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# Phenolic Profiles and Antioxidant Activities of Typical Teas Marketed in China as Affected by Steeping Time and Temperature

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**Abstract:** The objectives of this study were to assess how steeping temperature and steeping time affect phenolics and antioxidant profiles of various categories of tea marketed in China. The total phenolics, total flavonoids, tannin, DPPH free radical scavenging capacity (DPPH) and ferric reducing antioxidant power (FRAP) of four typical teas (green tea, black tea, oolong tea, and white tea) steeped by different combinations of temperature and time were investigated by colorimetric assays. Results indicated that phenolics and antioxidants in tea water increased with the higher steeping temperature and/or longer steeping time in general. However, the DPPH and FRAP value of fermented teas (black tea and oolong tea) were affected less by the longer time or the higher temperature, while unfermented teas (white tea and green tea) were affected more by longer time and higher temperature. The optimal steeping conditions heavily rely on categories of tea and the targeted active substances.

**Keywords:** Tea, phenolics, flavonoids, tannin, antioxidants, steeping time, temperature

## 1. Introduction

Tea is a popular beverage in the daily life of many societies. It is said that people in over 30 countries drink tea (Sharma, Bhattacharya, Kumar & Sharma, 2007). China is the cradle of tea. Tea was spread from Yunnan to the rest of Asia, and then it went to the Western countries (Mary & Robert, 2011). It is believed that oxidation reactions produce free radicals which may damage cells. Antioxidants are the molecules which have capacity in reducing or preventing oxidation caused by other substances. Therefore, antioxidants can stop the reaction by neutralizing the free radical intermediates (Xu & Chang, 2007). It is widely accepted that tea polyphenols can reduce the risk of coronary heart disease and other cancers (Langley-Evans, 2000).

Tannins are water-soluble polyphenols and exist in many different kinds of plant foods. Tannins have the potential to be anticarcinogens and antimutagens based on the antioxidative property (Chung, Wong, Wei, Huang & Lin, 1998). According to Su, Duan, Jiang, Duan, & Chen (2007), the polyphenolic profile and antioxidant activities of oolong tea may be affected by different steeping conditions. However, it is not fully understood how total phenolic content, total flavonoid content, condensed tannin content, DPPH-free scavenging activity, and ferric reducing antioxidant power of various Chinese teas are affected by different steeping time and temperature. The public has no general concepts of the optimal steeping conditions (time and temperature) for different teas to obtain the largest amount of phenolics and antioxidants. The objectives of this

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study were to investigate the antioxidant activities and phenolic contents of steeped tea water under various steeping conditions, and to provide constructive suggestions on the selection of steeping ways for various commercial Chinese tea products for tea drinkers.

## 2. Materials and Methods

### 2.1. Materials and Reagents

The commercial tea products marketed in China were collected from a local supermarket in Zhuhai. The detailed information on brand and place of origin was summarized in **Table 1**.

### 2.2. Chemicals and Reagents

Folin-Ciocalteu reagent was supplied by Sinopharm Chemical Reagent Co, Ltd (Beijing, China). 2-Diphenyl-1-picryhydrazyl (DPPH) was purchased from Sigma-Aldrich Co. (Germany). 6-Hydroxiy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox) and 2,4,6-tri[2-pyridyl]-s-triazine (TPTZ) were supplied by Shanghai Yuanye Biotechnology Co, Ltd (Shanghai, China). Acetic acid was purchased from Guangzhou Chemical Reagent Company (Guangzhou, China). Methanol was purchased from Taishan Yueqiao Reagent Company (Taishan, China). Sodium carbonate anhydrous, sodium hydroxide, sodium acetate, sodium nitrite, absolute ethanol, aluminum chloride, ferric chloride and other chemicals were purchased from Tianjin Damao Chemical Reagent Industry (Tianjin, China).

### 2.3. Sample Preparation of steeping tea

The tested samples were weighed at 1 g, and then put into a 100 mL beaker. Distilled water was heated to three different temperatures (70℃, 80℃, and 100℃). The heated water (50 mL) was used to steep tea for 1, 3, 5, and 7 min. Then, the steeped tea was separated by filtration. The volume of steeped tea water was measured using 100 mL measuring graduated cylinder. Finally, tea water samples were stored in a 50 mL centrifuge tube in a 4℃ refrigerator.

### 2.4. Determination of total phenolic content (TPC)

The TPC was determined by a Folin-Ciocalteu assay with a slight modification (Xu & Chang, 2007) using gallic acid as the standard. A calibration standard curve of gallic acid was used to calculate the TPC with a unit of milligrams of gallic acid equivalent per gram of tea water steeped with different steeping temperature and time.

### 2.5. Determination of total flavonoid content (TFC)

The TFC was determined by using a colorimetric method described previously (Xu & Chang, 2007). A calibration standard curve of catechin was used to calculate the TFC with a unit of milligrams of catechin equivalent per gram of tea water (mg CAE/g).

