Abstract

Wuyi Rock tea is one of well-known tea in China. The ‘Spring Tea Competition’ every year is a big event in tea industry of Wuyishan City. In this paper, 667 samples with four grades of Wuyi Rougui teas from ‘Spring Tea Competition, 2019’ were collected to determine quality indexes. The relationship between the quality index and tea grades was analyzed. The results showed that the higher the grade of teas, the higher the total quality score (TQS) of sensory evaluation. Most of tea quality indexes had the same tendency with TQS. The contents of tea polyphenols, soluble sugar, and catechins were significantly different between the different grades teas. PCoA showed that grades of teas could be effectively distinguished by the tea quality indexes. The contents of tea polyphenols, caffeine, epigallocatechin gallate, and epigallocatechin were significantly and positively correlated to TQS of sensory evaluation. These results suggested that higher content of multicomponents is the material basis of high quality tea. The tea polyphenols, caffeine and catechin can be used to evaluate the grade difference of Wuyi Rougui tea. The ratio of phenols to amino acids, ester catechins to non-ester catechins, and characteristic amino acids are important hallmark of the top tea.

Keywords: Wuyi Rock tea; Rougui (Camellia sinensis); sensory evaluation; tea grade; quality index.

Practical Application: Four grades of Wuyi Rougui teas could be effectively distinguished by the tea quality indexes.

1 Introduction

Wuyi Rock tea, got its name because tea tree grow in rock area of Wuyi Mountain and has the characteristics of rock rhyme, is one of the famous teas in China. Wuyi Rougui tea (Camellia sinensis) is one of the most important varieties of Wuyi Rock tea and is one of the largest varieties planted in area in Wuyishan City. Wuyi Rougui tea has the characteristics of rich aroma, mellow taste, sweet and strong, and is greatly loved by tea consumers. In order to promote the Wuyishan tea industry and product quality, the Wuyishan Tea Bureau holds ‘Spring Tea Competition’ every year. It is a big event in tea industry of Wuyishan City. The competition set up gold medal, first prize, and second prize. The grades of competing products are resulted from the sensory evaluation by six national professional tea panelists. Many tea industries enter the ‘Spring Tea Competition’ to compete for the medals, which can gain the honorary for their tea products and the affirmation of tea quality.

The taste of tea infusion is an important indicator for tea quality. The taste of tea infusion is mainly the sensory comprehensive stimulation caused by the substances which can be dissolved in tea infusion, including tea polyphenols, caffeine, catechins, amino acids, soluble sugar and so on (Chen et al., 2008). The astringency of tea infusion mainly comes from the catechins in polyphenols, especially ester catechins such as epigallocatechin gallate (EGCG) (Narukawa et al., 2011). The bitter taste of tea infusion is related to the content of caffeine in tea infusion, which is also an important factor to measure the quality of tea (Fernandez et al., 2000). The free amino acids in tea infusion are the amino acids that do not constitute proteins, are the most important components of tea and the evaluation index of tea quality (Yu & Yang, 2020; Nakagawa, 1975; Nagata & Sakai, 1984; Nishimura & Kato, 1988; Harbowy et al., 1997; Hayashi et al., 2008; Gu et al., 2012; Akitomi et al., 2013). The number of free amino acids varies with the different planting environments of tea trees. Different tea varieties have different amino acid content (Horanmi & Engelhardt, 2013). Even the same tea varieties have different amino acid content in different tea garden management conditions and different processing methods (Huo et al., 2014; Tan et al., 2016; Zhu et al., 2016; Salman et al., 2021). Although free amino acids only account for 1%~4% of the weight of tea, they are the important substances that constitute the taste of tea. Feng et al. (2014) showed that in albinous tea leaves, an increase in total amino acid content can reduce the astringency and bitterness of catechin and caffeine, thus enhancing the umami taste. Yin et al. (2014) showed that theanine can reduce the astringency caused by EGCG, while caffeine can enhance the return taste caused by theanine.

Although the tea grade is evaluated by the sensory evaluation of tea panelists in the ‘Spring Tea Competition’, few study refers...
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2 Materials and methods

2.1 Tea sample

The 667 tea samples were Wuyi Rock Tea (*Camellia sinensis* cv. Rougui) collected from ‘Spring Tea Competition’ sponsored by Wuyishan Tea Bureau in 2019. These samples included 91 of gold medal tea (I), 138 of first prize tea (II), 207 of second prize tea (III) and 231 of non-awarding tea (IV).

2.2 Sensory evaluation

The Sensory evaluation of tea quality were conducted by a tea tasting panel consisting of six professional panelists, according to standardised procedure of ‘Methodology of sensory evaluation of tea’, the National Standards of the People’s Republic of China (2009). The each tea sample was examined and scored by each of the five panelists independently. The sum total of the five quality features was expressed as the total quality score (TQS).

2.3 Determination of tea quality index

The 5g of each 667 tea samples was sampled respectively and were grounded and sieved by a 60-mesh. The powder samples of the same grade were fully mixed together for determination of quality index subsequently.

The water extract of tea sample was measured according to the National Standards of the People’s Republic of China (2013a). Three replicates were conducted.

The content of soluble sugar was determined by anthrone colorimetric method (Wang, 2006). Glucose (Sinopharm Chemical Reagent Co., Ltd., China) was used as a standard and detected at 620 nm. Three replicates were conducted.

The content of tea polyphenols was determined with the Folin-Ciocalteu phenol reagents (Sinopharm Chemical Reagent Co., Ltd, China), according to the National Standards of the People’s Republic of China (2008). Gallic acid (Beijing Solarbio Science & Technology Co., Ltd, China) was used as a standard and detected at 765 nm. Three replicates were conducted.

