Improving the quality of fermented black tea juice with oolong tea infusion

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Abstract Fresh tea leaves were crushed into juice and then fermented (oxidation) to obtain fermented black tea juice, which can be used to prepare black tea beverage. The effects of addition of oolong tea infusion or tossing of tea leaves on the sensory quality and theaflavins (TFs) concentration of fermented black tea juice were investigated. The results showed that both addition of tea infusion and tossing of fresh tea leaves increased the TFs/thearubigins (TRs) ratio and improved the sensory quality of fermented black tea juice. The TFs/TRs ratio was found to be significantly correlated with the scores for flavor ($r = 0.98$), mouth feel ($r = 0.94$), and overall acceptability ($r = 0.91$) of the fermented black tea juices from different processes. This result suggested that a relatively high concentration of catechins and stepwise enzymatic oxidation were the crucial factors that increased the TFs/TRs ratio and improved the sensory quality. The combination of adding tea infusion and tossing fresh tea leaves greatly improved the quality of the fermented black tea juice by markedly increasing the TFs/TRs ratio (87%). Results of the present study provided useful information for improving the quality of fermented black tea juice.

Keywords Fermented black tea juice · Process craft · Chemical components · Sensory quality

Introduction

Tea is one of the most popular beverages consumed everyday around the world. It has antioxidant properties (Polovka et al. 2003; Zaiter et al. 2016), which help prevent various diseases such as cancer and heart disease (Dufresne and Farnworth 2000; Sharangi 2009). Black tea is widely consumed in the western world and has recently become very popular in China. Many kinds of bottled black tea beverages are sold in the market, such as flavored tea beverage, pure tea beverage, milk tea beverage, and instant tea (Yin et al. 2010). However, most of the bottled black tea beverages are processed from black tea; the flavor of teas therefore mostly depends on black tea. Recently, a novel technique has been developed for the production of instant black tea by fermentation of fresh tea leaf juice (Sinija et al. 2007). However, the quality of fermented black tea leaf juice can still be improved.

Flavor, one of the most important factors for tea sensory quality, is mainly determined by taste and aroma compounds. Nonvolatile compounds, mainly catechins, theaflavins (TFs), thearubigins (TRs), amino acids, and caffeine, are responsible for the taste of black tea. Volatile compounds, including alcohols, aldehydes, ketones, and esters, contribute to the aroma (Alasalvar et al. 2012). Catechins are the major biochemical constituents present in tea leaves, and they undergo oxidation to TFs and TRs during fermentation (Someswararao and Srivastav 2012). TFs are responsible for the astringency, brightness, color, and briskness of black tea infusion (Owuor and Obanda 2007), while TRs contribute to the mouth feel (thickness)

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and color of the tea (John et al. 2014). The flavor of fermented black tea juice can be influenced by the fermentation process, which also influences the biochemical components and enzymes of fresh tea leaves (Samanta et al. 2015; Bhuyan et al. 2015).

Tossing, the critical step in the formation of high-quality oolong tea (Chen et al. 2011), is done to bruise the tea leaf edge to create more contacting surfaces for oxidation. There are three to five steps of tossing (10–30 min at different air temperatures) during the processing of oolong tea (Huang et al. 2003). The tossing of tea leaves could significantly promote the accumulation of flavor components and quality formation of oolong tea. This occurs via steps such as transformation of higher fatty acids into alcohols and aldehydes; decomposition of carotenoids into aromatic compounds; hydrolysis of primeverosides glucosides, protein, esters of catechins, and polysaccharides; and oxidation of alcohol, catechins, and amino acids (Guo et al. 2003; Chen et al. 2011).

The objective of the present study was to investigate the effect of oolong tea infusion on the chemical components and sensory quality of fermented juice in order to improve the quality of fermented black tea.

Materials and methods

Materials

New shoots (three or four leaves and a bud) were harvested in June 2014 from the tea garden of the Tea Research Institute of the Chinese Academy of Agricultural Sciences. Some parts of the new shoots were processed into green tea, and the others were processed into oolong tea. Processing steps of the green tea are as follows. After the new shoots were allowed to wither for 4 h, they were hot-panned at 135 °C for 7 min, rolled for 6 min, dried at 110 °C for 15 min, and then dried at 85 °C for 35 min. The steps for processing oolong tea are as follows: After the new shoots were tossed for 14 h, they were hot-panned at 135 °C for 7 min, rolled for 6 min, dried at 110 °C for 15 min, and then dried at 85 °C for 35 min.

