). Taken together, FT has similar characteristics to those of dark teas, such as Pu-erh tea and Fuzhuan brick tea. It suggests that the autumn green tea can be utilized to produce high-quality dark tea by *E. cristatum* (MF800948) fermentation.

As shown in Fig. 2G, AT and FT were low in theophylline and theobromine. By contrast, the content of caffeine with bitter taste was much higher; however, it significantly decreased from 13.56 mg/g in AT to 10.48 mg/g in FT. This is consistent with a previous report which showed that *A. niger* could lower the level of caffeine in tea (Qin et al., 2012). Moreover, total content of these three alkaloids in FT decreased.

Fig. 4. Comparison of autumn green tea (AT) and *E. cristatum* (MF800948) fermented autumn green tea (FT). (A-B) Results of OPLS-DA analysis, $R^2_X = 0.908$, $R^2_Y = 1$, $Q^2 = 0.998$; (C) Results of HCA analysis. Thea, $\gamma$-theanine; GABA, $\gamma$-aminobutyric acid; AAs, amino acids; S-hydrocarbons, saturated hydrocarbons; U-hydrocarbons, unsaturated hydrocarbons.
and such decrease, especially for the decrease of caffeine, might reduce the bitterness of AT.

3.3. Taste improvement of autumn green tea and relationship between taste and chemical compositions

The human tongue can generally recognize the difference between tastes when the taste intensities are different by 20%; thus, the 20% change is used as a unit of the E-tongue determination. As shown in Fig. 3A, sourness was not detected in both AT and FT, of which the taste intensities were below 0. The intensities of bitterness, aftertaste of bitterness, and saltiness of FT were slightly higher than those of AT and were all at relatively low levels. The sweetness of AT was slightly higher than that of FT, which might be due to the reduced content of carbohydrates in FT as the sweetness is mainly associated with carbohydrates (Zhu et al., 2020). It is worth noting that the intensities of astringency and astringent aftertaste of AT was significantly reduced after fermentation (p < 0.0001). As astringency of green tea is primarily from the EGCG, ECG, EGC, and EC (Xu et al., 2018), the reduction of astringency of AT is suggested to be attributed to the decreased catechins. The intensities of umami and richness of AT and FT were comparable. Since approximately 70% of the umami taste of green tea infusion is caused by free amino acids (Zhu et al., 2020), there are other compounds that impart the strong umami taste of FT. Herein, we hypothesized the theabrownins, of which the content increased in FT, might be the compounds mainly contributing to the taste of FT.

The taste characteristics of theabrownins were shown in Fig. 3B, and this is the first report on such data. Sourness, sweetness, and astringency were not detected in theabrownins solutions at different concentrations, as indicated by their intensities of below 0. The intensities of bitterness, aftertaste of astringency, umami, richness, and saltiness increased with increasing concentration of theabrownins. The intensities of aftertaste of astringency were low, as the maximum intensity at 7.2 mg/mL was only 0.63. However, theabrownins exhibited strong umami taste, which contributed to the umami taste of FT. The theabrownins at 0.6 mg/mL was comparable to the concentration of theabrownins in FT infusion prepared for the E-tongue determination. Compared with the theabrownins at 0.6 mg/mL and FT infusion, intensities of bitterness, aftertaste of bitterness, aftertaste of astringency, umami, richness, and saltiness were higher in FT infusion. This might be due to the coactions of theabrownins with other compounds in FT infusion, and/or the taste enhancement of theabrownins by other compounds.

Generally, astringency and aftertaste of astringency of AT was significantly reduced by E. cristatum (MF800948) fermentation. Meanwhile, the fermentation did not affect the umami and richness taste of AT. The taste quality of AT was improved after E. cristatum (MF800948) fermentation, for that FT has low astringency but high intensities of umami and richness. The taste characteristics of FT was closely related to the theabrownins with strong umami taste (not astringent taste). However, further research is required to study the taste interactions between theabrownins and other compounds in tea.

3.4. Effect of E. cristatum (MF800948) on the biotransformation of autumn green tea

The Z-scored data for OPLS-DA and HCA were in Supplementary Table S3. As shown in Fig. 4A, the AT samples were clearly separated from the FT samples by the principal component 1 (PC1). According to the OPLS-DA loading scatter plot (Fig. 4B) and the VIP values (Table S3), a total of 86 metabolites (p < 0.05) were identified as markers responsible for the differentiation of AT and FT. A heatmap derived from the HCA analysis displayed the dynamic changes of AT after E. cristatum (MF800948) fermentation (Fig. 4C). Each column represents a tea sample, and each row represents a metabolite. The color scale from blue to red indicates the varying content of a metabolite from low to high. Based on the data, the samples were divided into two groups, the AT group and the FT group, which is consistent with the OPLS-DA results. The contents of most compounds in AT, except for C, theophylline, theabrownins, alcohols and Ala, were decreased after fermentation.

