Research Article

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Influence of brewing conditions on taste components in Fuding white tea infusions

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Abstract

BACKGROUND: White tea has received increasing attention of late as a result of its sweet taste and health benefits. During the brewing of white tea, many factors may affect the nutritional and sensory quality of the resulting infusions. The present study aimed to investigate the effect of various infusion conditions on the taste components of Fuding white tea, including infusion time, ratio of tea and water, number of brewing steps, and temperature.

RESULTS: Brewing conditions had a strong effect on the taste compound profile and sensory characteristics. The catechin, caffeine, theanine and free amino acid contents generally increased with increasing infusion time and temperature. Conditions comprising an infusion time of 7 min, a brewing temperature of 100 °C, a tea and water ratio of 1:30 or 1:40, and a second brewing step, respectively, were shown to obtain the highest contents of most compounds. Regarding tea sensory evaluation, conditions comprising an infusion time of 3 min, a brewing temperature of 100 °C, a tea and water ratio of 1:50, and a first brewing step, resulted in the highest sensory score for comprehensive behavior of color, aroma and taste.

CONCLUSION: The results of the present study reveal differences in the contents of various taste compounds, including catechins, caffeine, theanine and free amino acids, with respect to different brewing conditions, and sensory scores also varied with brewing conditions.

Keywords: white tea; brewing; catechin; caffeine; theanine; free amino acids

INTRODUCTION

Tea is an extremely popular and widely consumed beverage throughout the world.[1−3] Its popularity is a result of health benefits, its pleasant flavor, and its activity as a stimulant. Tea drinking can reduce serum cholesterol, prevent low-density lipoprotein oxidation, and decrease the risk of cardiovascular disease and cancer.[4] The consumption of tea is good for health and longevity because of the presence of bioactive compounds, including phenolic molecules, caffeine, amino acids and vitamins.[2,4] Tea can be classified into green, black, oolong, dark and white based on different processing methods.[4−6]

White tea, the least processed form, is fermented only a little and is only made by new growth buds and young leaves, which are covered with a thin, silvery fuzz and are harvested only once a year in the early spring.[7,8] After picking, it is immediately dried to inhibit oxidation and give it a light, delicate and sweet taste, which is different from the taste of green tea.[6,9,10] The levels of total polyphenols and catechins in white tea are almost the same as those in green tea;[6] however, studies have found that white tea contains higher concentrations of total polyphenols, caffeine and catechins such as epigallocathechins (EGC), epicatechin gallate (ECG) and epigallocatechin gallate (EGCG) than green tea.[8,11−13] Thus, the strong antioxidant activity of white tea is linked with high concentrations of the main compounds, which explains its health benefits.[8,14] White tea has shown many health benefits, such as anti-oxidative, anti-inflammatory, anti-cancer,[10] anti-microbial[15] and anti-melanogenic effects[7], amongst others.[11,12] Therefore, white tea is a good resource rich in active components with functional properties.[16] However, white tea is one of the least studied teas[8] and research on it is scarce.[9,17]

The overall taste of tea infusions comprises three basic tastes: bitterness, umami and sweetness.[18] Several groups of compounds have a potential effect on the taste of tea, including phenolic compounds, purine alkaloids, amino acids, carbohydrates, nucleotides, organic acids and ions.[3] Bitterness, an important factor charactering tea taste,[19] is mainly a result of catechins and caffeine. Sweetness is mainly attributed to some sweet-tasting amino acids, as well as simple sugars such as sucrose, glucose and fructose.[18]

Tea polyphenols, particularly tea catechins, have been widely studied and are found to be responsible for bitterness and

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astringency.[3,18,20,21] Catechins account for approximately 30% of the dry weight of tea leaves.[22] Catechins are found to activate the human bitter taste receptors hTAS2R14 and hTAS2R39 and the effect also is dose-dependent, with non-linear responses at low and high concentrations.[3] Moreover, EGCG, in some situations, is used as a standard substance for measuring astringency.[18]

Purine alkaloids, especially caffeine, are the other major contributors to the bitter taste of tea.[3] It has been suggested that caffeine and other methylxanthines induce a bitter taste without activating bitter taste receptors.[3] In addition, caffeine, in contrast to catechins, also demonstrably enhances tea flavor.[20]

About 70% of the umami taste intensity of tea is contributed by amino acids, especially theanine and glutamic acid.[2] Theanine (5-*N*-ethyl glutamine) and L-glutamate account for almost two-thirds of the total amino acid content.[18,23] Theanine is a non-proteinogenic amino acid that makes up more than 50% of free amino acids,[2,3] and it is reported to contribute sweet, brothy and umami characteristics.[3]

Many factors may affect the quality of tea infusions, including the maturity of the tea leaves, processing methods and brewing conditions.[2,24] For example, both the time and temperature of the infusion can have a pronounced effect on extracting the catechins.[24] Saklar *et al.*[24] studied the effects of different brewing conditions on catechin content and sensory acceptance in Turkish green tea infusions, and found that EGCG content and sensory scores were both at a maximum when green tea was brewed at 85 °C for 3 min. Suyare *et al.*[1] found that infusion time affected the phenolic compounds and caffeine content in black tea.

