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Improving the sweet aftertaste of green tea infusion with tannase

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ABSTRACT

The present study aims to improve the sweet aftertaste and overall acceptability of green tea infusion by hydrolyzing (−)-epigallocatechin gallate (EGCG) and (−)-epicatechin gallate (ECG) with tannase. The results showed that the intensity of the sweet aftertaste and the score of overall acceptability of the green tea infusion significantly increased with the extension of the hydrolyzing treatment. (−)-Epigallocatechin (EGC) and (−)-epicatechin (EC) were found to be the main contributors for the sweet aftertaste, based on a trial compatibility with EGCG, ECG, EGC, and EC monomers, and a synergistic action between EGC and EC to sweet aftertaste was observed. A 2.5:1 (EGC/EC) ratio with a total concentration of 3.5 mmol/L gave the most satisfying sweet aftertaste, and the astringency significantly inhibited the development of the sweet aftertaste. These results can help us to produce a tea beverage with excellent sweet aftertaste by hydrolyzing the green tea infusion with tannase.

1. Introduction

Tea is one of the most popular beverages, and widely consumed in the world. Green tea in particular is popular in most Asian areas, especially in China and Japan. The overall taste of a green tea infusion comprises bitterness, astringency, umami (a brothy or savory taste), and sweetness (Tarachiwin, Ute, Kobayashi, & Fukusaki, 2007; Yu, Yeo, Low, & Zhou, 2014), and bitterness and astringency constitute its primary taste (Narukawa, Kimata, Noga, & Watanabe, 2010). However, a sweet aftertaste is often used as a positive term to describe a good tea infusion, which is frequently associated with oolong and green tea infusions. However, it is still unclear which chemicals influence the sweet aftertaste of tea infusions.

Catechins, which are the main components of polyphenols in green tea infusions, were found to have anticarcinogenic, antioxidant, and antimutagenic properties (Majchrzak, Mitter, & Elmadfa, 2004; Sharangi, 2009), and (−)-epigallocatechin gallate (EGCG) was identified as the most important and abundant catechin in green tea (Battestin, Macedo, & De Freitas, 2008). Furthermore, catechins have been found to be a major contributor to the astringency and bitterness of green tea infusions (Scharbert & Hofmann, 2005; Wright, Mphangwe, Nyrenda, & Apostolides, 2000). Increasing catechins concentration enhanced taste intensity, but it also caused a decrease in taste palatability (Narukawa et al., 2010). The taste intensity of gallated catechins are strong when compared with non-gallated catechins, in particular (−)-epicatechin gallate (ECG) shows the strongest taste (Narukawa et al., 2010; Scharbert & Hofmann, 2005). Catechins are associated with a sweet aftertaste in oolong tea infusion (Yamanishi, 1990) and cocoa powder (Bonvehi & Coll, 1997) after tasting bitter and astringent. A sweet aftertaste is mostly observed after the bitter taste, and its intensity is much different in various tea samples (Xu et al., 2013). However, it is still unclear how to improve the sweet aftertaste of green tea infusion.

Tannase (EC 3.1.1.20) is often used to catalyze the hydrolysis of gallated catechins (EGCG, (−)-gallocatechin gallate (GCG) and ECG), resulting in non-gallated catechins ((−)-epigallocatechin (EGC), (−)-gallocatechin (GC) and (−)-epicatechin (EC)) and gallic

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Table 1
Effect of tannase hydrolysis time on the taste attributes of green tea infusion.

Hydrolysis time (min)	Taste intensity			Overall acceptability
	Bitterness	Astringency	Sweet aftertaste	
0	4.5 ± 0.2[a]	4.7 ± 0.1[a]	1.3 ± 0.4[f]	4.5 ± 0.1[f]
15	4.1 ± 0.1[b]	4.3 ± 0.1[b]	2.0 ± 0.4[ef]	5.3 ± 0.2[e]
30	3.6 ± 0.2[c]	3.5 ± 0.2[c]	2.7 ± 0.3[e]	5.8 ± 0.2[d]
45	3.1 ± 0.1[d]	2.9 ± 0.2[d]	3.3 ± 0.2[d]	6.1 ± 0.2[c]
60	2.5 ± 0.2[e]	2.3 ± 0.2[e]	4.1 ± 0.2[c]	6.5 ± 0.2[b]
90	2.0 ± 0.2[f]	1.8 ± 0.2[f]	4.7 ± 0.2[b]	6.9 ± 0.1[a]
120	1.7 ± 0.2[f]	1.5 ± 0.3[f]	4.9 ± 0.2[ab]	7.1 ± 0.2[a]
150	1.8 ± 0.1[f]	1.4 ± 0.2[g]	5.0 ± 0.1[a]	7.2 ± 0.2[a]

