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Correlation between Sensory Evaluation Scores and Flavor Attributes of Black Teas from Around the World

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Abstract

Background: Black teas can be grouped into many types based on cultivar, region of origin, harvesting seasons, processing methods and other factors, all of which combine to produce different flavor attributes (taste and aroma). This study aimed to establish and predict the quality of different black teas based on the correlation between sensory evaluation scores and the principal chemical components.

Results and Discussion: Sensory evaluation, analysis of the principal chemical components, as well as correlation analysis of black teas from around the world, were performed in this study. Statistical analysis showed that sensory scores were significantly and positively correlated with tea polyphenols, caffeine, amino acids, thearubigins and thearubigins/theaflavins ratio, and the correlation coefficient was 0.4166, 0.6595, 0.4379, 0.4196, 0.4165, respectively, which determined black tea quality. Furthermore, the taste quality showed a significant and positive correlation with caffeine, thearubigins and the ratio of thearubigins/theaflavins, which correlation coefficient was 0.4396, 0.6109, 0.4938, respectively.

Conclusion: The aroma and taste of Chinese black teas were better than tea from other countries. The results may be attributed to the higher content of amino acids and caffeine in Chinese black teas.

Keywords: Black tea; Sensory quality; Chemical components; Correlation coefficient; Flavor comparison

Introduction

Tea (*Camellia sinensis* (L.) O. Kuntze) is a perennial crop and a very pleasant and popular beverage, which is consumed by over two-thirds of the world's population [1,2]. The world's tea production was around 5,561,339 metric tons in 2014. China is the world's largest producer of tea, contributing 37.9% of the total global production, followed by India (21.7%), Kenya (8.0%), Sri Lanka (6.1%), Vietnam (4.1%), Turkey (4.1%), Indonesia (2.7%) and Iran (2.1%) [3].

Black tea is the most prevalent type of tea in the world, which accounts for approximately 75% of the world's tea trade. Black tea is manufactured through processes including, withering, rolling (cutting), fermenting and drying [4]. Fermentation plays a crucial role in the manufacturing of black tea, during which the chemical components and subsequent taste, aroma, color, and nutritional and biological properties of teas are greatly altered [5,6]. Furthermore, the taste and flavor in the tea brewing process were influenced by polyphenols, caffeine, amino acids and other components [7]. The polyphenols were oxidized and transformed to form the black tea pigments, theaflavins (TF, golden yellow) and thearubigins (TR, orange brown), during the manufacturing process. TF and TR are mainly responsible for the brightness, briskness and color of tea and improve tea quality [1,8,9]. Furthermore, the formation of black tea cream when the tea infusion became cold was related to TR, TF and caffeine contents [10,11]. Previous work also showed that the formation of tea cream was regulated by various chemical interactions including polyphenol-caffeine interactions and complex polyphenol-polyphenol interactions. Polyphenol-caffeine complexation was influenced by a number of gallate and hydroxyl groups of the polyphenol [12]. In summary, polyphenols and caffeine are crucial components, which have a strong influence on the taste of black tea brew.

The quality of black tea depends on the chemical components of tea infusions and has traditionally been evaluated by a professional tea taster who has developed their own language to describe various quality attributes of the tea infusion [13]. The analytical methods available to identify chemical constituents impacting tea quality are precise [14], however, they are also complex, time consuming, labor-intensive, expensive and require large amounts of organic solvents. The use of organoleptic evaluation to identify tea quality is rapid but results may be inaccurate, and can be easily influenced by various factors, including the environment and the mood of the evaluator [15]. In this study, the quality of black tea was explored through the correlation of sensory scores and principal chemical components. Furthermore, the flavor attributes of tea samples from various countries were compared.

Materials and Methods

Samples

Thirty-seven teas, representing nine countries of origin, different manufacturing methods, varieties and prices were used in this study based on primary production regions for black tea. The black tea samples were collected from different countries including, China (n=22), Sri Lanka (n=5), Vietnam (n=2), Kenya (n=2), India (n=2), Nepal (n=1), Malawi (n=1), Indonesia (n=1), Arabia (n=1). There were 22 black tea samples from China, including samples from the southern Yangtze River area (n=11), the southern China area (n=9), the Southwest China area (n=1), and the northern Yangtze River

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area (n=1). Samples represented different manufacturing methods, including loose black tea of China that are coincident with Orthodox black tea and other countries, and CTC which is conventional black tea processed by cut, tear and curl methods. Details on samples collected are shown in Table 1.