Recently, white tea has received increasing attention,[6] although studies concerning the taste compounds and their relationship to infusion conditions are few. Fuding white tea is the most famous white tea in China and is becoming more and more popular among consumers. Thus, the present study aimed to investigate the effect of different infusion conditions on the taste components of Fuding white tea. Specifically, infusion time, ratio of tea and water, number of brewing steps, and infusion temperature were investigated to enhance our knowledge of the changes in taste compounds with different brewing conditions and provide theoretical basis for brewing and drinking white tea.

MATERIALS AND METHODS

Materials and chemicals

Fuding white tea (Bai Hao Yinzhen) was provided by the Fujian Bamin Tea Shop (Fujian, China). The moisture content of tea was 7.02 g 100 g^{-1}. L-theanine, caffeine, standard catechins, acetonitrile and methanol used in high-performance liquid chromatography (HPLC) experiments were purchased from Sigma-Aldrich Chemical Co. (Shanghai, China). All tea infusions were prepared with pure water from Hangzhou Wahaha Group Co., Ltd (Hangzhou, China). All other chemical reagents were of analytical grade.

Preparation of infusions

White tea was brewed under different conditions as shown in Table 1. Infusions were prepared in porcelain tea pots that were covered with porcelain lids during tea brewing. A water bath kettle was used to control the temperature of infused tea samples. When the brewing time was complete, white tea infusions were filtered and used for analysis.

Table 1. Different brewing conditions of Fuding white tea

Number	Ratio of tea and water (g mL^{-1})	Temperature (°C)	Brewing time (min)	Number of brewing steps
1	1:30	100	5	1
2	1:40	100	5	1
3	1:50	100	5	1
4	1:60	100	5	1
5	1:50	90	5	1
6	1:50	80	5	1
7	1:50	100	3	1
8	1:50	100	4	1
9	1:50	100	6	1
10	1:50	100	7	1
11	1:50	100	5	2
12	1:50	100	5	3
13	1:50	100	5	4
14	1:50	100	5	5

Analysis of taste component content

The taste components of Fuding white tea were monitored by determining catechins, caffeine, theanine and free amino acids. Catechins and caffeine were analyzed by HPLC in accordance with ISO 14502-2:2005.[25] The quantification was performed using a caffeine calibration curve. EGCG, EGC, ECG and epicatechin (EC) were assayed and content was quantified in accordance with ISO 14502-2:2005. Theanine in tea samples was analyzed by heating water extraction, purification and decolorization, and derivatization, then was determined by HPLC in accordance with China National Standards (GB/T 23193-2008, China).[26] For amino acid analysis, the samples were hydrolyzed with hydrochloric acid and determined with an amino acid analyzer in accordance with China National Standards (GB/T 5009.124-2003, China).[27]

Sensory evaluation

Sensory evaluation was performed in accordance with China National Standards outlined in GB/T 23776-2009.[28] Tea infusions prepared using different brewing conditions were given to 10 experimental subjects, who previously received extensive training in the sensory analysis of tea infusions and were qualified by China National Tea Sensory Appraisers. The panel's sensory responses with respect to color, taste and aroma were evaluated on a 100-point scale (where 90–99 = high intensity, 80–89 = neutral intensity and 70–79 = low intensity) in accordance with GB/T 23776-2009 (Table A.7).[28]

Statistical analysis

All samples were prepared and analyzed in triplicate. Mean ± SD values were calculated and statistical analysis was performed using analysis of variance (ANOVA) in SPSS, version 20.0 (IBM Corp., Armonk, NY, USA). $P < 0.05$ was considered statistically significant.

RESULTS AND DISCUSSION

Effect of brewing conditions on individual catechin content

EGCG, EGC, EC and ECG are major polyphenolic compounds in tea, and are known as tea catechins.[7,21,24,29] The effect of various infusion conditions on the EGCG, EGC, EC and ECG content of