The content of total free amino acids was determined with the ninhydrin reagents (Sinopharm Chemical Reagent Co., Ltd, China), according to the National Standards of the People’s Republic of China (2013c). L-Theanine (Beijing Solarbio Science & Technology Co., Ltd., China) was used as a standard and detected at 274 nm. Three replicates were conducted.

The content of caffeine was determined with ultraviolet spectrophotometry, according to the National Standards of the People’s Republic of China (2013b). Caffeine (Beijing Solarbio Science & Technology Co., Ltd., China) was used as a standard and detected at 274 nm. Three replicates were conducted.

The composition of catechins was measured with high performance liquid chromatography (HPLC) method, according to the National Standards of the People’s Republic of China (2008). The equipment for HPLC was a Waters e2695 HPLC (Waters Technologies, USA) equipped with Phenomenex Gemini C18 column (250 mm x 4.6 mm, 5 μm, USA). The detection wavelength was 278 nm. The mobile phase (A) was 0.09% acetonitrile and 0.02% acetic acid in water, and the mobile phase (B) was 0.8% acetonitrile and 0.02% acetic acid in water. The gradient elution program was A: B = 100:0 (0-10 min), A: B = 68:32 (10-25 min), and A: B = 100:0 (25-30 min). The column temperature was maintained at 35 °C. The injection volume was 10 μL and the flow rate was 1 mL min⁻¹. Five catechins, i.e. epigallocatechin gallate (EGCG), epicatechin gallate (ECG), epigallocatechin (EGC), gallocatechin (GC), gallocatechin gallate (GCG) purchased from Beijing Solarbio Science & Technology Co., Ltd., China, were used as standards. Three replicates were conducted.

The composition of free amino acids was measured with a Hitachi L-8900 automatic amino acid analyzer, according to the National Standards of the People’s Republic of China (2016), the mixture of amino acids (Merck Chemical Technology Co., LTD, Shanghai, China) was used as standards. Three replicates were conducted.

2.4 Statistical analysis

All experimental data were presented as mean ± standard error (SE). They were analyzed using a one-way analysis of variance (ANOVA), and followed the least significant difference (LSD) test (Williams & Abdi, 2010).

Restricted principal coordinate analysis (PCoA) and correlative analysis were all conducted with SPSS 20.0 software.

3 Results and discussion

3.1 Sensory evaluation

It is an international standard operation and process for sensory evaluation of tea quality by professional panelist. In Japan, evaluation of green ten (Tencha) is 200 points in total, including 40 points for leaf appearance, 65 points for smell, 20 points for color of the brew, 65 points for taste, and 10 points for leaf color in hot water (Miyauchi et al., 2014). In China, evaluation of oolong tea is 100 points in total, including 20% for appearance of dry tea, 30% for tea aroma, 35% for taste, 10% for infused leaves, and 5% for liquor color, according to ‘Methodology of sensory evaluation of tea’, the National Standards of the People’s Republic of China (2009). In this study, sensory evaluation of all Wuyi Rougui tea samples was conducted by six panelists independently. The total quality score (TQS) of four grades teas were I (93.29) > II (89.61) > III (83.59) > IV (70.13) (Table 1).

| Grade   | I   | II  | III | IV  |
|---------|-----|-----|-----|-----|
| TQS     | 93.29 ± 5.28 | 89.61 ± 3.42 | 83.59 ± 3.30 | 70.13 ± 7.19 |

Note: Means ± standard error (SE) were TQS of six panelists independently. (I) gold medal tea; (II) first prize tea; (III) second prize tea; (IV) non-awarding tea. TQS: total quality score.

Table 1. Sensory evaluation of Wuyi Rougui tea with different grades.
3.2 Quality index of Rougui tea

The content of water extract is closely related to the taste of tea infusion. The results showed that the water extracts in Rougui tea was in the range of 40.20-48.85% (Figure 1A). It was the highest in IV grade (48.85%) that was significant difference \( P < 0.05 \) with other grades. The water extracts was I (42.57%) > II (41.25%) > III (40.20%), however, there was no different significance \( P < 0.05 \) between them (Figure 1A).

The content of soluble sugar in Rougui tea was in the range of 49.73-56.17 (mg g\(^{-1}\)) (Figure 1B). It was the highest in I grade (56.17 mg g\(^{-1}\)) that was significant difference \( P < 0.05 \) with other grades. The content of soluble sugar was III (51.72 mg g\(^{-1}\)) > II (51.64 mg g\(^{-1}\)) > IV (49.73 mg g\(^{-1}\)), however, there was no different significance \( P < 0.05 \) between them (Figure 1B). Soluble sugars are some soluble oligosaccharides such as glucose and sucrose which contributes to the sweet taste of tea infusion, usually account for 4% of dry tea (Gu et al., 2012). Although the content of soluble sugar in tea infusion is relative low, it can reduce the bitterness and astringent of tea infusion (Gu et al., 2012; Yin et al., 2014). The higher the soluble sugar content in tea infusion, the more mellow rather than bitter the tea tastes.

The content of caffeine in Rougui tea was in the range of 23.14-24.99 (mg g\(^{-1}\)) (Figure 1C). It was the lowest in IV grade (23.14 mg g\(^{-1}\)) that was significant difference \( P < 0.05 \) with other grades. The content of caffeine was I (24.99 mg g\(^{-1}\)) > III (24.82 mg g\(^{-1}\)) > II (24.73 mg g\(^{-1}\)), however, there was no different significance \( P < 0.05 \) between them (Figure 1C). As a bitter substance, caffeine is an important taste substance of tea soup (Scharbert & Hofmann, 2005). Studies have shown that caffeine content is negatively correlated with tea quality (Xu et al., 2020). However, Gu et al. (2012) reported that the correlation coefficient of caffeine and tea quality is 0.869. Although caffeine is an important factor leading to the bitterness, appropriate content of caffeine can increase the taste of tea infusion. By comparison, the content of caffeine was only about half of the content of soluble sugar in these tea samples. Usually, caffeine accounts for 2%-4% of the total alkaloids of tea (Gu et al., 2012).