Chemicals

Catechin, epicatechin, epigallocatechin, epigallocatechin gallate, epicatechingallate were purchased from Sigma-Aldrich (St. Louis, MO, USA). Methanol, acetic acid and ethanol were of HPLC-grade and were purchased from Honeywell (Morris, NJ, USA). Other reagents were of analytical grade.

Sensory evaluation of black tea infusion

According to GB/T23776-2009 [16], 3 g of each black tea sample was infused with 150 mL of freshly boiled water for 5 min in a tea pot. The black tea infusion was then filtrated through a stainless-steel strainer into a porcelain tea bowl.

Six highly trained tea tasting panelists, who had previously achieved Chinese national certificates as senior tea panelists, participated in this study. During the process of sensory evaluation, the panelists used the method of collective evaluation of tea quality grade [17]. Five factors of sensory evaluation, including dry leaf appearance, liquor color, aroma, taste and infused leaf appearance [9,18]. were determined (Table 2). In case of CTC (Crush, Tear and Curl) black tea, that is usually graded on one of four scales of quality (such as whole leaf, broken leaf, fannings and dust), and an infusion of CTC was poured on the tea pot cover which had been used to brew tea for evaluation [9].

Polyphenols and caffeine analysis

The tea infusion was filtered through a 0.45 μm Millipore (Tianjin Branch billion Lung Experimental Equipment Co., Ltd) filter before determination using a HPLC system (Shimadzu LC-5P, Kyoto, Japan) fitted with a C_{18} column. The measurement was described as follows: flow rate: 1.0 mL min^{-1}; injection volume: 10 μL; mobile phase: A: methanol, B: 98% water and 2% acetic acid; gradient elution: 20%-25% A, 0-1 min; 25%-45% A, 1-12 min; 45%-90% A, 12-15 min; 90%-20%

No.	Classification	Sample name	Producing areas	Grade	Country
CS001	CTC	Uva tea	—	—	Sri Lanka
CS002	CTC	Vietnam tea	—	—	Vietnam
CS003	CTC	Ceylon tea	—	—	Sri Lanka
CS004	CTC	Malawi tea	—	—	Malawi
CS005	CTC	Assam tea	—	—	India
CS006	CTC	Darjeeling tea	—	—	India
CS007	CTC	Nepal tea	—	—	Nepal
CS008	CTC	Kenya tea	—	—	Kenya
CS009	CTC	Indonesia tea	—	—	Indonesia
CS010	CTC	Earl Grey Tea	—	—	Sri Lanka
CS011	CTC	FV523	—	—	Vietnam
CS012	CTC	Pure Kenya tea	—	—	Kenya
CS013	CTC	KANDY Tea	—	—	Sri Lanka
CS035	CTC	Arab tea	—	—	Arab
CS036	CTC	Ceylon tea	—	—	Sri Lanka
CS014	LBT	Lapsang souchong	SC	Grade 1	China
CS015	LBT	Golden junmee	SC	—	China
CS016	LBT	Lapsang souchong	SC	Grade 1	China
CS017	LBT	Golden junmee	SC	—	China
CS018	LBT	Panyong congou	SC	Special grade	China
CS019	LBT	Lapsang souchong	SC	Grade 1	China
CS020	LBT	Panyong congou	SC	Special grade	China
CS021	LBT	Keemun tea	SYR	—	China
CS022	LBT	Keemun tea	SYR	—	China
CS023	LBT	Hainan tea	SC	—	China
CS024	LBT	Wild tea	SC	Grade 1	China
CS025	LBT	Yunnan tea	SW	Special grade	China
CS026	LBT	Fuliang tea	SYR	Grade 1	China
CS027	LBT	Jiangxi tea	SYR	Premium grade	China
CS028	LBT	Ninggong tea	SYR	Special grade	China
CS029	LBT	Jiangsu tea	SYR	—	China
CS030	LBT	Jiangsu tea	SYR	—	China
CS031	LBT	Jiangsu tea	SYR	Special grade	China
CS032	LBT	White leaf tea	SYR	Special grade	China
CS033	LBT	Xinyang tea	NYR	—	China
CS034	LBT	Hunan tea	SYR	Grade 1	China
CS037	LBT	Zijuan tea	SYR	—	China

Notes: LBT: represents Loose black tea; SC: represents the Southern China tea area; SW: represents the Southwest China tea area; SYR: represents the Southern Yangtze River tea area; NYR: represents the Northern Yangtze River tea area

Table 1: Information on 37 black tea samples.

