Article

Using endogenous pigments to recolour roasted green tea

Hongkai Zhu (朱宏凯)¹,², Jianqiang Zhang (张坚强)³, Fei Liu (刘飞)⁴, Lin Chen (陈琳)¹,² and Yang Ye (叶阳)¹,²,*

¹Tea Research Institute, China Academy of Agricultural Sciences, Hangzhou, China; ²Key Laboratory of Tea Biology and Resource Utilization, Ministry of Agriculture, Hangzhou, China; ³Tea and Fruit Instructional Station of Yixing City, Yixing, China and ⁴Tea Research Institute of Sichuan Academy of Agricultural Science, Chengdu, China

*Correspondence to: Yang Ye, Tea Research Institute, China Academy of Agricultural Sciences, Hangzhou 310008, China. E-mail: yeyang@tricaas.com

Received 14 November 2020; Revised 23 January 2021; Editorial decision 7 February 2021.

Abstract

Roasted green tea exhibits undesirable dark green that can seriously affect sensory quality, market price, and consumer acceptance. The aim of this work was to propose a method of improving the appearance of the roasted green tea. In this study, rehydration with freeze-drying (RFD) was used to recolour the tea leaves by redistributing the endogenous pigments. The results indicated that the colour of the roasted green tea changed from dark green to bright green after the RFD treatment, the values of $L^*$ and $b^*$ were significantly increased ($P<0.05$), and the value of $a^*$ was significantly decreased ($P<0.05$). In addition, the RFD treatment making the yellow–green pigments transfer onto the surface of the tea leaves also induced a change in pigment contents, including chlorophylls, carotenoids, and flavonoid glycosides. The well-defined optimum parameters for the rehydration process were moisture content of tea leaves at 35 per cent, water temperature 25 °C, and a standing time of 1.5 h.

Keywords: Green tea; colour; pigments; rehydration; freeze-drying.

Introduction

Green tea is one of the most popular beverages in Asian areas because of its various health benefits in humans (Wang et al., 2015; Zhang et al., 2016). The traditional preparation of green tea includes fixing, shaping (rolling or carding), and drying. The so-called fixing procedure uses high temperature to inactivate the polyphenol oxidases and peroxidases, preventing the oxidation of polyphenols (Wang et al., 2000), resulting in the tea leaves keeping their original green colour (Oštádalová et al., 2015). The shaping process is used to form different appearances of tea products that could regulate the release of natural substances when brewing tea in a pot. Sun drying, bake drying, and roast drying are three primary drying methods for the Chinese green tea (He et al., 2011), but manufacturers prefer roast drying due to the formation of a better flavour and aroma (Graham, 1992). Roast drying allows tea leaves to touch the heated iron pan directly, warming the tea leaves faster and staying at a high temperature. However, the excessive heating will lead to the green tea exhibiting a dark or black colour, which may be associated with the formation of Maillard-derived colour products (Rizzi, 1997) and the degradation of chlorophyll (Wang et al., 2004). Consumers find it difficult to accept green tea with a black colour, which could lead to a large economic loss to producers and sellers. Therefore, there is a strong requirement to propose an effective method for improving the colour of roasted green tea without affecting the sensory quality.

It is interesting that the colour of roasted green tea can be changed from dark or dark green to bright green when the tea leaves are wet. This inspired using a feasible drying method to preserve the bright green colour of wet leaves that would contribute to improving the colour quality of roasted green tea. It is known that the freeze-drying is one of the best methods to remove water from biological materials (Sagar and Suresh Kumar, 2010) because it neither induces
the deterioration of colour (Ratti, 2001) nor damages the volatile flavour compounds (Krokida and Philippopoulos, 2006). Therefore, a two-step method has been designed to improve the colour of roasted green tea in this present work, using pure water to recover the bright green colour of the roasted green tea by wetting tea leaves, and then applying the freeze-drying method removed water to lock the bright green colour.