### 2.6. Determination of condensed tannin content (CTC)

Sample/standard solution/ blank (methanol) was added 50 µL into test tubes respectively. After that, 3 mL of 4% methanol vanillin solution was put into the test tube, and 1.5 mL concentrated hydrochloric acid was also added in the test tube. Then, the mixture stood for 15 min, and it could be measured at 500 nm using UV-spectrophotometer (Xu & Chang, 2007). A calibration standard curve of catechin was used to calculate the CTC with a unit of milligrams of catechin equivalent per gram of tea (mg CAE/g).

### 2.7. Free radical scavenging assay (DPPH)

0.2 mL of blank (ethanol)/ standard solution / sample extract was added to test tubes. And then, 3.8 mL of DPPH solution was added in the test tube. The mixed solution was mixed by a vortex evenly and stood at room temperature for 30 min. Then, the mixed solutions were measured at 517 nm using an UV-spectrophotometer. The percent of DPPH discoloration of the sample was calculated according to the equation percent discoloration= $[1-(A_{sample}/A_{control})]*100$ (Xu & Chang, 2007). A calibration standard curve of Trolox was used to calculate the Trolox equivalents (TE) with a unit of millimoles of Trolox per gram of tea water (mmole TE/g).

**2.8. Ferric reducing antioxidant power (FRAP) Assay**

100 µL of blank (distilled water), or standard solution, or diluted sample was added in a test tube. Secondly, 3 mL of FRAP solution was added into the test tube. Then, 300 µL distilled water was added. The mixture stood at 37℃ for 4 min. Then, the absorbance was measured at 593 nm by UV-spectrophotometer (Xu & Chang, 2007). A calibration standard curve of $Fe^{2+}$ was used to calculate the FRAP value with a unit of millimoles of $Fe^{2+}$ equivalent (FE) per gram of tea water (mmole FE/g).

**2.9. Statistical analysis**

All results were expressed as mean ± standard deviation based on triplicate steeping processing in which means were compared using Duncan's multiple range test at $p = 0.05$. Statistical analysis was performed using one-way analysis of variance (ANOVA) from SPSS statistics 19 system for Windows.

**3. Results**

**3.1. TPC in tea water steeped under various temperature and time**

The total phenolic content (TPC) (mg GAE/g) in white tea water steeped at 70℃ was much lower than the content in tea water steeped at 80℃ and 100℃. When the temperature was 80℃ and 100℃, **Fig. 1A** showed that the two lines nearly coincided. However, the TPC (mg GAE/g) at 100℃ was finally higher than 80℃. At 80℃, from 1 min to 7 min, the data were 1.79 mg/g, 5.23 mg GAE/g, 7.22 mg GAE/g, and 8.08 mg GAE/g, respectively. When the temperature reached 100℃, the data were 2.24 mg GAE/g, 5.02 mg GAE/g, 7.46 mg GAE/g, and 9.11 mg GAE/g, respectively.

**Fig. 1B** presented the TPC value (mg GAE/g) in oolong tea (Dahongpao). The TPC value clearly increased with the steeping time and temperature. First of all, for 70℃, the TPC in oolong tea steeped for 1, 3, 5, and 7 min were 6.13 mg GAE/g, 7.85 mg GAE/g, 8.93 mg GAE/g and 11.2 mg GAE/g, respectively. When the steeping temperature was 80℃, the TPC in oolong tea increased with the extension of steeping time (1 min to 7 min), ranged from 6.24 mg GAE/g to 14.7 mg GAE/g. Besides, at 100℃, the TPC in tea water steeped for 1 min, 3 min, 5 min and 7 min were 8 mg GAE/g, 13.9 mg GAE/g, 15.8 mg GAE/g and 24.1 mg GAE/g, respectively.

The TPC shown in **Fig. 1C** presented the TPC values (mg GAE/g) in black tea water (Jinjunmei) which was steeped at different times and temperatures. First, for black tea steeped at 70℃with steeping times from 1 min to 7 min, the TPC increased from 8.36 mg GAE/g to 12.9 mg GAE/g. Then, the steeping temperature at 80℃ increased TPC value from 7.47 mg GAE/g to 14.9 mg/g. When the temperature was 100℃, with the extension of steeping time (from 1 min to 7 min), the TPC in black tea water increased. However, the TPC value in tea water steeped for 5 min was 15.4 mg/g. It was higher than that steeped for 7 min, which was 14.5 mg GAE/g.