Fermentation process

The green tea or oolong tea (200 g) was extracted with distilled water (2.4 L) at 70 °C for 30 min, and then the extract was filtered through a 400-mesh screen to obtain a clarified extract. The withered leaves or tossed leaves (600 g) were crushed with a crusher for 4 min and then distilled water (6 L) was added. The crushed pulp or the mixture of crushed pulp and extracted infusion was fermented in a 13L Labfors fermentor (Infors AG,

Bottmingen, Switzerland) at 35 °C. During fermentation, oxygen gas was incorporated into the fermentation system at a rate of 1.0 m³/h. The fermented product was obtained after fermentation for 120–150 min, and the fermentation process was stopped by heating to approximately 90 °C with a microwave applicator, which inactivated the enzymes responsible for the oxidation reactions. The product was then subjected to centrifugation in a laboratory centrifuge at 10,000×*g* for 15 min to remove the colloidal particles and other suspended solid particles, which cause turbidity in the tea infusion. Finally, the fermented juice was prepared for analysis of chemical components and sensory quality.

HPLC analysis of chemical components of fermented juice

Analyses of catechins, caffeine, gallic acid, and TFs were performed by HPLC (Liang et al. 2003) using a Shimadzu LC-2010A HPLC system (Shimadzu Corporation, Kyoto, Japan). The tea infusion was filtered through a 0.2 μm Millipore filter before injection. The HPLC conditions were as follows: injection volume, 10 μL; column, 5 μm Diamonsil TM C18 (4.6 mm × 250 mm); column temperature, 40 °C; mobile phase A, acetonitrile/acetic acid/water solution (6:1:193); mobile phase B, acetonitrile/acetic acid/water solution (60:1:139); gradient, 100% mobile phase A to 100% mobile phase B by linear gradient during the early 45 min and then 100% mobile phase B up to 60 min; flow rate, 1 mL/min; detector, Shimadzu SPD ultraviolet detector (Shimadzu Corporation) at 280 nm.

Determination of TRs, total free amino acids, and polyphenols

TRs were determined using the method of Roberts and Smith (1963), which was slightly modified by Ngure et al. (2009). The content of free amino acids in the fermented juice was determined using the ninhydrin dyeing method (Xu et al. 2012), with glutamic acid as a standard. The concentration of polyphenols in the fermented juices was determined with the method described by Xu et al. (2013).

Analysis of color difference and total solids

The color difference of fermented tea juice was determined on a Minolta CT-310 automatic color difference meter (Konica Minolta China, Shanghai, China). Distilled water was used as control. The parameters in the three-dimensional color coordinate system for the fermented tea juice, *a** and *b**, represent red–green and yellow–blue, respectively (Liang et al. 2003). The total solids concentration of

the fermented juices was determined by drying 20 mL of the juice at 80 °C for 48 h (Yin et al. 2009).

Sensory evaluation

The sensory quality of fermented juices was evaluated by a professional team of 10 panellists in tea quality evaluation from the Tea Research Institute of the Chinese Academy of Agricultural Sciences. The aroma and taste of the fermented juices were scored by each member of the team. The nine-point hedonic scale was used (9 = like extremely, 5 = neutral, 1 = dislike extremely) for scoring. The scores of the taste and aroma were integrated into the acceptability score (Ibanoglu et al. 2006).

Analysis of volatiles

Volatiles of the fermented tea juice were determined by SPME–GC/MS. The SPME device (Bellefonte, PA, USA) was fused silica fiber with 50/30 µm divinylbenzene/carboxen/polydimethylsiloxane coating. The fiber was pre-conditioned for 10 min in the injection port of the gas chromatograph at 260 °C to remove any volatiles remaining on the fiber before each extraction. The fermented tea juice (150 mL) was infused in a 500-mL vial, and 20 µL of IS solution (ethyl caprate) was added. The vial was kept in a water bath at 50 °C to equilibrate for 5 min, and then the SPME fiber was exposed for 30 min to the headspace while the sample was maintained at 50 °C. After SPME liquid sampling, the SPME fiber was introduced into the GC injector in splitless mode and then left for 3 min to allow thermal desorption of the analytes.