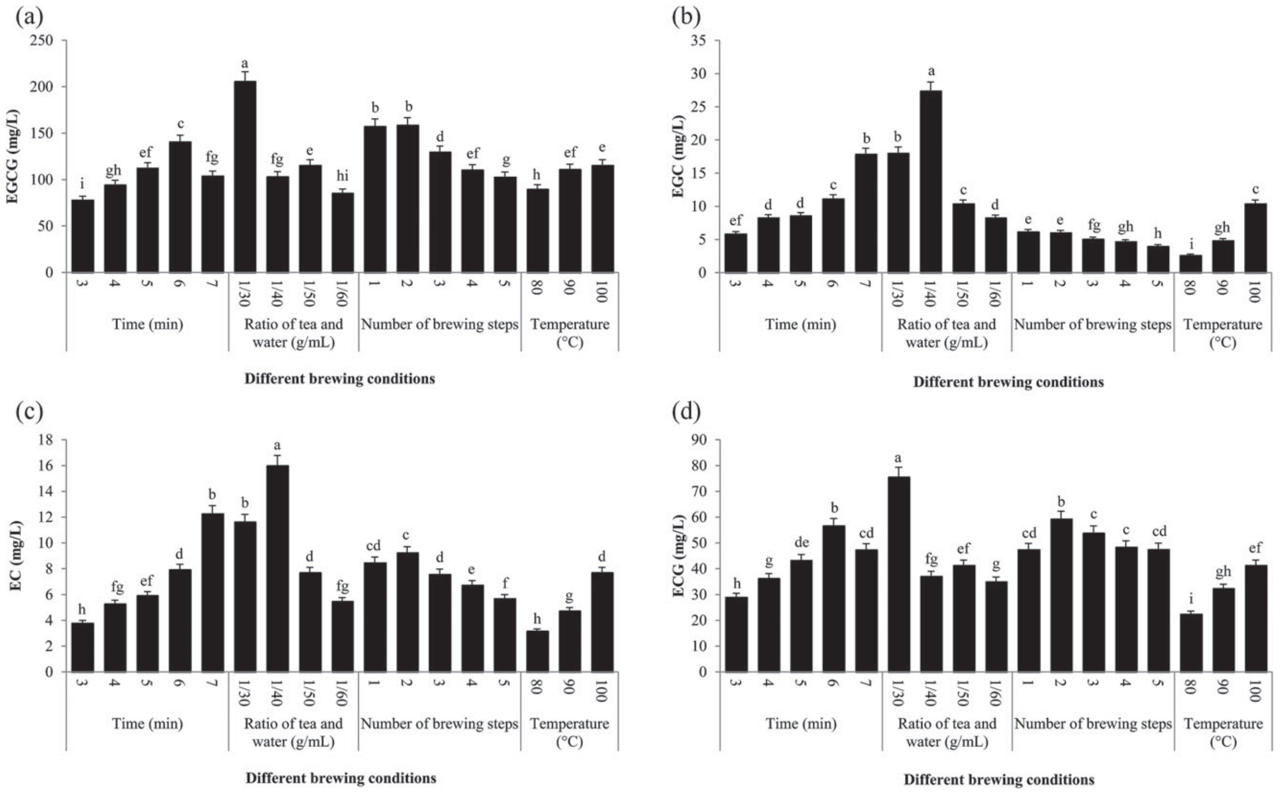

Figure 1. Effect of different brewing conditions on the content of (a) EGCG, (b) EGC, (c) EC and (d) ECG in Fuding white tea infusions.

Fuding white tea was studied, and individual catechins are shown in Fig. 1. EGCG with a bitter and astringent taste was the major catechin extracted in all infusions, and infusion temperature and time played an important role in extracting EGCG,[24] which was also the case in the present study. The EGCG content was 78.143 mg L^{-1} after a brewing time of 3 min, and then this reached a maximum of 140.681 mg L^{-1} at 6 min, and then decreased at 7 min (Fig. 1a). Regarding the ratio of tea and water, the EGCG content reached a maximum when the ratio of tea and water was 1:30, and the difference was significant ($P < 0.05$). With an increasing of number of brewing steps, the amount of EGCG decreased, although the EGCG content increased with increasing brewing temperature, reaching a maximum level of 115.611 mg L^{-1} at 100 °C.

The amount of EGC increased continuously with increasing brewing time, and reached a maximum value of 17.861 mg L^{-1} at 7 min, which was almost three-fold higher than the content measured after a brewing time of 3 min (Fig. 1b). Regarding the ratio of tea and water, the highest EGC level was observed at 1:40 (27.38 mg L^{-1}), whereas the lowest was detected at 1:60 (8.273 mg L^{-1}). The amount of EGC decreased with an increasing number of brewing steps but, similar to EGCG, the amount of EGC increased with increasing brewing temperature, and a temperature of 100 °C was found to be optimal for EGC extraction.

EC extraction also increased linearly with increasing brewing time, reaching 12.281 mg L^{-1} ($P < 0.05$) when infused for 7 min (Fig. 1c). Regarding the tea and water ratio, EC extraction decreased in the order: 1:40 > 1:30 > 1:50 > 1:60. This was also the case for EGC, as described above. Similar to EGCG, EC content also generally decreased with an increasing number of brewing steps, and reached a maximum of 9.257 mg L^{-1} after only two infusions. EC content was found to increase with increasing temperature, as was also observed for EGCG and EGC.

The influence of infusion time, ratio of tea and water, number of brewing steps and brewing temperature on ECG and EGCG content was essentially identical (Fig. 1d). Among all treatments, an infusion time of 5 min, a ratio of tea and water of 1:30, a single step, and an infusion temperature of 100 °C resulted in a maximum ECG level of 75.569 mg L^{-1}, whereas extraction was lowest with an infusion time of 5 min, a ratio of tea and water of 1:50, a single brewing step and an infusion temperature of 80 °C.

In general, the contents of EGCG, EGC, EC and ECG increased with increasing brewing time, in complete agreement with reports that the total polyphenol content is correlated with extraction time, and that the efficiency of white tea extraction can be increased further by lengthening the extraction time.[9] However, the amount of EGCG and ECG decreased at 7 min, presumably as a result of the epimerization of EGCG and ECG to non-epistructured GCG and CG,[30] respectively, as observed previously by Saklar *et al.*[24] Regarding the ratio of tea and water, EGCG and ECG reached maximum levels at a ratio of 1:30, whereas EGC and EC were maximal at 1:40. Upon decreasing the ratio of tea and water, white tea infusions are diluted, which leads to a lower extraction efficiency. Similarly, tea infusions were also diluted with an increase in the number of brewing steps. Temperature plays an important role in the extraction of catechin,[1] and this was also the case in the present study; the catechin content increased with increasing of temperature, presumably because heat made the cell walls more permeable to solvents and other compounds, and increased the solubility and diffusion coefficients of tea compounds.[24] However, Damiani *et al.*[6] compared hot white tea infusions with cold infusions and found that cold infusions contained a higher quantity of bioactive compounds. This may be a result of the long maceration period used (2 h), during which leaves may swell completely and all components have sufficient time to become extracted.