The TPC value of green tea water shown in **Fig. 1D** gave the increasing trends with longer steeping time and higher temperature. The TPC value in green tea water steeped at 70℃ from 1 min to 7 min were 19.9 mg GAE/g, 19.9 mg GAE/g, 28.6 mg/g, and 33.5 mg/g, respectively. The TPC value in green tea water steeped at 80℃ was nearly 1.5 times of that steeped at 70℃, which were 20.0 mg GAE/g, 38.2 mg GAE/g, 42.5 mg GAE/g, and 45.9 mg GAE/g, respectively. When temperature increased to 100℃, the TPC value (mg GAE/g) of green tea water was higher than that steeped at 80℃ and nearly two times the TPC in tea water steeped at 70℃. The TPC value steeped at 100℃ from 1 min to 7 min were 28.5 mg GAE/g, 41.9 mg GAE/g, 49.4 mg GAE/g, and 50.9 mg GAE/g, respectively.

**3.2. TFC in tea water steeped water various temperature and time**

The total flavonoid content (TFC) of teas steeped at different steeping times (1 min to 7 min) and temperatures (70℃ to 100℃) was summarized in **Table 2**. For white tea steeped at 70℃, with the increasing of steeping time from 1 min to 7 min, the TFC value significantly increased ($p < 0.05$) from 1.28 to 1.86 mg CAE/g. The same situation happened at 80℃ and 100℃. For black tea, the TFC values ranged from 2.16 to 3.57 mg CAE/g. The TFC value significantly ($p < 0.05$) increased with the extension of steeping time at each temperature set. The TFC value in oolong tea water increased significantly ($p <$ 0.05) with the longer steeping time (1 min to 7 min) and increased with the increasing of steeping temperature (70℃ to 100℃). Green tea also had an increasing trend of TFC with the increasing of steeping time at each temperature set, which ranged from 4.41 to 9.12 mg CAE/g.

**3.3. Tannin in tea water steeped under various temperature and time**

Condensed tannin content (CTC) in white tea, black tea, oolong tea and green tea steeped at different steeping times and temperatures were summarized in **Table 3**. The tannin content in white tea, black tea, oolong tea and green tea significantly increased with the increasing of steeping time from 1 min to 7 min. For white tea, the CTC ranged from 2.55 to 9.45 mg CAE/g. The range of CTC value in black tea was from 4.81 to 14.8 mg CAE/g. For oolong tea, the minimum one was 4.81 mg CAE/g and the maximum one was 14.8 mg CAE/g. The CTC of green tea were from 19.1 to 61.4 mg CAE/g.

**3.4. DPPH values of tea water steeped under various temperature and time**

The clear increasing trends of DPPH values in white tea water steeped for different steeping times with the increasing of temperature were presented in **Fig. 2A**. First, the steeping time was set for 1 min, with the increasing of steeping temperature from 70℃ to 100℃, the DPPH values increased from 11.3 mmole TE/g to 20.2 mmole TE/g. Secondly, the steeping time was set for 3 min, the DPPH value of white tea also increased with the increasing of steeping temperature. Within this, the DPPH value at 80℃ (31.3 mmole TE/g) was nearly two times of that of white tea water steeped at 70℃ (16.7 mmole TE/g). For steeping time at 5 min and 7 min, the DPPH-free radical scavenging capacities were similar but also increased with the increasing of steeping temperature.

The DPPH-free radical scavenging capacity of oolong tea shown in **Fig. 2B** was affected by different steeping times and temperatures. The data fluctuated at different steeping temperatures. At 1 min, the DPPH-free radical scavenging capacity at 70℃, 80℃, and 100℃ were 37.7 mmole TE/g, 38.1 mmole TE/g, and 33.5 mmole TE/g, respectively. When steeping time was set for 3 min, there was a decreasing trend with the increasing of steeping temperature, 39.9 mmole TE/g, 37.9 mmole TE/g, and 33.5 mmole TE/g. When steeping time was increased to 5 min, the DPPH-free radical scavenging capacity of tea water steeped at 70℃, 80℃, and 100℃ were 37.8, 36.7, and 36.5 mmole TE/g, respectively. When steeping time was set for 7 min, the DPPH-free radical scavenging capacity of tea water steeped at 70℃, 80℃, and 100℃ were 38.1, 36.4, and 36.6 mmole TE/g, respectively.

The data shown in **Fig. 2C** were the radical scavenging capacity of black tea. The DPPH values fluctuated at different steeping times and temperatures. All of the DPPH values were between 30 mmole TE/g to 40 mmole TE/g. The lowest DPPH value of black tea appeared at 70℃ when steeping time was set for 1 min, which was 33.7 mmole TE/g. The highest DPPH value was 36.1 mmole TE/g tea water steeped at 80℃ when the steeping time was set for 1 min.

The DPPH-free radical scavenging capacities of green tea at different steeping times and temperatures were presented in **Fig. 2D**. The DPPH-free radical scavenging capacity of tea water steeped at 70℃

increased with the extension of steeping time; however, the DPPH-free radical scavenging capacity of tea water steeped at 80℃ and 100℃ were nearly 10 times that steeped at 70℃. The DPPH-free radical scavenging capacity of tea water increased with the increasing of steeping time and temperature. The DPPH-free radical scavenging capacity at 100℃ was higher than 80℃ at different steeping times.