In the present work, response surface methodology (RSM) with central composite design (CCD) was employed to optimize the parameters of rehydration. A colour metre was used to measure the colour properties of tea leaves, and the cross-sectional changes in colour were observed by using the micro-image method. High-performance liquid chromatography (HPLC) was used to analyse the changes in pigments, including chlorophylls, carotenoids, and flavonoid glycosides in the roasted green tea both before and after rehydration with freeze-drying (RFD) treatment. Finally, sensory analysis was employed to evaluate the effects of the RFD on the overall quality of the roasted green tea.

Materials and Methods

Chemicals and reagents
Quercetin-3-glucoside (Q3G, ≥95 per cent), vitexin-2′′-O-rhamnoside (V2O, ≥98 per cent), quercetin-3-O-rutinoside (Q3O, ≥95 per cent), quercetin-3-d-galactoside (Q3Ga, ≥97 per cent), kaempferol-3-O-β-rutinoside (K3O, ≥98 per cent), myricetin-3-O-β-d-galactopyranoside (M3G, ≥85 per cent) were purchased from Sigma-Aldrich (St. Louis, MO, USA). The standard chlorophylls and carotenoids including neoxanthin (Neo, ≥90 per cent), lutein (Lut, ≥90 percent), chlorophyll b (CHb, ≥95 per cent), chlorophyll a (CHA, ≥95 per cent), α-carotene (ocar, ≥95 per cent) and β-carotene (βcar, ≥97 per cent) were also bought from Sigma-Aldrich (St. Louis, MO, USA). The standard pheophytons a (PHA) and pheophytons b (PHb) were prepared using the reported method of Loh et al. (2012). Acetonitrile, methanol, acetic acid, chloroform, and acetone were HPLC grade and purchased from Fisher Scientific (Essex, UK). Ultrapure water prepared using a Super Purity Water System (Purite Ltd., Thame, UK) was used for all experiments.

Sample preparation and experimental design
Roasted green tea samples were Yingshuang variety with one bud with two leaves, and were bought from South Zhejiang Tea Market (Songyang, China). The RFD treatment process for roasted green tea is shown in Figure 1. First, pure water was sprayed on 50 g roasted green tea in this present work, using pure water to recover the bright green colour of the roasted green tea by wetting tea leaves, and then applying the freeze-drying method removed water to lock the bright green colour.

Roasted green tea water (X2), and the standing time (X3) were the three independent experimental variables, and full factorial experiments were conducted to the design and statistical analysis. The factors and their experimental variables, and full factorial experiments were conducted to the design and statistical analysis. The factors and their

polynomial model. The optimized parameters of the rehydration process were used to prepare the RFD samples that were used to compare the difference in colour, pigments, and sensory properties with untreated roasted green tea.

Colours properties analysis of tea appearance
Tea colour was measured using a colorimeter (CM-3500d, Minolta, Japan), and both black and white tiles were used to calibrate the colorimeter before measurement. A tea sample of 3 g was poured into a glass Petri dish and the measurements were performed in triplicate on three random positions in the Petri dish. The Hunter Lab colour scale was used to present the colour characters, wherein the maximum and minimum for \( L^* \) are 100 and 0, respectively. For the chromaticity parameters, \( L^* \) represents brightness, positive \( a^* \) represents red, negative \( a^* \) represents green; positive \( b^* \) is considered as yellow and negative \( b^* \) is considered as blue. Hue angle was calculated using the following method (Bhat et al., 2013):

\[
\text{Hue} = \tan^{-1} (b^*/a^*), \text{when } a^* > 0 \text{ and } b^* > 0; \]
\[
\text{Hue} = 180^\circ + \tan^{-1} (b^*/a^*), \text{when } a^* < 0 \text{ and } b^* > 0; \]
\[
\text{Hue} = 360^\circ + \tan^{-1} (b^*/a^*), \text{when } a^* > 0 \text{ and } b^* < 0 \]

Analysis of chlorophylls and carotenoids
Pigment extraction
The described method of Lee et al. (2013) was used to extract pigments. Ground green tea powder, 1.0 g, was extracted three times, using 5 mL pigment extraction solvent each time (aceton:petroleum ether, 4:1, \( \text{v/v} \)). After vortexing and centrifugation (3,000 rev/min), the supernatants were collected and combined, and then filtered using a 0.45-μm filter (Nylon Acrodisc 13, Gelman, Singapore).

