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ORIGINAL ARTICLE

[redacted] white

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[redacted] white tea [redacted] and free [redacted] tested, and [redacted] effect on the main [redacted] was weakly acidic [redacted] the highest catechin [redacted] theanine, and amino acids, [redacted] with spring and tap water, [redacted] was performed to evaluate [redacted] and aroma, and sensory quality was [redacted] by water type, due primarily to differ- [redacted] ions. Pure water was more suitable for [redacted] tea with superior colour, aroma and taste.

[redacted] White tea · Water quality · Catechin · Caffeine · Theanine · Free amino acid

Introduction

Tea is the second most popular non-alcoholic beverage in the world, after water, and can be divided into unfermented green tea, partially fermented oolong tea and fermented black tea (Yu et al. 2014; Qin et al. 2013; Sereshti et al. 2013). Nowadays, tea attracts much attention due to its potential health benefits (Suyare et al. 2013), which arise from its main active compounds that include phenolics, amino acids, vitamins, caffeine and other purine alkaloids (Kocadagli et al. 2013; Sereshti et al. 2013). In general, tea is taken after brewing with hot water, and this infusion step is beneficial for extracting the active compounds (Suyare et al. 2013).

White tea is unfermented and prepared exclusively from young tea leaves and buds that have tiny, silvery hairs (Kim et al. 2015; Nunes et al. 2015; Rusak et al. 2008; Hajiaghaalipour et al. 2015) that differ from other teas (Zielinski et al. 2016). During growth, buds may be shielded from sunlight in order to reduce the chlorophyll content, which makes the leaves appear white (Kim et al. 2015). White tea has been reported to possess many health benefits, including antioxidant (Damiani et al. 2014), antibacterial (Tomaszewska et al. 2015), and anti-cancer (Hajiaghaalipour et al. 2015) effects, as well as other properties (Song et al. 2015). The strong antioxidant capacity of white tea is connected with its high catechin content (Azman et al. 2014). Catechins such as epigallocatechin gallate (EGCG), epigallocatechins (EGC), epicatechin gallate (ECG), and epicatechin (EC) are the principal bioactive compounds present in tea (Chen et al. 2010; Narukawa et al. 2010, 2011). White tea also contains high levels of polyphenols, caffeine, gallic acid and other constituents (Song et al. 2015; Hilal and Engelhardt 2007), and EGCG is the most abundant compound in white tea, followed by caffeine (Nunes et al. 2015). Thus, white tea possesses high levels of bioactive compounds and has demonstrable antioxidant activity, which makes it a promising source of functional compounds with physiological properties (Zielinski et al. 2016). However, while reports on green tea are numerous, investigations on white tea are more limited (Sanna et al. 2015).

✉ Shikang Zhang
zcyteafood@163.com

[1] Hangzhou Tea Research Institute, CHINA COOP, Hangzhou 310016, China

[2] Zhejiang Key Laboratory of Transboundary Applied Technology for Tea Resources, Hangzhou 310016, China

[3] College of Agriculture and Food Science, Zhejiang A & F

Many parameters may have an effect on the quality of tea infusions, such as the maturity of the leaves, processing factors and brewing conditions (Kocadagli et al. 2013; Saklar et al. 2015; Vuong et al. 2013). For instance, it has been reported that infusion time and temperature both have obvious effects on the extraction of catechins (Saklar et al. 2015). In addition, the type of water used for brewing can affect tea infusions (Mossion et al. 2008; Yau and Huang 2000). Water quality is dependent on several parameters, including pH, ion content and hardness (Yau and Huang 2000). Water with a pH in the range of 6.7–7.2 and a ferrous ion content <2 ppm was reported to be ideal (Yau and Huang 2000), and purified water, rather than tap water or natural water, was found to improve the quality of the infusion (Zhou et al. 2009). Yin et al. (2014) found that green tea infusions were best when made from water with a low Ca^{2+} concentration. Meanwhile, Mossion et al. (2008) analyzed the effect of water mineralization on the extraction of aluminium, calcium and organic carbon in tea infusions. Vuong et al. (2013) investigated the effects of pH on green tea constituents and found that a pH between 3 and 5.3 was appropriate.