### 3.5. FRAP of tea water steeped under various temperature and time

The ferric reducing antioxidant power (FRAP) of white tea was shown in **Fig. 3A**. It indicated that FRAP was affected by the steeping time and temperature. When steeping temperature was set for 70℃, the FRAP increased with the increasing of steeping time (1 min to 7 min), ranging from 0.02 to 0.1 mmole FE/g. Besides, for tea water steeped at 80℃, the FRAP increased with the increasing of steeping time from 0.07 to 0.19 mmole FE/g. The peak of the FRAP in white tea water appeared at 80℃ for 7 min. The same trend was found in tea water steeped at 100℃, the FRAP values were 0.08, 0.14, 0.18, and 0.18 mmole FE/g, when steeped for 1, 3, 5, 7 min, respectively.

There was an increasing trend in the FRAP value of oolong tea water with the increasing of steeping temperature from 70℃ to 100℃ (**Fig. 3B**). However, at each steeping time (1 min to 7 min), the data gave a decreasing slop. The lowest value appeared in tea water steeped at 100℃ and for 1 min. While the highest value was presented in tea water steeped at 70℃ and for 7 min. For oolong tea, the FRAP value of tea water steeped at 70℃ were 0.12, 0.18, 0.25, and 0.31 mmole FE/g, respectively. When temperature increased to 80℃, the FRAP values were 0.12, 0.17, 0.24, and 0.3 mmole FE/g, when steeped for 1, 3, 5, 7 min, respectively. Then, for the 100℃ steeping condition, the FRAP value increased from 0.1 to 0.26 mmole FE/g with the increasing of steeping time from 1 min to 7 min.

The FRAP values of black tea shown in **Fig. 3C** indicated that the data fluctuated at different steeping times and temperatures. However, for different steeping temperatures, the FRAP value increased with the increasing of steeping time (from 1 min to 7 min). The FRAP value in tea water steeped at 70℃ were 0.13, 0.17, 0.18, and 0.22 mmole FE/g, respectively. When temperature was 80℃, the FRAP values were 0.12, 0.17, 0.28, and 0.28 mmole FE/g. When the temperature was at 100℃, the FRAP values were 0.14, 0.22, 0.21, and 0.23 mmole FE/g.

For green tea, **Fig. 3D** showed that for tea water steeped at 70℃, the FRAP value increased with the increasing of steeping time from 1 min to 7 min, which were 0.25, 0.26, 0.55, and 0.69 mmole FE/g. At 80℃, the FRAP increased from 0.42 to 1.03 mmole FE/g when increasing the steeping time, where 1.03 mmole FE/g was the highest value. When the temperature was 100℃, the FRAP value increased with the increasing of steeping time (1 min to 5 min). The FRAP values were 0.59, 0.72, and 0.94 mmole FE/g, respectively. However there was a little decrease that appeared at 100℃ for 7 min steeping.

## 4. Discussion

### 4.1. Phenolic profiles of tea as affected by steeping time and temperature

Total phenolic content in white tea water increased with the increasing of steeping temperature and/or steeping time. The minimum value of TPC in white tea was 1.53 mg GAE/g, the maximum one was 9.11 mg GAE/g, which was much lower than TPC in green tea water. This was proved by Unachukwu et al (2010) who discovered that the TPC found in green tea bags was higher than that obtained in black tea bags. In current study, the TPC increased with the increasing of steeping time and temperature in oolong tea (Dahongpao). However, Su et al., (2007) indicated that the steeping of oolong tea at higher temperatures and/or longer times may lead to losses of phenolics and the reduction of antioxidant activities when the steeping time was controlled within 3 min to 10 min, and the steeping temperatures were 90℃ and 100℃.

Standley, Winterton, Mrnewick, Gelderblom, Joubert, & Britz (2001) reported that the decreased TPC might be affected by processing stages. Besides, Venditti, Bacchetti, Tiano, Carloni, Greci, & Damiani (2009) steeped tea with hot water (90℃, 7 min) and cold water (room temperature, 2 h), and reported that TPC was higher in hot tea water than in cold tea water. Therefore, the temperature did affect the TPC value, but higher temperature helped tea to give a higher TPC value. TPC in black tea showed an increasing trend along with the longer steeping time (1 min to 7 min) in the current study.

The TPC value of black tea steeped at 100℃ was lower than that steeped at 80℃ when the steeping time was 7 min. It was confirmed by Su et al (2007) that the higher steeping temperature or longer steeping time might decrease the antioxidant activities. TPC in green tea showed an increasing trend with the longer steeping time and/or higher steeping temperature. Unachukwu et al (2010) indicated that the TPC in different brands of tea varied from 21.0 mg GAE/g to 17.6 mg GAE/g. The TPC values of black tea in this experiment were higher than the data presented by Unachukwu et al (2010). It may be caused by different processing steps or methods. The lower temperature (70℃) steeped at different steeping times and less steeping time (1 min) at 80℃ and 100℃ showed similar data. Therefore, higher temperature or longer steeping time may help to increase the TPC or antioxidant activities in green tea.