An Agilent 6890 gas chromatograph interfaced with an Agilent HP 5973 MSD ion trap mass spectrometer was used to perform the analysis. A DB-5MS capillary column (60 m × 0.25 mm × 0.32 µm) was used separately. The GC oven temperature was programmed as follows: 50 °C holding for 5 min, an increase to 180 °C at a rate of 3 °C/min, and then holding for 2 min; an increase to 250 °C at a rate of 10 °C/min and finally holding at 250 °C for 3 min. Helium (>99.9% percentage purity) at a flow rate of 1 mL/min was used as carrier gas. The mass spectrometer was operated in the EI mode at an electronic energy of 70 eV. The injector and ion source temperatures were 250 and 230 °C, respectively, and MS scanning was done in the range of 35–400 AMU. The identification of the volatile compounds was based on the National Institute of Standards and Technology Library (98L). In addition, the linear retention indices (RIs) were calculated by using *n*-paraffins C₆–C₂₀ as external references (Alasalvar et al. 2012). The concentrations of the constituents were calculated in µg/L on the basis of the IS solution when ethyl caprate (230 µg/

L) was used as the internal standard, and the experiment was carried out three times for each tea sample.

Statistical analysis

Results are expressed as means of at least three replicates. Analysis of variance, determination of significant differences among means, and correlation analysis were performed with one-way ANOVA using SPSS 16.5 (IBM, Armonk, NY, USA).

Results and discussion

Effect of oolong tea infusion on the chemical components and sensory quality of fermented juice

Fresh tea leaves were crushed to process fermented black tea juice. In the former study, the concentrations of solids, amino acids, and TFs of the juice were found to be higher than those in black tea infusion, and the sensory quality (including liquor color, taste, and aroma) were also found to be better (Xia et al. 2000). However, adding oolong tea extract prepared from low-grade oolong tea leaves could improve the sensory quality and increase the concentrations of TFs of fermented black tea juice (Table 1). Figure 1 shows the production process for the fermented black tea juices prepared from fresh tea leaves and oolong tea infusion. Fermented black tea juice M processed from a mixture of fresh tea pulp and oolong tea infusion showed concentrations of soluble solids (62%), TFs

Table 1 Chemical components and sensory qualities of the fermented tea juices prepared using the different production processes

Fermented tea juice	M	N
Soluble solids (mg/mL)	12.74 ± 1.13 ^a	7.85 ± 0.58 ^b
Polyphenols (%)	34.28 ± 2.21 ^b	38.05 ± 1.78 ^a
Caffeine (%)	3.49 ± 0.25 ^b	5.96 ± 0.40 ^a
Amino acids (%)	7.40 ± 0.36 ^b	8.25 ± 0.28 ^a
TFs (%)	1.79 ± 0.22 ^a	1.08 ± 0.15 ^b
TRs (%)	12.12 ± 0.37 ^a	11.90 ± 0.44 ^a
TFs/TRs	0.15 ± 0.01 ^a	0.09 ± 0.01 ^b
Aroma	6.7 ± 0.3 ^a	6.1 ± 0.3 ^b
Taste	6.8 ± 0.4 ^a	6.3 ± 0.2 ^b
Overall acceptability	6.7 ± 0.3 ^a	6.2 ± 0.3 ^b

Data are means of three replicates

Concentrations of main chemical components indicate the contents of main chemical components compared against the content of soluble solids (w/w)

^{a,b}Different letters in the same column indicate significant differences between mean values ($p < 0.05$)

Fig. 1 Production processes for the fermented black tea juices with and without oolong tea infusion

concentrations (66%), and TFs/TRs ratios (63%) higher than those of the fermented black tea juice N processed from fresh tea leaves. The scores for aroma, taste, and overall acceptability of juice M were also found to be higher than those of juice N (Table 1). This difference may be due to the chemical components of the mixture with added oolong tea infusion, which were used as the substrates for the enzymatic reaction.