A, 15-16 min; maintained for 4 min.

Determination of free amino acids

The content of free amino acids in the tea infusions was estimated with a spectrophotometer (Model UV-5800; Shanghai yuan Analytical Instrument Co., Ltd., China). The ninhydrin dying method was used as described by GB/T8314-2003 for determination of total amino acid content, which was established at 570 nm, using glutamic acid as the standard.

Determination of TF and TR

Biochemical assessment of tea quality was carried out by estimation of TF and TR in black tea. A system analysis method for estimating TF, TR and TB in black tea was employed, using the simplified Roberts' method [19] as described previously [20], with slight modifications. The absorbance was measured on a UV spectrophotometer. The tea infusion was prepared by refluxing 3 g tea with 125 mL freshly boiled distilled water for 10 min on a water bath. The infusion (30 mL) was mixed with 30 mL ethyl acetate by shaking for 5 min. On separation of the two phases, the bottom layer (A_1) was drained off and the ethyl acetate extract (A_2) contained the TF and part of TR. A quantity (2 mL) of the ethyl acetate extract (A_2) was diluted with 25 mL ethanol (E_1). The tea infusion (15 mL) was mixed with 15 mL *N*-butyl alcohol by shaking for 3 min. Then to 2 mL of the bottom layer (B_1), 2 mL of aqueous saturated oxalic acid solution and 6 mL of water was added, and it was made up to 25 mL with ethanol (E_2). The ethyl acetate extract (15 mL, A_2) was mixed with 15 mL aqueous 2% sodium bicarbonate by shaking for 30 s and left aside. On separation of the two phases, the bottom layer (C_1) was drained off and the ethyl acetate extract (C_2) contained the TF. A quantity (4 mL) of ethyl acetate extract (C_2) was diluted with 25 mL of ethanol (E_3). To 2 mL of the bottom layer (A_1), 2 mL of aqueous saturated oxalic acid solution and 6 mL water was added and it was made up to 25 mL with ethanol (E_4). E_1, E_2, E_3, E_4 were measured at 380 nm with a spectrometer. The tea pigments were calculated as follows:

$$TF\ (\%) = E_3 \times 2.25$$

$$TR\ (\%) = (2 \times E_1 + 2 \times E_4 - E_3 - 2 \times E_2) \times 7.06$$

$$TB\ (\%) = 2 \times E_2 \times 7.06$$

Statistical analysis

Results are presented as mean values (at least 3 replicates), the statistical significance of the sensory attributes and chemical components of black tea was evaluated by nonparametric testing at a 5% significance level and 1% significance level (Microsoft Office 2010). Differences were considered to be significant at $p \leq 0.05$, and to be extremely significant at $p \leq 0.01$.

Results and Discussion

Analysis of sensory evaluation and quality scores of tea samples

Full-type black tea from China and broken-type tea from other countries was collected and sensory evaluation analyses were performed. The aroma of Chinese black tea was relatively better than tea from other countries, and included some unique aroma characters, such as the orchid fragrance in CS020, the sugar aroma of CS025, smoky flavor of CS019, and the aroma of high sharpness persisting (Tables 3 and 4). The aroma characters of black tea samples collected from other countries were mainly sweet and fruity fragrances, and a slightly flat aroma. The durability of aroma from Chinese black tea was better than that from other samples. In addition, Sri Lankan Black Tea (CS036) was only one sample from other countries had a floral scent.