Green tea water had the highest TFC at the given conditions among the four tested samples, which means green tea has a stronger antioxidant capacity. White tea was lower than the other three. Black tea and oolong tea water had a similar level of antioxidants; however, oolong tea water had higher TFC than black tea water in the current study. It indicated that a higher steeping temperature and longer steeping time could effectively affect the TFC in tea. Miean & Mohamed (2000) showed the TFC of black tea was around 1.49 mg CAE/g, when the sample was treated with aqueous methanol and other chemical substances.

The highest CTC value in white tea water appeared at 80℃ for 7 min, which may be considered as the optimal steeping condition of white tea. Though black tea had a peak CTC value at 100℃ for 7 min, the CTC value at 70℃ was also considered as a good steeping condition. The CTC in both oolong tea and green tea increased with the increases of steeping time and the temperature. For green tea, when the temperature reached 100℃, the steeping time for 5 min and 7 min had less differences. The TFC in green tea was also much higher than for the other three tea samples in this study.

**4.2. Antioxidant capacities of tea as affected by steeping time and temperature**

For white tea, the DPPH-free radical scavenging capacity increased with longer steeping time and higher steeping temperature. The DPPH value ranged from 11.3 to 34.2 mmole TE/g. The highest DPPH value appeared at 80℃ for 3 min. It may be the optimum steeping condition for white tea. The DPPH of oolong tea at different steeping time and temperature had less differences. The data were close, which were between 33.5 to 39.9 mmole TE/g. The effects of steeping temperature (70℃ to 100℃) and time (1 min to 7 min) on the DPPH of oolong tea water were not that obvious. However, there was a little decreasing trend with the increasing of steeping temperature from 70℃ to 100℃. Based on these points, a lower temperature (70℃) should be considered when steeping oolong tea. The DPPH free radical scavenging capacity tested in black tea was affected by different steeping times (1 min to 7 min) and temperatures (70℃ to 100℃) (**Fig. 2C**). They fluctuated between 33 and 36 mmole TE/g, but no specific trend of increasing or decreasing was associated with changes of temperature or time. The DPPH-free radical scavenging capacity of black tea water steeped at 70℃ was lower than that steeped at

80℃ and 100℃.

From the data shown in **Fig. 2D**, it was obvious that the DPPH-free radical scavenging capacity of green tea water steeped at 70℃ was much lower than those at 80℃ and 100℃. There was a huge difference between steeping temperature at 70℃ and above 70℃ (80℃ and 100℃). Considering the steeping time, a less significant effect of the DPPH-free radical scavenging capacity of green tea was observed. Besides, the DPPH-free radical scavenging capacity of green tea water steeped at 80℃ and 100℃ was much higher than for other kinds of teas. Based on the data, green tea had a huge capacity for DPPH-free radical scavenging capacity at higher temperatures (above 70℃). The free radical scavenging capacity in the four tested samples from high to low in order were: green tea, oolong tea, black tea, and white tea. The document (Chen, Feng & Zhang, 2009) suggested that the DPPH-free radical scavenging capacity in the different order was black tea, green tea, and oolong tea. The differences may be caused by the different types of tea and the methods of extraction.

The FRAP was very low when white tea was steeped at 70℃, and steeped for less than 5 min. Based on the data shown in **Fig. 3A**, longer steeping time and higher temperature were supposed to get higher FRAP for white tea. For white tea, the FRAP value calculated by Andlauer & Heritier (2011) was about 0.48 mmole FE/g, but the current value of FRAP presented in **Fig. 3A** was 0.19 mmole FE/g. The differences may be caused by the different steeping ways or sources of white tea. The FRAP of black tea water was higher than white tea water, and had similar content level with oolong tea water. When the steeping temperature reached 80℃, the FRAP value at 5 min and 7 min were the same. The FRAP value was lower at 100℃ with the steeping times of 5 min and 7 min when compared to that steeped at 80℃. Therefore, 80℃ for 5 to 7 min may be the optimum steeping condition for black tea to get a higher FRAP value.

The FRAP value of oolong tea decreased with the increasing of steeping time. Therefore, it may be more effective to gain antioxidants by longer steeping time. The highest FRAP value appeared at 70℃ when the steeping time was 7 min. The FRAP value was about 0.32 mmole FE/g in oolong tea (Andlauer & Heritier, 2011), and the highest value of FRAP was 0.31 mmole FE/g in the current study. Therefore, the data of oolong tea was identical to that of Andlauer & Heritier (2011). It may increase the FRAP value of oolong tea water with a longer steeping time. However, in the current experiment, the maximum steeping time was set at 7 min.