Data are means (±SD) of three replicates.
[a,b,c,d,e,f,g]Different letters in the same column indicate significant differences between mean values ($p < 0.05$).

acid (GA) (Lekha & Lonsane, 1997; Huang, Cai, Ni, Xiao, & Cai, 2014), to lower the tea cream, and to improve color appearance. Additionally, tannase is used in the processing of the green tea beverage, green tea concentrate, and instant green tea powder to improve the taste quality of these products (Chávez-González et al., 2012; Zhang, Zhang, & Chen, 2013). Compared to the control, tannase-treated green tea infusion presented better mouthfeel (Lu, Chu, Yan, & Chen, 2009). However, the effect of tannase on the sweet aftertaste of green tea infusion is still unclear. This study aims to clarify the role of catechins, whose quantity can be adjusted through tannase, in the sweet aftertaste of green tea infusion. The results may be useful to improve the taste quality of green tea.

2. Materials and methods

2.1. Chemicals

Tannase (500 U/g) was purchased from Beijing Winovazyme Biological Science & Technology Co., Ltd. (Beijing, China). Caffeine, EGC, EC, ECG, EGCG, and theanine were provided by Taiyo Green Power Co., Ltd. (Wuxi, China). Dried NaOH was bought from Shanghai Suke Chemical Co., Ltd. (Shanghai, China). Green tea was obtained from the Tea Research Institute of the Chinese Academy of Agricultural Sciences. The pure water from Hangzhou Wahaha Group Co., Ltd. (Hangzhou, China) was used for all the experiments. The pH of the water was 6.79 ± 0.03, and its electroconductibility was 1.83 ± 0.12 μS/cm.

2.2. Preparation of green tea infusion

The green tea (20–60 mesh) was steeped in pure water with a leaf/water ratio of 1:30 (w/w) at 80 °C for 15 min. The extract was filtered out through a 600 mesh screen, and then the infusion was quickly cooled down to 45 °C in a cooling tank. The cooled infusion was then treated with tannase (1:5000, w/v) at 45 °C for different times (0, 15, 30, 45, 60, 90, 120, and 150 min). The resulting solution was heated to 90 °C within 5 min to inactivate the enzymatic reaction. The pH of the hydrolyzed tea infusion was adjusted back to 6.0 ± 0.1 by adding aqueous NaOH (1.0 mol/L). Then, the samples were immediately used for sensory evaluation and analysis of chemical constituents. For sensory evaluation, the tea infusion was diluted in a 1:1 (infusion/water) ratio (v/v) with pure water.

2.3. Analysis of catechins and GA

Catechins and GA were analyzed by high performance liquid chromatography (HPLC) (Xu et al., 2015). The tea infusion was filtered through a 0.2 μm Millipore filter before injection (Model Shimadzu LC-2010A, Shimadzu Corporation, Kyoto, Japan). The HPLC separation was performed on a Diamonsil®C_{18} column (5 μm, 4.6 mm × 250 mm) at 40 °C. The elution was performed using two phases with different ratios of acetonitrile/acetic acid/water: phase A, with a 6:1:193 ratio, and phase B, with a 60:1:139 ration. The elution was run for 45 min in a linear gradient from 100% phase A to 100% phase B, after which it was run for 15 more minutes using 100% phase B. The flow rate of the mobile phase was 1 mL/min, and the eluate was detected by a Shimadzu SPD ultraviolet detector (Shimadzu Corporation, Kyoto, Japan) at 280 nm.

