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Effect of brewing time and temperature on antioxidant capacity and phenols of white tea: relationship with sensory properties

S. Pérez-Burillo[1], R. Giménez[1], J.A. Rufián-Henares[1,2*]& S. Pastoriza[1]

[2]*Departamento de Nutrición y Bromatología, Facultad de Farmacia,*

Universidad de Granada, Granada, Spain

[2]*Instituto de Investigación Biosanitaria ibs.GRANADA, Universidad de Granada, Spain*

[*] Corresponding author:

José A. Rufián-Henares, Dpto. Nutrición y Bromatología,

Facultad de Farmacia, Universidad de Granada

Campus de Cartuja, 18012, Granada, Spain.

Telephone: +34 958 24 07 49

Fax: +34 958 24 95 77

E-mail: jarufian@ugr.es

ABSTRACT

White tea is highly consumed due to its sensory properties and health benefits, although most scientific reports don't include the analysis of both properties. Therefore, the objective of the present study was to unravel the best brewing conditions for optimal extraction of the bioactive compounds and antioxidant capacity, while realising the best sensory properties. Infusions of eighty commercial teas (sold in bags or leaves) were obtained at different time-temperature ratios, studying bioactive compounds (caffeine and individual catechins), antioxidant capacity and sensory analysis. Brewing at 98ºC for 7 min was the best condition to obtain a high content of antioxidant polyphenols and pleasant sensory properties. Those teas sold in bags give rise to tea brews with almost double antioxidant capacity. In conclusion, it is very important to link sensory and chemical data to obtain optimal sensorial quality and the highest healthy properties in white tea infusions.

KEYWORDS: White tea, green tea, antioxidant capacity, brewing conditions, catechins.

1. Introduction

Green tea is one of the most consumed beverages around the world due to its sensory attributes and socio-cultural factors, especially in Asia (Hilal & Engelhardt, 2007). However, white tea (an unfermented tea made from the new growth buds and young leaves of the plant) is well recognized by its higher sensorial quality and health properties (Cabrera, Artacho & Giménez, 2006). Thus, tea has been related to beneficial effects on several diseases such as neurodegenerative and cardiovascular diseases, diabetes, obesity and basically, to every pathology involving oxidative stress (Higdon & Frei 2003). Such protection is most probably due to a wide range of bioactive compounds in tea beverage such as flavonoids, other polyphenols, caffeine or theanine (Vuong, 2014). Flavan-3-ols, commonly called catechins, can account for up to 30% of the dry weight of white and green tea leaves, being epigallocathin-gallate (EGCG) the major component (Cabrera et al., 2006). Consumption of 200-300 mg of EGCG (5-6 tea cups/day) has beneficial effects on cardiovascular health (da Silva Pinto, 2013) since EGCG and other catechins are very effective scavengers of radical oxygen species (ROS) and radical nitrogen species (RNS) both *in vitro* and *in vivo*.

The presence of these bioactive molecules depends on several factors. On one hand, the industrial process to obtain the commercial product from fresh leaves affects the amount of these compounds (Gorjanović et al., 2012). Thus, white and green teas suffer several drying steps, being less aggressive in white tea (Cabrera, Giménez & López, 2003; Pastoriza, Mesías, Cabrera & Rufián-Henares, 2017). On the contrary, black and red tea suffer an oxidation process where phenolics and other substances are oxidized (Vuong, 2014). On the other hand, preparing the beverage by infusion becomes another critical point since this process allows the extraction of bioactive compounds from tea (Damiani, Bacchetti, Padella, Tiano & Carloni, 2014). The extraction of catechins

depends on time and temperature, so monitoring these parameters while making the infusion is of great importance to get all the benefits from tea (Komes, Horžić, Belščak, Ganić & Vulić, 2010). This extraction process affects not only the antioxidant capacity of the tea beverage but also its organoleptic characteristics, since the extracted molecules also play a role in taste (Pastoriza, Pérez- Burillo & Rufián-Henares, 2017). Finally, the physical state of tea leaves also play a role on sensory properties. In this sense, Castiglioni, Damiani, Astolfi & Carloni (2015) found that milled leaves (usually sold in bags) have a more astringent taste than those obtained from whole leaves (those found in high-quality teas).

Different researchers have studied the extraction kinetics of catechins from white tea, based on water temperature and extraction time (Dai et al., 2017; Lin, Xia, Hsieh, Liu & Mau, 2017; Tan, Engelhardt, Lin, Kaiser & Maiwald, 2017) but they usually lack the study of sensory analysis. On the other hand, there are scientific reports that centered on the effect of water temperature and extraction time on sensory properties (Lin et al., 2014; Castiglioni et al., 2015; Lantano, Rinaldi, Cavazza, Barbanti & Corradini, 2015) or even antioxidant capacity, but lacked analysis of the extraction of bioactive compounds. Therefore, the aim of this research was to perform a deep study on the effect of the extraction time and temperature on the release of healthy molecules and antioxidant capacity of white tea (Chinese Pai Mu Tan) infusion, in relation to their sensory attributes. After deciding the best time-temperature binomial for optimal sensory properties, the antioxidant capacity and bioactive compounds content of white and green teas commercialized in Spain were then measured. In addition to these studies, the influence of commercial presentation of teas (whole leaves Vs. bagged teas) was also assessed.

2. Materials and methods

2.1. Reagents, standards and solvents

Trolox ((±)-6-Hydroxy-2,5,7,8-tetramethylchromane-2-carboxylic acid), 2,2′-Azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt, 2,4,6-Tri(2-pyridyl)-*s*-triazine (TPTZ), Folin-Ciocalteu reagent, iron (III) chloride hexahydrate, sodium acetate, potassium persulphate, sodium hydroxide, sodium carbonate, caffeine, gallic acid (GA), epicatechin (E), epicatechin gallate (EG), epigallocatechin (EGC) and epigallocatechin galate (EGCG) were from Sigma-Aldrich (Germany). All solvents were of HPLC quality (Sigma-Aldrich, Madrid, Spain). Doubly distilled deionized water was obtained from a Milli-Q system (Millipore, Milford, MA). Bronchales mineral water (Bronchales, Teruel, Spain) was used for tea infusion. It was a mineral water with very low mineral content: bicarbonates 8 mg/L, chloride 2.52 mg/L, sulphate 9.97 mg/L, silica 8 mg/L, calcium 2.71 mg/L, magnesium 2.75 mg/L, sodium 1.05 mg/L and potassium 1.21 mg/L.