Effect of the production process on the color and sensory quality of the fermented black tea juice

Fresh tea leaves with different treatments were fermented to investigate how the addition of oolong tea infusion improves the sensory quality of fermented black tea juice. Figure 2 shows the production process for the four fermented tea juices.

The color indicators a^* and b^* were found to be significantly correlated with the total quality score and the TF concentrations of the black tea infusions (Liang et al. 2003). Values of a^* and b^* for the fermented black tea juice fall on the positive scale, suggesting that the fermented black tea juices were red and yellow in color. In this study, the values of a^* and b^* for fermented black tea juices A and B were both lower than those for fermented black tea juices C and D (Fig. 3). This result suggests that

the juices C and D have red and yellow hues deeper than those of juices A and B. However, there was no significant difference between juices A and B or C and D (Fig. 3). The value of a^* was significantly correlated with the TR content ($r = 0.64$, $p < 0.05$), while the value of b^* was significantly correlated with the TF content ($r = 0.70$, $p < 0.05$) and TR ($r = 0.81$, $p < 0.05$). The values of a^* and b^* were also positively correlated with the scores for color, aroma, flavor, mouth feeling, and overall acceptability, which were consistent with those reported by Liang et al. (2003). These results suggested that the sensory quality of juices C and D was better than those of juices A and B. The fermented black tea juices were evaluated for various quality attributes according to the standard tea testing procedure. The quality attributes included aroma, flavor, strength, mouth feeling, and overall acceptability. The mean sensory scores of the different quality attributes and overall acceptability of the fermented black tea juices were determined and statistically analyzed for variance (Table 2). The juice D had the highest scores in terms of aroma, flavor, mouth feeling, and overall acceptability, while juice A had the lowest scores. The juice C had the highest score for strength, while juice B had the lowest score. The sensory scores of both juices C and D were higher than those of both juices A and B, while the sensory

Fig. 2 Four production processes for the fermented black tea juices

score for juice B or D was higher than that of juice A or C (Table 2).

The above results suggest that the fermented black tea juices processed from the mixture of tea infusion and pulp from fresh tea leaves (with green tea infusion or oolong tea infusion) had sensory scores higher than those of fermented black tea juices processed from the pulp of fresh tea leaves (without green tea infusion or oolong tea infusion). The fermented black tea juices processed from tossed leaves had sensory scores higher than those of fermented black tea

juices processed from withered leaves. The results indicate that both addition of tea infusion and tossing of tea leaves can improve the sensory quality of fermented black tea juice.

Effect of the production process on the compounds in fermented black tea juice

The concentrations of the main chemical components in the fermented black tea juices subjected to different treatments

Fig. 3 Color differences among the fermented black tea juices prepared using the four production processes

are shown in Table 3. The soluble solids concentrations in juices C and D were nearly two times higher than those in juices A and B. The concentrations of polyphenols, amino acids, caffeine, TFs, and TRs in juices C and D were much higher than those in juices A and B. The TFs/TRs ratios for juice D was much higher than those for juices A, B, and C, while there was no significant difference between the values for juices B and C (Table 3).

Tea pigments, which mainly include TFs and TRs, are the crucial components of fermented juices that determine quality (Sinija et al. 2007). For juices A to D, both the concentrations of TFs and TRs and the TF/TR ratios

increased (Table 3). Relative to the concentrations of TFs and TRs and the TFs/TRs ratios for juice A, those of juice B increased to 99, 7, and 87%, respectively. The scores for flavor ($r = 0.98$, $p < 0.01$), mouth feel ($r = 0.95$, $p < 0.01$), and overall acceptability ($r = 0.92$, $p < 0.01$) were found to significantly correlate with the concentrations of TFs. Similarly, the scores for color ($r = 0.87$, $p < 0.01$), flavor ($r = 0.97$, $p < 0.01$), mouth feel ($r = 0.98$, $p < 0.01$), and overall acceptability ($r = 0.97$, $p < 0.01$) significantly correlated with the concentrations of TR. These results are similar to those reported by Liang et al. (2003). The scores for flavor ($r = 0.98$, $p < 0.01$), mouth feel ($r = 0.94$, $p < 0.01$), and overall acceptability ($r = 0.91$, $p < 0.01$) were also significantly correlated with the TFs/TRs ratios of the fermented black tea juices.