Green tea had the highest FRAP among the four types of teas. The highest value of FRAP in green tea water was 1.03 mmole FE/g. Andlauer & Heritier (2011) indicated that the FRAP value of green tea was about 1.05 to 1.15 mmole FE/g. Therefore, the current results of green tea can be confirmed. Besides, the highest FRAP value appeared at 80℃ for 7 min. It might be considered as the optimal steeping condition of green tea for obtaining antioxidants. Even though the data generally increased with the increases of time and temperature, the peak value may not appear at the highest temperature or the longest steeping time.

## 5. Conclusions

In conclusion, among the four kinds of teas, green tea stands out with relatively higher content of total phenolic, total flavonoid, tannin, DPPH-free radical scavenging capacity, and ferric reducing antioxidant power. The DPPH-free radical scavenging capacity of green tea water was above 300 mmole TE/g when steeped at 80℃ and 100℃. It was much higher than the others. The antioxidant capacity and active substances tested in the four kinds of tea were generally increased with higher temperatures and/or longer steeping times. However, not all the samples showed this with regularity. The FRAP and DPPH values of black tea fluctuated and it was hard to identify the factors. Also, the DPPH-free radical scavenging capacity of oolong tea decreased with the increasing of steeping time at certain temperatures.

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**Table 1**. Tea Samples

| Categories of teas | Commercial brand | Place of origin |
|---|---|---|
| Green tea (Xihulongjing) | Long xinhe<br>Fujian gande longxin Trading Co,. Ltd | Quanzhou, Fujian Provence, China |
| Oolong tea (Dahongpao) | Long xinhe<br>Fujian gande longxin Trading Co,. Ltd | Wuyi Mountain, Fujian Provence, China |
| Black tea (Jinjunmei) | Long xinhe<br>Fujian gande longxin Trading Co,. Ltd | Wuyi Mountain, Fujian Provence, China |
| White tea | Lin Hongmao<br>Peking Lin Hongmao Tea Co,. Ltd | Fujian Provence, China |

**Table 2**. Total flavonoid content of teas steeped at different temperature and time.

| Temperature | Steeping Time | White tea (mg CAE/g) | Black tea (mg CAE/g) | Oolong tea (mg CAE/g) | Green tea (mg CAE/g) |
|---|---|---|---|---|---|
| 70℃ | 1 min | 1.28±0.07c | 2.26±0.1c | 2.3±0.02c | 4.41±0.22c |
| | 3 min | 1.48±0.07b | 2.68±0.07b | 2.72±0.15b | 5.53±0.51b |
| | 5 min | 1.73±0.07a | 2.72±0.03b | 2.8±0.15b | 6.18±0.34b |
| | 7 min | 1.86±0.16a | 2.97±0.17a | 3.32±0.09a | 6.98±0.35a |
| 80℃ | 1 min | 1.3±0.1c | 2.16±0.03d | 2.33±0.06d | 5.14±0.23c |
| | 3 min | 1.97±0.09b | 2.57±0.18c | 2.84±0.25c | 6.84±0.53b |
| | 5 min | 2.15±0.16ab | 3.25±0.07b | 3.42±0.05b | 8.07±0.39a |
| | 7 min | 2.3±0.08a | 3.57±0.06a | 4.01±0.18a | 7.94±0.24a |
| 100℃ | 1 min | 1.45±0.06c | 2.19±0.11c | 2.88±0.18c | 6.06±0.08c |
| | 3 min | 1.86±0.06b | 2.97±0.22b | 2.98±0.11c | 7.51±0.45b |
| | 5 min | 2.69±0.14a | 3.38±0.01a | 4.58±0.35b | 8.44±0.5a |
| | 7 min | 2.68±0.18a | 3.46±0.1a | 5.5±0.49a | 9.12±0.33a |

Data are expressed as mean ± standard deviation (n = 3); values within each type of tea marked by the same letter within same column are not significantly ($p$ < 0.05) different.