The content of tea polyphenols in Rougui tea was in the range of 166.44-203.08 (mg g\(^{-1}\)) (Figure 1D). It was I (203.08 mg g\(^{-1}\)) > II (194.48 mg g\(^{-1}\)) > III (188.09 mg g\(^{-1}\)) > IV (166.44 mg g\(^{-1}\)), and was significant difference \( P < 0.05 \) between the four grades tea samples. By comparison, the content of tea polyphenols was only about half of the content of soluble sugar, and was about the same as the content of caffeine. The free amino acids is one of the important indicators for tea quality and nutritional ingredient (Das et al., 2019; Gu et al., 2012).

The content of soluble sugar in Rougui tea was in the range of 49.73-56.17 (mg g\(^{-1}\)) (Figure 1B). It was the highest in I grade (56.17 mg g\(^{-1}\)) that was significant difference \( P < 0.05 \) with other grades. The content of soluble sugar was III (51.72 mg g\(^{-1}\)) > II (51.64 mg g\(^{-1}\)) > IV (49.73 mg g\(^{-1}\)), however, there was no different significance \( P < 0.05 \) between them (Figure 1B). Soluble sugars are some soluble oligosaccharides such as glucose and sucrose which contributes to the sweet taste of tea infusion, usually account for 4% of dry tea (Gu et al., 2012). Although the content of soluble sugar in tea infusion is relative low, it can reduce the bitterness and astringent of tea infusion (Gu et al., 2012; Yin et al., 2014). The higher the soluble sugar content in tea infusion, the more mellow rather than bitter the tea tastes.

Figure 1. Quality index of Wuyi Rougui tea with different grades. (A) Water extracts (%); (B) Soluble sugar (mg g\(^{-1}\)); (C) Caffeine (mg g\(^{-1}\)); (D) Total free amino acids (mg g\(^{-1}\)); (E) Tea polyphenols (mg g\(^{-1}\)); (F) Ratio of phenol to amino acid. The lowercases represent a significant level at \( P < 0.05 \). (I) gold medal tea; (II) first prize tea; (III) second prize tea; (IV) non-awarding tea.
was 3-4 times as much as the content of the content of soluble sugar, and was 7-8 times as much as the content of caffeine. Tea polyphenols are the most abundant inclusions in tea and also an important flavor substance (Scharbert et al., 2004). Tea polyphenols, accounting for about one third of the dry matter of fresh leaves and three quarters of the water extract, are one of the important indicators for tea quality (Gu et al., 2012). Chen & Yang (2015) reported that in Wuyi Rougui tea, the content of tea polyphenols of Famous rock area was significantly higher than that of Dan rock area. Ye et al. (2017) reported that the content of tea polyphenols in Wuyi Rougui tea leaves was authentic rock region > semi-authentic rock region > ordinary region. Our results showed that the higher the grade of tea sample, the higher the content of tea polyphenols, that may be the reason for the "intense" taste of tea infusion.

The ratio of phenol to amino acid (P/A ratio) is a traditional index for evaluation of tea quality. The P/A ratio of I, II, III, and IV grades were 8.04, 7.64, 7.27, and 6.55, respectively (Figure 1F). Generally, high P/A ratio contributes tea infusion with strong throat feeling and thick and heavy taste, and low P/A ratio contributes high freshness and soft feeling taste.

### 3.3 Catechins components in the tea with different grades

Catechins account for about 70% of tea polyphenols and contribute astringent taste in tea infusion. Especially, ester catechins, whose composition and concentration not only constitute the main body of the astringency, but also the thickness of tea infusion and tea quality (Gu et al., 2012). The results of catechin components in Rougui tea showed that (Table 2), EGCG content was I (32.75 ± 0.02 mg g⁻¹) = II (32.44 ± 0.02 mg g⁻¹) that was significant (P < 0.05) higher than III (32.75 ± 0.00 mg g⁻¹), and III was significant (P < 0.05) higher than IV (30.82 ± 0.00 mg g⁻¹). EGC content was I (17.30 ± 0.00 mg g⁻¹) = II (17.11 ± 0.00 mg g⁻¹) that was significant (P < 0.05) higher than III (16.50 ± 0.00 mg g⁻¹), and III was significant (P < 0.05) higher than IV (16.17 ± 0.00 mg g⁻¹). GC content was significant (P < 0.05) difference that was I (15.62 ± 0.00 mg g⁻¹) > II (14.74 ± 0.00 mg g⁻¹) > III (14.43 ± 0.00 mg g⁻¹) > IV (14.05 ± 0.00 mg g⁻¹). ECG content was I (8.61 ± 0.00 mg g⁻¹) that was significant (P < 0.05) higher than II (8.37 ± 0.00 mg g⁻¹) = III (8.30 ± 0.00 mg g⁻¹), and II and III were significant (P < 0.05) higher than IV (8.18 ± 0.00 mg g⁻¹). GCG content was I (1.56 ± 0.00 mg g⁻¹) that was significant (P < 0.05) higher than II (1.40 ± 0.00 mg g⁻¹) = III (1.41 ± 0.00 mg g⁻¹) = IV (1.39 ± 0.00 mg g⁻¹). The total content of five catechins was significant (P < 0.05) difference that was I (75.84 ± 0.00 mg g⁻¹) > II (74.06 ± 0.00 mg g⁻¹) > III (72.34 ± 0.00 mg g⁻¹) > IV (70.61 ± 0.00 mg g⁻¹). EGCG was the highest of the five components accounting for about 43%. The second was EGC and GC accounting for about 23% and 20%, respectively. The third was ECG accounting for about 11%. The lowest was GCG accounting for about 2.0%. More specifically, the ester catechins (include EGCG, ECG and GCG) of four grade teas accounted for 56-57%, and the non-ester catechins (include GC and EGC) accounted for 42-43%. The ratio of ester type to non-ester type was 1.3034, 1.3252, 1.3385, and 1.3369, respectively in I, II, III, and IV (Table 2). Xu et al. (2020) studies showed that the content of catechin in high-grade tea was significantly higher than that in low-grade tea. Wang et al. (2018) reported that the bitterness of tea was mainly caused by ester catechin, and the ratio of ester catechin to non-ester catechin could reflect the degree of bitterness. Our results showed that higher catechins contents in higher grade tea samples contribute strong throat feeling and thick and heavy taste in tea infusion, but which have lower ratios of ester type to non-ester type that reduce the bitterness from the ester catechins.