According to the above results, both tossing of fresh tea leaves before fermentation and addition of tea infusion helped increase the TFs/TRs ratio with 20 and 30%, and the combination of adding tea infusion and tossing of tea leaves (such as adding semi-fermented tea infusion) greatly increased the TFs/TRs ratio with 80%.

Catechins were the main components of polyphenols in the tea leaves, undergoing oxidation to TFs and TRs mediated by oxidase during fermentation. We found that most catechins were oxidized in the fermented black tea juices (Table 4). However, only a small amount of TFs formed, and most of the catechins formed TRs or highly polymerized substances. There was no significant

Table 2 Mean sensory scores for the quality attributes of the fermented black tea juices

Fermented juice	Aroma	Flavor	Strength	Mouth feeling	Overall acceptability
A	6.4 ± 0.4 ^c	5.4 ± 0.3 ^d	5.5 ± 0.3 ^c	4.9 ± 0.5 ^b	5.5 ± 0.3 ^c
B	6.6 ± 0.3 ^c	6.0 ± 0.2 ^c	5.4 ± 0.4 ^c	5.2 ± 0.3 ^b	5.8 ± 0.4 ^c
C	7.2 ± 0.2 ^b	6.6 ± 0.3 ^b	6.8 ± 0.3 ^a	6.3 ± 0.2 ^a	6.7 ± 0.2 ^b
D	7.8 ± 0.3 ^a	7.6 ± 0.4 ^a	6.2 ± 0.2 ^b	6.5 ± 0.4 ^a	7.2 ± 0.3 ^a

Data are means of three replicates

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

Table 3 Concentrations of the main chemical components in the fermented black tea juices

Samples	A	B	C	D
Soluble solids, mg/mL	8.04 ± 0.24 ^b	7.77 ± 0.33 ^b	14.62 ± 0.47 ^a	14.03 ± 0.41 ^a
Polyphenols (%)	3.35 ± 0.09 ^c	3.18 ± 0.05 ^c	5.75 ± 0.28 ^a	5.22 ± 0.14 ^b
Amino acids (%)	0.74 ± 0.07 ^b	0.71 ± 0.06 ^b	1.24 ± 0.02 ^a	1.22 ± 0.04 ^a
Caffeine (%)	0.39 ± 0.04 ^b	0.34 ± 0.02 ^b	0.47 ± 0.02 ^a	0.49 ± 0.02 ^a
TFs (%)	0.10 ± 0.01 ^d	0.12 ± 0.02 ^c	0.25 ± 0.03 ^b	0.33 ± 0.03 ^a
TRs (%)	0.99 ± 0.05 ^b	0.98 ± 0.04 ^b	1.90 ± 0.13 ^a	1.85 ± 0.12 ^a
TFs/TRs	0.10 ± 0.00 ^c	0.12 ± 0.01 ^b	0.13 ± 0.01 ^b	0.18 ± 0.00 ^a

Data are means of three replicates

Concentrations of main chemical components indicate the content of main chemical components compared against the content of soluble solids (w/w)

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

Table 4 Concentrations of the main catechins and theaflavins of the samples (mg/mL)