2.4. Sensory evaluation of green tea infusion

The solutions and the hydrolyzed infusions were scored by a trained team of nine panelists (6 men and 3 women, 23–48 years old) from the Tea Research Institute of the Chinese Academy of Agricultural Sciences at room temperature. Scores for different taste attributes, including bitterness, astringency, sweet aftertaste, and overall acceptability, were given by each member of the team. The regular nine-point scale (Ibanoglu, Ainsworth, Ozer, & Plunkett, 2006) was modified for scoring, i.e. 8–10 'extremely strong', 6–8 'strong', 4–6 'neutral', 2–4 'weak', and 0–2 'very weak'. For the sensory evaluation, a 50 mL sample solution was served in a transparent glass cup. The different types of tastes were evaluated as follows. First, the intensity of bitterness was recorded by tasting a sample solution that was kept and swirled in the panelists' mouth for 7–8 s, then the solution was spit out, and the intensity of astringency was recorded within 3–4 s. After recording the astringency, the oral cavity was washed with pure water and the intensity of the sweet aftertaste was recorded in 4–5 s. And the overall acceptability was evaluated base on the above tastes. There was a 5 min interval between samples. The results were analyzed statistically to determine significant differences between the mean scores of the different samples (Kallithraka, Bakker, & Clifford, 1997). Each evaluation was repeated three times on differ-

Table 2
Effect of tannase hydrolysis time on the concentrations of the catechins and gallic acid (mmol/L) in green tea infusion.

Hydrolysis time (min)	EGCG	ECG	EGC	EC	Gallic acid
0	3.21 ± 0.13[a]	1.81 ± 0.05[a]	2.12 ± 0.04[h]	1.71 ± 0.02[g]	0.39 ± 0.05[g]
15	2.93 ± 0.07[b]	1.57 ± 0.04[b]	2.38 ± 0.05[g]	1.94 ± 0.04[f]	0.88 ± 0.03[f]
30	2.61 ± 0.05[c]	1.21 ± 0.04[c]	2.69 ± 0.05[f]	2.29 ± 0.04[e]	1.54 ± 0.06[e]
45	2.28 ± 0.04[d]	1.01 ± 0.02[d]	3.02 ± 0.09[e]	2.53 ± 0.05[d]	2.11 ± 0.08[d]
60	1.86 ± 0.05[e]	0.76 ± 0.07[e]	3.42 ± 0.07[d]	2.77 ± 0.05[c]	2.75 ± 0.05[c]
90	0.75 ± 0.05[f]	0.29 ± 0.04[f]	4.59 ± 0.05[c]	3.26 ± 0.07[b]	4.41 ± 0.11[b]
120	0.20 ± 0.05[g]	0.08 ± 0.02[g]	5.10 ± 0.04[b]	3.45 ± 0.05[a]	5.11 ± 0.14[a]
150	0.04 ± 0.01[h]	0.04 ± 0.01[h]	5.29 ± 0.05[a]	3.49 ± 0.03[a]	5.34 ± 0.12[a]

EGCG: (−)-epigallocatechin gallate; ECG: (−)-epicatechin gallate; EGC: (−)-epigallocatechin; EC: (−)-epicatechin.
Data are means (±SD) of three replicates.
[a,b,c,d,e,f,g,h]Different letters in the same column indicate significant differences between mean values ($p < 0.05$).