### 3.4 Characteristic amino acids profile in the tea with different grades

Amino acids are another important constitutes of contributor to taste of tea infusion (Chen & Yang, 2015; Akitomi et al., 2013). Although the content of total free amino acids were no significant difference between the four grades tea samples (Figure 1D), the components of amino acids in four tea samples were further determined, and 14 amino acids were identified in tea infusion (Table 3). The total contents of 14 amino acids were IV (7.6120 mg g⁻¹) > I (6.9361 mg g⁻¹) > III (6.8545 mg g⁻¹) > II (6.6584 mg g⁻¹). The highest component was theanine which accounted for about 41%-40% of the total contents, was IV (3.4096 mg g⁻¹) > I (3.0724 mg g⁻¹) > III (2.8724 mg g⁻¹) > II (2.7715 mg g⁻¹) and was significant difference (P < 0.05) between IV, I, and II and no significant different between II and III. Asparagine, alanine, and glutamic acid accounted for about 8%, respectively. Serine and histidine accounted for about 6%, respectively. Valine accounted for about 4%. Threonine and phenylalanine accounted for about 3%, respectively. Isoleucine and tyrosine accounted for about 2%, respectively. No significant difference (P < 0.05) of γ-aminobutyric acid (GABA), leucine, and glycine between the four tea samples (Table 3).

| Composition | A          | B          | C          | D          |
|-------------|------------|------------|------------|------------|
| GC          | 15.62 ± 0.02a | 14.74 ± 0.10b | 14.43 ± 0.04c | 14.05 ± 0.05d |
| EGC         | 17.30 ± 0.06a | 17.11 ± 0.05a | 16.50 ± 0.02b | 16.17 ± 0.13c |
| GCG         | 1.56 ± 0.01a  | 1.40 ± 0.01b  | 1.41 ± 0.01b  | 1.39 ± 0.01b  |
| ECG         | 8.61 ± 0.04a  | 8.37 ± 0.01b  | 8.30 ± 0.03b  | 8.18 ± 0.02c  |
| EGCG        | 32.75 ± 0.14a | 32.44 ± 0.12a | 31.70 ± 0.08b | 30.82 ± 0.18c |
| Total       | 75.85 ± 0.29a | 74.08 ± 0.16b | 72.26 ± 0.18c | 70.62 ± 0.40d |
| Ester catechins | 56.59%  | 56.99%  | 57.24%  | 57.21%  |
| Non-ester catechins | 43.41%  | 43.01%  | 42.76%  | 42.79%  |
| Ratio of ester to non-ester catechins | 1.3034 | 1.3252 | 1.3385 | 1.3369 |

Note: Means standard error (± SE) from three replications for each determination is shown. The lowerscases represent a significant level at P < 0.05. GC: gallocatechin; EGC: epigallocatechin; GCG: gallocatechin gallate; ECG: epicatechin gallate; EGCG: epigallocatechin gallate. Ester catechins include GCG, ECG, and EGCG. Non-ester catechins include GC and EGC.
amino acids were not exactly consistent with the tea grades, they also reflected the role of amino acids in taste of tea infusion. The dissolution of hydrophilic amino acids in tea infusion is much faster than that of hydrophobic amino acids, and within 15 min theanine comprises about 30% of the free amino acids in tea infusion (Kocadağlı et al., 2013). It was suggested that theanine could be synthesized from glutamic acid and ethylamine, and theanine and glutamate are the major contributors to the umami taste of green tea (Scharbert & Hofmann, 2005; Feldheim et al., 1986; Deng et al., 2008; Kaneko et al., 2006). The proportion of theanine accounted for total content was 44.30% in I, 41.62% in II, 41.91% in III, and 44.79% in IV, respectively (Table 3). Jia et al. (2018) reported that the contents and ratios of theanine, sweet and umami amino were higher in high quality of tea leaves than that in the low quality of tea leaves. Their results also showed that ratios of theanine, sweet and umami amino acids were 8%, 5% and 6% higher, respectively in Yu plantation (a authentic rock area tea garden) than that in Qishan plantation (an ordinary tea garden). Sensory evaluation score were positively correlated with the ratios of theanine, sweet and umami amino acids. As sweet aftertaste is the most notable character of Wuyi Rock Tea, the characteristic amino acids are dominant contributors to sweet