The tea infusion color of Assam black tea (CS005) was especially good in redness and brightness, and the evaluation score of liquor was the highest of all the black tea samples, after sensory evaluation scores. The score of tea liquor of Malawi black tea (CS004) was the lowest of all the samples, and the liquor had a deep red and dark color. The sensory evaluation results of the tea liquor samples from other countries indicated no significant differences. However, the tea liquor from the southern Yangtze River and the northern Yangtze River were mostly orange-yellow in color, while a yellow tea infusion was not apparent in teas from other areas in China. The degree of redness of black teas from the southern and the northern Yangtze River areas was slightly weaker than that found in teas from other areas in China and from other countries in the world, and this may be due to the different tea cultivars and the degree of fermentation used. The liquor color of teas from the southern and the northern Yangtze River areas were mostly orange in color. The quantities of TF and TR produced largely govern the liquor characters (color, brightness, briskness, strength and 'quality') of teas [21,22]. It is therefore likely that the degree of the withering conducted on the tea leaf may influence the development of liquor characters and the overall quality of black teas [4].

The briskness, umami and strength of infusion were the most important factors for evaluating the taste of black tea. The umami taste of Chinese black teas (except CS030) was better than that of teas from other countries. From Table 3, it can be seen that the umami taste of CS016, CS020, CS021, CS025, CS026, CS028, CS033 and CS037 was relatively high, while the umami taste scores of Chinese black tea (CS030), Vietnamese black tea (CS002) and Kenyan black tea (CS012) was the lowest. Furthermore, the briskness and strength of Assam black tea and Nepal black tea were the best.

In particular, the difference in tea taste between tea samples may have been due to the different manufacturing methods employed. Chinese black tea is mainly full-type black tea, while the black tea from the other countries is mainly broken-type tea (crush, tear and curl) [23-25].

Analysis of chemical constituents in tea samples

The variation in content of polyphenols in Chinese black tea samples was relatively larger than that in other samples, and although there was no obvious trend, the content of polyphenols in sample CS037 was higher than in other samples. Sample CS037 was made from a purple leaf cultivar, named 'Zijuan', which is a specific cultivar in Yunnan big-leaf tea population with a national improved tea variety, Menghai big-leaf tea, which has high levels of tea ployphenols (TPs) [26], and good pharmacological effects [27]. Moreover, the polyphenol content in Vietnamese Black Teas, CS002 and CS011, was lower than that in samples from other countries. The polyphenol content was highest in tea samples CS005 and CS006, which were from India (except CS037).

Classification	Appearance	Liquor	Aroma	Taste	Infused
Loose black tea	25	10	25	30	10
CTC	20	10	30	30	10

Table 2: The proportion of five factors in different types of black tea.