HPLC analysis
Analysis of prepared samples was performed in a Waters 2695 system (Elnsree, UK) with a PDA detector. An RP C18 column (5 μ, 4.6x150 mm, Phenomenex, Cheshire, UK) was used for the separation of pigments. The mobile phase consisted of mobile phase A (acetonitrile:acetic acid:water, 3:0.5:96.5, \( \text{v/v/v} \)) and mobile phase B (acetonitrile:methanol:chloroform, 75:15:10, \( \text{v/v/v} \)). Gradient elution started at 20 per cent solvent A and 80 per cent solvent B, increased solvent B linearly to 100 per cent over 20 min and maintained solvent B content for 15 min. The column was kept at 25 °C, the flow rate was 1 mL/min, and the injection volume was 10 μL. UV spectra were recorded from 250 nm to 700 nm and peak areas measured at 450 nm.
Analysis of flavonoid glycosides
The content of flavonoid glycosides were measured using the described method of Wu et al. (2012) with a slight modification. A 2.0 g tea sample with 100 mL ultrapure water was refluxed at 100 °C for 2 h, the extracted solution was transferred into a volumetric flask and diluted to 100 mL. Before HPLC analysis, the final solution was filtered using a 0.45-μm filter (Nylon Acrodisc 13, Gelman, Singapore). A Waters 2695 HPLC system was used to analyse samples, equipped with a 2998 PDA detector and a C18 RP column (5 μm, 4.6×150 mm, Phenomenex, Cheshire, UK). The mobile phase consisted of mobile phase A (acetonitrile:acetic acid:water, 30:0.5:96.5, v:v:v) and mobile phase B (acetonitrile:acetic acid:water, 30:0.5:96.5, v:v:v). Gradient elution started at 95 per cent solvent A and 5 per cent solvent B, increased solvent B linearly to 15 per cent over 25 min. Then, solvent B was increased to 25 per cent over 18 min. Finally, solvent B increased to 85 per cent over 19 min. The column was kept at 25 °C, the flow rate was 1 mL/min, the injection volume was 20 μL, and peak areas were measured at 370 nm.

Sensory evaluation
The evaluation of sensory quality was conducted according to the AQSIQ and SAC (2009) method. The evaluation system adopted a 100-point scale, including five attributes (appearance, taste, aroma, infusion colour, and infused leaf), and the corresponding weighting factors were 0.2, 0.3, 0.3, 0.1, and 0.1, respectively. First, we observed colour, shape, cleanliness, and uniformity of tea samples to evaluate the appearance. Then 3 g green tea was brewed for 5 min using 150 mL boiling water, the tea infusion was used to evaluate the colour, aroma, and taste, and the infused tea leaves were used to evaluate the raw material grade of tea sample. All samples were blinded to assessment by three official tasters.

Statistical data analysis
Response surfaces design was performed in Design Expert trial version 11 (StatEase Inc., Minneapolis, MN, USA). Variance analysis and Pearson correlation analysis were employed by using IBM SPSS Statistics 23 software (IBM Co., Armonk, NY, USA).

### Results and Discussion

Optimization of rehydration process
The Hue angle has been widely used to evaluate the greenness of green tea (Wang et al., 2004); therefore, it was employed as the quality index of colour in the present work. The quadratic polynomial regression model was used to predict the Hue value of treated tea leaves, the Hue value (Y) was the function of X1, X2, and X3, and it was fitted as follows:

\[ Y = 95.24 + 1.02X_1 + 0.27X_2 + 0.43X_1X_2 - 0.29X_1X_3 + 0.08X_1X_3 + 0.18X_2X_3 - 1.1X_1^2 - 0.55X_2^2 - 0.40X_3^2 \]

The evaluation of variances of the model is shown in Table 2. It was found that the P-value of the regression model was statistically significant (P<0.05), but the P-value of the lack of fit of the model was not statistically significant (P>0.05). The results indicated that the regression model was valid. The experimental values and predicted values for the Hue values of treated green tea are shown in Figure 2. Plotted points are clustered around the diagonal line, and the determination coefficient (R²) reached 0.9027, indicating the regression model was a good fit. Moreover, the surface and contour plots show the effects of different variables on Hue angle (Figure 3). It was found that the Hue value increased with the increase of the three variables and then decreased, but the moisture content of tea leaves presented a much higher impact in comparison with the other two variables within the range of the test. The moisture content was suggested to be the major influencing factor on the Hue value during the rehydration process. According to the centres of the contour plots shown in the variables coordinates (Figure 3), the well-defined optimum parameters were moisture content of tea leaves at 35 per cent, water temperature at 25 °C, and a standing time of 1.5 h.