**Table 3.** Condensed tannin content of teas steeped by different temperature and time.

| Temperature | Steeping Time | White tea (mg CAE/g) | Black tea (mg CAE/g) | Oolong tea (mg CAE/g) | Green tea (mg CAE/g) |
|---|---|---|---|---|---|
| 70℃ | 1 min | 2.55±0.16c | 6.53±0.31a | 5.19±0.04d | 19.11±0.61d |
| | 3 min | 2.58±0.13c | 6.67±0.46a | 6.41±0.42c | 22.11±0.59c |
| | 5 min | 3.07±0.25b | 6.67±0.46a | 9.73±0.72a | 27.41±0.53b |
| | 7 min | 3.96±0.12a | 6.38±0.61a | 8.51±0.42b | 34.81±0.45a |
| 80℃ | 1 min | 2.88±0.26d | 4.14±0.13d | 4.81±0.2d | 44.11±3.26b |
| | 3 min | 5.53±0.31c | 5.4±0.31c | 7.63±0.45c | 54.62±4.01a |
| | 5 min | 6.44±0.33b | 5.99±0.28b | 8.69±0.51b | 53.66±4.38a |
| | 7 min | 9.45±0.48a | 6.6±0.09a | 10.92±0.81a | 57.97±5.15a |
| 100℃ | 1 min | 3.07±0.27c | 4.76±0.08c | 7.62±0.7c | 44.16±4.09b |
| | 3 min | 4.4±0.4b | 6.14±0.48b | 9.39±0.53b | 47.82±3.46b |
| | 5 min | 6.94±0.23a | 6.58±0.59ab | 10.43±0.58b | 61.41±4.61a |
| | 7 min | 6.96±0.19a | 7.39±0.45a | 14.79±1.54a | 60.57±3.52a |

Data are expressed as mean ± standard deviation (n = 3); values within each type of tea marked by the same letter within same column are not significantly ($p$ < 0.05) different.

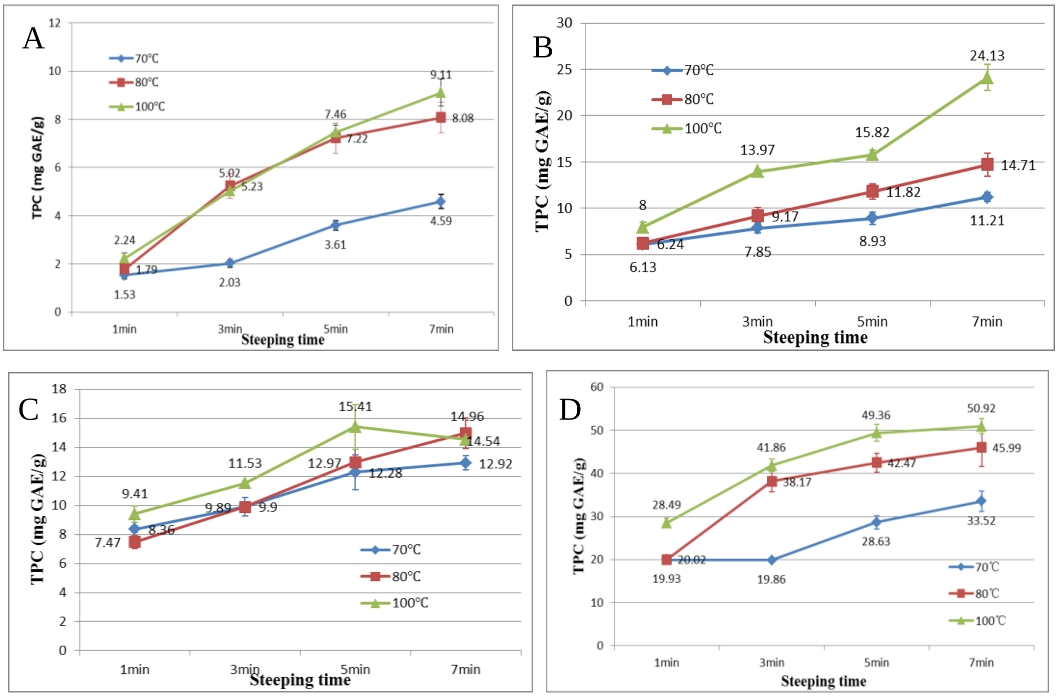


**Fig. 1.** TPC content (mg GAE/g) in white tea (A), oolong tea-Dahongpao (B), black tea-Jinjunmei (C), and green tea-Xihulongjing (D) steeped with different temperature and time.