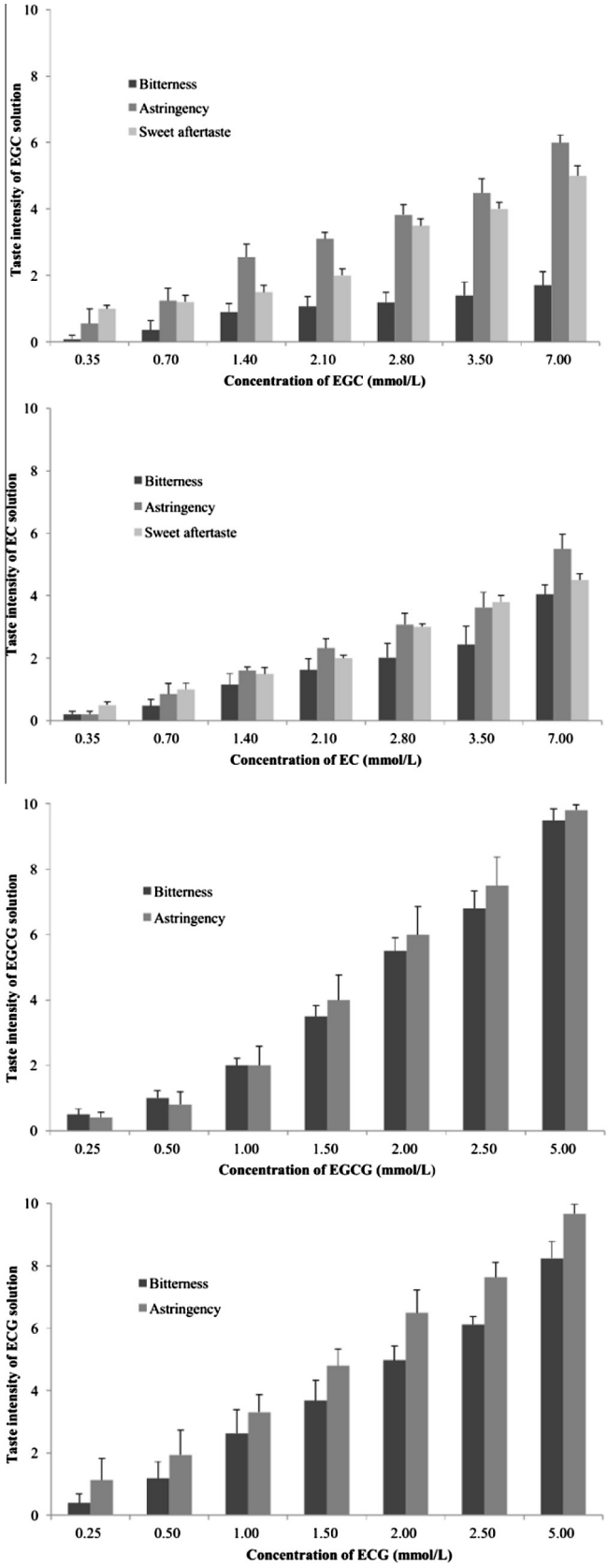

Fig. 1. Taste intensities of the monomer solutions of the catechins with different concentrations. EGCG: (−)-epigallocatechin gallate; ECG: (−)-epicatechin gallate; EGC: (−)-epigallocatechin; EC: (−)-epicatechin. Data are means (±SD) of three replicates.

ent days with the order of the samples being randomized in each test.

2.5. Taste analysis for catechin solutions with different concentrations

Sensory evaluation of the solutions of the monomeric EGCG, EGC, ECG, or EC with a series of concentrations was carried out using the method described above (Section 2.4) to obtain the taste attributes of different catechins. Mixed solutions of EGCG/EGC, ECG/EC, or EGC/EC with different ratios were studied to understand the effect of the ratio and the type of combination of gallated catechins/non-gallated catechins on the sweet aftertaste. A series of concentration (0, 0.5, 1.0 and 2.0 mmol/L) of EGCG, caffeine, and theanine were mixed with EGC or EC (1.0 mmol/L) to investigate the effect of EGCG, caffeine, and theanine on the sweet aftertaste of EGC or EC.

2.6. Statistical analysis

All results were recorded as mean ± standard deviation (3 replicates). The analysis of significant differences between the means was determined by one-way ANOVA using SPSS (version 17, SPSS Inc., Chicago, USA).

3. Results and discussion

3.1. Effect of tannase hydrolysis on the sweet aftertaste of green tea infusion

The taste of green tea infusion improved from the tannase treatment (Table 1). Before the hydrolysis with tannase, the green tea infusion tasted bitter and astringent with little sweet aftertaste. With growing times of hydrolysis, the intensities of bitterness and astringency of the green tea infusions significantly decreased, while the intensity of sweet aftertaste and the score of overall acceptability significantly increased (Table 1). In a previous study, the mouthfeel and overall acceptability of tannase-treated green tea infusion were improved (Lu et al., 2009), but the sweet aftertaste of the infusion was not investigated. In our study, we found that the intensity of the sweet aftertaste sharply increased during the first 60 min of hydrolysis (Table 1), an intensity score that was greater than the threshold value for sweet aftertaste (2.0) that was obtained by our panelists' analysis. Furthermore, the sweet aftertaste of the tea infusion was distinctive when the hydrolysis proceeded after 60 min, since the intensity of sweet aftertaste was more than 3.5 (Table 1). Therefore, we think that 60 min is the optimal time to obtain a tea infusion with excellent sweet aftertaste, since it is also important to retain as much EGCG in the tea infusions as possible, despite the sweet-aftertaste being more intense after 90, 120, and 150 min of hydrolysis. After all, EGCG is the most bioactive compound in tea infusions (Almajano, Carbo, Jiménez, & Gordon, 2008; Komes, Horžić, Belščak, Ganić, & Vulić, 2010), even though a tannase-treated tea infusion was found to have higher antioxidant and scavenging activity than an untreated one (Battestin et al., 2008; Huang et al., 2014).