2.2. Tea samples

White teas [n = 13 for white bagged teas (WTB); n = 21 for white tea leaves (WTL)] and green teas [n = 27 for green bagged teas (GTB); n = 19 for green tea leaves (GTL)] were purchased from 16 local tea shops (Granada, Spain). Tea infusions were prepared as follows: Two grams of tea leaves (or a tea bag) was put into 150 mL of water. Several infusions were made using in each occasion a different pair of time-temperature. Mineral water was heated at 60, 70, 80, 90 and 98ºC and the tea sample was left for 3, 5, 7, 10 and 15 min to obtain the corresponding infusion. The samples were then stored at -80ºC until they were analyzed. For comparative analysis of the white-green tea samples,

tea samples were prepared at 98ºC for 7 min. Each sample was prepared in triplicate and each one was analyzed three times.

2.3. Antioxidant assays

2.3.1. ABTS method

The ABTS assay was conducted as described by Roberta, Pellegrini, Proteggente, Pannala, Yang & Rice-Evans (2009) with slight modifications (Jiménez-Zamora, Delgado-Andrade & Rufián-Henares, 2016). The $ABTS^{+\cdot}$ was produced by reacting 7 mM ABTS stock solution with 2.45 mM potassium persulphate and allowing the mixture to stand in the dark at room temperature for 12-16 h before use. The $ABTS^{+\cdot}$ working solution (stable for 2 days) was diluted with a mixture of ethanol:water (50:50) to an absorbance of 0.70 ± 0.02 at 730 nm. After adding 20 µL of sample or trolox standard to 280 µL of diluted $ABTS^{+\cdot}$ solution, the absorbance reading was taken at 20 min. by using a Fluostar Omega microplate reader (BMG Labtech, Ortenberg, Germany). Aqueous solutions of Trolox were used for calibration (0.15-1.15 mM). The results are expressed as mmol equivalents of Trolox per L of infusion.

2.3.2. FRAP method

The ferric reducing ability of the extract of each sample was estimated following the procedure described by (Benzie & Strain, 1996) with some modifications. Briefly, 280 µL of FRAP reagent, freshly prepared and warmed at 37ºC, was mixed with 20 µL of sample. The FRAP reagent contained 2.5 ml of a 10 mM TPTZ solution in 40 mM HCl plus 2.5 mL of 20 mM $FeCl_3 \cdot H_20$ and 25 mL of 0.3 M acetate buffer, pH 3.6. The samples

were incubated at 37ºC and readings at the absorption maximum (595 nm) were taken at 30 minutes by using a Fluostar Omega microplate reader (BMG Labtech, Ortenberg, Germany). Trolox solutions were used to perform the calibration curve. The results are expressed as mmol equivalents of Trolox per L of infusion.

2.3.3. Folin-Ciocalteu method

The total phenolic content was measured following the procedure Folin-Ciocalteu with some modifications (Moreno-Montoro, Olalla-Herrera, Giménez-Martínez, Navarro-Alarcón & Rufián-Henares, 2015). Briefly, 15 μL of Folin-Ciocalteu reagent, 60 μL of sodium carbonate (10%), 190 μL of distilled water and 30 μL of sample were mixed. The samples were incubated at 37ºC and readings at the absorption maximum (595 nm) were taken at 60 minutes by using a Fluostar Omega microplate reader (BMG Labtech, Ortenberg, Germany). Gallic acid solutions were used to perform the calibration curve. Results are expressed as mg gallic acid equivalents per L of infusion.

2.4. Catechins and caffeine determination

The determination of catechins and caffeine in white tea was performed by using an UPLC (Accela 600 UPLC, Thermo-Fisher Scientific, Bremen, Germany) equipped with a diode array detector (DAD) and a reversed-phase column (Hypersil ODS C_{18}, 3 μm, 2.1 mm × 100 mm, Thermo Scientific, Bremen, Germany) according to Cabrera *et al.* (2003). Gradient mobile phase consisted on a solution of acetic acid (3 mL) in 100 mL water (v/v) (eluent A) and methanol (v/v) (eluent B). The gradient was as follows: 0–5 min, 20 % B; 5–7 min, linear gradient from 20 to 24 % B; 7–10 min, 24 % B; 10–20 min,

linear gradient from 24 to 40 % B; 20–25 min, linear gradient from 40 to 50 % B; 25–28 min linear gradient from 50 to 20 % B; 28–30 min 20 % B. Elution was performed at a solvent flow rate of 0.6 ml/min. Chromatograms were recorded at 280 nm. An external calibration line was used for quantification. Catechin and caffeine amounts in white tea infusions were calculated as mg/L.

2.5. Sensory evaluation

Sensory evaluation was carried out using both a consumer panel and a trained panel. Consumer panel was composed of 51 consumer panelists from Granada, who performed the Consumer Preference Test, which aimed to establish the best brewing conditions (time-temperature) for white teas. Consumers were recruited from green-white tea drinkers who were willing to taste white tea. The first test consisted of the analysis on the overall likeness for tea samples obtained after 5 min in water at 60, 70, 80, 90 and 98ºC. After selection of the preferred temperature (98ºC), the likeness for tea samples based on the infusion time (7, 10 and 15 min) was also evaluated. Every consumer evaluated 4 of the 8 samples each time and 5 min were given to evaluate each sample. Consumers cleansed their palates between evaluations by eating apple and rinsing their mouths with the mineral water used to prepare the tea infusions.