Samples	A	B	C	D	Green tea infusion	Semi-fermented tea infusion
GC	0.12 ± 0.03 ^b	0.09 ± 0.00 ^c	0.18 ± 0.01 ^a	0.18 ± 0.01 ^a	0.13 ± 0.02 ^b	0.08 ± 0.00 ^c
EGC	0.06 ± 0.01 ^d	0.04 ± 0.01 ^d	0.09 ± 0.01 ^c	0.08 ± 0.01 ^c	1.99 ± 0.02 ^a	1.25 ± 0.05 ^b
EGCG	0.05 ± 0.00 ^d	0.03 ± 0.00 ^e	0.06 ± 0.00 ^{cd}	0.07 ± 0.00 ^c	2.83 ± 0.03 ^a	1.68 ± 0.05 ^b
EC	0.06 ± 0.00 ^d	0.04 ± 0.00 ^e	0.06 ± 0.00 ^d	0.09 ± 0.01 ^c	0.43 ± 0.00 ^a	0.27 ± 0.01 ^b
ECG	0.01 ± 0.00 ^d	0.01 ± 0.00 ^d	0.01 ± 0.00 ^d	0.02 ± 0.00 ^c	0.36 ± 0.03 ^a	0.21 ± 0.00 ^b
Total catechins	0.32 ± 0.06 ^e	0.22 ± 0.02 ^f	0.43 ± 0.03 ^d	0.48 ± 0.03 ^c	5.82 ± 0.06 ^a	3.55 ± 0.12 ^b
TF	0.25 ± 0.02 ^c	0.18 ± 0.01 ^c	0.46 ± 0.03 ^b	0.63 ± 0.03 ^a	–	–
TF3G	0.02 ± 0.01 ^c	0.02 ± 0.00 ^c	0.05 ± 0.01 ^b	0.07 ± 0.01 ^a	–	–
TF3'G	0.02 ± 0.01 ^c	0.01 ± 0.00 ^c	0.06 ± 0.00 ^b	0.08 ± 0.01 ^a	–	–
TFDG	0.07 ± 0.02 ^c	0.04 ± 0.00 ^d	0.18 ± 0.02 ^b	0.24 ± 0.02 ^a	–	–
Total TFs	0.37 ± 0.05 ^c	0.25 ± 0.02 ^d	0.75 ± 0.06 ^b	1.02 ± 0.07 ^a	–	–

Data are means of three replicates

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

difference in the catechin concentrations between juices C and D (Table 4), although the concentrations of catechins in the green tea infusion were much higher than those in the semi-fermented tea infusion. The above results suggest that a higher concentration of catechins (about two times that of typical concentrations) results in much higher TFs/TRs ratios in fermented black tea infusions, such as juice D. But excessively high concentrations of catechins could inhibit the enzyme reaction, leading to little increase in TFs/TRs ratio (as in the case of juice C). Therefore, stepwise enzymatic oxidation of relatively high concentrations of catechins formed fermented black tea juice with high sensory quality, such as juice D.

TFs are composed of theaflavin (TF, theaflavin-3-gallate, theaflavin-3'-gallate, and theaflavin-3, 3'-gallate (TFDG)). The difference in TF concentrations among the four fermented black tea juices mainly came from the different concentrations of TF and TFDG. The concentrations of TF and TFDG in juices C and D were much higher than those in juices A and B (Table 4). The difference in TF formation between juices A and C could be related to the different concentration of the enzyme–substrate, catechins. However, juice C did not show a TF concentration higher than that of tea juice D even though juice C contained more catechins and an equal amount of oxidase as compared with juice D. This finding is similar to that for semi-fermented oolong tea, in which catechins were oxidized by oxidase to theasinensins other than TFs (Li et al. 2007).

Effect of the production process on the volatiles of fermented black tea juice

Nineteen volatiles were identified by GC–MS (Table 5; Fig. 4). The concentrations of various volatiles differed among the four fermented black tea juices. The concentrations of 2-methylbutanal, 3-methylbutanal, benzyl alcohol, benzeneacetaldehyde, (Z)-linalool oxide, (E)-linalool oxide, linalool, phenylethyl alcohol, (Z)-3-hexenyl butanoate, nerol, and geraniol in juices C and D increased relative to those of juices A and B; while the concentrations of hexanal, 2-hexenal, 3-hexen-1-ol, and (Z)-3-hexenyl acetate decreased. On the basis of the odor descriptions in Table 5, most of the increased volatiles belong to the primary aroma-active compounds of black tea (benzyl alcohol, benzeneacetaldehyde, linalool oxide, linalool, nerol, and geraniol), which impart a fruity, sweet, or floral aroma. The decreased volatiles (hexanal, 2-hexenal, 3-hexen-1-ol, and (Z)-3-hexenyl acetate) mainly impart an herbaceous flavour. This result indicates that the aroma quality of juices C and D is much closer to that of black tea than it is to juices A and B. The concentrations of aroma-active compounds in juice D were also found to be higher than those of juice C. The above results of chemical analyses are consistent with the sensory score for aroma quality (Table 5). According to the above results, the high concentrations of aroma-active compounds in the fermented tea juices may also be due to the addition of tea infusion and the tossing of tea leaves.