Tea polyphenols, caffeine and amino acids play an important role in the quality of the infusion, thus there may be a relationship between water quality and such components (Zhou et al. 2009). However, few studies have addressed this relationship (Zhou et al. 2009). The present study investigated the effect of water quality on the main components of Fuding white tea, namely catechins, caffeine, theanine and free amino acids. Three water types (pure, tap, and spring) were tested.

Materials and methods

Materials and chemicals

Fuding white tea (Bai Hao Yinzhen) with a moisture content of 7.02 g/100 g was provided by the Fujian Bamin Tea Shop. Theanine, caffeine, standard catechins, acetonitrile, and methanol used in high performance liquid chromatography (HPLC) were all of HPLC grade and were purchased from Sigma-Aldrich Chemical Co. (Shanghai, China). Pure water was provided by Hangzhou Wahaha Group Co., Ltd. (Hangzhou, China), spring water was prepared by Nongfu Spring (Jiande) Xinanjiang Beverage Co., Ltd., and tap water was from our laboratory. All other chemicals used were of analytical grade.

Determination of water physicochemical properties

The physicochemical properties of pure, tap and spring water were determined including main cations contents and pH. Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} contents were analyzed by atomic absorption spectrometry and pH was determined by pH meter.

Preparation of infusions

White tea (3.0 g) was extracted once with 150 mL of boiling water at 100 °C for 5 min. Infusions were prepared in porcelain tea pots covered with porcelain lids during brewing. Upon completion of brewing, infusions were filtered and used for analysis.

Analysis of the main components

The main components of Fuding white tea (catechins, caffeine, theanine and free amino acids) were monitored. Catechins in samples from different treatments were analyzed by HPLC according to ISO 14502-2:2005. Caffeine was determined by following ISO 10727:1995. Theanine was determined by HPLC according to national standards (GB/T 23193-2008, China). Free amino acids were determined with an amino acid analyzer according to national standards (GB/T 5009.124-2003, China). Finally, solids were analyzed according to national standards (GB/T 8305-2013, China).

Sensory evaluation

Sensory evaluation was performed according to the national standards outlined in GB/T 23776-2009. Tea infusions prepared using different brewing conditions were consumed by the experimental subjects, and sensory responses (colour, taste and aroma) were evaluated on a 100-point scale, where 90–99 = high intensity, 80–89 = neutral intensity, and 70–79 = low intensity, as described in GB/T 23776-2009.

Statistical analysis

All samples were prepared and analyzed in triplicate. Mean ± standard deviation were calculated and statistical analysis was performed using ANOVA in SPSS (version 20.0). A p value < 0.05 was considered statistically significant.

Results and discussion

Water physicochemical properties

Physicochemical properties of pure, tap and spring water were listed in Table 1. The pH was between weak acid and weak base, and was the highest in tap water (pH = 7.4), lowest in pure water (pH = 6.6), and intermediate in

Table 1 Physicochemical properties of different water types

Water types	pH	Cations (mg/L)			
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}
Pure water	6.6	<0.01	<0.01	0.04	0.02
Tap water	7.4	31.0	4.1	10.8	3.9
Spring water	7.3	4	0.5	0.8	0.35

spring water (pH = 7.3). Contents of Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} were significantly larger in tap water than spring.

Effect of water quality on individual catechin content

The effect of water quality on the catechin content of Fuding white tea, specifically EGCG, EGC, EC and ECG, was investigated, and different water types were found to have an influence on the amount of catechins extracted (Fig. 1). EGCG was the major catechin in all infusions, consistent with previous results (Saklar et al. 2015), and levels were the highest in infusions prepared with pure water (115.611 mg/L), compared with only 83.704 mg/L for tap water and 100.82 mg/L for spring water. The EGC content reached a maximum value of 10.419 mg/L in infusions prepared with pure water, which was nearly twice that obtained using tap water. As with EGCG and EGC, the highest EC level was achieved with pure water (7.718 mg/L), while the lowest level was observed with tap water (5.374 mg/L). The effect of water type on the ECG content was in agreement with the trend observed with EGCG, EGC and EC, but the differences were not significant ($p > 0.05$).