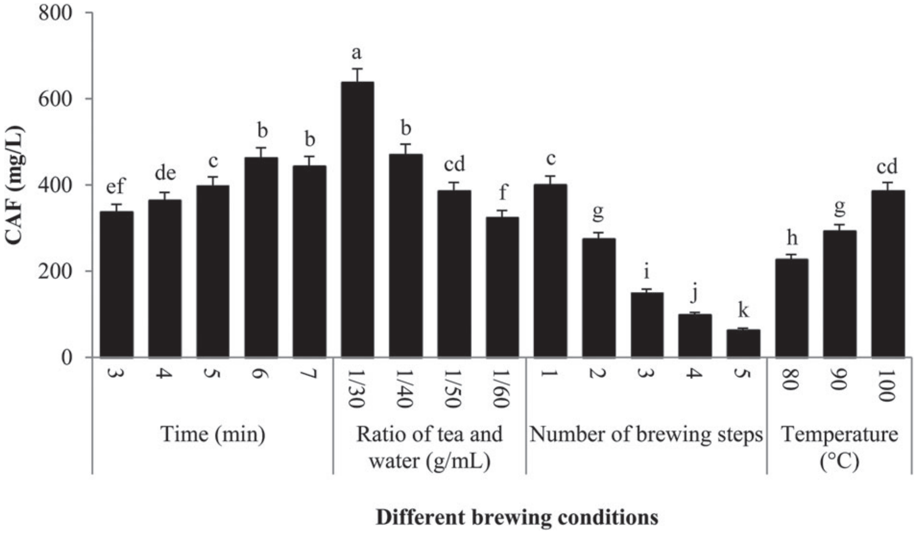

Figure 2. Effect of different brewing conditions on caffeine content in Fuding white tea infusions.

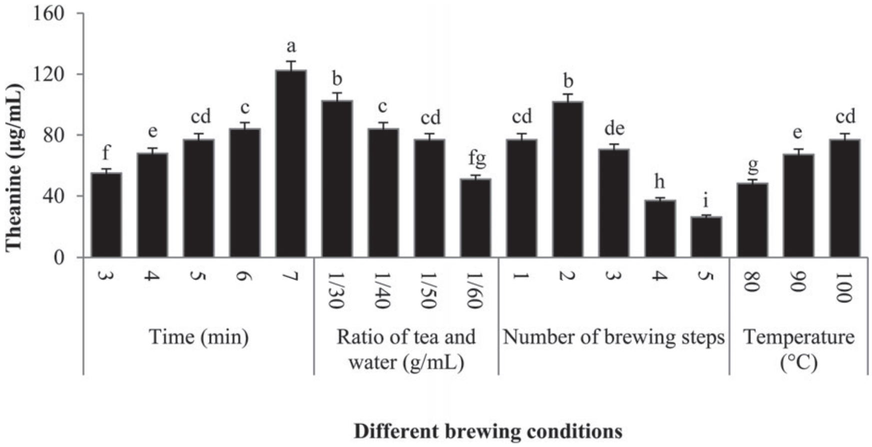

Figure 3. Effect of different brewing conditions on theanine content of Fuding white tea infusions.

Effect of brewing conditions on caffeine content

Caffeine is the major component in green, black, oolong and pu-erh teas.[1] In the present study on white tea, caffeine was also found to be the most abundant compound. Figure 2 shows the effect of different brewing conditions on caffeine content. Caffeine levels increased with increasing infusion time, reaching 462.931 mg L^{-1} within 6 min but then decreased at 7 min. Caffeine content decreased significantly with decreasing ratio of tea and water, as well as an increasing number of brewing steps, as result of dilution effects ($P < 0.05$). Meanwhile, the amount of caffeine increased with increasing temperature. Among all treatments, the highest caffeine level was obtained with an infusion time of 5 min, a ratio of tea and water of 1:30, a single brewing step, and an infusion temperature of 100 °C.

Effect of brewing conditions on theanine content

Theanine is a non-proteic amino acid that is reported to be more abundant in white tea than in other teas.[22] In the present study, the amount of theanine extracted increased linearly with increasing brewing time (Fig. 3); at 7 min, theanine content was significantly higher than at other brewing times ($P < 0.05$). Regarding the ratio of tea and water, theanine content was decreased with a decreasing ratio as result of dilution effects. Theanine content at a ratio of 1:30 (102.5 μg mL^{-1}) was twice of that at 1:60 (51.1 μg mL^{-1}). Theanine content first increased then decreased with an increasing number of brewing steps; the highest theanine content was achieved with two brewing steps (101.80 μg mL^{-1}), whereas the lowest level was observed after five steps (26.10 μg mL^{-1}). Two brewing steps was therefore optimal. As with catechins and caffeine, theanine content of Fuding white tea was higher with increasing infusion temperature; a brewing temperature of 100 °C yielded a significantly higher content than that achieved at 80 °C ($P < 0.05$). However, unlike catechins and caffeine, the highest theanine content was achieved with an infusion time of 7 min, a ratio of tea and water of 1:50, a single brewing step, and a temperature of 100 °C.