Catechins in green tea (mainly EGCG, EGC, ECG, and EC) are responsible for astringency and bitterness (Narukawa et al., 2010), and the concentrations of EGCG and ECG in green tea infusion are much higher than EGC and EC. Consequently, the green tea infusion exhibits astringency and bitterness with little sweet aftertaste. Table 2 shows the catechins and GA concentrations in the green tea infusion hydrolyzed for different times. The ratio of EGCG/EGC (w/w) and ECG/EC (w/w) for 60 min of hydrolysis was about

Table 3
Effect of the ratio of EGCG/EGC, ECG/EC on the tastes of the solutions of mixed EGCG/EGC and mixed ECG/EC.

EGCG	EGC	Bitterness	Astringency	Sweet aftertaste	ECG	EC	Bitterness	Astringency	Sweet aftertaste
mmol/L					mmol/L				
3.5	0.0	8.4 ± 0.3^{a}	8.8 ± 0.2^{a}	0.0^{g}	3.5	0.0	7.0 ± 0.2^{a}	8.5 ± 0.2^{a}	0.0^{g}
3.0	0.5	7.9 ± 0.3^{b}	8.5 ± 0.2^{a}	0.4 ± 0.2^{f}	3.0	0.5	6.6 ± 0.3^{ab}	8.1 ± 0.2^{a}	0.5 ± 0.2^{f}
2.5	1.0	6.9 ± 0.2^{c}	7.8 ± 0.2^{b}	0.9 ± 0.1^{e}	2.5	1.0	6.1 ± 0.2^{b}	7.5 ± 0.2^{b}	0.8 ± 0.1^{f}
2.0	1.5	5.7 ± 0.3^{d}	6.6 ± 0.3^{c}	1.3 ± 0.2^{d}	2.0	1.5	5.3 ± 0.3^{c}	6.6 ± 0.3^{c}	1.2 ± 0.2^{e}
1.5	2.0	3.8 ± 0.2^{e}	5.2 ± 0.1^{d}	1.8 ± 0.2^{c}	1.5	2.0	4.1 ± 0.2^{d}	5.2 ± 0.2^{d}	1.8 ± 0.2^{d}
1.0	2.5	2.3 ± 0.2^{f}	4.9 ± 0.2^{de}	3.0 ± 0.2^{b}	1.0	2.5	3.4 ± 0.1^{e}	4.0 ± 0.2^{e}	2.6 ± 0.2^{c}
0.5	3.0	2.0 ± 0.3^{f}	4.6 ± 0.3^{ef}	3.7 ± 0.1^{a}	0.5	3.0	2.9 ± 0.2^{f}	3.8 ± 0.3^{ef}	3.1 ± 0.1^{b}
0.0	3.5	1.5 ± 0.2^{g}	4.3 ± 0.2^{f}	4.0 ± 0.2^{a}	0.0	3.5	2.5 ± 0.2^{f}	3.5 ± 0.2^{f}	3.5 ± 0.2^{a}

EGCG: (−)-epigallocatechin gallate; ECG: (−)-epicatechin gallate; EGC: (−)-epigallocatechin; EC: (−)-epicatechin.
Data are means (±SD) of three replicates.
^{a,b,c,d,e,f,g}Different letters in the same column indicate significant differences between mean values ($p < 0.05$).

Table 4
Tastes of the solutions of mixed EGC/EC with different ratios of EGC/EC.

EGC	EC	Bitterness	Astringency	Sweet aftertaste
mmol/L				
3.5	0.0	1.5 ± 0.2^{f}	4.4 ± 0.2^{a}	4.0 ± 0.2^{bc}
3.0	0.5	1.7 ± 0.1^{ef}	4.2 ± 0.1^{a}	4.3 ± 0.1^{ab}
2.5	1.0	1.9 ± 0.2^{de}	4.0 ± 0.2^{ab}	4.5 ± 0.1^{a}
2.0	1.5	2.1 ± 0.2^{cd}	3.9 ± 0.2^{bc}	4.2 ± 0.1^{bc}
1.5	2.0	2.2 ± 0.2^{bc}	3.7 ± 0.2^{cd}	4.0 ± 0.2^{bc}
1.0	2.5	2.4 ± 0.1^{a}	3.8 ± 0.2^{c}	3.9 ± 0.1^{cd}
0.5	3.0	2.4 ± 0.2^{ab}	3.6 ± 0.1^{d}	3.7 ± 0.1^{d}
0.0	3.5	2.6 ± 0.1^{a}	3.5 ± 0.1^{d}	3.8 ± 0.1^{d}

EGC: (−)-epigallocatechin; EC: (−)-epicatechin.
Data are means (±SD) of three replicates.
^{a,b,c,d,e,f}Different letters in the same column indicate significant differences between mean values ($p < 0.05$).