The trained panel was composed of 12 trained panelists who performed a Descriptive Sensory Analysis (taste and aroma). The panelists had completed 50 h of sensory training and had a minimum of 200 h of general sensory testing including olive oil, coffee, vegetables, and tea. All panelists were given a 4-h reorientation to white tea and the green tea lexicon previously developed by Lee & Chambers (2007). The panelists were familiar with tea drinks and were not allowed to use drinks, smoke or drink-eat

anything (except water) one hour before the session. Each member was offered one sample at a time, cleaning their palate between evaluations by rinsing it with mineral water and apple (Castiglioni et al., 2015). The panelists recorded orthonasal smell, retronasal aroma (brown, citrus, floral, fruity, green, seaweed, spinach) and taste (astringent, bitter, persistent and sweet). The intensities of sensory attributes were expressed on a 0-5 scale (0 = absent, 1 = barely, 2 = fairly, 3 = rather, 4 = highly, 5 = extremely).

2.6. Antioxidant capacity and polyphenols intake calculations

The dietary antioxidant capacity and polyphenols intake was calculated as the individual contribution of each juice, taking into consideration both the amount of food per serving and the daily consumption (Mercasa, 2017). Thus, the antioxidant capacity and polyphenols of each tea infusion was compared with the usual Spanish serving size (Salvador i Castells, 2000). The contribution to the daily intake of antioxidant capacity and polyphenols of each juice was referred to the results previously published by Saura-Calixto & Goñi (2006).

2.7. Statistical analysis

Statistical significance of the data obtained was tested by one-way analysis of the variance (ANOVA), followed by the Duncan test to compare the means that showed significant variation ($p < 0.05$). Evaluation of the relationship between different assays was carried out by computing the relevant correlation coefficient (Pearson linear correlation) at $p < 0.05$ confidence level. Multivariate analysis was performed by principal component analysis (PCA) with those means computed from aforementioned

analyses. All statistical analyses were performed using Statgraphics Plus software, version 5.1, 2001 (Statgraphics Technologies Inc., The Plains, VI, USA).

3. Results and discussion

3.1. Time-temperature relation with bioactive compounds extraction and antioxidant capacity.

3.1.1. Catechins and caffeine.

The influence of water temperature and infusion time on the extraction of catechins and caffeine was assessed with different time-temperature pairs as described in the materials and methods section. The content of gallic acid, epicatechin, epicatechin gallate, epigallocatechin, epigallocatechin gallate and caffeine were determined and depicted in **Table 1**. In general, increase in the infusion time amounted to extraction of more bioactive compounds, but temperatures from 60 to 80ºC did not exert any significant effect. At such temperatures, only 15 min produced a statistically significant ($p < 0.05$) higher concentration of gallic acid, epigallocatechin and caffeine. At temperatures higher than 80ºC, the content of gallic acid, epigallocatechin gallate and caffeine increased greatly (almost at an exponential increase) when infusion time was above 10 min (**Table 1**). On the contrary, epicatechin, epicatechin gallate and epigallocatehcin showed a lineal increase. Little changes were obtained after 3-5 min of extraction, while 7 min of infusion gave significant increases ($p < 0.05$) for all the assessed bioactive compounds, always higher at 98ºC.

The results reported by other researchers are in accordance with the results obtained in this study, both the amount of catechins and caffeine extracted and the effect of heating temperature and infusion time, being the main factors when extracting

bioactive compounds (Komes *et al*., 2010; Saklar, Ertas, Ozdemir & Karadeniz, 2015). Some of these researchers (Saklar *et al*., 2015; Lin *et al*., 2017) also reported that catechins extraction reaches a plateau after 10-15 min of extraction. On the contrary, Braud, Peyre, de Sousa, Armand, Rahmani & Maixent (2015) stated that catechins did not increase after 5 min of extraction, finding no significant differences among infusing for 5 or 15 min. (Damiani *et al*., 2014) compared cold extraction versus hot extraction, and found out that infusion at 20-25ºC for two hours increased total phenolic content and individual catechins. Moreover, the results obtained in this study show higher values for most of the individual catechins reported by these authors, except for EGC. Lantano *et al*. (2015) compared the extraction of bioactive compounds with three alternative extraction methods: 4ºC for 12 hours, 75ºC for 4 min and 80ºC for 5 min adding ice to the resulting infusion; these researchers also found out that temperature is the main factor to extract catechins, although extraction time also plays a role since cold extraction (4ºC) yielded high amounts of catechins. Finally, it has been also reported that cold and hot extractions yield different profiles of catechins; hot extraction releases higher amounts of larger molecules while decreasing smaller ones (Lin, Xia & Liu, 2014). This could be related to oxidation during the longer extraction times of catechins performed along cold extraction.

3.1.2. Antioxidant capacity.

The effect of time-temperature brewing conditions on the overall antioxidant capacity of white tea was also assessed. The ABTS method showed that the antiradical capacity of white tea gradually grew in a lineal manner with infusion time and water temperature (**Table 2**). Statistically significant changes ($p < 0.05$) were obtained from 7

min brewing with all the temperatures assessed except 60ºC. In the case of the reducing capacity of white tea brew (FRAP assay, Figure 2B) the kinetics obtained were still lineal. However, temperatures below 98ºC had very low reducing activity with significant increases only after 15 min. Such behavior was similar to that found for the main part of bioactive compounds studied (**Table 1**). The extraction of total phenolics (Folin-Ciocalteu assay, **Table 2**) was similar to that of the FRAP method and bioactive compounds. Therefore, a water temperature of 98ºC with brewing times from 7-15 min could increase the extraction of bioactive compounds and obtaining a good antiradical and reducing capacity on the tea brew.

Langley-Evans (2000) and Braud *et al.* (2015) studied the influence of time and temperature on the antioxidant capacity through the FRAP and DPPH methods, respectively. These authors found out that antioxidant capacity reached a maximum within 5-7 min of infusion compared to 15 and 30 min of extraction, while the maximum activity was obtained at temperatures of 90ºC (range 20-90ºC). The results stated by Komes *et al.* (2010) and Castiglioni *et al.* (2015) also show how total phenolics and antioxidant capacity increases significantly with water temperature, which is in agreement with the findings of this study. Other authors (Damiani *et al*., 2014; Lin *et al*., 2014) found a higher antioxidant capacity of total phenols in white teas extracted with the cold extraction method versus hot extraction. This could be related to the high brewing time (12-24 hours depending on the researcher).