Each amino acid has a different taste. Amino acids with small molecular chain contribute considerably strong sweetness, while amino acids with a branched chain produce particularly bitter taste (Nishimura & Kato, 1988; Akitomi et al., 2013; Narukawa et al., 2011). Matoba & Hata (1972) research showed that hydrophobic amino acids have a bitter taste. Some hydrophilic amino acids, such as glutamate and glycine, are easy to combine with taste receptors to produce sweet taste, because of their small molecular chains (Akitomi et al., 2013). On in-depth analysis of these special characteristics of amino acids of Wuyi Rougui tea, we found that in these 4 tea samples (Table 4), the hydrophilic amino acids accounted for 79.44-82.90% and the hydrophobic amino acids accounted for 17.10-20.56%. The ratio of hydrophilic amino acids to hydrophobic amino acids was IV (4.85) > I (4.26) > III (4.03) > II (3.86). The sweet amino acids accounted for 86.74-87.29% and it was II (87.72%) > I (87.29%) > IV (87.14%) > III (86.74%). The bitter amino acids accounted for 12.28-13.26% and it was III (13.26%) > IV (12.86%) > I (12.71%) > II (12.28%). The ratio of sweet amino acids to bitter amino acids was II (7.14) > I (6.87) > IV (6.78) > III (6.54). The umami amino acids accounted for 50.20-53.41% and it was IV (53.41%) > I (52.57%) > III (50.49%) > II (50.20%). Although the trends of these characteristics of amino acids were not exactly consistent with the tea grades, they also reflected the role of amino acids in taste of tea infusion. The dissolution of hydrophilic amino acids in tea infusion is much faster than that of hydrophobic amino acids, and within 15 min theanine comprises about 30% of the free amino acids in tea infusion (Kocadağlı et al., 2013). It was suggested that theanine could be synthesized from glutamic acid and ethylamine, and theanine and glutamate are the major contributors to the umami taste of green tea (Scharbert & Hofmann, 2005; Feldheim et al., 1986; Deng et al., 2008; Kaneko et al., 2006). The proportion of theanine accounted for total content was 44.30% in I, 41.62% in II, 41.91% in III, and 44.79% in IV, respectively (Table 3). Jia et al. (2018) reported that the contents and ratios of theanine, sweet and umami amino were higher in high quality of tea leaves than that in the low quality of tea leaves. Their results also showed that ratios of theanine, sweet and umami amino acids were 8%, 5% and 6% higher, respectively in Yu plantation (a authentic rock area tea garden) than that in Qishan plantation (an ordinary tea garden). Sensory evaluation score were positively correlated with the ratios of theanine, sweet and umami amino acids. As sweet aftertaste is the most notable character of Wuyi Rock Tea, the characteristic amino acids are dominant contributors to sweet

| Table 3. The content of amino acids components in Rougui tea with different grades (mg g⁻¹). |
|-------|-------|-------|-------|
| Amino acid | I     | II    | III   | IV    |
| Theanine  | 3.0724 ± 0.0161b | 2.7715 ± 0.0879c | 2.8724 ± 0.0330c | 3.4096 ± 0.0373a |
| Asparagine | 0.5846 ± 0.0121c | 0.5548 ± 0.0120c | 0.6181 ± 0.0085b | 0.6724 ± 0.0208a |
| Alanine   | 0.5792 ± 0.1499a | 0.6789 ± 0.0615a | 0.6602 ± 0.1522a | 0.6657 ± 0.0304a |
| Glutamic acid | 0.5737 ± 0.0566b | 0.5713 ± 0.0103b | 0.5884 ± 0.0130b | 0.6561 ± 0.0304a |
| Serine    | 0.4515 ± 0.0070b | 0.4128 ± 0.0093c | 0.4561 ± 0.0121b | 0.4772 ± 0.0069a |
| Histidine | 0.4189 ± 0.0189ab | 0.3804 ± 0.0491b | 0.4169 ± 0.0727ab | 0.4927 ± 0.0155a |
| Valine    | 0.3040 ± 0.0035b | 0.2951 ± 0.0051b | 0.3166 ± 0.0032a | 0.3265 ± 0.0096a |
| Threonine | 0.2277 ± 0.0207a | 0.1968 ± 0.0123b | 0.2063 ± 0.0017b | 0.2311 ± 0.0215a |
| Phenylalanine | 0.2128 ± 0.0046a | 0.1844 ± 0.0157b | 0.2148 ± 0.0161a | 0.2319 ± 0.0040a |
| Isoleucine | 0.1443 ± 0.0132ab | 0.1233 ± 0.0188b | 0.1412 ± 0.0127ab | 0.1622 ± 0.0129a |
| Tyrosine  | 0.1421 ± 0.0025b | 0.1276 ± 0.0055c | 0.1442 ± 0.0013b | 0.1631 ± 0.0058a |
| GABA      | 0.1209 ± 0.0038a | 0.2266 ± 0.2305a | 0.1539 ± 0.0578a | 0.1631 ± 0.0590a |
| Leucine   | 0.0782 ± 0.0019a | 0.0871 ± 0.0040a | 0.0924 ± 0.0018a | 0.0950 ± 0.0136a |
| Glycine   | 0.0258 ± 0.0028a | 0.0478 ± 0.0352a | 0.0330 ± 0.0081a | 0.0457 ± 0.0238a |
| Total     | 6.9361      | 6.6584     | 6.8545     | 7.6120     |

Note: Means standard error (± SE) from three replications for each determination is shown. The lowercases represent a significant level at P < 0.05. GABA, γ-Aminobutyric acid. The data in bracket are the proportion of each component in total content.
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3.4 Restricted principal coordinate analysis (PCoA)

Sensory evaluation grade is more superficially reflected in the color, aroma, taste and shape of tea, and the measured quality indexes may explain more problems. The changes in quality indexes may indicate the grade of Wuyi Rock Tea. Thus the restriction principal coordinate analysis on quality indexes of Wuyi Rougui teas were carried out (Figure 2). The results showed that Wuyi Rougui teas with different grades were completely separated (Figure 2A). The coordinate axis 1 (PCOA1) can distinguish I, II, III from IV, which can explain 93.97% of the difference. Differences among I, II and III were dominated by principal coordinate 2 (PCOA2), and explanatory degree was 3.46%. The explanatory degree of quality index (PCoA1 and PCoA2) reached 69.14%.