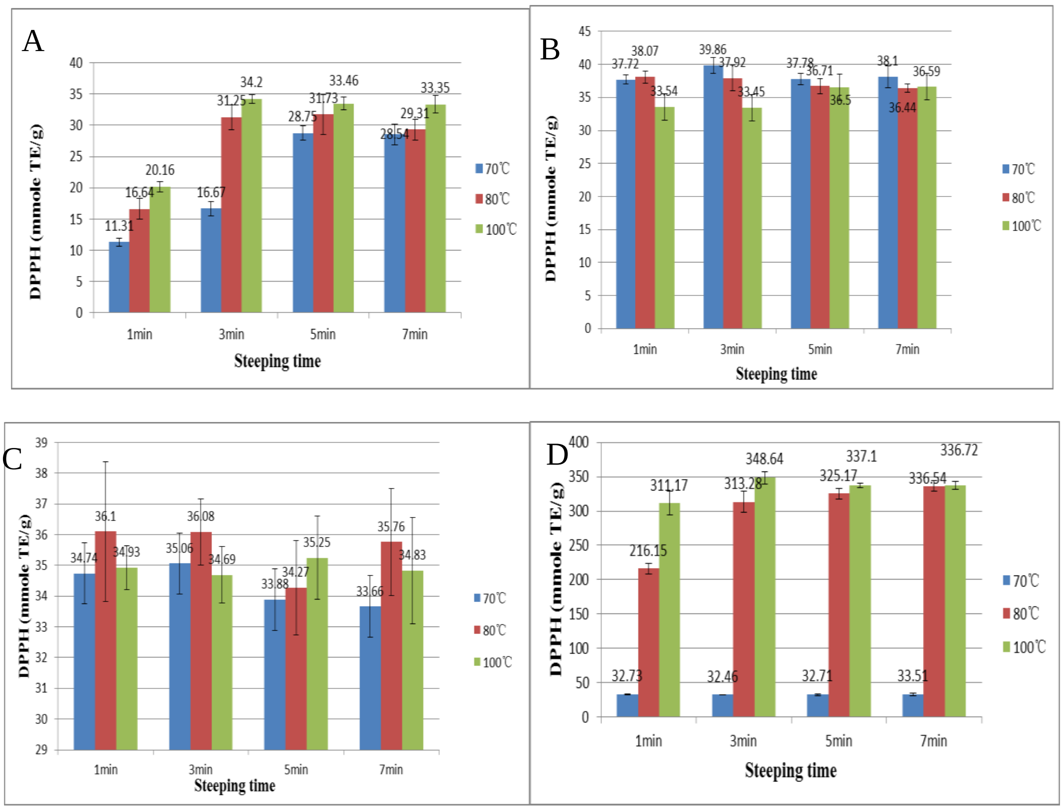


**Fig. 2.** DPPH-free radical scavenging capacity (mmole TE/g) of white tea (A), oolong tea-Dahongpao (B), black

tea-Jinjunmei (C), and green tea-Xihulongjing (D) steeped with different temperature and time.

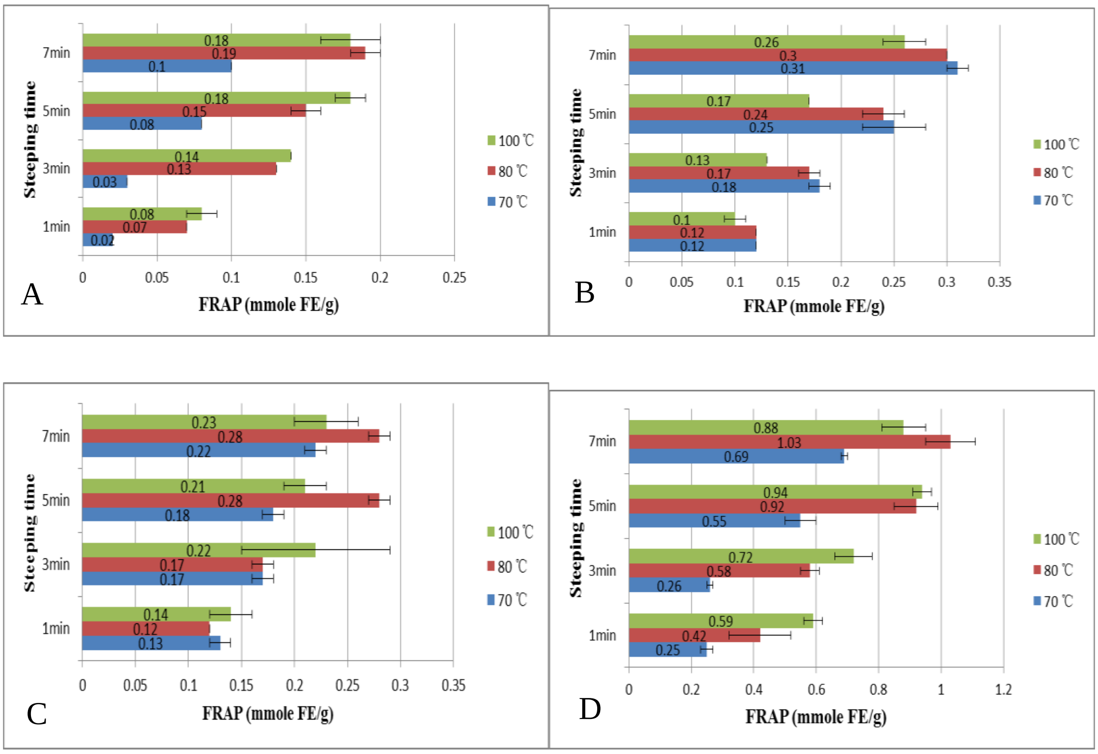


**Fig. 3.** FRAP (mmole FE/g) of white tea (A), oolong tea-Dahongpao (B), black tea-Jinjunmei (C), and green tea-Xihulongjing (D) steeped with different temperature and time.