No.	Aroma	Liquor	Taste
China			
CS014	Sweet and flower fragrance, umami, lasting	Orange and redness, clarity and brightness	Sweet and mellow, umami
CS015	Sweet and potato fragrance, lasting	Orange and redness, clarity and brightness	Longan flavour, slightly umami
CS016	Longan fragrance, lasting	Orange and redness, clarity and brightness	Longan flavour, umami
CS017	Caramel-like, slightly lasting	Redness, brightness	More mellow, slightly taster-after
CS018	Longan fragrance, slightly lasting	Redness, brightness	Mellow, umami
CS019	Smoke-like, lasting	Orange and redness, clarity	Mellow, smoked odour, little umami
CS020	Sweet and orchid fragrance□high and lasting	Orange and redness, clarity and brightness	More mellow, umami
CS021	Sweet and fruity fragrance, slightly high and lasting	Orange and redness, clarity and brightness	Mellow, umami
CS022	Sweet fragrance, stuffy smell, none high and none lasting	Redness, brightness	Mellow, slightly umami
CS023	Sweet and loquat fragrance, high and lasting	Redness, brightness	Briskness and strength, little umami
CS024	Stuffy smell, none high and none lasting	Deep redness, slightly brightness	More mellow, slightly taster-after, slightly umami
CS025	Sweet and sugar-like, high and lasting	Orange and redness, clarity and brightness	Sweet and mellow, umami
CS026	Sweet and flower fragrance, high and lasting	Redness, clarity	More mellow, umami
CS027	Potato fragrance, slightly high and slightly lasting	Redness, slightly brightness	More mellow, slightly umami
CS028	Sweet and flower fragrance, slightly high and little lasting	Orange and redness, clarity and brightness	Mellow, umami
CS029	Sweet and little smoked, slightly lasting	Redness, little brightness	More mellow, little umami
CS030	Sweet fragrance, slightly high and slightly lasting	Redness, little brightness	More mellow, none umami
CS031	Sweet fragrance, little lasting	Orange yellow little, brightness	Mellow, little umami
CS032	Sweet and little flower fragrance	Orange yellow, clarity and brightness	Mellow, little umami
CS033	Sweet and longan fragrance	Golden yellow, most clarity and brightness	More mellow, umami, astringency
CS034	potato fragrance	Golden yellow, clarity and brightness	More mellow, little umami
CS037	Sweet fragrance, slightly high and slightly lasting	Orange yellow, clarity and brightness	Sweet and mellow, umami
Other countries			
CS001	Sweet and little rose fragrance	Redness, little brightness	Pure, little umami, little strength
CS002	sweet fragrance and staleness odour, slightly lower	Deep redness, little brightness	Flat and staleness flavour, none umami
CS003	Stuffy smell	Deep redness, slightly brightness	Mellow, little umami
CS004	Staleness odour	Deep redness, little dark	More mellow, slightly strength, little umami
CS005	Sweet fragrance, pure, little high	Redness, clarity and brightness	Briskness and strength, slightly umami
CS006	Chinese herbaceous peony fragrance, flat	Orange and redness, clarity and brightness	More mellow, slightly umami
CS007	Sweet fragrance, flat	Redness, little brightness	Briskness and strength, little umami
CS008	Sweet fragrance, flat	Deep redness, little brightness	Mellow, little staleness flavour little umami
CS009	Sweet fragrance, little staleness odour, flat	Redness, clarity	Mellow, staleness flavour, little umami
CS010	Bergamot odour, high	Redness, brightness	Mellow, fries flavour, slightly umami
CS011	Sweet fragrance, little staleness odour	Orange and redness, slightly brightness	Pure, little umami
CS012	Sweet and little caramel fragrance, little high	Redness, slightly brightness	Flat flavour, none umami
CS013	Sweet fragrance, flat	Redness, little brightness	Mellow, little umami
CS035	Sweet fragrance and bergamot odour, soft and high	Deep redness, little brightness	More mellow, slightly sour
CS036	Sweet and flower fragrance, slightly high and slightly lasting	Orange and redness, slightly brightness	More mellow, slightly umami

Table 3: The sensory evaluation of different black teas.

The polyphenols content in Sri Lanka`s black tea samples were similar to the polyphenol levels in Chinese black tea (Table 5).

Caffeine is an important flavor substance in black tea infusion and is responsible for the stimulating effect of tea liquor [9]. The caffeine content of Chinese tea samples was higher than that in teas from other countries, probably due to differences in tea varieties and processing methods as caffeine content did not significantly change during the processing of black tea [28]. In addition, the caffeine content in tea samples from the southern Yangtze River area was not significantly different (Table 5). Furthermore, sample CS036 from Sri Lanka was significantly higher in caffeine content which was 9.01%.

Free amino acids in tea can play an essential role in tea aroma and taste qualities [29] and are major contributors to the freshness of tea [30]. The amino acid content in tea samples from the southern Yangtze River area in China was higher than that in teas produced in other areas in China or in other countries. This southern Yangtze River area is a major tea production area, due to the occurrence of optimum climatic conditions, such as mild temperatures, abundant rainfall, high humidity