### Table 1. Independent variables and their coded values were used to the optimization of rehydration process

| Independent variable | Symbol | Coded levels |
|----------------------|--------|--------------|
|                      |        | -1.682       | -1           | 0            | +1           | +1.682       |
| Moisture content (%) | X₁     | 15           | 25           | 35           | 45           | 55           |
| Water temperature (°C) | X₂     | 5            | 15           | 25           | 35           | 45           |
| Standing time (h)    | X₃     | 0.5          | 1.0          | 1.5          | 2.0          | 2.5          |

### Table 2. Analysis of variance for the response surface model

| Source      | Sum of square | Degrees of freedom | Mean square | F-value | P-value |
|-------------|---------------|--------------------|-------------|---------|---------|
| Model       | 39.86         | 9                  | 4.43        | 10.31   | 0.0006  |
| X₁          | 14.29         | 1                  | 14.29       | 33.27   | 0.0002  |
| X₂          | 1.03          | 1                  | 1.03        | 2.39    | 0.1534  |
| X₃          | 2.47          | 1                  | 2.47        | 5.74    | 0.0376  |
| X₁X₂        | 0.6613        | 1                  | 0.6613      | 1.54    | 0.2431  |
| X₁X₃        | 0.0512        | 1                  | 0.0512      | 0.1192  | 0.7371  |
| X₂X₃        | 0.2592        | 1                  | 0.2592      | 0.6032  | 0.4553  |
| X₁²         | 17.33         | 1                  | 17.33       | 40.34   | 0.0001  |
| X₂²         | 4.34          | 1                  | 4.34        | 10.10   | 0.0099  |
| X₃²         | 2.35          | 1                  | 2.35        | 5.47    | 0.0415  |
| Residual    | 4.30          | 10                 | 0.4297      |         |         |
| Lack of fit | 1.61          | 5                  | 0.3222      | 0.5998  | 0.7058  |
| Pure error  | 2.69          | 5                  | 0.5372      |         |         |
| Total       | 44.16         | 19                 |             |         |         |
Colour analysis of tea leaves

Generally, attractive colours serve as an important reference for consumers selecting and purchasing food products. The degradation of colour will induce the misjudgement of flavours and aromas in food or beverages (Wan et al., 2014). For most green tea, a bright green colour was regarded as an excellent quality. In the present work, the parameters of colour for the typical roasted green tea (control group) and the RFD-treated samples (treatment group) are depicted in Table 3. It can be seen that there were significant differences \((P < 0.05)\) between the control group and treatment group in all colour parameters. The treatment group was characterized by lower \(a^*\) and higher \(L^*\), indicating the treatment group presented more brightness and greenness colour in tea leaves. The increased \(b^*\) value showed the colour of the treatment group heading towards development of yellow, which contributes to the formation of a fresh and tender colour. In addition, the higher \(Hue\) value in the treatment group further indicated the roasted green tea became more green after the RFD treatment.

As shown in Figure 4, normal photos and microphotos were used to exhibit the difference in colour for the appearance and the cross-section of tea leaves before and after the RFD treatment. The control group exhibited a dark appearance (Figure 4A) that is a typical colour of roasted green tea, while the treatment group presented bright green in the normal photo (Figure 4B). Seeing the photos of the cross-sections, it could be seen that the control group presented a uniform black olive colour in the cross-section of tea leaves (Figure 4A), whereas the treatment group presented an obvious layering in colour, yellow-green substances were enclosed on the surface of tea leaves, and the dark brown colour was agglomerated in the interior (Figure 4B). These results indicated that the endogenous pigments with yellow-green have been moved to the surface of tea leaves by the RFD treatment, leading to the appearance of tea leaves changing to bright green.