Effect of brewing conditions on the free amino acid content

Free amino acids can be divided into sweet, bitter and umami based on their different taste characteristics, and the effects of different brewing conditions on these amino acids were investigated (Figs 4–6). The content of sweet amino acids in white tea infusions varied with different brewing conditions (Fig. 4). Specifically, the content of Asp was highest, followed by Ala and Gly. Being hydrophilic, Asp leached into the infusion much faster than did hydrophobic amino acids. In general, the content of sweet amino

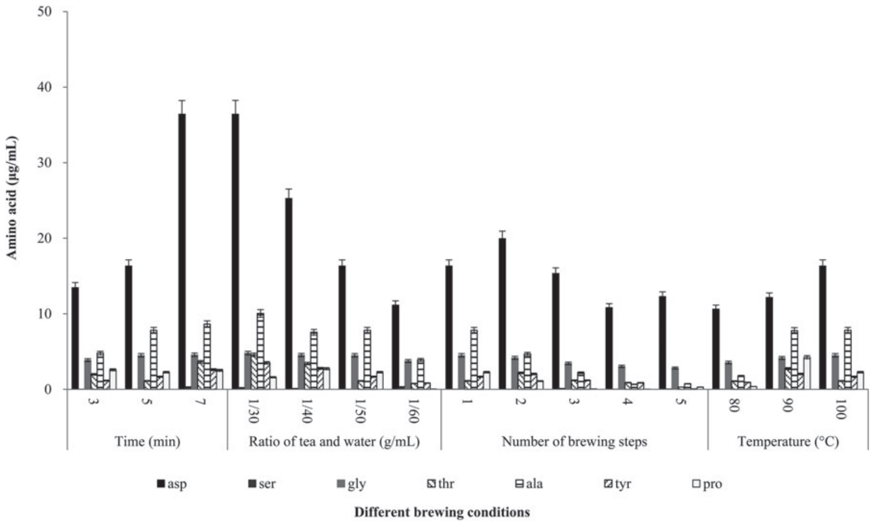

Figure 4. Effect of different brewing conditions on the content of sweet amino acids in Fuding white tea infusions.

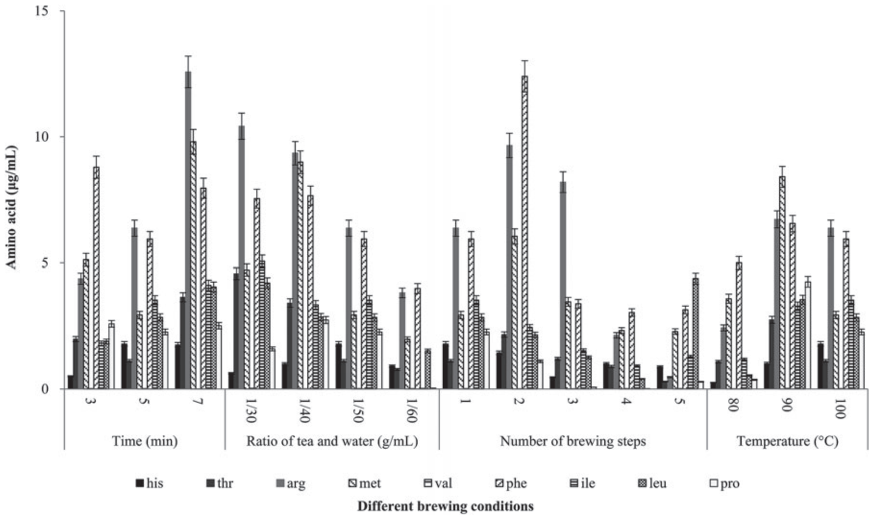

Figure 5. Effect of different brewing conditions on the content of bitter amino acids in Fuding white tea infusions.

acids increased with increasing brewing time, indicating that a longer time and a higher temperature were more conducive to extracting sweet amino acids into infusions. As the ratio of tea and water decreased, Asp content significantly decreased ($P < 0.05$), whereas the amount of Ala and Gly changed only slightly. Asp content reached a maximum after two brewing steps, and the amount of Ala and Gly decreased with an increase number of brewing steps. After five brewing steps, Ser, Thr, Ala, Tyr and Pro content was extremely low. Consistent with the taste compounds described above, Asp, Ala and Gly content was found to increase with increasing temperature, presumably as a result of heat rendering the cell walls more permeable, as described above.

Leaching rates also differed between bitter amino acids (Fig. 5). In general, Arg, Met and Phe were the most abundant bitter amino acids. Arg and Met reached maximum levels after an infusion time of 7 min; however, Phe extraction was maximal after only 3 min. Regarding the ratio of tea and water, Arg content decreased with decreasing ratio, and Met and Phe reached maximum levels at a ratio of 1:40 (8.99 and 7.66 μg mL^{-1}, respectively). Interestingly, these three bitter amino acids were poorly extracted by a single brewing step, and two infusions were needed to achieve maximal leaching. Temperature also influenced the extraction of amino acids but, unlike catechins and caffeine, 90 °C was more beneficial for extracting bitter amino acids.