No.	Appearance	Aroma	Liquor	Taste	Infuse leaves	Total score
China						
CS014	22.5	22.5	8.5	25.5	7.25	86.25
CS015	21.25	22.5	8.65	25.5	8	85.9
CS016	20	22.5	8.5	27	7.25	85.25
CS017	21.25	20	9.15	25.5	8	83.9
CS018	20	20	9	24	7.75	80.75
CS019	18.75	21.25	8	24	7.25	79.25
CS020	20	23.75	8.5	27	8.5	87.75
CS021	19.38	22.5	8.5	27	8.5	85.88
CS022	20	19.38	9	25.5	7	80.88
CS023	21.25	22.5	8.75	24	9	85.5
CS024	20	17.88	8.5	25.5	8	79.88
CS025	21.25	22.5	8.5	27	7.4	86.65
CS026	22.25	22.5	8	27	9	88.75
CS027	22.5	21.38	8.5	25.5	8	85.88
CS028	21.25	22.5	8.25	27	8	87
CS029	20	20.63	8.3	23.25	8.15	80.33
CS030	21.25	21.25	8.15	21	8.5	80.15
CS031	21.25	21	7.9	24	8.5	82.65
CS032	22.5	22.5	8.5	25.5	8.65	87.65
CS033	21.25	21.25	9	27	7.75	86.25
CS034	21.25	21.25	8.5	25.2	8.3	84.5
CS037	22.5	23.75	7.9	27	8	89.15
Other countries						
CS001	16	25.5	7.9	24	8	81.4
CS002	16	22.95	8	21	7	74.95
CS003	16	21	8.4	24	7.5	76.9
CS004	15	21.3	7	24	7.5	74.8
CS005	16	25.5	9.25	26.25	8	85
CS006	14	25.5	8.85	26.4	8	82.75
CS007	14.5	24	8.8	25.5	8	80.8
CS008	16	24.75	8	24	7	79.75
CS009	15	22.5	8.4	22.5	7.5	75.9
CS010	17	25.5	8.5	22.5	7.75	81.25
CS011	16	23.25	8	25.5	8	80.75
CS012	16	25.5	8.25	21	7	77.75
CS013	15.6	24	8	24.75	8	80.35
CS035	17	24	8	23.25	8	80.25
CS036	18	26.25	8	25.5	7.5	85.25

Notes: Tea samples conduct two sensory evaluation of different times of the same day, the scores are calculated according to score coefficient of table 2

Table 4: The scores of individual attributes of sensory evaluation.

and moderate sunshine [31]. Hence, the high content of amino acids in the teas was mainly due to the suitable climatic characteristics. The amino acid content was highest in sample CS032, which was made from a white-leaf cultivar. White-leaf is a typical albino tea cultivar found in China that has a high level of amino acids, which are essential components affecting tea taste quality [32]. The content of amino acids in the Vietnamese black teas, CS002 and CS011, were relatively lower, compared to samples from other countries, and amino acids contents in the Kenyan sample CS008 was the lowest. In addition, the amino acid levels in black teas from China were similar to levels in Sri Lankan teas. However, amino acids contents in Chinese black teas were higher than in Sri Lankan teas due to geographical locations [33], which were similar to results reported in previous studies [34,35].

There was no obvious difference in TF content or in the TR/TF ratio between samples (Table 5). The TR content in samples CS005 and CS006 from India were the highest, while sample CS009 from Indonesia had the lowest, which was consistent with the liquor and taste of tea samples (Table 3). The TR contents in samples from the Southern China area were higher than those in other tea producing areas, while CS030 and CS031 from the southern Yangtze River area had lower TR contents than other samples from the same area. This may be due to differences in the production processes employed. In addition, the highest TB content was in Sri Lankan tea samples. Black tea pigment is a key factor in forming the color and taste of tea infusion, and polyphenols in fresh tea leaves are consumed and chemically transformed into various oxidation products including dimeric, oligomeric and polymeric constituents, such as TF, theasinensins, TR and TB [36,37]. TF mainly determine the brightness of the tea infusion, with higher levels of TF forming better brightness. The TR level is mainly related to liquor and concentration and is a very important chemical component with regard to taste and concentration of tea infusion. In general, TB have a negative impact on black tea quality, with high contents resulting in the tea infusion becoming dark in color and losing astringency properties, while moderate levels of TB are essential to form the red infusion of black tea. The TR/TF ratio is another important factor in determining the quality of black tea, which levels ranging from 10 to 12 resulting in balanced liquor and taste [38].

Correlation analysis between tea liquor, taste and pigments

The relevance of sensory score of black tea color, taste and tea pigments (TF, TR and TB) was performed through correlation coefficient statistical analysis. Table 6 shows that the correlation coefficient of sensory quality (liquor and taste) and tea pigments had a correlation. The score of tea liquor was extremely significant and positive correlation with TR content, which correlation coefficient was 0.5839, TF content and the TR/TF value with tea liquor`s correlation coefficient was 0.3028 and 0.2122, only showed positive correlation. However, TB showed a negative correlation with tea liquor score. Therefore, it is feasible to employ the TR content to reflect the color of black tea infusion. In addition, there were extremely positive and significant correlations between tea taste scores and TR content and TR/TF values, the correlation coefficient was 0.6109 and 0.4938, respectively. However, the TB content showed a significantly negative correlation with tea taste. The results imply that the TR content and TR/TF values could be used to evaluate the taste quality of black tea.