Table 5 Aroma-active compounds detected by GC–MS analysis

Peak	Compounds ($\mu\text{g/L}$)	RI	MI ^c	Odour description	A	B	C	D
1	2-Methylbutanal	641	MS, RIL	Malty	2.44 ^c	2.03 ^d	3.31 ^a	2.84 ^b
2	3-Methylbutanal	651	MS, RIL	Malty	2.52 ^c	2.04 ^d	3.81 ^a	3.19 ^b
3	Hexanal	802	MS, RIL	Green, grassy	8.26 ^a	7.26 ^b	6.17 ^c	5.82 ^d
4	2-Hexenal	854	MS, RIL	Green apple-like	40.60 ^b	61.02 ^a	29.01 ^c	27.06 ^c
5	3-Hexen-1-ol	858	MS, RIL	Lettuce-like	110.40 ^a	81.72 ^b	25.06 ^d	43.24 ^c
6	2-Hexenol	880	MS, RIL	Green, grassy, fruity	20.54 ^b	29.98 ^a	3.08 ^d	5.95 ^c
7	Benzaldehyde	964	MS, RIL	Bitter almond-like	5.01 ^a	5.95 ^a	5.31 ^a	5.15 ^a
8	(Z)-3-hexenyl acetate	1007	MS, RIL	Green, banana-like	3.12 ^a	1.94 ^b	2.01 ^b	2.37 ^b
9	Benzyl alcohol	1039	MS, RIL	Fruity	1.73 ^c	2.20 ^b	3.06 ^a	2.88 ^a
10	Benzeneacetaldehyde	1042	MS, RIL	Sweet, fruity	3.18 ^c	6.60 ^b	5.65 ^b	7.54 ^a
11	(Z)-linalool oxide	1070	MS, RIL	Floral	19.66 ^b	17.78 ^b	27.44 ^a	29.63 ^a
12	(E)-linalool oxide	1088	MS, RIL	Floral	17.59 ^b	16.93 ^b	27.06 ^a	28.78 ^a
13	Linalool	1101	MS, RIL	Fruity	29.31 ^b	30.73 ^b	51.73 ^a	58.04 ^a
14	Nonanal	1106	MS, RIL	Citrus-like, soapy	0.98 ^a	1.03 ^a	0.93 ^a	0.71 ^b
15	Phenylethyl alcohol	1118	MS, RIL	Peach-like	6.23 ^d	9.20 ^c	14.80 ^b	17.09 ^a
16	(Z)-3-hexenyl butanoate	1178	MS, RIL	Fruity	2.89 ^b	3.76 ^b	6.80 ^a	6.16 ^a
17	Decanal	1207	MS, RIL	Herbal, fatty	1.81 ^a	1.75 ^a	1.47 ^a	1.93 ^a
18	Nerol	1233	MS, RIL	Rosy, floral	0.98 ^d	1.11 ^c	1.71 ^b	2.02 ^a
19	Geraniol	1276	MS, RIL	Rosy, floral	3.21 ^d	4.18 ^c	7.68 ^b	9.01 ^a

Data are means of three replicates

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

^c Method of identification: MS, identified by MS; RIL, identified by retention index and compared with those reported in the literature

Fig. 4 GC–MS profile of the fermented tea juice

Conclusion

Similar to the process for oolong tea, both the addition of tea infusion to crushed fresh tea leaves or the tossing of fresh tea leaves were found to help improve the quality of the fermented black tea juice by increasing the TFs/TRs ratio. This combination greatly improved the quality of the

fermented black tea juice by markedly increasing the TFs/TRs ratio. The increase in TFs/TRs ratio was due to the stepwise enzymatic oxidation of relatively high concentrations of catechins in the fermented black tea juice, according to analyses of the sensory quality and chemical components. The results are useful for improving the quality of fermented black tea juice.

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