1:1.8 and 1:3.6, respectively. After the degalloylation of EGCG and ECG, the bitterness and astringency of green tea infusion decreased while the sweet aftertaste enhanced. The hydrolysis of EGCG and ECG yields EGC, EC, and GA and, since GA is a familiar phenolic compound (Yen, Duh, & Tsai, 2002) with a little sour and astringent taste, the enhancement of the sweet aftertaste should come from EGC and/or EC. This result indirectly explains why the oolong tea infusion is less bitter and astringent with a sweeter aftertaste than the green tea infusion (Yamanishi, 1990): oolong tea has more EGC and EC, and less EGCG and ECG than green tea. Statistical analysis show that there were positive and significant correlations between the concentrations of EGCG ($r = 0.96$) or ECG ($r = 0.99$) and the intensities of bitterness, and correlations between the concentrations of EGCG ($r = 0.95$) or ECG ($r = 0.99$) and the intensities of astringency. In contrast, the scores for sweet aftertaste were positively correlated with the concentrations of EGC ($r = 0.95$) and EC ($r = 0.99$). These results support that the degalloylation of EGCG, and ECG through tannase increase the intensity of sweet aftertaste of the green tea infusion. Finally, it should be mentioned that the scores for overall acceptability of the green tea infusions treated with tannase also increased (Table 1).

3.2. The sweet aftertaste of the non-gallated catechins EGC and EC

To further clarify the contribution of non-gallated catechins to the sweet aftertaste of green tea infusion, solutions of the EGCG, ECG, EGC, and EC were also subjected to tasting (Fig. 1). The solutions of EGC and EC tasted bitter, astringent, and had a sweet aftertaste, while the solutions of EGCG and ECG tasted only bitter and astringent. At the same concentration, the intensity of the sweet aftertaste and astringency of the EGC solution was a little higher than the EC one, while the intensity of bitterness of the EC solution was much higher than the EGC one. With the increase of the concentration, the intensities of bitterness, astringency, and sweet aftertaste of both EGC and EC solutions increased. There were significant correlations between the intensities of bitterness ($r = 0.89/0.99$), astringency ($r = 0.95/0.98$), or sweet aftertaste ($r = 0.94/0.94$), and the concentrations of the EGC and EC solutions (Fig. 1). Based on the above results, it is clear that the sweet aftertaste can come from both EGC and EC.

The sweet aftertaste of catechins in oolong tea (Yamanishi, 1990) and cocoa powder (Bonvehi & Coll, 1997) has been reported. The absence of such a report for green tea is not surprising, since the highly abundant gallated catechins (EGCG and ECG), which taste bitter and astringent, mask the sweet aftertaste of less-abundant non-gallated catechins (Narukawa et al., 2010). Gallated catechins hold more hydrogen bond donor groups and hydrogen bond acceptor groups than non-gallated catechins (Drewnowski, 2001), which can help explain the strong bitter and astringent taste of gallated catechins and the sweet aftertaste of non-gallated catechins.

When consumers tasted non-gallated catechins (Nayak & Carpenter, 2008), the bitterness was felt first, and the astringency followed, since the astringency arises from the loss of lubricity owing to the precipitation of salivary proteins (Rossetti, Bongaerts, Wantling, Stokes, & Williamson, 2009). The sweet aftertaste was the last feel, even though astringency may inhibit and delay the development of the sweet taste of simple catechins. However, the sweet aftertaste gives consumers a good feeling.

With the increase of the concentration, the intensities of bitterness and astringency for both EGCG and ECG solutions increased (Fig. 1). There were significant correlations between the intensities of bitterness ($r = 0.97/0.96$) or astringency ($r = 0.95/0.95$) and the concentrations of EGCG or ECG solutions. The intensities of bitterness and astringency for both EGCG and ECG solutions were much higher than for EGC and EC (Fig. 1). These results are consistent with those reported by Narukawa et al. (2010). According to the above results, increasing the concentrations of EGC and EC and decreasing the concentrations of EGCG and ECG can improve the sweet aftertaste of a mixture solution of EGCG, ECG, EGC, and EC, which is consistent with the taste result of the hydrolyzed green tea infusion.