The effect of brewing conditions on the extraction of the umami amino acids Asp, Glu, Ser and Met was investigated (Fig. 6), and Ser was scarce in all conditions tested compared to the other three amino acids, of which Asp was the most abundant. A brewing time of 7 min and a tea and water ratio of 1:50 was effective for extracting Asp, as was a brewing time of 5 min and a ratio of 1:30. Indeed, brewing time and the ratio of tea and water were more important for Asp extraction than the number of brewing steps and the infusion temperature.

In conclusion, the effects of different brewing conditions on the extraction of free amino acids differed as a result of differences in the rate of leaching. However, even the highest free amino acid content (36.41 μg mL^{-1}) was below the threshold at which their contributions to the taste were not likely to be significant.

Sensory analysis

The effect of different tea infusion conditions on the sensory attributes of color, aroma and taste were investigated, and all

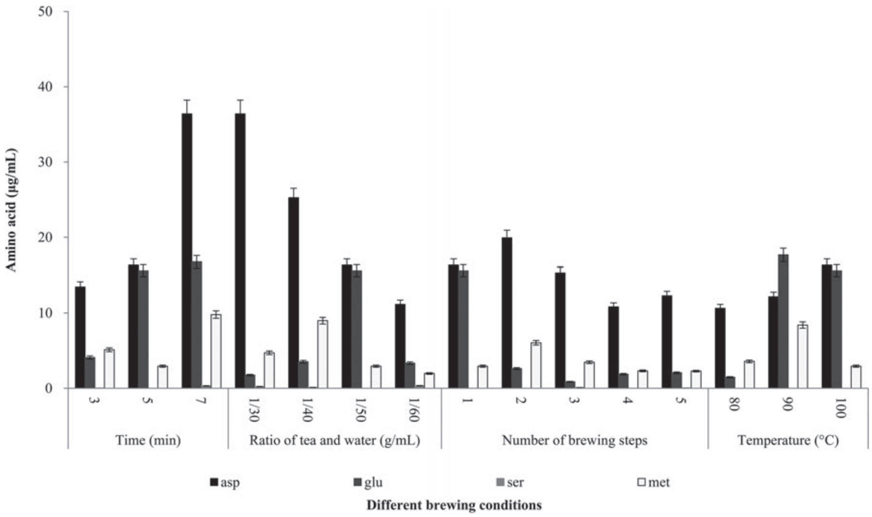

Figure 6. Effect of different brewing conditions on the content of umami amino acids in Fuding white tea infusions.

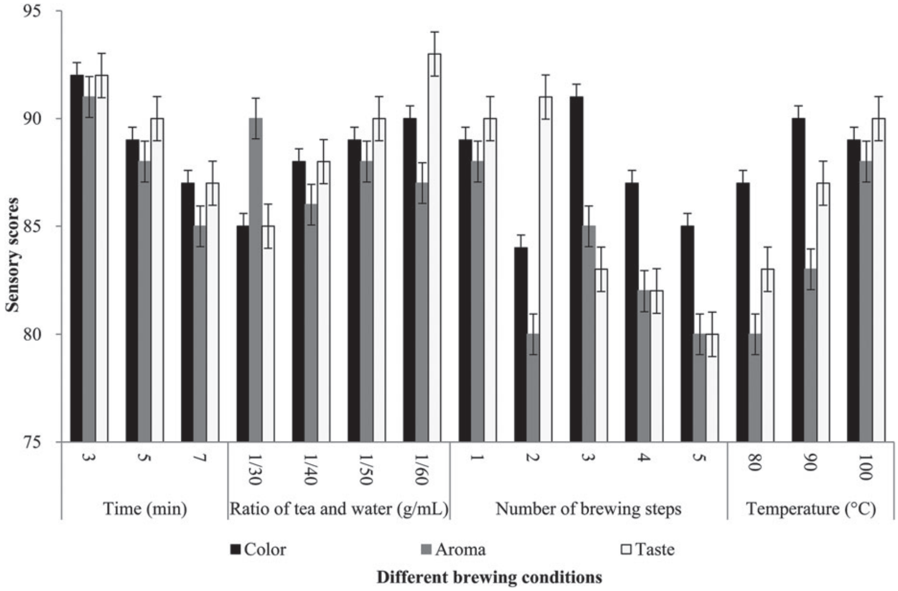

Figure 7. Effect of different brewing conditions on sensory scores in Fuding white tea infusions.

sensory scores decreased with increasing brewing time (Fig. 7). Water-soluble pigments are the main compounds that contribute to the color of tea infusions, and these include flavonols, anthocyanins and flavanones. As the infusion time was prolonged, color score decreased, possibly as a result of pigment oxidation, whereas aroma scores presumably decreased because of the volatilization of flavor compounds. Taste compounds were gradually infused with increasing brewing time, although only EGCG and caffeine reached a threshold indicating that they make a significant contribution to the bitterness and astringency of tea infusions. Thus, increasing the brewing time increased the amount of EGCG and caffeine, which increased bitterness and astringency, although at the expense of a decrease in sensory scores, which was in accordance with a previous study reporting that the infusion taste scores reached a maximum approaching 3–5 min and then decreased after 5 min because of the perceived bitterness taste.[24]

A decrease in the ratio of tea and water resulted in a dilution of the tea infusion, and color and taste scores increased with decreasing infusion concentration. The increase in taste scores might be related to the decreasing EGCG and caffeine content, which decreased bitterness and astringency. With a decrease in the ratio of tea and water, taste scores were negatively correlated with EGCG and caffeine content. However, aroma scores reached a maximum at a ratio of 1:30, probably as a result of the high concentration of tea infusion.