In general, the catechin content was the highest in tea infusions made with pure water, intermediate with spring water, and the lowest with tap water, consistent with a previous report that catechins were more easily epimerised and then rapidly degraded in infusions prepared with tap water, compared with purified water (Wang and Helliwell 2000), and also with the observation that green tea extracts prepared with tap water contained less polyphenols (Zhou et al. 2009). This could be explained by the complexity of ions in tap water including Ca^{2+}, Na^{+}, Mg^{2+}, K^{+}, or by differences in pH between tap and purified water (Wang and Helliwell 2000). Ions such as Ca^{2+} and Mg^{2+} may combine with tea polyphenols, causing them to be partially retained in the tea residue (Zhou et al. 2009). The catechin content was reported to decrease when the concentration of Ca^{2+} was above 40 mg/L, due to catechin–metal ion interactions (Xu et al. 2013). Moreover, Ca^{2+} ions in mineral and tap water could be complexed with pectins from cell walls, which may decrease the extraction efficiency (Mossion et al. 2008). Additionally, the pH of tea infusions also affected epimerization of catechins. Epistructured catechins tend to be more easily epimerized to non-epistructured forms in solutions with a pH between 6 and 8 (Vuong et al. 2013). Thus, the ions and pH of pure, spring and tap water influenced the epimerization of catechins, and pure water produced infusions with a higher catechin content than spring or tap water.

Effect of water quality on caffeine content

Caffeine is the most abundant compound in green, black, oolong, and pu-erh teas (Suyare et al. 2013), and this was also the case in white tea in the present study (Fig. 2). Unlike catechins, the maximum caffeine content was achieved with spring water (396.207 mg/L), followed by pure water (386.584 mg/L), while tap water extracted the least caffeine (381.721 mg/L). The pH of the brewing solution did not influence the extraction efficiency of caffeine (Vuong et al. 2013), but the extraction rate was

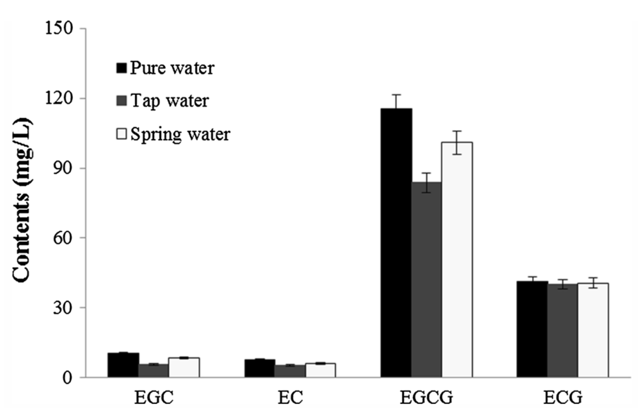

Fig. 1 Effect of water quality on the EGCG, EGC, EC, ECG content in Fuding white tea infusions

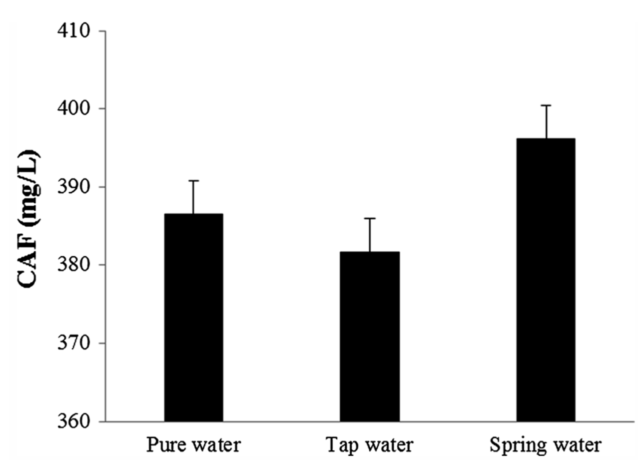

Fig. 2 Effect of water quality on the caffeine content in Fuding white tea infusions

reported to decrease with increasing calcium content, compared with ultra-pure water (Mossion et al. 2008), in partial agreement with the results of the present study. Indeed, infusions prepared with tap water containing ions contained less caffeine than infusions prepared with pure water, while infusions extracted with spring water had higher caffeine levels than those made using pure water.