The restriction principal coordinate analysis of 14 free amino acids in Wuyi Rougui tea can distinguish Wuyi Rougui tea with different grades (Figure 2B). PCoA1 is the largest principal coordinate component, and can explain 75.14% of differences, while PCOA2 is different among I, II, III and IV, with 12.52% of explanation degree. The total explanation degree of free amino acids was 87.66%.

3.5 Correlation analysis

The correlation analysis was conducted to investigate the relationship between TQS and quality indicators. As shown in Table 5, TQS were significantly positively correlated to tea polyphenols ($P < 0.01$), and caffeine, EGCG and EGC ($P < 0.05$). Hydropholic amino acids were significantly negative correlated to umami amino acids ($P < 0.05$) and water extract ($P < 0.01$). Sweet amino acids were significantly negatively correlated to bitter amino acids ($P < 0.01$). Umami amino acids were significantly positively correlated to water extract ($P < 0.05$). Water extract were significantly negatively correlated to tea polyphenols and caffeine ($P < 0.05$). Soluble sugar was significantly positively to EGCG, ECG, GCG, GC ($P < 0.01$) and EGC ($P < 0.05$). Tea polyphenol was significantly positively to caffeine ($P < 0.01$).

Therefore, the higher the contents of tea polyphenol, caffeine, and caffeine, aftertaste of Wuyi Rock Tea (Jia et al., 2018). We suggested that both content and proportion of tea chemicals are important to taste of tea infusion. The high grade tea has a more reasonable proportion of various types of amino acids.

3.6 Correlation analysis

The correlation analysis was conducted to investigate the relationship between TQS and quality indicators. As shown in Table 5, TQS were significantly positively correlated to tea polyphenols ($P < 0.01$), and caffeine, EGCG and EGC ($P < 0.05$). Hydropholic amino acids were significantly negative correlated to umami amino acids ($P < 0.05$) and water extract ($P < 0.01$). Sweet amino acids were significantly negatively correlated to bitter amino acids ($P < 0.01$). Umami amino acids were significantly positively correlated to water extract ($P < 0.05$). Water extract were significantly negatively correlated to tea polyphenols and caffeine ($P < 0.05$). Soluble sugar was significantly positively to EGCG, ECG, GCG, GC ($P < 0.01$) and EGC ($P < 0.05$). Tea polyphenol was significantly positively to caffeine ($P < 0.01$).

Therefore, the higher the contents of tea polyphenol, caffeine,
EGCG and EGC, the higher the TQS. High contents of sweet amino acids, umami amino acids, soluble sugar, and low contents of hydrophobic amino acids and bitter amino acids may end up benefiting those good teas.

4 Conclusions

The quality indexes of tea infusion were higher as the higher of tea grades in the four Wuyi Rougui teas. The grades of Wuyi Rougui teas could be effectively distinguished by the quality indexes of tea infusion. The contents of tea polyphenols, caffeine, EGCG, and GCG were significantly and positively correlated to TQS of sensory evaluation. We suggested that higher content of hydrophobic amino acids and hydrophilic amino acids and bitter amino acids may end up benefiting those good teas.

Table 5. Correlation between the total quality score and quality indexes.

| Index | TQS | HAA | DAA | SAA | BAA | UAA | WE | SS | TP | FAA | CA |
|-------|-----|-----|-----|-----|-----|-----|----|----|----|-----|----|
| TQS  | 1   |     |     |     |     |     |    |    |    |     |    |
| HAA  | 0.06| 1   |     |     |     |     |    |    |    |     |    |
| DAA  | 0.70| 0.08| 1   |     |     |     |    |    |    |     |    |
| SAA  | 0.59| 0.81| 0.27| 1   |     |     |    |    |    |     |    |
| BAA  | -0.56 | -0.84 | -0.27 | -1.00** | 1   |     |    |    |    |     |    |
| UAA  | -0.44 | -0.06 | -0.95* | -0.08 | 0.08 | 1   |    |    |    |     |    |
| WE   | -0.79 | -0.16 | -0.99** | -0.42 | 0.41 | 0.89* | 1   |    |    |     |    |
| SS   | 0.82 | -0.46 | 0.37 | 0.14 | -0.10 | -0.12 | -0.44 | 1   |    |     |    |
| TP   | 0.98** | 0.16 | 0.81 | 0.61 | -0.59 | -0.59 | -0.89* | 0.71 | 1   |     |    |
| FAA  | -0.19 | 0.02 | 0.57 | -0.32 | 0.29 | -0.79 | -0.44 | -0.43 | -0.02 | 1   |    |
| CA   | 0.95* | -0.06 | 0.87 | 0.40 | -0.37 | -0.69 | -0.92* | 0.76 | 0.97** | 0.11 | 1   |
| EGC   | 0.93* | -0.21 | 0.45 | 0.40 | -0.36 | -0.18 | -0.55 | 0.96** | 0.84 | -0.44 | 0.83 |
| ECG   | 0.84 | -0.38 | 0.33 | 0.23 | -0.19 | -0.06 | -0.42 | 0.99** | 0.72 | -0.50 | 0.74 |
| GCG   | 0.66 | -0.53 | 0.10 | 0.05 | -0.01 | 0.15 | -0.18 | 0.96** | 0.51 | -0.61 | 0.55 |
| EGC   | 0.91* | -0.07 | 0.34 | 0.53 | -0.49 | -0.03 | -0.46 | 0.91* | 0.80 | -0.58 | 0.75 |
| GC    | 0.86 | -0.30 | 0.33 | 0.32 | -0.27 | -0.05 | -0.43 | 0.98** | 0.75 | -0.53 | 0.75 |