3.3. Optimal ratio of gallated/non-gallated catechins for the sweet aftertaste

Since the taste of green tea infusion is possibly influenced by the ratio of gallated/non-gallated catechins, the effects of this ratio on taste were also investigated in catechin solutions. The experimental results showed that the intensities of bitterness and

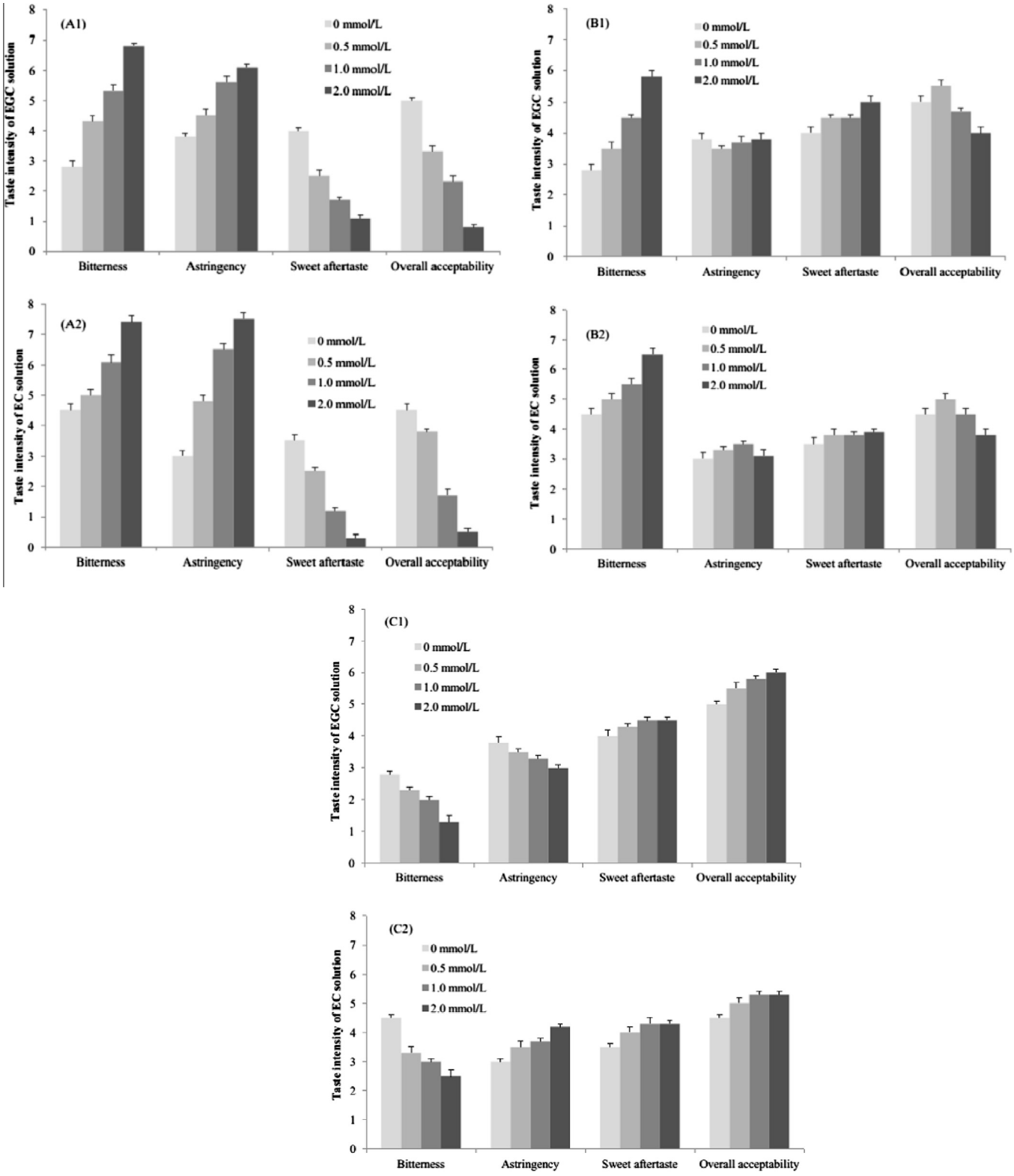

Fig. 2. Effect of EGCG (A), caffeine (B) and theanine (C) on the taste intensity of EGC and EC solutions. EGCG: (−)-epigallocatechin gallate; EGC: (−)-epigallocatechin; EC: (−)-epicatechin. Data are means (±SD) of three replicates.