Effect of water quality on solids content

The influence of water type on the solids content was investigated (Fig. 3), and was found to be higher in samples prepared with tap and spring water than with pure water ($p < 0.05$). However, differences between tap and spring water were not significant ($p > 0.05$). This may be due to differences in the chemical composition or pH in the different water types. It was reported that the extraction of tea solids was increased during brewing under acidic conditions (pH 1–2) or alkaline conditions (pH 8–9) (Vuong et al. 2013). Tap and spring water were weakly alkaline, which may explain the higher solids content compared with pure water, which was weakly acid.

Effect of water quality on theanine content

Theanine is a non-proteic amino acid that is more abundant in white tea than other teas (Pinto 2013). Interestingly, the effect of water quality on theanine content differed from that of catechins and caffeine (Fig. 4). The theanine content was the highest in tea infusions made using spring water ($p < 0.05$), while infusions prepared with pure water had a slightly lower theanine content than those prepared with tap water. As with caffeine, the pH of the tea infusion did not affect the theanine content. Thus, differences in theanine content may be due to differences in the chemical composition of different water types.

Effect of water quality on free amino acids content

The effect of water type on the free amino acid content of Fuding white tea infusions was investigated (Fig. 5). The total amino acid content was the highest in infusions prepared with tap water (114.18 μg/mL), lowest with pure water (74.54 μg/mL), and intermediate with spring water (82.34 μg/mL). Among all the amino acids, Asp and Glu were the most abundant, while Ser and Val were present at the lowest levels. Asp, Glu, Ser, Thr, Arg, Ala, Tyr, Cys-s, Met, Phe, Ile, Leu, and Lys were all highest in infusions prepared with tap water, and accounted for 94% of all amino acids identified. Meanwhile, His and Gly, and Val and Pro were the highest in infusions made with pure and spring water, respectively. All amino acids present in relatively high abundance were the highest with tap water. In contrast to catechins, caffeine and theanine, infusions made with tap water had higher amino acid content. Zhou et al. (2009) found that the amino acid content in green tea extracts was lower in infusions made with deionized water compared with distilled water and activated carbon-adsorbed water.

Sensory analysis

The effect of water type on the sensory attributes (colour, aroma and taste) of white tea infusions was investigated. Water-soluble pigments such as flavonols, anthocyanins, flavanones and flavanols are the main compounds that contribute to the colour of tea infusions. The highest colour sensory score was obtained for infusions prepared with pure water, followed by spring water, while the lowest colour score was obtained with tap water (Fig.