Upon changing the number of brewing steps, color and aroma first decreased, then increased, and finally decreased again, whereas taste scores increased then decreased. The color of tea infusions reached a maximum score after three brewing steps, although the aroma score was maximal after only one step, and taste scored most highly after two infusions.

At a brewing temperature of 80 °C, water-soluble pigments were not fully infused into water, whereas, at 90 °C, color score reached its maximum. However, when the temperature was increased to 100 °C, the oxidation of water-soluble pigments led to a decrease in color score. By contrast, the aroma and taste scores increased with increasing temperature, suggesting that a higher temperature was more conducive for releasing volatile compounds and extracting taste compounds. With the increase in temperature, the scores for taste were positively correlated with both EGCG and caffeine content.

Sensory characteristics are known to be correlated with chemical constituents.[3] In the present study, changes in infusion color and aroma were correlated with the stability of water-soluble pigments and volatile compounds, respectively. Regarding taste, epigallocatechin-3-gallate, catechins, caffeine and flavanol-3-glycosides are reported to be key contributors to the taste of tea, whereas amino acids, theaflavins, organic acids and soluble carbohydrates do not play a significant role.[31] In the present study, only EGCG and caffeine met the threshold indicating that they played an important role in the bitterness and astringency of tea infusions.

Interactions between taste components, both synergistic and antagonistic, are reported to influence taste: when EGCG and caffeine were both present, bitterness and astringency were enhanced; similarly, when EGCG and theanine were combined, the umami taste was lost, although bitterness was decreased and astringency was increased.[18] Thus, in the present study, these taste compounds together made a contribution to the taste of tea infusions. In general, an infusion time of 3 min, a tea and water ratio of 1:50, a single step and an infusion temperature of 100 °C resulted in an infusion with satisfactory color, aroma and taste.

CONCLUSIONS

The present study investigated the influence of different brewing conditions on the taste compounds in Fuding white tea infusions. The results revealed that brewing conditions strongly affected the taste compound profile and sensory characteristics. In general, a longer brewing time and a higher infusion temperature increased the amount of catechin, caffeine, theanine and free amino acids extracted. However, a tea and water ratio of 1:30 or 1:40 and two brewing steps proved optimal for the majority of taste compounds. Sensory scores were also influenced by brewing conditions, presumably as result of changes in the chemical components. An infusion time of 3 min, a tea and water ratio of 1:50, a single brewing step and an infusion temperature of 100 °C resulted in tea with a satisfactory color, aroma and taste combination. In the white tea infusions, catechins, caffeine, theanine and free amino acids contributed their own unique taste, although interactions between taste components made an important contribution to the taste of the infusion.