3.2. Sensory analysis

Previous chemical assays showed that a brewing temperature of 98ºC could be the best to obtain a tea beverage with superior antioxidant capacity and a high content of

bioactive compounds (**Tables 1** and **2**). However, these temperatures don't preclude good organoleptic characteristics since white tea is usually brewed at 70ºC and green tea at 90ºC (Damiani *et al.*, 2014; Castiglioni *et al*., 2015). Thus, a consumer preference test was performed to establish the optimal conditions to obtain a pleasant white tea infusion while maintaining a high content of catechins. As depicted in **Figure 1A**, the percentage of panelists that liked tea brews increased along with extraction temperature. Brewing at 70ºC (the recommended temperature for white tea) only reached 13% of likes, similar to that obtained for 80ºC (14%). An increase in preference was obtained with the recommended temperature for green tea (27% at 90ºC) but brewing in boiled water (98ºC) was preferred by 43% of consumers.

Since 98ºC was the preferred temperature for white tea and it was the temperature at which the maximum concentration of catechins and caffeine was extracted, 98ºC was selected to unravel the best extraction time (from 7 to 15 min) through the consumer and trained panelists. As depicted in **Figure 1B**, half of the consumer panelists preferred a tea infusion brewed for 7 min whereas only 24% and 25% of the panelists preferred those brewed for longer times (10 and 15 min, respectively). Consumers declared (data not shown) that such teas were quite astringent and "strong", which could be related to the large amount of individual (**Table 1**) and total polyphenols (**Table 2**) extracted at 98ºC.

As regards the Descriptive Sensory Analysis, the trained panel found a lower bitterness and astringency for the sample brewed for 7 min (**Figure 1C**). In the same way, sweetness and persistency was similar to the sample brewed for 10 min. Regarding orthonasal smell, teas brewed for 7 and 10 min obtained a "rather" mark (**Figure 1C**). In the case of the retronasal aroma seven descriptors were used: brown, citrus, floral, fruity, green, seaweed and spinach. These descriptors were selected from the lexicon of flavor descriptive analysis of green tea (Lee & Chambers, 2007) since white tea is a variety of

green tea with better sensory properties (Cabrera, Artacho & Giménez, 2006). As depicted in **Figure 1D**, white tea brewed for 7 min was described mainly by "floral", "fruity" and "green" attributes, which ranked with a similar score to green teas from Japan (Lee & Chambers, 2010) and Korea (Lee, Chamber & Chambers IV, 2013). On the contrary, the tea sample obtained after 15 min of brewing was described by "brown", "seaweed" and "spinach" attributes, which ranked similar to those green tea samples from China (Lee & Chambers, 2010). Higher "seaweed" ranking of those teas obtained after longer brewing times could be a negative descriptor for Spanish panelists due to the low intake of seaweed in Spain, compared to countries like Japan or Korea. Therefore, the best brewing time-temperature was 98ºC for 7 min, which was selected for the profiling of Spanish white and green teas.

3.3. Relationship between sensory properties and chemical composition of white tea

The correlation between the composition of tea and its sensory profile is an issue due to the myriad of chemical species that play a role on taste and aroma. For example, there is a link between the sensory quality of Oolong tea and its different volatile compounds (Lee *et al*., 2013; Ziu, Chen, Wang, Niu & Xiao, 2017); many of which are detected in green tea during sensory analysis. However, only few research were focused on the relationship between taste active chemical species and probed bioactivity (like catechins or caffeine) or healthy properties (i.e. antioxidant capacity) with sensory attributes. This is the reason why the authors decided to study the linear relationship among all the assessed chemical variables obtained during optimization of infusion time of white tea brewed at 98ºC with the taste and smell attributes described by descriptive sensory analysis (**Figure 1C**). Statistically significant linear correlations ($p < 0.05$)

ranging from 0.6020 to 0.8998 were obtained between total polyphenols, antioxidant capacity and catechins-caffeine content with taste attributes like bitterness or astringency (**Table S1**), when compared in pairs. These are logical results since polyphenols are the main antioxidant compounds found in tea. In addition, it is important to bear in mind that tea catechins and caffeine play a role on tea astringency and bitterness (Tokuşoğlu, Ünal & Balaban, 2008) so that the correlation of these bioactive compounds with such sensory attributes with increasing infusion time could be expected. To deepen the contribution of each type of chemical, the correlations were grouped depending on the chemical nature-bioactivity of the compounds: polyphenols versus caffeine versus antioxidant capacity. It was observed that linear correlations of bitterness ranged from 0.6020-0.6976 for individual polyphenols. Such range is similar to that found for antioxidant capacity and total polyphenols (**Table S1**). This could be explained by taking into account that tea polyphenols are the main players of tea antioxidant capacity. However, a higher linear correlation between bitterness and caffeine was found (0.8875), which could be related with the stronger bitter sensation of caffeine compared to the milder one of tea polyphenols (Eschenauer & Sweet, 2006). On the contrary, correlations between astringency and polyphenols (individual or total) as well as antioxidant capacity was higher with phenolic compounds (ranging from 0.8614 to 0.8998) than in caffeine (0.6489). It is widely recognized that polyphenols have a strong astringent sensation (Soares, Brandao, Mateus & de Freitas, 2017) that plays a role on food acceptance by consumers.

On the other hand, no statistical correlation was obtained for smell attributes and persistency or sweetness. In the case of smell, this could be explained by taking into account that smell is related to volatile compounds (Ziu *et al*., 2017) and those measured in this study (catechins and caffeine) are not volatile. In addition, although the reason for

the lack of correlation with persistency or sweetness is not fully understood, it can be assumed that this finding is related to lower differences of these sensory attributes, so that they cannot correlate with the concentrations of catechins and caffeine measured along the chemical analyses performed.

Other authors (Lee & Chambers, 2010) claimed that the correlation in pairs of sensory properties with chemical components of teas is difficult if such compounds are not volatile. However, three years later, the same authors used PCA to describe the evolution of sensory profile of green tea (both aroma and taste descriptors) through five consecutive brewing steps, including data of volatile compounds obtained by GC-MS (Lee *et al*., 2013). Consequently, in order to solvent the lack of correlation of chemical compounds with sensory profile when compared by pairs during optimization of brewing time, the researchers decided to perform a PCA analysis including sensory attributes as well as chemical species. Such principal component analyses allowed for obtaining a small number of linear combinations of the 16 parameters assessed that explained as much as possible, data variability: The first component explained a 63.3% of sample variability while the second explained an additional 24.7% (total variability correlated was 88%). As depicted in the PCA biplot (**Figure 2**), the general trend of white tea with increasing infusion time was to intensify aroma, taste and bioactive compounds content. Although 7 min was selected as the optimum infusion time at 98**°**C, larger infusion times may be enjoyed by consumers who prefer stronger flavor, astringency and bitterness.