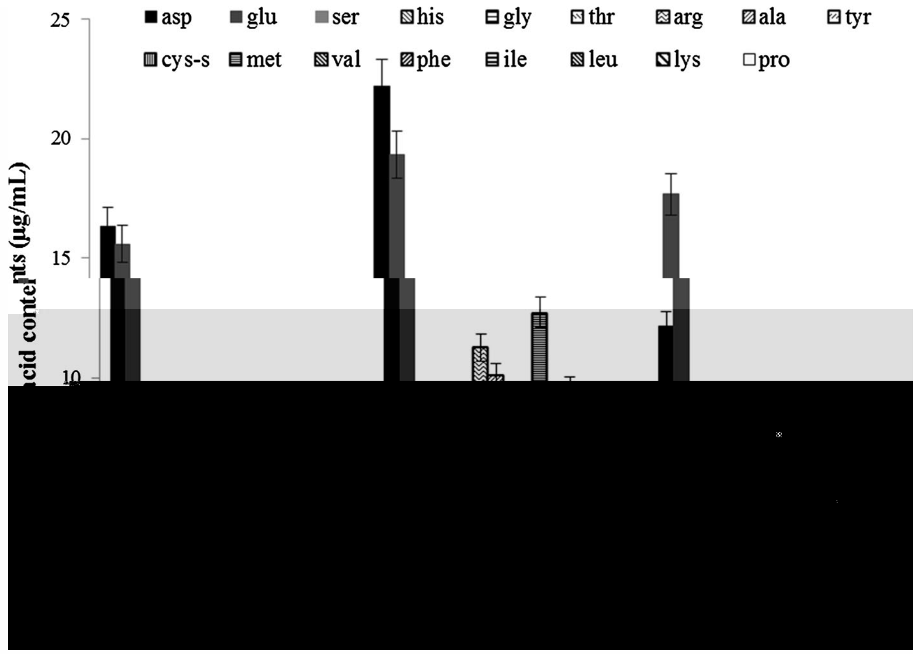

Fig. 5 Effect of water quality on the amino acids content in Fuding white tea infusions

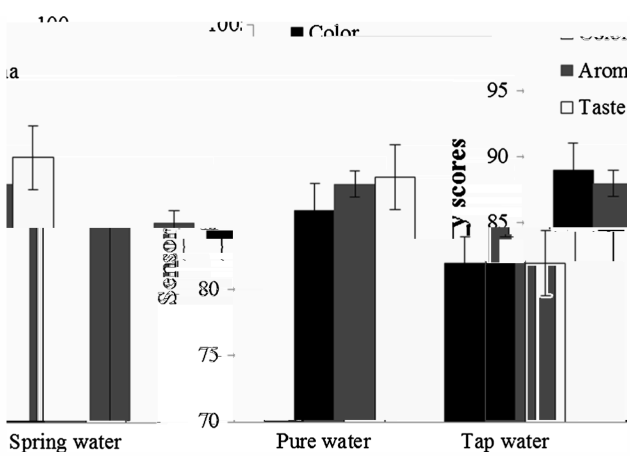

Fig. 6 Effect of water quality on the sensory scores in Fuding white tea infusions

The aroma score was the highest in samples prepared with pure and spring water, and was 88 in both cases, while the score for tap water infusions was 85. The aroma of green tea infusions was reported to be affected by Ca^{2+}, Fe^{2+}, Al^{3+} and Zn^{2+} ions (Yin et al. 2014). Thus, the low aroma score for tap water in the present study may be due to the effect of ions on the volatilization of flavor compounds.

Among all taste compounds identified, only EGCG and caffeine reached a threshold that indicated a significant contribution to the bitterness and astringency of tea infusions. As with colour, water quality had a comparable effect on the taste of tea infusions, which also displayed the same trend as EGCG content. It was reported that Ca^{2+}, Fe^{2+}, Al^{3+} and Zn^{2+} ions markedly influenced the taste of green tea infusions, and the same tea brewed with water of different hardness, which was dependent on the Ca^{2+} and Mg^{2+} content, produced infusions with distinctly different taste (Yin et al. 2014). Meanwhile, significant differences in the taste of green tea were previously reported for tea beverages made using tap, purified, distilled, soft and mineral water (Yin et al. 2014). This could explain the lower taste score for tap water in the present study.

In conclusion, water type effected on the sensory characteristics of white tea infusions, in agreement with the effect on sensory quality of green tea infusions observed earlier due to differences in ion content (Yin et al. 2014). In the present study, pure water, which was slightly acidic (pH = 6.6) and had the lower ion content compared with tap and spring water, scored most highly for colour, aroma and taste, and ions are known to affect these sensory parameters (Yin et al. 2014).

Conclusion

Water is the main determinant of tea quality. The influence of water type on the extraction of the main compounds in Fuding white tea were investigated, and results revealed that water type clearly affected both the content of various compounds and the sensory characteristics of the infusion. Pure water achieved a higher catechin content than both spring and tap water, presumably due to its weak acidity and lower structural viscosity from small organic molecules. However, caffeine and theanine were the highest with spring water, and the amino acid content was maximal with tap water. The sensory quality of white tea infusions was similarly influenced by water type, and the ion content appeared to be the main contributor. Pure water produced white tea with the highest colour, aroma and taste sensory scores.

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