Note: * and ** represent a significant level at $P < 0.05$ and $P < 0.01$, respectively. TQS: total quality score; HAA: Hydrophilic amino acids; DAA: Hydrophilic amino acids; SAA: Sweet amino acids; BAA: Bitter amino acids; UAA: Umami amino acids; WE: Water extract; SS: Soluble sugar; TP: Tea polyphenol; FAA: Free amino acid; CA: Caffeine; EGCG: epigallocatechin gallate; EGC: epicatechin gallate; GC: gallocatechin; GCG: gallocatechin gallate.

References

Akitomi, H., Tahara, Y., Yasuura, M., Kobayashi, Y., Ikezaki, H., & Toko, K. (2013). Quantification of tastes of amino acids using taste sensors. Sensors and Actuators. B, Chemical, 179, 276-281. http://dx.doi.org/10.1016/j.snb.2012.09.014.

Chen, H. K., & Yang, J. F. (2015). Analysis of the chemical component on quality of Rougui tea in different rock areas. Shipin Anquaan Zhiliang Jiance Xuebao, 6(4), 1287-1294.

Chen, H., Zhang, M., Qu, Z., & Xie, B. (2008). Antioxidant activities of different fractions of polysaccharide conjugates from green tea (Camellia Sinensis). Food Chemistry, 106(2), 559-563. http://dx.doi.org/10.1016/j.foodchem.2007.06.040.

Das, P. R., Kim, Y., Hong, S. J., & Eun, J. B. (2019). Profiling of volatile and non-phenolic metabolites—amino acids, organic acids, and sugars of green tea extracts obtained by different extraction techniques. Food Chemistry, 296, 69-77. http://dx.doi.org/10.1016/j.foodchem.2019.05.194. PMid:31202308.

Feng, L., Gao, M. J., Hou, R. Y., Hu, X. Y., Zhang, L., Wan, X. C., & Wei, S. (2014). Determination of quality constituents in the young leaves of albino tea cultivars. Food Chemistry, 155, 98-104. http://dx.doi.org/10.1016/j.foodchem.2014.01.044. PMid:24594160.

Fernandez, P. L., Martin, M. J., Gonzalez, A. G., & Pablos, F. (2000). HPLC determination of catechins and caffeine in tea: differentiation of the presence and significance of theanine in the tea plant. Journal of the Science of Food and Agriculture, 37(6), 527-534. http://dx.doi.org/10.1002/jsfa.2740370604.
of green, black and instant teas. Analyst, 125(3), 421-425. http://dx.doi.org/10.1039/a909219f. PMid:10829341.

Gu, Q., Lu, J. S., & Ye, B. C. (2012). Tea chemistry. Anhui: Press of University of Science and Technology of China.

Harbowy, M. E., Baldentine, D. A., Davies, A. P., & Cai, Y. (1997). Tea chemistry. Critical Reviews in Plant Sciences, 16(5), 415-480. http://dx.doi.org/10.1080/07352689709701956.

Hayashi, N., Chen, R., Ikezaki, H., & Ujihara, T. (2008). Evaluation of the umami taste intensity of green tea by a taste sensor. Journal of Agricultural and Food Chemistry, 56(16), 7384-7387. http://dx.doi.org/10.1021/jf800993x. PMid:18620401.

Horanni, R., & Engelhardt, U. H. (2013). Determination of amino acids in white, green, black, oolong, pu-erh teas and tea products. Journal of Food Composition and Analysis, 31(1), 94-100. http://dx.doi.org/10.1016/j.jfoodcom.2013.03.005.

Huo, D., Wu, Y., Yang, M., Fa, H., Luo, X., & Hou, C. (2014). Discrimination of chinese green tea according to varieties and grade levels using artificial nose and tongue based on colorimetric sensor arrays. Food Chemistry, 145, 639-645. http://dx.doi.org/10.1016/j.foodchem.2013.07.142. PMid:24128526.

Jia, X. L., Ye, J. H., Wang, H. B., Li, L., Wang, F. Q., Zhang, Q., Chen, J. B., Zheng, X. Y., & He, H. B. (2018). Characteristic amino acids in tea leaves as quality indicator for the evaluation of Wuyi Rock Tea in different culturing regions. Journal of Applied Botany and Food Quality, 91, 187-193.

Kaneko, S., Kumazawa, K., Masuda, H., Henze, A., & Hofmann, T. (2006). Molecular and sensory studies on the umami taste of Japanese green tea. Journal of the Science of Food and Agriculture, 86(7), 728-2694. http://dx.doi.org/10.1002/jsfa.2011.0205232. PMid:16569062.

Kocadağlı, T., Özdemir, K. S., & Gökmen, V. (2013). Effects of infusion conditions and decaffeination on free amino acid profiles of green and black tea. Food Research International, 53(2), 720-725. http://dx.doi.org/10.1016/j.foodres.2012.10.010.

Matoba, T., & Hata, T. (1972). Relationship between bitterness of peptides and their chemical structures. Agricultural and Biological Chemistry, 36(8), 1423-1431. http://dx.doi.org/10.1007/BF00213691.1972.10860410.