Correlation analysis of tea taste, polyphenols and caffeine

The correlation coefficients of tea polyphenols, caffeine and black tea taste scores are shown in Table 7. The tea taste scores were positively correlated with contents of polyphenols and caffeine, indicating that determination of polyphenols and/or caffeine contents can assay black tea taste.

Correlation analysis of tea taste, aroma and amino acids

As shown in Table 8, the amino acid contents were positively correlated with tea taste and aroma scores. Therefore, amino acids levels can also be considered as important chemical components to estimate tea taste and aroma.

In particular, the aroma and taste characteristics of Chinese black tea were better than tea from other countries, while the black tea liquor from all samples were not significantly different. A possible explanation is that Chinese full-type black tea is usually brewed with freshly boiled water and is drank directly, whereas milk and sugar may be added to broken-type black tea infusion during consumption [39-41]. Although

No.	Polyphenols	Caffeine	Amino acids	Theaflavins	Thearubigins	Theabrownins	TR/TF
China							
CS014	14.81	6.07	0.13	1.02	10.69	8.7	10.48
CS015	20.77	9.89	0.36	1.04	12.93	4.14	12.43
CS016	12.54	8.54	0.25	1.5	15.09	5.72	10.06
CS017	12.64	6.46	0.34	0.94	10.16	7.47	10.81
CS018	15.76	7.55	0.27	1.24	13.75	5.87	11.09
CS019	10.41	4.91	0.18	0.72	11.3	4.76	15.69
CS020	14.02	6.64	0.45	0.93	10.11	5.27	10.87
CS021	17.66	7.73	1.08	1.05	13.59	5.39	12.94
CS022	13.2	7.21	0.76	1.08	13.52	7.6	12.52
CS023	28.28	8.43	0.52	0.99	12.07	7.16	12.19
CS024	15.13	7.9	0.56	1.26	13.16	7.37	10.44
CS025	26.16	8.69	0.48	0.91	12.95	5.69	14.23
CS026	20.8	8.36	1.06	1.02	11.36	7.88	11.14
CS027	17.36	7.13	0.75	0.8	10.65	6.38	13.31
CS028	17.4	7.21	0.92	0.98	12.18	7.79	12.43
CS029	17.78	7.06	0.66	1.25	10.87	6.75	8.7
CS030	18.68	7.74	0.55	1.03	8.66	8.02	8.41
CS031	17.82	7.36	0.97	0.67	8.26	5.93	12.33
CS032	17.73	6.54	1.24	1.34	14.74	4.39	11
CS033	13.66	7.56	0.71	1.36	13.72	5.78	10.09
CS034	21.55	7.72	0.74	1.12	11.48	4.21	10.25
CS037	31.73	7.79	0.48	0.78	10.18	4.94	13.05
Other countries							
CS001	15.8	4.86	0.24	0.72	7.77	7.78	10.79
CS002	11.86	5.44	0.19	0.68	7.85	7.85	11.54
CS003	16.58	4.39	0.12	1.11	12.32	9.26	11.1
CS004	14.73	5.05	0.33	0.84	9.57	8.98	11.39
CS005	17.52	5.94	0.46	1.05	16.3	8.74	15.52
CS006	24.02	6.72	0.19	1.15	13.8	2.95	12
CS007	25.53	5.05	0.37	1.13	12.52	7.24	11.08
CS008	18.15	5.37	0.09	1.33	10.31	5.65	7.75
CS009	15.63	4.44	0.75	0.96	6.18	7.06	6.44
CS010	17.51	6.2	0.46	1.35	11.75	5.79	8.7
CS011	10.25	5.88	0.23	1.62	12.29	5.21	7.59
CS012	17.04	5.64	0.54	1.24	8.23	7.7	6.64
CS013	17.72	5.48	0.16	1.36	11.24	9.45	8.26
CS035	14.52	5.73	0.24	0.83	5.75	9.05	6.93
CS036	26.86	9.01	0.79	0.8	9.3	5.62	11.63

Table 5: Determination of the chemical components (%) in different black teas.