3.4. Antioxidant capacity differences between commercial white and green teas

The usual brewing temperature to obtain green tea infusions is 90-98ºC (boiling water) while that for white tea is around 70ºC (Cabrera *et al*., 2003; Damiani *et al*., 2014;

Castiglioni *et al*., 2015). Such infusion temperature plays a role both in the organoleptic properties of the tea brew as well as in the amount of bioactive compounds extracted. However, as discussed in the previous section, both the consumer and the analytically trained panelists preferred the white tea infusion obtained after brewing at 98ºC for 7 min. Therefore, these extraction conditions were used to test the differences in the antioxidant capacity and total phenols of commercial white (n = 34) and green teas (n = 46) sold in Spain (**Table 3**). The effect of tea form (loose leaves Vs. bagged teas) was also evaluated. A statistically higher antioxidant capacity ($p < 0.05$) was found in green teas compared to white teas, whichever the physical form of tea and antioxidant method. These results are in line with those reported by other authors (Unachukwu, Ahmed, Kavalier, Lyles & Kennelly 2010; Carloni *et al*., 2013) who described a slightly higher antioxidant capacity of green tea compared with white tea. The same differences were observed for total phenols, which could be attributed to a higher content of catechins in green tea leaves compared to those of white teas, related with the maturity state (Zhang, Li, Ma & Tu, 2011; Zhao, Chen, Lin, Harnly, Yu & Li, 2011). As expected, bagged teas showed a higher antioxidant capacity that loose leaves teas, both for white and green teas (**Table 3**). The phenomenon has been explained by other authors (Komes *et al*., 2010; Sharpe, Hua, Schuckers & Andrescu, 2016) taking into account that loose leaves are usually hand-rolled into tiny pellets, so the extraction time is most likely insufficient to extract a higher antioxidant content. On the contrary, bagged teas have lower quality but they are ground in fine particles so the extraction efficiency of bioactive compounds is higher than in loose leaves teas.

Every food consumed has an impact on the overall antioxidant capacity, with the corresponding effect on human health. Thus, the contribution of white and green tea consumption on the daily intake of antioxidant compounds and polyphenols was

calculated. The mean antioxidant capacity intake in Spain range from 6014 to 3549 μmol Trolox equivalents/day for the FRAP and ABTS methods, respectively (Saura- Calixto & Goñi, 2006). The consumption of tea in Spain in 2016 was 36.6 g/inhabitant/year, corresponding to 0.10 g/inhabitant/day (Mercasa, 2017). Thus, an intake of 7-89 μmol Trolox equivalents/day could be expected (**Table 4**), which means a contribution of 0.9-2.5% of the daily antioxidant activity intake for the ABTS method and 0.1-0.3% for the FRAP method. Although such contribution is calculated taking into account the mean intake in Spain, a realistic approach could be the calculation based on the intake of antioxidant capacity per serving (150 mL). For the ABTS method, the contribution increased up to 16-46% of the daily intake and 2-5% for the FRAP method (**Table 4**). Thus, one serving provides a high amount of antioxidant capacity as far as 1620 μmol Trolox equivalents. The differences found depending on the type of tea and physical presentation should be highlighted. Therefore, green tea provides the highest antioxidant capacity, although a serving of white tea also contains up to 780 μmol Trolox equivalents (with probably superior sensory properties). Another point to take into account is that bagged teas contributed almost doubled the value of loose leaves to the daily intake of antioxidant capacity.

In the case of polyphenols, the daily intake of polyphenols in Spain (Saura-Calixto & Goñi, 2006) is 1171 mg gallic acid equivalents. Thus, tea intake contributes only to 0.6-0.8% of the daily polyphenols intake. However, when a serving (150 mL) is used for calculations, the contribution of teas to the daily intake of polyphenols reaches 11-14%, since each serving provides around 150 mg of polyphenols. In this case, no large differences were observed between white-green teas of bagged-loose leaves teas.

4. Conclusions

After chemical and sensory analysis, optimal infusion conditions for white tea were set at a water temperature of 98ºC and a brewing time of 7 min. Under such conditions, a large amount of bioactive compounds and antioxidant capacity can be extracted into the tea brew while obtaining a pleasant mildly bitter-astringent brew with flowers and citrus notes. In addition, although Spanish commercial green teas have a higher antioxidant capacity, the daily contribution of a white tea cup should not be underestimated since the amount of polyphenols provided to the Spanish diet is noteworthy. Therefore, this research stresses the importance of linking sensory and chemical data to obtain the best sensorial quality and the optimal healthy properties in white tea infusions.

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Conflict of interest

The authors declare that there are no conflicts of interest.

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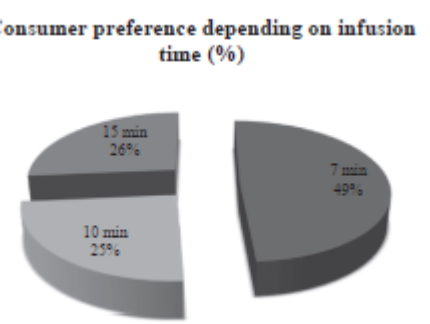
Figure captions

Figure 1. Effect of brewing temperature and infusion time on consumer preference of white tea and sensory properties of white tea brewed at 98ºC. 1A: Consumer preference (% panellists) depending on brewing temperature (60, 70, 80, 90 and 98ºC). 1B: Consumer preference (% panellists) depending on brewing time (7, 10 and 15 min) at 98ºC. 1C: Descriptive Sensorial Analysis of smell and taste; 1D: Descriptive Sensorial Analysis of aroma attributes; Brewing time (7, 10 and 15 min) selected for improved antioxidant capacity and total phenols.