Miyachi, S., Yuki, T., Fuji, H., Kojima, K., Yonemine, T., Tomio, A., Bamba, T., & Fukusaki, E. (2014). High-quality green tea leaf production by artificial cultivation under growth chamber conditions considering amino acids profile. Journal of Bioscience and Bioengineering, 118(6), 710-715. http://dx.doi.org/10.1016/j.jbiosc.2014.05.008. PMid:24915994.

Nagata, T., & Sakai, S. (1984). Differences in caffeine, flavanols and amino acids contents in leaves of cultivated species of camellia. Japanese Journal of Breeding, 34(4), 459-467. http://dx.doi.org/10.1270/jsbsb1951.34.459.

Nakagawa, M. (1975). Contribution of green tea constituents to the intensity of taste element of brew. Nippon Shokuhin Kogyo Gakkaishi, 22(2), 59-64. http://dx.doi.org/10.3136/nsskk1962.22.59.

Narukawa, M., Noga, C., Ueno, Y., Sato, T., Misaka, T., & Watanabe, T. (2011). Evaluation of the bitterness of green tea catechins by a cell-based assay with the human bitter taste receptor hTAS2R39. Biochemical and Biophysical Research Communications, 405(4), 620-625. http://dx.doi.org/10.1016/j.bbrc.2011.01.079. PMid:21272567.

National Standards of the People's Republic of China. (2008). GB/T 8313-2008: determination of total polyphenols and catechins content in tea. Beijing.

National Standards of the People's Republic of China. (2009). GB/T 23776-2009: methodology of sensory evaluation of tea. Beijing.

National Standards of the People's Republic of China. (2013a). GB/T 8305-2013: determination of tea extract. Beijing.

National Standards of the People's Republic of China. (2013b). GB/T 8312-2013: determination of tea caffeine. Beijing.

National Standards of the People's Republic of China. (2013c). GB/T 8314-2013: determination of total free amino acids in tea. Beijing.

National Standards of the People's Republic of China. (2016). GB/T 5009.124-2016: determination of amino acids in foods. Beijing.

Nishimura, T., & Kato, H. (1988). Taste of free amino acids and peptides. Food Reviews International, 4(2), 175-194. http://dx.doi.org/10.1080/87559128809540828.

Salman, S., Yilmaz, C., Gökmen, V., & Özdemir, E. (2021). Effects of fermentation time and shooting period on amino acid derivatives and free amino acid profiles of tea. Lebensmittel-Wissenschaft + Technologie, 137, 110481. http://dx.doi.org/10.1016/j.lwt.2020.110481.

Scharbert, S., & Hofmann, T. (2005). Molecular definition of black tea taste by means of quantitative studies, taste reconstitution, and omission experiments. Journal of Agricultural and Food Chemistry, 53(13), 5377-5384. http://dx.doi.org/10.1021/jf050294d. PMid:15969522.

Scharbert, S., Jezussek, M., & Hofmann, T. (2004). Evaluation of the taste contribution of theaflavins in black tea infusions using the taste activity concept. European Food Research and Technology, 218(5), 442-447. http://dx.doi.org/10.1007/s00127-004-0888-3.

Tan, J., Dai, W., Lu, M., Lv, H., Guo, L., Zhang, Y., Zhu, Y., Peng, Q., & Lin, Z. (2016). Study of the dynamic changes in the non-volatile chemical constituents of black tea during fermentation processing by a non-targeted metabolomics approach. Food Research International, 79, 106-113. http://dx.doi.org/10.1016/j.foodres.2015.11.018.

Wang, T. T., Cai, Z. J., Pu, W. X., Luo, X., Luo, M., & Zhou, X. T. (2018). Analysis of Sensory Quality and Main Chemical Component Contributors of Green Tea in Sichuan. Food Analytical Methods, 39(4), 155-160.

Wang, X. K. (2006). Principles and techniques of plant physiological and biochemical experiments. Beijing: Higher Education Press.

Williams, L. J., & Abdí, H. (2010). Fisher’s least significant difference (LSD) test. In N. Salkind (Ed.), Encyclopedia of research design (pp. 1-6). Thousand Oaks: Sage.

Xu, X. Y., Chen, S., Yu, X. M., Zhao, X. M., Lin, H. Z., & Liu, G. Y. (2020). Quality differences of different grades of Wuyi rougui tea with different baking degrees. Shipin Kexue, 41(13), 22-28.

Ye, J. H., Luo, S. C., Zhang, Q., Jia, X. L., Wang, H. B., Liu, B. S., Hong, Y. C., Wang, F. Q., Chao, Q. L., Cao, S. X., Zhou, J. W., & He, H. B. (2017). Difference of fresh tea leaf quality from different tea plantations in Wuyishan. Fujian Nong-Lin Daxue Xuebao. Ziran Kexue Ban, 46(5), 495-501.

Yin, J. F., Zhang, Y. N., Du, Q. Z., Chen, J. X., Yuan, H. B., & Xu, Y. Q. (2014). Effect of Ca2+ concentration on the tastes from the main chemicals in green tea infusions. Food Research International, 62, 941-946. http://dx.doi.org/10.1016/j.foodres.2014.05.016.

Yu, Z. M., & Yang, Z. Y. (2020). Understanding different regulatory mechanisms of proteinaceous and non-proteinaceous amino acid formation in tea (Camellia sinensis) provides new insights into the safe and effective alteration of tea flavor and function. Critical Reviews in Food Technology, 60(5), 844-858. http://dx.doi.org/10.1080/00090805.2018.1552245. PMid:30614265.

Zhu, Y., Luo, Y., Wang, P., Zhao, M., Li, L., Hu, X., & Chen, F. (2016). Simultaneous determination of free amino acids in pu-erh tea and their changes during fermentation. Food Chemistry, 194, 643-649. http://dx.doi.org/10.1016/j.foodchem.2015.08.054. PMid:26471603.