Variables	Liquor score	Taste score	Theaflavins	Thearubigins	Theabrownins	TR/TF
Liquor score	1					
Taste score	0.3002	1				
Theaflavins	0.3028	0.1159	1			
Thearubigins	0.5839**	0.6109**	0.5384	1		
Theabrownins	-0.1874	-0.3327*	-0.1521	-0.3118	1	
TR/TF	0.2122	0.4938**	-0.4757	0.4651	-0.2127	1
*P<0.05; **P<0.01						

Table 6: The correlation coefficient between sensory quality (liquor and taste) and black tea pigment.

Variables	Taste score	Polyphenols	Caffeine
Taste score	1	--	--
Polyphenols	0.2232	1	--
Caffeine	0.4396**	0.4331	1
*P<0.05; **P<0.01			

Table 7: The correlation coefficient of black tea taste score and chemical components (polyphenols and caffeine).

Variables	Taste score	Aroma score	Amino acids
Taste score	1	--	--
Aroma score	0.4528	1	--
Amino acids	0.2396	0.3108	1
*P<0.05; **P<0.01			

Table 8: The correlation coefficient between sensory quality (taste and aroma) and amino acids.

Variables	Sensory evaluation score	Polyphenols	Caffeine	Amino acids	Theaflavins	Thearubigins	Theabrownins	TR/TB
Sensory evaluation score	1	--	--	--	--	--	--	--
Polyphenols	0.4166**	1	--	--	--	--	--	--
Caffeine	0.6595**	0.4331	1	--	--	--	--	--
Amino acids	0.4379**	0.2008	0.4183	1	--	--	--	--
Theaflavins	-0.0042	-0.1812	0.0422	-0.0749	1	--	--	--
Thearubigins	0.4196**	0.073	0.354	0.1067	0.5384	1	--	--
Theabrownins	-0.3943*	-0.2491	-0.4198	-0.1912	-0.1521	-0.3118	1	--
TR/TF	0.4165**	0.2388	0.2943	0.1492	-0.4757	0.4651	-0.2127	1
*P<0.05; **P<0.01								

Table 9: The correlation coefficient between sensory quality and chemical compositions.

the aroma and taste of the broken-type tea were relatively lower, the taste could be improved via addition of other substances, which may mask the original taste of the tea. Therefore, Chinese black tea aroma and taste are quite important for tea quality formation, and the appearance of dry tea is also an essential factor in the evaluation of tea quality.

Correlation analysis between sensory quality and chemical composition of black tea

The correlation between the sensory quality of black tea and the chemical composition is shown in Table 9. The sensory quality score was extremely significant and positively correlated with the content of tea polyphenols, caffeine, amino acids, TR and TR/TF, which correlation coefficient was 0.4166, 0.6595, 0.4379, 0.4196, 0.4165, respectively. There was a significant and negative correlation between the TB content and sensory evaluation scores. Surprisingly, TF showed a negative correlation with the sensory quality of black tea. However, there was a positive correlation between the tea taste, color and TF (Table 6). It may be that the appearance, aroma and infusion of black tea impacted the sensory quality scores, or they may have been impacted by other factors. Therefore, the effect of TF on the sensory quality of black tea warrants further investigation.

Moreover, the comprehensive effects of these chemical compounds in forming the unique quality of black tea needs to be studied further, including their effects on high and lasting aroma, mellowness, umami taste, astringency, sweet taste, redness and brightness of liquor etc. [42-50]. TF is an important chemical component of the color and taste quality of black tea infusion, which was positively correlated with the quality of the liquor and taste of black tea [35,51].

Conclusion

In summary, a comprehensive analysis of 37 different black tea samples from nine countries was performed. The aroma and taste of Chinese black teas were better than teas from other countries, with the aroma of sharpness persisting from Chinese black tea. Teas from other countries had mainly sweet and fruity fragrances, but the aroma of teas from other countries was also slightly flat. The liquor colors of teas from the southern and northern regions of the Yangtze River were mostly orange in color. The umami tastes of Chinese black teas were better than those from other countries, and the umami tastes of teas from Vietnam and Kenya were relatively lower. This study indicated that the evaluated sensory scores were extremely significant and positively correlated with tea polyphenols, caffeine, amino acids and TR/TF values.

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