Figure 2. Principal component analysis of sensory properties and chemical composition of white teas depending on brewing time at 98ºC.

Figure 1.

1A



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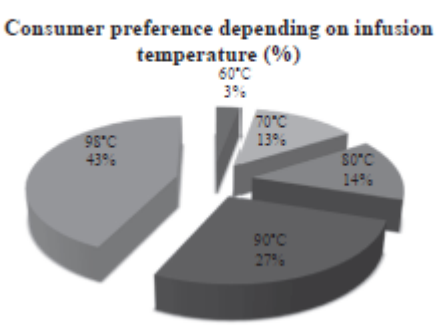

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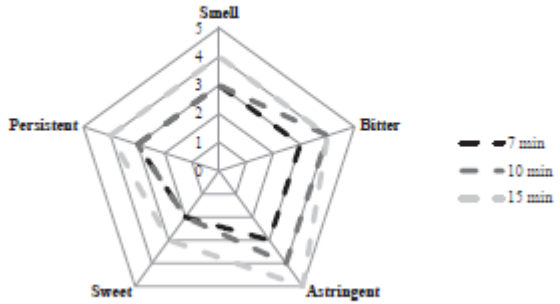

1D

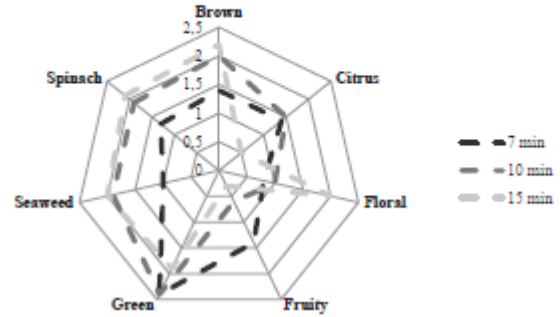

Figure 2.

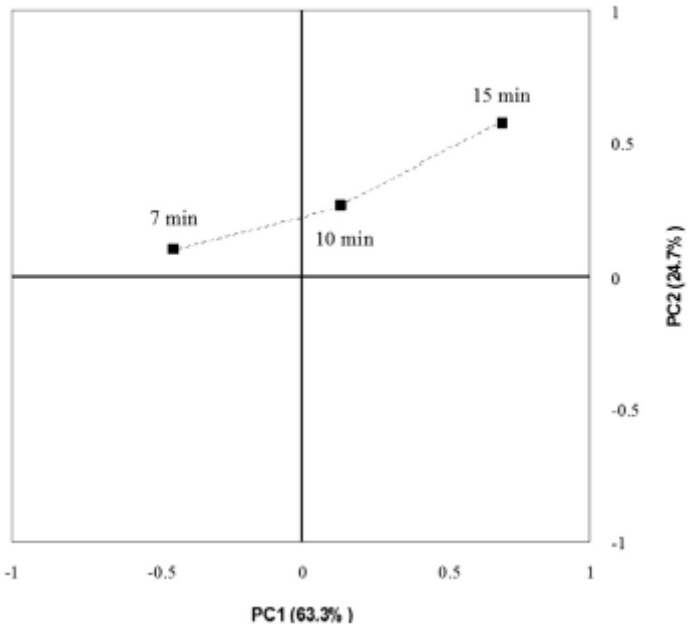

Table 1. Evolution of catechins and caffeine of white tea infusions with heating time and brewing temperature.