The differential compounds selected by the OPLS-DA for metabolic pathway analysis were listed in Table S4. The result of pathway analysis was presented as a bubble plot (Fig. 5). Each bubble in the bubble plot represents a metabolic pathway, and the bubble size indicates the pathway impact value obtained from the topology analysis and is corresponded to the absissa values of “Pathway Impact”. In addition, the color of the bubble indicates the p-value calculated from the pathway enrichment analysis and is represented as the negative logarithm ($\log_{10}$) of the p-value: the darker the color, the smaller the p-value and the more significant the pathway in the enrichment. The detailed results from the pathway analysis were provided in Table S4. The highly enriched metabolic pathways of the differential compounds included: aminoacyl-tRNA biosynthesis; alanine, aspartate and glutamate metabolism; glycine, serine and threonine metabolism; arginine biosynthesis; and butanoate metabolism. Some other enriched pathways were methane metabolism; arginine and proline metabolism; glyoxylate and dicarboxylic metabolism; and cysteine and methionine metabolism. These metabolic pathways are mainly associated with amino acid metabolism, as well as the metabolism of other related compounds, such as fatty acids degradation, monoterpenoid biosynthesis and flavonoid biosynthesis.

The main metabolic pathways and related metabolites were integrated in Fig. 6. The differential metabolites marked in red had higher contents in FT, whereas those marked in green had lower contents. The contents of most amino acids decreased after E. cristatum (MF800948) fermentation. As a precursor of phenylpropanoid biosynthesis, phenylalanine (Phe) is channeled into flavonoid biosynthesis to finally generate catechins and flavonol glycosides (Zhu et al., 2020). In this study, catechins in AT decreased after fermentation, which in turn promoted the production of theabrownins. Because of the difficulty in separation and structural characterization, detailed information of theabrownins remains unclear presently. Theabrownins are reported to be polymerized phenolic substances, and are formed from polyphenols, especially for the catechins (Zhu et al., 2020). The quinones, oxidized from phenols (catechins), are important in the production of theabrownins. Quinones can be further oxidized and polymerized to theaflavins and thearubigins, and then produce theabrownins with other substances (e.g. polysaccharides, proteins, and caffeine). On the other hand, quinones can be directly oxidized and polymerized into theabrownins without being converted into theaflavins and thearubigins.
intermediates (Zhu et al., 2020). The metabolic process can be induced by both the microbial fermentation and by the treatment with microbial extracellular enzymes, such as polyphenol oxidase (PPO), peroxidase (POD), pectinase, cellulase, and laccase (Wang et al., 2015; Wang, Gong, Chisti, & Sirisansaneeyakul, 2016). However, further researches should be conducted to elucidate the formation mechanisms of theabrownins. On the whole, amino acids and catechins were greatly metabolized during fermentation, which was closely associated with the changes of other compounds. Such changes contributed to the quality improvement of AT by increasing contents of theabrownins and alcohols in FT.

4. Conclusions

In summary, this study revealed that the quality of autumn green tea (AT) was improved by E. cristatum (MF800948) fermentation. The E. cristatum (MF800948) fermented autumn green tea (FT) not only had increased flowery aroma, but also had less astringency. The improved aroma quality was associated with the increased contents of terpene alcohols with flowery aroma, such as linalool and linalool oxides. The reduced astringency was mainly due to the decreased contents of polyphenols (especially for the catechins) and increased content of theabrownins in FT. This study also reported the taste characteristics of theabrownins, confirming that theabrownins had strong umami taste without astringency. The aminoacyl-tRNA biosynthesis; alanine, aspartate and glutamate metabolism; glycine, serine and threonine metabolism; arginine biosynthesis; and butanoate metabolism were closely related to the fermentation of AT. The study demonstrated that E. cristatum (MF800948) had beneficial effect on the quality of autumn green tea, providing insights into the utilization of autumn green tea. Nevertheless, further research should be carried out to identify the changes of other metabolites during fermentation, as well as their correlations with theabrownins.

CRediT authorship contribution statement


Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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