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REFERENCES

1. Suyare Arayjo R, Nisha N, Gabriela Barbosa O, Priscila Alves de O, Tais Oliveira Matos S, Aline Geovania Passos dos S *et al.*, Effect of infusion time on phenolic compounds and caffeine content in black tea. *Food Res Int* **51**:155–161 (2013).
2. Kocadağlı T, Özdemir KS and Gökmen V, Effects of infusion conditions and decaffeination on free amino acid profiles of green and black tea. *Food Res Int* **53**:720–725 (2013).
3. Yu P, Yeo AS, Low MY and Zhou W, Identifying key non-volatile compounds in ready-to-drink green tea and their impact on taste profile. *Food Chem* **155**:9–16 (2014).
4. Sereshti H, Samadi S and Jalali-Heravi M, Determination of volatile components of green, black, oolong and white tea by optimized ultrasound-assisted extraction-dispersive liquid-liquid microextraction coupled with gas chromatography. *J Chromatogr A* **1280**:1–8 (2013).
5. Qin Z, Pang X, Chen D, Cheng H, Hu X and Wu J, Evaluation of Chinese tea by the electronic nose and gas chromatography–mass spectrometry: correlation with sensory properties and classification according to grade level. *Food Res Int* **53**:864–874 (2013).
6. Damiani E, Bacchetti T, Padella L, Tiano L and Carloni P, Antioxidant activity of different white teas: Comparison of hot and cold tea infusions. *J Food Comp Anal* **33**:59–66 (2014).
7. Kim YC, Choi SY and Park EY, Anti-melanogenic effects of black, green, and white tea extracts on immortalized melanocytes. *J Vet Sci* **16**:135 (2015).
8. Nunes AR, Alves MG, Tomás GD, Conde VR, Cristóvão AC, Moreira PI *et al.*, Daily consumption of white tea (*Camellia sinensis* (L.)) improves the cerebral cortex metabolic and oxidative profile in prediabetic Wistar rats. *Br J Nutr* **113**:832–842 (2015).
9. Rusak G, Komes D, Likic S, Horzic D and Kovac M, Phenolic content and antioxidative capacity of green and white tea extracts depending on extraction conditions and the solvent used. *Food Chem* **110**:852–858 (2008).
10. Hajiaghaalipour F, Kanthimathi MS, Sanusi J and Rajarajeswaran J, White tea (*Camellia sinensis*) inhibits proliferation of the colon cancer cell line, HT-29, activates caspases and protects DNA of normal cells against oxidative damage. *Food Chem* **169**:401–410 (2015).
11. Song J-L, Zhou Y, Feng X and Zhao X, White tea (*Camellia sinenesis* (L.)) ethanol extracts attenuate reserpine-induced gastric ulcers in mice. *Food Sci Biotechnol* **24**:1159–1165 (2015).
12. Dias TR, Gonçalo DT, Teixeira NF and Silva BM, White tea (*Camellia sinensis* (L.)): antioxidant properties and beneficial health effects. *Int J Food Sci Nutr Diet* **2**:19–26 (2013).
13. Hilal Y and Engelhardt U, Characterisation of white tea – comparison to green and black tea. *J Verbrauch Lebens* **2**:414–421 (2007).
14. Azman NAM, Peiró S, Fajarí L, Julià L and Almajano MP, Radical scavenging of white tea and its flavonoid constituents by electron paramagnetic resonance (EPR) Spectroscopy. *J Agric Food Chem* **62**:5743–5748 (2014).
15. Tomaszewska E, Winiarska-Mieczan A and Dobrowolski P, Hematological and serum biochemical parameters of blood in adolescent rats and histomorphological changes in the jejunal epithelium and liver after chronic exposure to cadmium and lead in the case of supplementation with green tea vs black, red or white tea. *Exp Toxicol Pathol* **67**:331–339 (2015).
16. Zielinski AAF, Haminiuk CWI and Beta T, Multi-response optimization of phenolic antioxidants from white tea (*Camellia sinensis* L. Kuntze) and their identification by LC-DAD-Q-TOF-MS/MS. *LWT – Food Sci Technol* **65**:897–907 (2016).
17. Sanna V, Lubinu G, Madau P, Pala N, Nurra S, Mariani A *et al.*, Polymeric nanoparticles encapsulating white tea extract for nutraceutical application. *J Agric Food Chem* **63**:2026–2032 (2015).
18. Yin J-F, Zhang Y-N, Du Q-Z, Chen J-X, Yuan H-B and Xu Y-Q, Effect of Ca^{2+} concentration on the tastes from the main chemicals in green tea infusions. *Food Res Int* **62**:941–946 (2014).
19. Hayashi N, Ujihara T, Chen R, Irie K and Ikezaki H, Objective evaluation methods for the bitter and astringent taste intensities of black and oolong teas by a taste sensor. *Food Res Int* **53**:816–821 (2013).
20. Chen Q, Zhao J, Guo Z and Wang X, Determination of caffeine content and main catechins contents in green tea (*Camellia sinensis* L.) using taste sensor technique and multivariate calibration. *J Food Comp Anal* **23**:353–358 (2010).
21. Narukawa M, Kimata H, Noga C and Watanabe T, Taste characterisation of green tea catechins. *Int J Food Sci Technol* **45**:1579–1585 (2010).
22. Pinto MdS, Tea: a new perspective on health benefits. *Food Res Int* **53**:558–567 (2013).
23. Shu K, Kenji K, Hideki M, Andrea H and Thomas H, Molecular and sensory studies on the umami taste of Japanese green tea. *J Agric Food Chem* **54**:2688–2694 (2006).
24. Saklar S, Ertas E, Ozdemir IS and Karadeniz B, Effects of different brewing conditions on catechin content and sensory acceptance in Turkish green tea infusions. *J Food Sci Technol* **52**:6639–6646 (2015).
25. ISO 14502-2:2005. *Determination of Substances Characteristic of Green and Black Tea – Part 2: Content of Catechins in Green Tea – Method Using High-Performance Liquid Chromatography*. MOD, Switzerland (2005).

26 General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China and Standardization Administration of China. *Determination of Theanine in Tea – High Performance Liquid Chromatography (GB/T 23193-2008)*. Standards Press of China, Beijing (2008).

27 Ministry of Health of the People's Republic of China and Standardization Administration of China. *Determination of Amino Acids in Foods (GB/T 5009124-2003)*. Standards Press of China, Beijing (2003).

28 General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China and Standardization Administration of China. *Methodology of Sensory Evaluation of Tea (GB/T 23776-2009)*. Standards Press of China, Beijing (2009).

29 Narukawa M, Noga C, Ueno Y, Sato T, Misaka T and Watanabe T, Evaluation of the bitterness of green tea catechins by a cell-based assay with the human bitter taste receptor hTAS2R39. *Biochem Biophys Res Commun* **405**:620–625 (2011).

30 Ananingsih VK, Sharma A and Zhou W, Green tea catechins during food processing and storage: a review on stability and detection. *Food Res Int* **50**:469–479 (2013).

31 Kraujalyte V, Pelvan E and Alasalvar C, Volatile compounds and sensory characteristics of various instant teas produced from black tea. *Food Chem* **194**:864–872 (2016).