Bioactive compound	**Temperature** (°C)	**Infusion time** (minutes)				
		3	5	7	10	15
Gallic acid	60	12.1 ± 1.2 ^{a,1}	12.4 ± 1.0 ^{a,1}	19.2 ± 1.0 ^{a,2}	22.2 ± 2.1 ^{a,2}	26.8 ± 2.0 ^{a,3}
	70	12.8 ± 1.0 ^{a,1}	20.2 ± 2.0 ^{b,2}	21.7 ± 2.0 ^{a,2}	26.1 ± 2.0 ^{a,3}	28.3 ± 2.0 ^{a,3}
	80	13.2 ± 0.9 ^{a,1}	23.1 ± 2.0 ^{b,2}	31.3 ± 2.5 ^{b,3}	39.5 ± 3.1 ^{b,4}	42.6 ± 3.6 ^{b,4}
	90	13.7 ± 0.8 ^{a,1}	34.2 ± 2.6 ^{c,2}	42.2 ± 3.2 ^{c,3}	82.7 ± 5.7 ^{c,4}	126 ± 10 ^{c,5}
	98	25.1 ± 1.5 ^{b,1}	43.6 ± 3.2 ^{d,2}	43.7 ± 4.0 ^{c,2}	105 ± 10 ^{d,3}	160 ± 10 ^{d,4}
Epicatechin	60	1.42 ± 0.21 ^{a,1}	1.56 ± 0.12 ^{a,1}	1.72 ± 0.11 ^{a,1}	1.79 ± 0.11 ^{a,1}	1.45 ± 0.12 ^{a,1}
	70	1.94 ± 0.65 ^{a,1}	2.74 ± 0.11 ^{a,1}	2.88 ± 0.12 ^{a,1}	2.67 ± 0.12 ^{a,1}	2.19 ± 0.32 ^{a,1}
	80	2.04 ± 0.45 ^{a,1}	2.81 ± 0.32 ^{a,1}	3.72 ± 0.45 ^{a,1}	3.30 ± 0.23 ^{a,1}	3.61 ± 0.54 ^{a,1}
	90	3.36 ± 0.36 ^{a,1}	6.90 ± 0.99 ^{a,2}	8.04 ± 1.21 ^{a,2}	12.6 ± 1.2 ^{a,3}	20.8 ± 2.0 ^{a,4}
	98	7.46 ± 0.99 ^{a,1}	9.72 ± 0.87 ^{a,1}	22.9 ± 2.0 ^{a,2}	38.5 ± 3.0 ^{a,3}	62.9 ± 4.1 ^{a,4}
Epicatechin gallate	60	3.46 ± 0.45 ^{a,1}	3.55 ± 0.32 ^{a,1}	4.03 ± 0.56 ^{a,1}	4.52 ± 0.45 ^{a,1}	4.54 ± 0.54 ^{a,1}
	70	3.98 ± 0.62 ^{a,1}	4.43 ± 0.56 ^{a,1}	4.48 ± 0.42 ^{a,1}	4.63 ± 0.46 ^{a,1}	4.90 ± 0.56 ^{a,1}
	80	4.37 ± 0.33 ^{a,1}	4.24 ± 0.45 ^{a,1}	4.53 ± 0.23 ^{a,1}	4.73 ± 0.54 ^{a,1}	4.85 ± 0.45 ^{a,1}
	90	4.74 ± 0.01 ^{a,1}	16.4 ± 1.3 ^{b,2}	27.1 ± 2.6 ^{b,3}	48.6 ± 4.2 ^{b,4}	55.8 ± 5.0 ^{b,4}
	98	6.84 ± 0.09 ^{b,1}	18.3 ± 1.2 ^{b,2}	47.4 ± 4.0 ^{c,3}	64.6 ± 5.1 ^{c,4}	87.0 ± 7.1 ^{c,5}
Epigallocatechin	60	0.15 ± 0.10 ^{a,1}	0.32 ± 0.10 ^{a,1}	0.37 ± 0.10 ^{a,1}	0.68 ± 0.11 ^{a,2}	0.98 ± 0.22 ^{a,3}
	70	1.59 ± 0.50 ^{b,1}	1.65 ± 0.10 ^{b,1}	1.76 ± 0.11 ^{b,1}	2.04 ± 0.33 ^{b,1}	2.66 ± 0.11 ^{b,2}
	80	1.97 ± 0.40 ^{b,1}	2.41 ± 0.20 ^{c,1}	4.91 ± 0.55 ^{c,2}	7.94 ± 0.99 ^{c,3}	5.49 ± 0.45 ^{c,2}
	90	4.90 ± 0.56 ^{c,1}	5.44 ± 0.41 ^{d,1}	23.8 ± 3.6 ^{d,2}	53.9 ± 4.2 ^{d,3}	103 ± 10 ^{d,4}
	98	24.5 ± 2.4 ^{d,1}	29.5 ± 2.1 ^{e,1}	47.5 ± 4.0 ^{e,2}	100 ± 9 ^{e,3}	160 ± 11 ^{e,4}
Epigallocatechin gallate	60	5.05 ± 0.56 ^{a,1}	5.29 ± 0.56 ^{a,1}	5.31 ± 0.54 ^{a,1}	5.47 ± 0.41 ^{a,1}	6.33 ± 0.60 ^{a,1}
	70	5.55 ± 0.45 ^{a,1}	5.59 ± 0.45 ^{a,1}	5.64 ± 0.74 ^{a,1}	5.84 ± 0.32 ^{a,1}	8.02 ± 0.70 ^{a,2}
	80	7.31 ± 0.46 ^{b,1}	8.92 ± 0.88 ^{a,2}	14.4 ± 1.0 ^{a,3}	19.9 ± 2.03 ^{b,4}	52.0 ± 4.2 ^{b,5}
	90	9.73 ± 0.56 ^{c,1}	10.1 ± 1.2 ^{a,1}	22.4 ± 2.2 ^{a,2}	60.1 ± 7.03 ^{c,3}	107 ± 10 ^{c,4}
	98	13.3 ± 1.2 ^{d,1}	18.4 ± 1.5 ^{a,2}	52.4 ± 5.4 ^{a,3}	231 ± 31 ^{d,4}	298 ± 16 ^{d,5}
Caffeine	60	1.19 ± 0.11 ^{a,1}	1.46 ± 0.12 ^{a,1}	2.70 ± 0.25 ^{a,2}	2.91 ± 0.23 ^{a,2}	3.94 ± 0.30 ^{a,3}
	70	4.82 ± 0.56 ^{a,1}	5.74 ± 0.89 ^{a,1}	6.11 ± 0.56 ^{a,1}	10.2 ± 1.5 ^{b,2}	13.7 ± 0.11 ^{b,3}
	80	5.76 ± 0.23 ^{a,1}	7.58 ± 0.47 ^{a,2}	13.7 ± 1.2 ^{a,3}	16.0 ± 1.0 ^{c,3}	18.3 ± 1.2 ^{c,3}
	90	12.1 ± 0.8 ^{a,1}	16.4 ± 0.9 ^{a,2}	25.0 ± 2.9 ^{a,3}	51.3 ± 4.1 ^{d,4}	119 ± 7 ^{d,5}
	98	37.3 ± 2.6 ^{a,1}	41.2 ± 4.2 ^{a,1,2}	45.0 ± 3.1 ^{a,2}	58.5 ± 5.1 ^{d,3}	125 ± 8 ^{d,4}

Different letters indicate statistically significant differences $p < 0.05$ within the same column (and chemical compound).
Different superscript numbers indicate statistically significant differences $p < 0.05$ within the same line.

Table 2. Evolution of antioxidant capacity and total phenols of white tea infusions with heating time and brewing temperature.