The content of pigments

As shown in Figure 5A, the content of Q3G, Q3O and M3G in the treatment group were significantly higher than the control group \((P < 0.05)\), whereas the content of V2O and K3O were significantly lower than the control group \((P < 0.05)\). The content of Q3Ga was not significantly different \((P > 0.05)\) between the control group and the treatment group. The content changes of flavonoid glycosides may be connected with the metabolic transformation, oxidative degradation, and hydrolytic action during the RFD treatment process. It is known that flavonoids are natural pigments that are widely distributed in plants (Merken and Beecher, 2000) and have been reported to participate in the formation of the colour of tea infusion and leaves (Chaturvedula and Prakash, 2011). However, the glycoside form of flavonoids are the predominantly existing species in the plant rather than the nonglycosylated form (Wang and Helliwell, 2001). The glycosylation made flavonoids present much better stability and water solubility (Schwinn et al., 1997). Therefore, it could be expected that the hydrophilic flavonoid glycosides via the RFD treatment were easily transferred onto the surface of tea leaves, resulting in the recoloration of the appearance of green tea.

Chlorophylls are significant pigments for the green colour of tea leaves (Wang and Ruan, 2009). It was reported that chlorophylls

![Figure 2. Scattergram of experimental value and predicted value for the Hue of the RFD treated samples. RFD, rehydration with freeze-drying.](https://academic.oup.com/doi/10.1093/fqsafe/fyab006/6278315)

![Figure 3. Response surface plots on the Hue values of the treated roasted green tea as affected by moisture content, water temperature, and standing time. (A) moisture content of tea leaves and water temperature at a constant standing time (h); (B) moisture content of tea leaves and standing time at a constant water temperature (°C); (C) water temperature and standing time at a constant moisture content of tea leaves.](https://academic.oup.com/doi/10.1093/fqsafe/fyab006/6278315)
could be derived from some water-soluble pigments during tea processing, such as the pheophytins and pheophorbide with olive brown colour and the chlorophyllides with blue–green colour (Suzuki and Shioi, 2003; Wang et al., 2004). These derived pigments also produce significant effects on the formation of the green tea colour. In the present work, almost all chlorophyll compounds were significantly increased \((P<0.05)\) in the treatment group except for CHa (Figure 5B). The results indicated that the RFD treatment produced significant effects on the content of chlorophylls in tea leaves. Roasted green tea was rehydrated in the initial step of the RFD treatment, which increased the content of free water, producing the formation of a tiny solution system in the tea leaves. The solution system provided a favourable condition for the organic acids to replace the magnesium ion of chlorophylls, promoting the conversion from chlorophyll to pheophytin (Chen and Chen, 1993; Suzuki and Shioi, 2003). The subsequent freeze-drying step further promoted the formation of pheophytin (Kao et al., 2011). Therefore, it was observed that the content of pheophytins (Pha, Pha1, and Phb) was significantly increased \((P<0.05)\) in the treatment group. Moreover, the solution system may also provide convenience for the formation of chlorophyll b in the treatment group. It was reported that the activity of chlorophyllase can remain at a low level in green tea after being heated rather than being totally killed (Kohata et al., 1998; Suzuki and Shioi, 2003). The reserved chlorophyllide oxygenase may provide the opportunity to convert the 7-methyl group of chlorophyllide into a formyl group, then ligated it with a phytol side chain forming chlorophyll b (Tanaka and Tanaka, 2011).

Carotenoids contribute the formation of aroma compounds in tea processing (Ravichandran, 2002) as well as playing an important role in the colour of tea leaves (Taylor et al., 1992). More than 38 carotenoids were detected in the green tea, but most carotenoids presented in very low concentrations (Suzuki and Shioi, 2003). Three major carotenoids of commercial tea include Neo, Lut, carotene, and the corresponding content ranged 11–71 nmol/L, 192–644 nmol/L, 233–404 nmol/L, respectively (Lu et al., 2009). Our detection of carotenoid content was consistent with the former research. Moreover, it was found that the content of Lut \((P<0.05)\) was significantly increased in the treatment group, but there was no significant difference \((P>0.05)\) between the control group and the treatment group in the content of Neo, βcar and αcar (Figure 5C).