astringency of the mixed solutions decreased as the ratio of gallated/non-gallated catechins decreased, and the sweet aftertaste intensity enhanced with the decrease of the ratio of EGCG/EGC and ECG/EC in the mixed solutions (Table 3). However, the optimal ratio and taste intensity of the mixed solutions of EGCG/EGC were different from those of the mixed solutions of ECG/EC. For example, an intensity value of sweet aftertaste of 3.0 corresponded to EGCG/EGC and ECG/EC ratios of 2:5 and 1:6, respec-

tively. After comprehensive consideration of the sweet aftertaste, we suggest these two ratios as suitable target ratios for a green tea infusion after hydrolyzation.

3.4. Optimal ratio of EGC/EC for the sweet aftertaste

The effect of the EGC/EC ratio on the taste was also investigated (Table 4). The intensity of sweet aftertaste was found significantly increased in the EGC/EC mixed solutions compared to the single solution, which may have resulted from a synergistic action. An EGC/EC ratio of 2.5:1 gave the most satisfying sweet aftertaste when the total concentration of EGC and EC was 3.5 mmol/L. This information can be used for selecting the green tea raw materials and the tannase treatment conditions necessary to produce a tea beverage with a high sweet aftertaste.

3.5. Effect of main chemicals on the sweet aftertaste of EGC and EC solutions

In a green tea infusion, the sweet aftertaste of EGC and EC can also be influenced by other tea chemicals. EGCG, caffeine, and theanine are known to be the key chemical compositions affecting the taste of green tea infusions (Nakagawa, 1975). Therefore, the effects of these main chemicals of green tea infusion on the taste of EGC and EC solutions were also investigated. EGCG, which is one of the major catechins, is astringent and bitter (Yin et al., 2014). The effect of EGCG on the taste of EGC and EC solutions is shown in Fig. 2A. With the increase of the additional concentration of EGCG, the intensities of bitterness and astringency of both EGC and EC solutions increased, while the intensity of the sweet aftertaste and the score of overall acceptability decreased (Fig. 2A), with these two effect probably being correlated. Astringency has been described as the dry, rough, and puckering-like sensation after tasting a tea infusion or a wine that contained polyphenols or catechins (Rossetti et al., 2009; Yin et al., 2014). EGCG, which has high salivary protein binding activity (Nayak & Carpenter, 2008), was found to be highly astringent (Rossetti et al., 2009), probably inhibiting the development of the sweet aftertaste.

Caffeine is the most important purine in tea and it was considered indispensable for the flavor of green tea (Khokhar & Magnusdottir, 2002). The addition of caffeine was found to rapidly increase the intensity of the bitterness of EGC and EC solutions (Fig. 2B), which agrees with the bitter taste of a solution of caffeine (Yin et al., 2014). However, the addition of caffeine did not significantly influence the intensities of astringency and sweet aftertaste for those two solutions, even though the intensity of the sweet aftertaste of the EGC solution increased slightly. Finally, the scores of overall acceptability of both EGC and EC solutions decreased due to the increased bitter taste.

Theanine, which is the most important amino acid in tea infusions, is responsible for the umami taste and significantly contributes to the flavor of green tea (Hayashi, Chen, Ikezaki, & Ujihara, 2008; Yu et al., 2014). A solution of theanine tastes a little sweet and umami (Yin et al., 2014). The addition of theanine was found to slightly decrease the intensities of bitterness and astringency of EGC and EC solutions, and slightly increase the scores of overall acceptability of both solutions, but not significantly increase the intensity of the sweet aftertaste (Fig. 2C).

4. Conclusion

EGC and EC contribute to the sweet aftertaste of green tea infusions. Suitable EGCG/EGC and ECG/EC ratios of 2:5 and 1:6, respectively, can yield excellent sweet aftertaste of green tea infusions, while keeping a reasonable amount of bioactive EGCG or ECG. An EGC/EC ratio of 2.5:1 gave the most satisfying sweet aftertaste, with a total concentration of EGC and EC of 3.5 mmol/L. Moreover, astringency significantly inhibited the development of a sweet aftertaste, while bitterness did not significantly influence the sweet aftertaste, with umami slightly improving the sweet aftertaste of EGC and EC solutions. Overall, this study suggests that the sweet aftertaste of green tea infusion can be improved by increasing non-gallated catechins through a tannase treatment.

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