Antioxidant capacity	**Temperature**	**Infusion time** (minutes)				
	(ºC)	3	5	7	10	15
TEAC$_{ABTS}$	60	0.90 ± 0.09 ^{a,1}	0.80 ± 0.10 ^{a,1}	1.67 ± 0.32 ^{a,2}	1.31 ± 0.20 ^{a,2}	3.60 ± 0.34 ^{a,3}
	70	1.17 ± 0.14 ^{b,1}	1.50 ± 0.21 ^{b,2}	1.82 ± 0.12 ^{a,2}	1.80 ± 0.60 ^{a,2}	5.03 ± 0.56 ^{b,3}
	80	1.44 ± 0.14 ^{b,c,1}	2.70 ± 0.12 ^{c,2}	2.54 ± 0.33 ^{b,2}	3.02 ± 0.16 ^{b,2}	6.13 ± 0.65 ^{b,3}
	90	1.48 ± 0.13 ^{b,c,1}	3.80 ± 0.22 ^{d,2}	5.09 ± 0.62 ^{c,3}	4.19 ± 0.23 ^{c,2,3}	9.22 ± 0.98 ^{c,4}
	98	1.50 ± 0.12 ^{c,1}	4.10 ± 0.44 ^{d,2}	7.23 ± 0.88 ^{d,3}	8.40 ± 0.99 ^{d,3}	12.3 ± 1.2 ^{d,4}
TEAC$_{FRAP}$	60	0.14 ± 0.01 ^{a,1}	0.38 ± 0.02 ^{a,2}	0.29 ± 0.11 ^{a,2}	0.47 ± 0.13 ^{a,2}	2.02 ± 0.23 ^{a,3}
	70	0.21 ± 0.10 ^{a,1}	0.50 ± 0.13 ^{b,2}	0.52 ± 0.06 ^{b,2}	0.51 ± 0.01 ^{a,2}	4.74 ± 0.45 ^{b,3}
	80	0.37 ± 0.06 ^{b,1}	0.65 ± 0.15 ^{b,2}	0.80 ± 0.15 ^{c,2}	0.73 ± 0.06 ^{b,2}	5.96 ± 0.55 ^{c,3}
	90	0.39 ± 0.07 ^{b,1}	0.71 ± 0.14 ^{b,2}	1.05 ± 0.09 ^{d,3}	1.08 ± 0.12 ^{c,3}	6.54 ± 0.32 ^{c,d,4}
	98	0.58 ± 0.04 ^{c,1}	1.18 ± 0.09 ^{c,2}	1.20 ± 0.12 ^{d,2}	1.38 ± 0.13 ^{d,2}	7.01 ± 0.45 ^{d,3}
Folin-Ciocalteu	60	6.01 ± 0.61 ^{a,1}	26.7 ± 1.2 ^{a,2}	37.7 ± 2.1 ^{a,3}	41.9 ± 4.1 ^{a,3}	156 ± 10 ^{a,4}
	70	6.10 ± 0.54 ^{a,1}	47.5 ± 4.1 ^{b,2}	55.1 ± 4.5 ^{b,2}	50.8 ± 2.4 ^{b,2}	264 ± 21 ^{b,3}
	80	28.7 ± 2.1 ^{b,1}	60.4 ± 5.2 ^{c,2}	93.9 ± 9.0 ^{c,3}	77.6 ± 8.5 ^{c,3}	429 ± 33 ^{c,4}
	90	28.8 ± 2.0 ^{b,1}	74.8 ± 6.5 ^{d,2}	89.0 ± 7.2 ^{c,2}	135 ± 12 ^{d3}	520 ± 51 ^{d,4}
	98	58.3 ± 4.1 ^{c,1}	132 ± 11 ^{e,2}	143 ± 11 ^{d,2}	168 ± 10 ^{e,3}	619 ± 56 ^{d,4}

Different letters indicate statistically significant differences $p < 0.05$ within the same column and antioxidant capacity method.
Different superscript numbers indicate statistically significant differences $p < 0.05$ within the same line.
$TEAC_{ABTS}$: Trolox Equivalent Antioxidant Capacity measured with the ABTS method.
$TEAC_{FRAP}$: Trolox Equivalent Antioxidant Capacity measured with the FRAP method (Ferric Reducing Capacity of Plasma).

Table 3. Antioxidant capacity and total phenols of commercial white and green teas.

Tea type	$TEAC_{ABTS}$ (mmol Trolox/L)	$TEAC_{FRAP}$ (mmol Trolox/L)	Total phenols (mg gallic acid/L)
WTL	3.7 ± 0.3^{a}	2.8 ± 0.1^{a}	885 ± 64^{a}
WTB	5.2 ± 0.3^{b}	5.4 ± 0.3^{b}	906 ± 77^{a}
GTL	6.0 ± 0.2^{c}	3.8 ± 0.2^{c}	1043 ± 5^{b}
GTB	10.8 ± 0.3^{d}	7.9 ± 0.2^{d}	1131 ± 96^{b}

Different letters indicate statistically significant differences $p < 0.05$.
WTL: White tea leaves; WTB: White tea bag; GTL: Green tea leaves; GTB: Green tea bag.
$TEAC_{ABTS}$: Trolox Equivalent Antioxidant Capacity measured with the ABTS method.
$TEAC_{FRAP}$: Trolox Equivalent Antioxidant Capacity measured with the FRAP method (Ferric Reducing Capacity of Plasma).

Table 4. Contribution of tea consumption to the daily antioxidant activity (AOX) and polyphenols intake in the Spanish diet.

Tea type	**Analytical assay**	**AOX/daily intake[1]** (μmol trolox/day)	**Contribution to daily antioxidant capacity intake** (%)	**AOX/serving intake[2]** (μmol trolox/serving)	**Contribution to daily antioxidant capacity intake** (%)
WTL	$TEAC_{ABTS}$	31	0.9	555	16
	$TEAC_{FRAP}$	7	0.1	135	2
WTB	$TEAC_{ABTS}$	43	1.2	780	22
	$TEAC_{FRAP}$	8	0.1	150	2
GTL	$TEAC_{ABTS}$	50	1.4	900	25
	$TEAC_{FRAP}$	12	0.2	225	4
GTB	$TEAC_{ABTS}$	89	2.5	1620	46
	$TEAC_{FRAP}$	17	0.3	300	5
Tea type	**Analytical assay**	**Polyphenols/daily intake[1]** (mg/day)	**Contribution to daily polyphenols intake** (%)	**Polyphenols/serving intake[2]** (mg/serving)	**Contribution to daily polyphenols intake** (%)
WTL	*Folin-Ciocalteu*	7	0.6	133	11
WTB	*Folin-Ciocalteu*	7	0.6	136	12
GTL	*Folin-Ciocalteu*	9	0.7	156	13
GTB	*Folin-Ciocalteu*	9	0.8	170	14

[1]Considering tea consumption for a whole year.

[2]Consideing the complete serving ingested a particular day.

WTL: White tea leaves; WTB: White tea bag; GTL: Green tea leaves; GTB: Green tea bag.

$TEAC_{ABTS}$: Trolox Equivalent Antioxidant Capacity measured with the ABTS method.

$TEAC_{FRAP}$: Trolox Equivalent Antioxidant Capacity measured with the FRAP method (Ferric Reducing Capacity of Plasma).