Investigation showed that the content of carotenoids was decreased during the tea processing, and the freeze-drying could maximize
maintaining carotenoids contents (Loranty et al., 2010; Lee et al., 2015). However, the increase of Lut content has been the first to be found so far. It could be assumed that the process of rehydration provided the humid conditions not only promoting the transformation from lutein esters to Lut (Lujan-Montelongo et al., 2018), but at the same time inducing other carotenoids to form Lut via complicated processes (Cazzonelli and Pogson, 2010; Nisar et al., 2015).

Correlation analysis of the Hue angle and pigments
Pearson correlations between the Hue angle and 17 pigments (Figure 6) were used to explore the contribution of the determined pigments on the colour of tea leaves after RFD treatment. As shown in Figure 6, the green petal presented a positive correlation, the red petal presented a negative correlation, and the purple petal was the \(P\)-value of correlation. It could be found that most flavonoid glycosides registered a strong positive correlation with the Hue angle, but K3O, Q3Ga, and V2O presented negative correlations. This result is consistent with previous investigation; not all flavonoids could produce highly positive effects on the colour of green tea leaves due to the limitation of their contents and colours (Wang et al., 2004; Peterson et al., 2005). Chlorophyll compounds are major contributors for the green colour of tea leaves; all chlorophyll compounds presented a positive correlation with the Hue and the correlation coefficients were higher than 0.8. For carotenoids compounds, the \(\beta\)car registered the weakest positive correlation with the Hue, with a correlation coefficient of only 0.11. Both Lut and Neo presented stronger positive correlations with Hue, and the correlation coefficients reached 0.99 and 0.98, respectively. The coefficient between Hue and acar also exceeded 0.8 in positive correlation. The results of correlation analysis indicated that the determined pigments of this work played significant roles in recoloring the green tea colour.

Sensory evaluation
The sensory differences of the roasted green tea before and after RFD treatment are listed in Table 4. The score of appearance was
Using endogenous pigments to recolour roasted green tea

Table 4. Sensory evaluation of roasted green tea in the control group and the treatment group

| Sensory component       | Sensory score | Control comment       | Sensory score | Treatment comment       |
|-------------------------|--------------|-----------------------|--------------|-------------------------|
| Appearance              | 83.67±1.53b  | Dark green            | 89.67±1.15a  | Light green             |
| Infusion colour         | 89.83±2.75a  | Yellow-green          | 91.50±0.50a  | Bright, yellow-green    |
| Aroma                   | 91.00±3.04a  | Chestnut aroma        | 89.67±1.53a  | Freshness with a little chestnut aroma |
| Taste                   | 90.50±1.32a  | A little bitter, mellow| 91.17±1.04a  | Mellow, fullness        |
| Infused leaves           | 90.67±0.29a  | Intact                | 90.33±0.58a  | Intact                  |
| Total score             | 89.23±1.09a  | —                     | 90.37±0.83a  | —                       |

Control group was the typical roasted green tea, while the treatment group was the RFD-treated sample. The same lowercase letters within a row indicate no significant differences at P>0.05, respectively; “—” means no comment. RFD, rehydration with freeze-drying.

significantly increased (P<0.05) in the treatment group, which was mainly attributed to the quality promotion of tea colour. A slight increase in the score of infusion colour could be found in the treatment group, but without significant difference (P>0.05) with the control group. Although the score of aroma was not significantly different (P>0.05), the aroma type was slightly changed from chestnut to freshness with a little chestnut after the RFD treatment. Moreover, the bitterness was slightly decreased in the treatment groups, which may be related to the change of content and composition for flavonoid glycosides and Maillard reaction product. Flavonoid glycosides and Maillard reaction products are reported to contribute the mainly bitter flavour in tea soup (Bin and Peterson, 2016). The infused tea leaf did not have any change in score between the treatment group and the control group, indicating the RFD treatment not damage or change the tissue structure of tea leaves.

Conclusion

In the present study, it was confirmed that RFD treatment could effectively change the colour of roasted green tea from dark green to bright green. Research results indicated that RFD treatment induced a favourable condition for the formation and transformation of pigments, while the freeze-drying promoted the redistribution of water-soluble pigments on the surface of tea leaves. The RFD-treated tea samples could not influence other sensory characteristic of the roasted green tea, except for colour.

Author Contributions

Hongkai Zhu: Formal analysis, investigation, methodology, validation, visualization, roles/writing original draft; Jiangang Zhang: Formal analysis, investigation, methodology, validation, visualization, writing—review and editing; Fei Liu: Methodology, validation, formal analysis, visualization, writing—review and editing; Lin Chen: Methodology, validation, formal analysis, visualization; Yang Ye: Conceptualization, methodology, project administration, resources, validation, visualization, writing—review and editing.

Funding

This research was funded by the Earmarked Fund for China Agriculture Research System (CARS-19).

Conflict of Interest

The authors declare no conflict of interest.

References

AQSIQ (General Administration of Quality Supervision, Inspection and Quarantine of the People’s Republic of China), SAC (Standardization Administration of the People’s Republic of China). (2009). Methodology of sensory evaluation of tea, GB/T 23776-2009. China Standards Press, Beijing, China. (In Chinese).

Bhat, R., Abdullah, N., Din, R. H., et al. (2013). Producing novel sago starch based food packaging films by incorporating lignin isolated from oil palm black liquor waste. Journal of Food Engineering, 119(4): 707–713.

Bin, Q., Peterson, D. G. (2016). Identification of bitter compounds in whole wheat bread crumbs. Food Chemistry, 203: 8–15.

Cazzonelli, C. I., Pogson, B. J. (2010). Source to sink: regulation of carotenoid biosynthesis in plants. Trends in Plant Science, 15(5): 266–274.

Chaturvedula, V. S. P., Prakash, I. (2011). The aroma, taste, color and bioactive constituents of tea. Journal of Medicinal Plants Research, 5(11): 2110–2124.

Chen, B. H., Chen, Y. Y. (1993). Stability of chlorophylls and carotenoids in sweet potato leaves during microwave cooking. Journal of Agricultural and Food Chemistry, 41(8): 1315–1320.

Graham, H. N. (1992). Green tea composition, consumption, and polyphenol chemistry. Preventive Medicine, 21(3): 334–350.

He, X. Y., Liu, J. F., Huang, Z. H. (2011). Preparation of cold brew tea by explosion puffing drying at variable temperature and pressure. Drying Technology, 29(8): 888–895.

Kao, T. H., Chen, C. J., Chen, B. H. (2011). An improved high performance liquid chromatography–photodiode array detection–atmospheric pressure chemical ionization–mass spectrometry method for determination of chlorophylls and their derivatives in freeze-dried and hot-air-dried Rhinacanthus nasutus (L.) Kurz. Talanta, 86: 349–355.

Kohata, K., Hanada, K., Yamauchi, Y., et al. (1998). Phloemborphide a content and chlorophyllase activity in green tea. Bioscience, Biotechnology, and Biochemistry, 62(9): 1660–1663.

Krokida, M. K., Philippopoulos, C. (2006). Volatility of apples during air and freeze drying. Journal of Food Engineering, 73(2): 135–141.

Lee, L. S., Choi, J. H., Son, N., et al. (2013). Metabolomic analysis of the effect of shade treatment on the nutritional and sensory qualities of green tea. Journal of Food Engineering, 62(9): 293–303.

Lee, J., Hwang, Y. S., Kang, I. K., et al. (2015). Lipoxygenase and dietary fiber content in wheat bread crumb. Journal of Food Composition and Analysis, 41(8): 1315–1320.

Loranty, A., Rembialkowska, E., Rosa, E. A. S., et al. (2010). Identification, quantification and availability of carotenoids and chlorophylls in fruit, herb and medicinal teas. Journal of Food Composition and Analysis, 23(3): 432–441.
Lu, J. L., Pan, S. S., Zheng, X. Q., et al. (2009). Effects of lipophillic pigments on colour of the green tea infusion. International Journal of Food Science & Technology, 44(12): 2505–2511.

Lujan-Montelongo, J. A., Mendoza-Figueroa, H. L., Silva-Cuevas, C., et al. (2018). Highly regioselective enzymatic synthesis of lutein-3-monoesters. Tetrahebedron Letters, 59(46): 4096–4101.

Merken, H. M., Beecher, G. R. (2000). Measurement of food flavonoids by high-performance liquid chromatography: a review. Journal of Agricultural and Food Chemistry, 48(3): 577–599.

Nisar, N., Li, L., Lu, S., et al. (2015). Carotenoid metabolism in plants. Molecular Plant, 8(1): 68–82.

Ošťádalová, M., Tremlová, B., Pokorná, J., et al. (2015). Chlorophyll as an indicator of green tea quality. Acta Veterinaria Brno, 83(10): 103–109.

Peterson, J., Dwyer, J., Bhagwat, S., et al. (2005). Major flavonoids in dry tea. Journal of Food Composition and Analysis, 18(6): 487–501.

Ratti, C. (2001). Hot air and freeze-drying of high-value foods: a review. Journal of Food Engineering, 49(4): 311–319.

Ravichandran, R. (2002). Carotenoid composition, distribution and degradation to flavour volatiles during black tea manufacture and the effect of carotenoid supplementation on tea quality and aroma. Food Chemistry, 78(1): 23–28.

Rizzi, G. P. (1997). Chemical structure of colored Maillard reaction products. Food Reviews International, 13(1): 1–28.

Sagar, V. R., Suresh Kumar, P. (2010). Recent advances in drying and dehydration of fruits and vegetables: a review. Journal of Food Science and Technology, 47(1): 15–26.

Schwinn, K. E., M. Davies, K., Deroles, S. C., et al. (1997). Expression of an Antirrhinum majus UDP-glucose:flavonoid-3-O-glucosyltransferase transgene alters flavonoid glycosylation and acylation in lisianthus (Eustoma grandiflorum Grise.). Plant Science, 125(1): 53–61.

Suzuki, Y., Shiio, Y. (2003). Identification of chlorophylls and carotenoids in major teas by high-performance liquid chromatography with photodiode array detection. Journal of Agricultural and Food Chemistry, 51(18): 5307–5314.

Tanaka, R., Tanaka, A. (2011). Chlorophyll cycle regulates the construction and destruction of the light-harvesting complexes. Biochimica et Biophysica Acta (BBA)—Bioenergetics, 1807(8): 968–976.

Taylor, S., Baker, D., Owuor, P., et al. (1992). A model for predicting black tea quality from the carotenoid and chlorophyll composition of fresh green tea leaf. Journal of the Science of Food and Agriculture, 58(2): 185–191.

Wan, X. A., Zhou, X., Mu, B. B., et al. (2014). Crossmodal expectations of tea color based on flavor: a preliminary study with naive assessors. Journal of Sensory Studies, 29(4): 285–293.

Wang, H. F., Helliwell, K. (2001). Determination of flavonoids in green and black tea leaves and green tea infusions by high-performance liquid chromatography. Food Research International, 34(2–3): 223–227.

Wang, X., Huang, J. H., Fan, W., et al. (2015). Identification of green tea varieties and fast quantification of total polyphenols by near-infrared spectroscopy and ultraviolet-visible spectroscopy with chemometric algorithms. Analytical Methods, 7(2): 787–792.

Wang, L. F., Park, S. C., Chung, J. O., et al. (2004). The compounds contributing to the greenness of green tea. Journal of Food Science, 69(8): S301–S305.

Wang, H. F., Provan, G. J., Helliwell, K. (2000). Tea flavonoids: their functions, utilisation and analysis. Trends in Food Science & Technology, 11(4): 152–160.

Wang, K. B., Kuan, J. Y. (2009). Analysis of chemical components in green tea in relation with perceived quality, a case study with Longjing teas. International Journal of Food Science & Technology, 44(12): 2476–2484.

Wu, C. Y., Xu, H. R., Hirtler, J. H., et al. (2012). Determination of the flavone glycosides in various tea cultivars. Journal of Tea Science, 32(2): 122–128. (In Chinese)

Zhang, Y. N., Yin, J. F., Chen, J. X., et al. (2016). Improving the sweet aftertaste of green tea infusion with tannase. Food Chemistry, 192: 470–476.